Cognitive-communication Abilities in Bilinguals with a History of Mild Traumatic Brain Injury

by

Halah Alateeq

A Dissertation Presented in Partial Fulfillment
of the Requirements for the Degree
Doctor of Philosophy

Approved July 2020 by the
Graduate Supervisory Committee:

Tamiko Azuma, Chair
Ileana Ratiu
Michael Lavoie

ARIZONA STATE UNIVERSITY

August 2020

ABSTRACT

Mild TBI (mTBI) has been associated with subtle executive function (EF) and cognitive-communication deficits. In bilinguals, there are unique cognitive demands required to control and process two languages effectively. Surprisingly, little is known about the impact of mTBI on EF, communication, and language control in bilinguals. Therefore, the aim of this study was to examine the cognitive-communication abilities in bilinguals with a history of mTBI, identify any language control impairments, and explore the relationship between these language control impairments and domain-general cognitive control abilities. To this end, three-hundred and twenty-seven monolingual and bilingual college students with and without mTBI history participated in two experiments. In these experiments, EF, communication, and language control were examined using experimental and clinical tasks as well as self-rating scales. In Experiment 1, there was an interaction between mTBI history and language group (monolinguals vs. bilinguals) in how participants performed on a clinical measure of EF and a verbal fluency task. That is, only bilinguals with mTBI scored significantly lower on these tasks. In addition, there was a significant correlation between errors on a language switching task and performance on non-verbal EF tasks. In Experiment 2, a subgroup of bilinguals with persistent cognitive and behavioral symptoms reported greater everyday communication challenges in their first and second languages. Also, unbalanced bilinguals reported greater EF difficulties than monolinguals and balanced bilinguals regardless of mTBI history. In conclusion, bilinguals may face unique cognitive-communication challenges after mTBI. Factors related to the bilingual experience (e.g., language balance, daily language use) should be considered in clinical evaluation and future research

DEDICATION

To my mother and father, I am who I am today because of you. Thank you for loving and supporting me unconditionally and encouraging me to follow my dreams even when it meant moving across the world.

ACKNOWLEDGMENTS

First, I have to extend my deepest appreciation to my mentor and the chair of my committee, Dr. Tamiko Azuma, for her guidance throughout my Ph.D. career. Thank you for your direction and patience as I made mistakes and learned from them. You have been the model of mentor and teacher I aspire to be.

I would also like to thank my committee members. Dr. Ileana Ratiu, thank you for your continued support and feedback. I have been inspired by your research since day one, and I am grateful for this opportunity to learn from you. Dr. Michael Lavoie, thank you for your guidance and advice since the earliest stages of this dissertation work.

Also, I would like to thank the (past and present) members of the Attention, Memory, and Language lab and research assistants for their hard work during the project's recruitment and data scoring phases. Also, to all the participants in the study, thank you for your time and participation. To my dear friends, the past and present Ph.D. students in the Speech and Hearing Sciences program, I am lucky to have shared this experience with you.

Lastly, I have to thank my family for always being there for me despite the physical distance. To my second family, the Schulz's, thank you for your love and support. Most importantly, thank you to my fiancé for being the support system I needed to complete this dissertation. None of this would have been possible without you.

TABLE OF CONTENTS

Page

LIST OF TABLES

LIST OF FIGUERES

INTRODUCTION

Language production for successful communication can be cognitively demanding involving any or all of the following behaviors: planning the next word, flexibly moving between topics, suppressing irrelevant responses, maintaining and updating certain words and topics in mind (Byom & Turkstra, 2017). None of these linguistic behaviors are possible without the involvement of higher-order Executive Functions (EF) such as planning, switching, inhibition, and maintaining and updating of information in working memory. After a traumatic brain injury (TBI), language impairments such as word-finding difficulties, difficulty inhibiting inappropriate utterances, and difficulty organizing sentences may emerge. These language impairments following TBI are believed to be due a disruption to domain-general cognitive processes, hence, referred to as cognitive-communication impairments.

In bilinguals, who need to juggle two languages effectively, unique demands are placed on the cognitive processes controlling language (Green & Abutalebi, 2013). The bilingual experience with its unique demands is believed to be driving adaptive changes in the neural circuitry controlling language, which also subserves domain-general cognitive control. In addition, bilingual patients with neurological deficits often show concomitant language and cognitive control deficits. However, while the current clinical guidelines for TBI recognize the possible devastating effects on cognitive abilities, such as memory, attention, and EF, these guidelines fail to recognize the potential impact of brain injury on language in bilinguals.

Present Study

The present study aims to (1) examine the cognitive-communication abilities in bilinguals with a history of mTBI, (2) identify any language control impairments bilinguals with mTBI may experience and (3) explore the relationship between these language control impairments and domain-general cognitive control abilities.

LITERATURE REVIEW

Executive functions (EF) are a set of cognitive processes that allow us to shift our mindset quickly, inhibit irrelevant behaviors, plan purposeful behaviors, and maintain and update goals until the plan is achieved (Jurado & Rosselli, 2007). Three of the most commonly studied EF are inhibitory control, switching, and working memory, which are believed to mediate higher-order functions such as planning and problem solving (Diamond, 2013). These same cognitive components are involved in *cognitive control* (Davidson et al., 2006), a term that is often used interchangeably with EF.

First, inhibitory control (i.e., inhibition) is "the ability to override, interrupt, or abort ongoing processes, especially when those processes are well engrained" (Banich & Depue, 2015). According to Diamond, inhibitory control is not a unitary construct; instead, it comprises of three separable processes, a view that is well established (Cipolotti et al., 2016; Friedman & Miyake, 2004; Koch et al., 2010). First of the inhibitory processes is *interference control at the perception level,* which refers to selectively ignoring distracting stimuli (e.g., auditory, visual, tactile) while attending to the task in hand. Second, *interference control at the cognitive level,* which refers to inhibiting proactive interference from thoughts, memories, or emotions. This subcomponent may include suppression of an interfering memory of a previous task or interfering thoughts of an anticipated upcoming task. Third, *Response inhibition – at the behavior level* refers to actively overriding a prepotent or automatic response. Recently, theorists have differentiated between stopping an ongoing response (e.g., stop/signal task) and inhibiting a prepotent response before it starts (e.g., go/no-go task); however, both are considered part of the response inhibition mechanism (Eagle et al., 2008).

The other extensively studied EF is *working memory*, which refers to the ability to actively maintain and manipulate information for a short period (Diamond, 2013). Similar to (Friedman & Miyake, 2017; Miyake, Friedman, et al., 2000), Diamond differentiates between merely storing information in working memory (short-term memory) and storing *and* manipulation of information. Miyake, Friedman, et al. (2000) only include the specific updating function of working memory as a subcomponent of EF; however, others commonly include both (i.e., storing and updating; e.g., Zelazo, 2015).

Lastly, task switching can be synonymous with cognitive flexibility or set-shifting, which refers to "the ability to switch between response sets" (Anderson, 2002, p. 74). Diamond's developmental view of EF places cognitive flexibility higher than inhibition and working memory for possibly two reasons: 1) it emerges later in life, 2) its dependence on the other two functions. That is, in order to shift mental sets, one needs to inhibit previous tasks (inhibition of proactive interference) and maintain the new task active in working memory. This hierarchical view is also influenced by her findings supporting the late emergence of cognitive flexibility compared to the other two functions (Davidson et al., 2006).

In everyday situations, cognitive flexibility can be explained by having to switch from writing an email to answering the phone and back to writing that email. In experimental paradigms, this EF is typically tested by asking participants to shift between different (often 2) tasks. For instance, switching between classifying numbers (as odd or even) to classifying letters (as vowels or consonants) depending on their location in a quadrant (i.e., letter-number task; Rogers & Monsell, 1995). Typically, participants take longer and make more errors on switch trials than on non-switch trials (Monsell, 2003). This discrepancy between the switch and non-switch trials is known as the *switch cost*, which is believed to result from a "carry-over effect" from a previous rule or primed stimuli (Gilbert & Shallice, 2002; Wylie & Allport, 2000), or as a result of a top-down slowdown required to reconfigure the cognitive system for new rules (Monsell et al., 2000; Rogers & Monsell, 1995). There are supporters for both explanations; however, the recent consensus is that these two views do not need to be mutually exclusive (Monsell, 2003).

These EF are mediated by complex and distributed brain circuits that connect the prefrontal cortex (PFC) with other cortical and subcortical regions (Heyder et al., 2004). The PFC plays a vital role in exerting top-down control to guide intended behaviors, which may involve maintaining an activity until the goal is achieved, updating representation when needed, and inhibiting irrelevant responses (Miller & Cohen, 2001). In a review of the neuroimaging literature, the inferior frontal gyrus, medial superior frontal gyrus, anterior cingulate gyrus, and the pre-sensory motor area (pre-SMA) are also involved in set switching (Derrfuss et al., 2005). Alvarez and Emory (2006) found that activation of the dorsolateral prefrontal cortex (DLPFC), the ventromedial and orbitofrontal cortices in response to a switching task is commonly reported in the literature. In addition, these researchers found that DLPFC communicated with the caudate nucleus head mediating functions, including switching, planning, and verbal fluency. Moreover, Scherf et al. (2006) reported activation of the following brain regions associated with working memory: the right DLPFC, the right anterior cingulate gyrus, bilateral anterior insula, the right superior temporal gyrus, the right inter-occipital sulcus, and the right basal ganglia.

Assessment of Executive Function

In general, there are problems with the way the EF is conceptualized across different fields because of: 1) the lack of an agreed-upon operational definition, 2) the ambiguity in what the core components are, 3) the lack of consensus on how to best measure these components, and 3) the lack of theory explaining how these subcomponents interact with each other (Barkley, 2012).

In the speech-language pathology (SLP) world, EF are perceived as part of the cognitive-communication abilities that may be compromised in certain clinical populations such as aphasia, traumatic brain injury, and attention deficit and hyperactivity disorders. Clinically, EF are viewed as "integrative cognitive processes that determine goal-directed and purposeful behavior and are superordinate in the orderly execution of daily life functions" (Cicerone et al., 2000, p. 1605). This umbrella term includes many functions such as volition, planning, purposive action, effective performance (Lezak, 2004), flexibility of thinking, inhibition, and problem-solving (Delis et al., 2001). Moreover, because SLPs are encouraged to take a holistic, patient-centered approach to assessment and intervention of EF, the comorbid social, emotional, and motivational impairments are often recognized and addressed.

Therefore, clinicians often conceptualize various linguistic and cognitive-communication deficits, including those affecting EF through the lens of the International Classification of Functioning, Disability, and Health (ICF) model. The World Health Organization (WHO) developed the ICF model to guide clinicians in different fields to “address functioning and disability related to a health condition within the context of the individual’s activities and participation in everyday life” (ASHA, 2018). The model includes three different levels relating to an overall health condition: body functions and structure, activity, and participation. For example, to evaluate a young patient with EF deficits due to traumatic brain injury this model could be applied as follows: 1) *body structure:* refers to the brain injury itself (e.g., site and size of the lesion), 2) *body functions:* include the EF deficits (e.g., difficulty inhibiting distractors, difficulty in shifting mindset), 3) *activity*: any limitations in performing everyday tasks (e.g., unable to take class notes), 4) *environmental factors:* such as noting that the patient is in a big class with no access to disability resources or facilitation, 5) *personal factors*: such as no support from friends or classmates, and 6) *participation:* is how all of these factors impact his/her participation in society (e.g., failing academically and having to drop out of college).

There are advantages in viewing EF deficits from a holistic point of view with the patient’s functional reintegration in the community as the ultimate goal. First, the assessment, in this case, focuses not only on the EF impairments but on how they affect the person’s affective, emotional, and social wellbeing. Many have criticized the current views of EF that focus on the “cold” components and neglect the “hot” (Barkley, 2012). *Cold* EF, here, refer to the purely cognitive functions such as switching, inhibition, and planning; however, *hot* refers to the emotional, motivational, and affective aspects of EF (Anderson et al., 2010; Ardila, 2008). Both aspects are closely related to the frontal lobe with the dorsolateral prefrontal cortex subserving the cold functions, and the lateroventral prefrontal cortex mediating the hot functions (Ardila, 2008; Stuss & Alexander, 2000).

Therefore, due to the proximity of both regions and the extensive connections between the prefrontal cortex and subcortical and limbic system areas, deficits of cold and hot EF often co-occur. Therefore, addressing them both in the assessment of EF is very important.

Another advantage of utilizing the ICF model in clinical assessment is in considering the patient's everyday activities and how the EF deficits are impacting his/her lifestyle. It has been argued that many of the neuropsychological assessments of EF lack ecological validity. That is, they do not tell us much about how the patient is functioning in everyday situations. Therefore, clinicians have been using self-ratings and questionnaires from the patients and their relatives to gather information about how these deficits in EF can be manifested in everyday activities. For example, the Dysexecutive Questionnaire (DEX) is one of the most commonly used questionnaires by SLPs to assess EF. In addition to questions on cognitive aspects such as inhibition, shifting, and planning, this questionnaire taps into the emotional and affective aspects. Combining data from self-evaluations such as the DEX with traditional test batteries is highly informative. First, it allows the clinician to target functional therapy goals, as per the ICD model. Also, it provides valuable information about how patients perceive their impairments and how they self-assess their EF abilities.

Additionally, clinicians often incorporate a battery of tests to examine the broad array of EF. For example, to test EF within a communication context, the Functional Assessment of Verbal Reasoning and Executive Strategies (FAVRES) is often used by SLPs. In this test, patients are asked to solve different everyday problems, such as using a calendar to schedule meetings while allowing time for other responsibilities (Turkstra &

Byom, 2010). Another test battery used clinically is the behavioural assessment of the dysexecutive syndrome (BADS). This test showed good ecological validity when compared to functional questionnaires (Norris & Tate, 2000). It comprises of different subtests such as the key search, and the zoo map. In the key search, patients are asked to strategically plan a search for a lost key in a given area (line drawn). In the zoo map, patients are asked to plan a route around a zoo following certain rules. Both tests create opportunities to plan and solve problems similar to those faced in everyday life.

On the other hand, there are some challenges in clinical assessments of EF. For instance, there is an overall problem with task impurity when it comes to EF testing (Miyake, Emerson, et al., 2000), and it is particularly evident in the complex measures clinicians use. The complexity here reflects the fact that multiple executive and non-EF are involved in a test like the FAVERS or the BADS. Therefore, when a breakdown occurs on any of the subtests, the clinician needs to make a clinical decision on what caused that breakdown based on contextual cues (Constantinidou et al., 2012). For example, when a patient is given the zoo map subtest, mentioned above, and the patient fails to complete the task successfully, then it is up to the clinician to infer what went wrong during the process. Strategic planning required in this task is believed to be a higher-order EF that relies on other simpler EF such as inhibition, switching, and working memory (Diamond, 2016). Therefore, the patient could fail the zoo map subtest for any of the following reasons: 1) impulsive initiation of the task without reading the rules, 2) once started, difficulty stopping to review the rules, 3) inability to switch back and forth between reading the rules and completing the map or 4) difficulty maintaining the rules while completing the map, as well as other possible scenarios. This job could be challenging for the clinician, mainly when these deficits are subtle.

On the other hand, in cognitive psychology, different EF are often measured individually. That is, each subcomponent is measured using isolated simple tasks with serious efforts to minimize task impurity. For example, unlike clinical measures where inhibition is sometimes inferred contextually through different tests, in cognitive psychology, this EF and its subcomponents are measured in a variety of isolated tasks—for example, using the Flanker task, where a person is asked to indicate the direction of an arrow while ignoring other surrounding arrows, to measure interference suppression, a subcomponent of inhibition.

Experimental tasks are often criticized for lacking ecological validity. For example, some argue that laboratory tasks do not take the interplay between cognition and emotion into consideration; thus, they inherently unable to tell us much about EF in real situations (Ardila, 2008). Barkley (2012) argues from a revolutionary point of view that EF evolved to guide behaviors and solve problems in humans' environments and not to sort cards (pg., 32). However, these experimental tasks are useful in isolating complex, intertwined cognitive processes to further our understanding of how they work and interact. In order to provide a clear theory of how EF works, researchers need to understand how its components are related to each other (Barkley, 2012). Therefore, combining both experimental and ecologically valid clinical measures of EF in research and practice is a step towards better understanding this construct.

Executive Function in Bilinguals

In recent years, EF have been studied extensively in the bilingual literature mostly focusing on the *bilingual advantage*, a research endeavor that has yielded inconclusive results (e.g., Adesope et al., 2010; Paap & Greenberg, 2013; Van den Noort et al., 2019). To that end, researchers have examined whether bilinguals outperform monolinguals on non-verbal measures of different EF such as inhibition (e.g., Blumenfeld & Marian, 2014), set-shifting (e.g., Prior & MacWhinney, 2010), and working memory (e.g., Ratiu & Azuma, 2015). However, this line of research often utilizes highly structured tasks to examine isolated EF without clear evidence of whether these bilingualism-related cognitive advantages extend to everyday activities. This leaves clinicians uncertain about how bilinguals perform on clinical and more functional measures of EF.

Clinical measures of EF tend to rely heavily on language, which can be particularly challenging for bilinguals. In fact, a bilingual disadvantage on verbal tasks has been frequently reported in the literature. For example, bilinguals are slower at naming pictures (Ivanova & Costa, 2008), have more tip-of the tongue instances (Gollan et al., 2005), and name fewer items in verbal fluency tasks (Gollan et al., 2002). There are different accounts regarding the source of this disadvantage in bilinguals. One of which is that bilinguals, even though have a larger vocabulary repertoire from both their languages combined, they may have a smaller vocabulary size in each (e.g., Bialystok & Luk, 2012). The other account attributes this verbal disadvantage to the competition between lexicons from two languages for each semantic representation. To control the competition from the simultaneously active lexicons from both languages, top-down inhibition of lexical representations is exerted (Green 1998). This competition at the lexical level, may, in part, explain the disadvantage noted on verbal tasks in bilinguals.

Cognitive and Language Control in Bilinguals

One of the prominent theories in bilingual cognition is the Adaptive Control Theory by Green and Abutalebi (2013). According to this theory, juggling two languages places certain demands on the processes controlling language, driving these processes to adapt accordingly. Adaptation here could be observed as structural neural changes, functional changes (e.g., due to increased neural connectivity), or even as improved control of the two languages at the behavioral level. In addition, Green and Abutalebi proposed that the context of the bilingual experience and the daily demands on both languages are important factors in the degree of these adaptive changes. That is, only intense and frequent experiences derive adaptive changes. For example, bilinguals who switch *daily* and *frequently* between languages with different monolingual communicative partners (i.e., dual-language context) exert more effort to keep the languages separate and to inhibit the non-target language, thus placing a higher demand on the control processes.

This "ability to keep the two languages separated to avoid interference and to select one language or the other in a given conversational context" (Calabria et al., 2018, p. 1) is known as the *Bilingual language control*. Controlling the competition from L1 and L2 and guiding the selection of the target language/word is believed to be mediated by the same network of cortical and subcortical regions subserving cognitive control (Abutalebi & Green, 2007). This network comprises predominantly of frontal regions, including the PFC, which has been reported extensively in the literature investigating bilingual language control (Abutalebi & Green, 2007, 2016; Luk et al., 2012) and EF (e.g., Alvarez & Emory, 2006). The PFC plays a significant role in exerting top-down control to guide goal-directed behaviors (Miller & Cohen, 2001). The role of the PFC is even more critical when the task at hand is "ambiguous …or when multiple responses are possible" (Miller & Cohen, 2001, p. 171). According to these authors, the PFC then redirects neural activity by "biasing" the weak irrelevant signal over the stronger prepotent one. This biasing function may be particularly important in the case of bilinguals, where one language is more dominant than the other (Abutalebi & Green, 2007).

Additionally, in a meta-analysis that included 106 bilinguals, Luk et al. (2012) identified 8 regions involved in bilingual language control, 4 of which were frontal. These areas included: 1) the left inferior frontal gyrus (BA 44 & 47), 2) the left middle frontal gyrus (BA 9 & 46), 3) the right precentral gyrus (BA 6), and 4) the midline pre-supplementary motor area (pre-SMA; BA 6). The left inferior frontal gyrus, commonly reported area in bilingual language control, is believed to be crucial for overriding automatic processes such as responses from L1 (or the dominant language; Abutalebi & Green, 2016). In a recent study, the overlap between brain areas activated during linguistic and non-linguistic, inhibition tasks were examined in bilinguals and monolinguals (Coderre et al., 2016). The linguistic tasks involved a modified Flanker, where the flanking stimuli in the middle is a word (left or right), and the distracting words are *up* and *down,* and a semantic categorization task (i.e., living/non-living items). The bilinguals alternated between languages (English and Spanish) while the monolinguals performed the task in English. Behaviorally, monolinguals, and bilinguals performed similarly on both Flanker tasks; however, fMRI data showed a unique difference. In conjunction analysis of linguistic and non-linguistic tasks, there were no overlapped brain areas in monolinguals; however, the left inferior frontal gyrus appeared to be activated in both tasks in bilinguals. These findings, which are in line with others (e.g., Branzi et al., 2015), highlight the importance of the left inferior frontal gyrus in bilingual language control and support the notion that language control in bilinguals might be domain-general.

The Dorsolateral prefrontal cortex (DLPFC; BA46) is critical for many EF such as switching, inhibition, working memory, and planning (Alvarez & Emory, 2006). The DLPFC has also been reported to involve bilingual language control (Abutalebi & Green, 2016; Hernandez, 2009). In an fMRI study, 12 early Spanish/English bilingual participants completed a covert naming task in both languages in switch and non-switch blocks (Hernandez, 2009). Comparisons between the switch and non-switch blocks revealed activation of the right DLPFC, right precentral gyrus, right pre-SMA, and the superior parietal lobules. According to the author, these findings suggest that a similar neural network is recruited for language switching as well as executive control. Interestingly, in another study, the right DLPFC was more activated in a naming task in the dominant language than the non-dominant one, and in highly proficient bilinguals compared to the less proficient (Videsott et al., 2010).

Another area in the frontal lobe that has been recognized for its role in bilingual language control is the pre-SMA (Abutalebi et al., 2011; Abutalebi & Green, 2016; Luk et al., 2012). In their 2011 study, Abutalebi and colleagues found that the pre-SMA, along with the anterior cingulate gyrus, were activated in both language switching and a non-linguistic conflict monitoring task in bilinguals. The authors concluded that this area plays a domain-general role in error detecting and conflict monitoring that is observed in language switching in bilinguals.

Cognitive-communication deficits after Traumatic Brain Injury

Traumatic brain injury (TBI) refers to any injury to the brain that may disrupt its functions with varying degrees of severity (Constantinidou & Kennedy, 2017). Based on the Mayo Clinic Classification system for TBI, these injuries are classified as moderate-severe, mild, or probable (possible; Malec et al., 2007). There is no arguing that TBI is heterogeneous, with factors such as severity and location playing a major role in how it is manifested behaviorally. However, the frontal lobe and closely associated circuits (e.g., basal ganglia, thalamus) are particularly vulnerable to TBI (Rabinowitz & Levin, 2014). These same brain regions are involved in the control of higher-order cognitive processes such as attention, EF, and memory (Aron et al., 2004; Peters et al., 2013). Therefore, it is not a surprise that the impairments of these cognitive functions are what mostly being reported after a TBI. Common cognitive symptoms after TBI may include lack of concentration, difficulty attending to more than one thing at a time, disinhibition, and other attention, memory, processing speed and EF problems (Lezak et al., 2004; Rabinowitz & Levin, 2014; Yeates et al., 2017).

In addition to these commonly reported cognitive symptoms, individuals with TBI often experience language impairments such word-finding difficulties, difficulty inhibiting inappropriate utterances, difficulty organizing words and sentences, and shorter, less complex sentences. For example, patients who may not show remarkable deficits in language measures or during reading, writing, and speech tasks may continue to exhibit some difficulty finding words (Lezak et al., 2004). These word-finding difficulties are commonly described as paraphasia (literal or semantic; e.g., calling a "screwdriver" a "wrench"), subordinate semantic errors (e.g., calling a "table" "furniture" due to difficulty accessing the target word and compensating by using the category name; Hough, 2008), or perseveration errors (Barrow et al., 2003). In addition to these word-finding difficulties, Coelho and colleagues have reported problems in discourse (i.e., connected speech) after TBI such as difficulty organizing sentences and reduced syntactic complexity (2005, 2012).

These linguistic impairments after TBI are attributed to an overall disruption in the cognitive processes rather than an isolated linguistic deficit as in aphasia (Murdoch & Theodoros, 2001). That is, the deficits in attention, memory, EF, and other cognitive processes are underlying the impairments in language processing. This contemporary view of language impairments as a cognitive-communication disorder emerged in the early 1980s when researchers realized that these aphasia-like symptoms post TBI cannot be viewed as classic aphasia. This is mainly because the language difficulties resulting from closed head injuries show different patterns of impairment and recovery than those experienced after focal damage to the perisylvian region.

Unfortunately, despite moving away from viewing language impairments after TBI as aphasia, clinicians continue to use language measures designed to diagnose and manage aphasia with their TBI patients. However, researchers agree that "…an approach to diagnosing and treating language disorders that had been developed from knowledge and experience with other types of neurological impairments could not be successfully applied to TBI" (Murdoch & Theodoros, 2001, p. 203). This inappropriate use of aphasia-related language measures with the TBI population may be the reason why language abilities are often considered intact after TBI. It has been argued that these measures are insensitive to the subtle impairments in language that individuals with TBI may experience in everyday situations.

Cognitive and Language Control Deficits in Bilinguals after Neurological Deficits

Reports of concomitant cognitive and language control deficits after cortical and subcortical lesions are common in the bilingual literature (e.g., Adrover-Roig et al., 2011; Calabria et al., 2014; Fabbro et al., 2000; Fabbro et al., 2004). Symptoms of bilingual language control impairments include pathological *Language switching,* which refers to alternating languages between utterances, and *language mixing*, which refers to switching between languages within an utterance (Calabria et al., 2014; Fabbro et al., 2000). Fabbro et al. (2000) reported a case study of a bilingual man speaking both Italian and Fiuralian who exhibited pathological language switching after developing a brain tumor in the left frontal lobe extending to the basal ganglia and the cingulate gyrus. The patient did not show any aphasic symptoms in any of his languages and did not show difficulties translating between languages. However, when requested to speak in one language (i.e., L1), the patient would involuntary switch languages between utterances up to 40% of the time. This was paired with overall verbal disinhibition, such as telling inappropriate jokes and apologizing for them. The patient was fully aware of his involuntary language switching, however, unable to control it, indicating difficulties in exercising bilingual language control to keep the two languages separated.

Moreover, Calabria et al. (2014) reported a case of a well-educated 44-year-old Catalan-Spanish bilingual who experienced pathological language switching and mixing due to an inflammatory disease affecting the superior left temporal lobe, left caudate nucleus, and cerebellum. Similar to the previous case study, this patient involuntarily switched from L1 to L2 and had more intrusions from L2 into her L1 speech. For instance, when asked to speak in her L1 (Catalan), she produced 60% of her speech in L2 (Spanish); however, when asked to speak in L2, 90% of her speech was in that language. This patient had comparable translation skills and object naming scores in both languages; however, a deferential performance was noted on a verb naming task. On a cued language switching task, the patient made more errors and spent more time switching between languages compared to 10 matching control. Similar to her performance in spontaneous speech, the patient made more errors switching into L1 than into L2. These findings suggest a difficulty inhibiting L2 due to a bilingual language control deficit.

Similarly, Abutalebi et al. (2000) discussed a case of an Armenian-English-Italian trilingual with non-fluent parallel aphasia marked by reduced spontaneous speech, perseverations, and pathological language mixing of all three languages. This 74-year-old female had a left subcortical stroke involving the left caudate nucleus that resulted in involuntary, multidirectional language mixing. Despite her awareness and frustration of her spontaneous language mixing, she was unable to control it even when asked to speak in one language. The authors attributed her language mixing deficits to difficulty in monitoring lexical and semantic alternatives and controlling the selection of target language/words, functions that are associated with the basal ganglia, and the left caudate, specifically.

It has been proposed that impairments in language control are due to an underlying difficulty in inhibition (Green, 2007). Researchers have tested this account in bilinguals with neurological deficits by examining executive and linguistic control aspects for signs of parallel impairments. For example, the case in (Calabria et al., 2014) showed executive control deficits in addition to the language deficits described earlier. In that study, the patient's performance on switching and inhibition tasks was compared to 10 matching healthy control. The patient made more errors (30.9%) than controls (7.1%) on the switching task and had longer reaction time and higher conflict cost on the inhibition task. These switching and inhibition deficits, in addition to, the cross-language intrusions may suggest a domain-general cognitive control of language that is affected by fronto-subcortical lesions.

On the other hand, Gray and Kiran (2016) investigated the relationship between cognitive and language control in bilinguals with aphasia and found distinct patterns of deficits. In their study, 10 bilinguals with aphasia (due to left hemispheric stroke) and 30 healthy bilingual controls completed a linguistic (i.e., judging whether two words were related in within- and between- language conditions) and a non-linguistic (Flanker) control tasks. On the Flanker, both bilinguals with aphasia and healthy control showed a congruency effect in reaction time. That is, they were faster incongruent trials than incongruent trials. However, on the linguistic task, no congruency effect was observed in either group. That is, there was no difference in performance judging the semantic relatedness of words within and between languages. Based on these findings, the author concluded that there was a dissociation between language and cognitive control in their sample of bilinguals with aphasia, suggesting a domain-specific language impairment.

Similarly, Green et al. (2010) reported cases of two bilinguals with aphasia with disassociated language and cognitive control impairments. The first patient had a subcortical lesion affecting the left basal ganglia, and the second patient had a history of thrombo-embolic stroke affecting the left parietal, frontal, and temporal lobes. These patients showed a differential pattern of impairments on linguistic (i.e., lexical decision) and non-linguistic tasks (e.g., Stroop and Flanker). For example, the first patient, with a subcortical lesion, showed more difficulty on the verbal than the non-verbal tasks. However, the second patient showed more impairment on the non-verbal than the verbal one. According to the authors, these findings do not necessarily negate the domain-general control account, and that the deficits might be due to a mild inhibitory control impairment that is not picked up by the experimental tasks used.

Cognitive and Language Control Deficits in Bilinguals after TBI

Studies examining language and cognitive sequelae of TBI in bilinguals are limited. Ratiu and Azuma (2017) examined EF and language control in bilinguals after a mild TBI (mTBI). In their study, bilinguals with and without a history of mTBI were compared based on their performance on several tasks of inhibition, switching, and working memory tasks. Bilinguals with mTBI performed significantly worse on the inhibition task, but not on the switching and working memory measures. Additionally, performance on these tasks predicted the number of errors bilinguals made during a reading task, in terms of language intrusions, which could be due to similar inhibition and switching mechanisms mediating both verbal and nonverbal tasks.

Experiment 1

The first aim of the current study is to examine EF abilities in bilinguals with a history of mTBI on a battery of experimental and clinical tasks and to compare their performance to healthy control bilinguals and to monolinguals with and without mTBI history. It is hypothesized that bilinguals with mTBI will perform worse than healthy control bilinguals as reported in the literature (Ratiu & Azuma, 2017, 2019). In addition, we hypothesize that bilinguals with mTBI may perform worse than monolinguals on the clinical EF task due to its verbal nature, a common finding in research involving neurotypical bilinguals.

The second aim of this study is to examine the performance of bilinguals with mTBI on a novel verbal fluency and language switching task compared to healthy control bilinguals. It is hypothesized that at least a subgroup of bilinguals with mTBI will show reduced verbal fluency and will display more language control errors, characterized by a failure to switch to the target language. These findings may suggest that the cognitive sequelae of mTBI could negatively impact bilinguals' ability to control their languages. Additionally, this study will investigate whether one language is more susceptible to language control errors and reduced fluency than the other. Several studies have concluded that more inhibition ability is required to suppress the dominant language than the non-dominant one (e.g., de Bruin et al., 2014). Therefore, it is hypothesized that more language intrusion errors from the non-dominant language would be observed after TBI.

The third aim is to study the correlation between performance on the language switching task and the non-verbal EF measures. A correlation between the verbal language switching task and the non-verbal EF is hypothesized suggesting a domain-general control of language in bilinguals.

Lastly, this study aims to explore mTBI and bilingualism-related variables such as language proficiency and language use and how it may impact cognitive and language control in bilinguals with mTBI.

Method

Participants

One hundred and seventy-five young monolingual and bilingual adults with and without a history of mTBI were recruited from Arizona State University (ASU) undergraduate courses. They received partial course credit for their participation. Informed consent was provided before participation in this study, and the experimental protocol was reviewed and approved by the ASU institutional review board (see Appendix A). Eleven participants were excluded for either not completing the online questionnaire or reporting a history of dyslexia, learning disability, or neurological damage other than mTBI (e.g., stroke). Out of the remaining 164 participants, 80 self-identified as monolinguals, and 84 identified as bilinguals speaking English and at least one other language. Detailed demographic, language, and head injury history is provided in Table 1 (see Appendix B for the detailed mTBI and language history for the bilingual mTBI group).

Table 1

Demographic, Language, and Head Injury History for Participants in Experiment 1

	Monolinguals (n=80)		Bilinguals (n=84)	
	No mTBI (n=24)	Hx of mTBI (n=56)	No mTBI (n=61)	Hx of mTBI (n=23)
Demographics				
Gender (Female) [a]	12	27	11	28
Age	19.05 (1.2)	20.25 (4.1)	19.47 (1.4)	20.32 (3.0)
SES [b]	3.33 (1.0)	3.41. (1.0)	3.07 (1.2)	3.7 (1.10
Language History				
L 1 Understanding			9.46 (.9)	9.40 (1.0)
L1 Speaking			9.18 (1.2)	9.00 (1.6)
L1 Reading			8.75 (2.3)	8.55 (2.6)
L1 Writing			8.52 (2.5)	7.70 (3.0)

	Monolinguals (n=80)		Bilinguals (n=84)	
	No mTBI (n=24)	Hx of mTBI (n=56)	No mTBI (n=61)	Hx of mTBI (n=23)
L2 Understanding			7.21 (2.3)	7.55 (2.1)
L2 Speaking			7.05 (2.0)	6.80 (2.0)
L2 Reading			7.02 (2.3)	6.95 (2.6)
L2 Writing			6.85 (2.3)	6.05 (2.8)
L2 Age of Acquisition			8.02 (3.8)	8.11 (5.7)
Simultaneous bilinguals [a]			27	12
% of L1 use			63.07 (24.2)	59.00 (25.0)
ESL [a]			46	12
Cambridge English Test	21.92 (3.3)	21.62 (2.2)	17.85 (4.7)	19.22 (4.6)
Other languages [a]				
Spanish			16	5
Chinese (e.g., Mandarin)			27	4
Arabic			7	1
Other			11	13
Head Injury History				
Total number of His		2.07 (1.7)		1.35 (1.0)
Diagnosed MTBI [a]		38		10
Years since last MTBI		5.14 (5.9)		6.25 (5.5)
Persistent Symptoms [a]		21		5
LOC [a]		11		4
Sports-related MTBI [a]		33		5

Note: Mean (SD) unless indicated otherwise. [a] Frequency. [b] Socioeconomic status (SES) was measured by quantifying maternal education as follows: 1=less than high school, 2= high school, 3=some college, 4=bachelors, 5=masters, 6=doctorate.

Material and Procedure

The participants completed two parts of this study: an online questionnaire and an in-person language and cognitive testing session. A link was sent to the participants to complete a questionnaire electronically. Participants who failed to complete the questionnaire at home did so at the beginning of their scheduled testing session. On the day of the appointment, each participant completed an approximately hour-long in-person testing protocol individually in a computer-equipped room. Throughout the session, participants were reminded to take breaks when/if needed.

General Questionnaire. Before completing any of the experimental tasks, all participants completed a 40-item online questionnaire. This questionnaire included questions about demographic, educational, and medical history as well as language experience (Appendix C). The medical history section contained questions about diagnosed and/or suspected TBI and the resulting acute and/or persistent symptoms, if any. Based on their answers on this section of the questionnaire, participants were classified as having no history of mTBI (healthy control) or with a history of diagnosed or suspected mTBI (mTBI group). For bilinguals, a modified version of the Language Experience and Proficiency Questionnaire (LEAP-Q; Marian et al., 2007) was administered. The bilingual participants were asked to rate their self-perceived proficiency in English and their other language across different modalities.

Inhibition Measures. To measure the ability to inhibit irrelevant information while attending to relevant stimuli (Eriksen, 1995), the *Flanker task* was presented using E-Prime 2.0 software on PC compatible computers. Participants were asked to indicate whether a central arrow was pointing to the left or the right by pressing keys labeled L and R (the N and M keys, respectively, on a standard keyboard). Ninety-six trials were administered for each of the following conditions: (1) control: The arrow presented in isolation, (2) interference control: The central arrow flanked by two arrows on the left and right pointing in the same direction or a different direction, (3) response inhibition:

The participants told to respond when the arrow is flanked by diamonds, but not when the arrow is flanked by Xs. The arrow was presented for 2000 milliseconds or until a response was elicited. Participants were instructed to respond as fast and accurate as possible. For each condition, participants completed 12 practice trials followed by accuracy feedback. No feedback was provided for the experimental trials. The performance on this task was measured based on accuracy (% correct) and mean reaction time (RT) for each of the three conditions (control, interference control, and response inhibition).

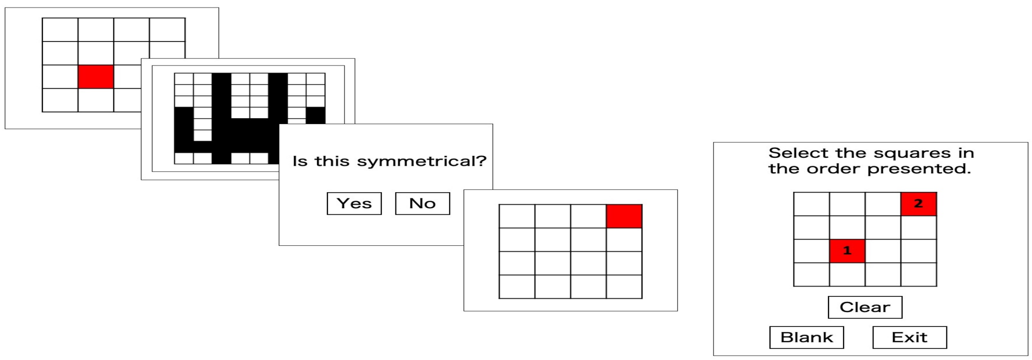
Switching Measure. A computerized version of the *Berg Card Sorting Test* (BCST; an adaptation of the WCST) was administered using the Psychology Experiment Building Language PEBL software (Mueller, 2013). Participants were asked to sort 128 virtual cards based on color, number, or shape into one of 4 decks of cards. The sorting rule was not revealed to the participant, but feedback was provided after each trial. Thus, the participant had to guess the rule initially and maintain or change the assumed rule based on the feedback. After ten correct responses, the sorting rule changed, requiring the participant to figure out the new rule. The task was scored based on (a) accuracy (percentage of cards correctly sorted), (b) perseverative errors (i.e., failing to switch from an old rule to a new rule), and (b) non-perseverative errors (e.g., choosing a deck that does not match the card in any of the three parameters).

Working Memory Measures. Computerized versions of the *digit forward and digit backward span tasks* were administered using PEBL (Mueller, 2013). In these tasks, the participants were presented a series of single digits at the rate of one number per second visually on a computer monitor and aurally over headphones. At a prompt, participants were asked to recall the numbers by typing them in the same order (digit forward) or reverse order (digit backward). The lists started with a sequence of three digits and increased in length when the participant correctly answered 2 out of 3 trials. The task was terminated after two consecutive errors for any given span. Performance on the tasks was scored as the highest span level successfully completed by the participant with a maximum possible span of 10.

Also, the modified *Symmetry Span* task was presented using E-Prime software (Foster et al., 2015). In this task, participants recalled the location of red shaded areas in 4x4 grids while making symmetry judgments (Figure 1). Before the experimental trials, the participants practiced each part of the task separately. First, they performed the recall task in which they were asked to remember the position of red squares presented sequentially for 800 milliseconds. Then, they performed the symmetry judgment task in which they had to make decisions about whether a shape was symmetrical about its vertical axis. Second, they performed three practice trials with both tasks combined. Participants were advised to maintain an accuracy level of 85% on the symmetry judgment task while trying to recall the location of the red squares in order accurately. The experimental trials consisted of successive pairs of symmetry judgment questions and grid presentations. Participants used a computer mouse to indicate the squares in the order that they appeared on a blank grid and their yes/no symmetry judgments. After each recall screen, participants were provided accuracy feedback for the recall and symmetry judgment tasks. The performance was measured using the partial credit score, which reflects the number of correctly recalled items within different trials. This scoring method was recommended by (Conway et al., 2005) to allow for more variability among participants.

Figure 1

Schematic Representation of the Symmetry Span Task



Clinical EF Measure. The *Zoo Map,* a subset from *the Behavioural Assessment of the Dysexecutive Syndrome* (BADS; Wilson et al., 1996), was used to measure the ability to formulate and execute a plan. In this task, the participants were asked to plan a route around a zoo to visit multiple animals (e.g., bears, birds, llamas). They were given a set of rules to obey when planning the route (e.g., start at the entrance and end at the exit, use the unshaded paths only once). The instructions were provided in a written format in addition to recorded verbal instructions. To complete the task accurately, the participant must take one of four possible solutions (routes). The participants were instructed to complete the task as fast as possible, and timing started immediately after the recorded instructions.

Performance on this task was measured by (1) the number of correct places visited, (2) the number and type of errors made, and (3) time to complete the task. The type of errors was divided into *Rule-breaking Errors* and *Other Errors*. Rule-breaking Errors included *omissions* of places to visit (i.e., not going to one of the places listed in the instructions), *intrusions* (i.e., visiting a place not listed in the instructions), and *path errors* of crossing a certain path more than once when instructed not to. Other Errors do not involve breaking any of the explicit rules. For example, crossing through the grass (not using the designated paths) and using discontinuous lines (e.g., attempting to visit a place then starting a new line somewhere else).

The Digit Fluency Tasks for Monolinguals. Participants were asked to produce as many digits in 1 minute in 3 conditions: 1) odd digits only, 2) even digits only, and 3) alternating between even and odd digits (Figure 2). The participants were instructed to produce these digits in random order. Therefore, they cannot produce numbers in a sequence (e.g., 1,3,5,7 in the odd condition or 1,2,3,4 in the alternating condition). They were also instructed not to repeat any response twice in any of the conditions and to be quick. The participants were reminded of these instructions after each condition. The tasks were recorded in Audacity software for Windows (Version 2.3.2) for later transcription and scoring by the researcher and trained research assistants. Scoring of this task was based on 1) the total items produced, 2) the total correct items, 3) the number of repetition errors, 4) the number of sequence errors, and 5) the number of failure-to-switch errors in the alternating category (e.g., saying two odd numbers back to back). These five scores were calculated separately for each 15-second interval.

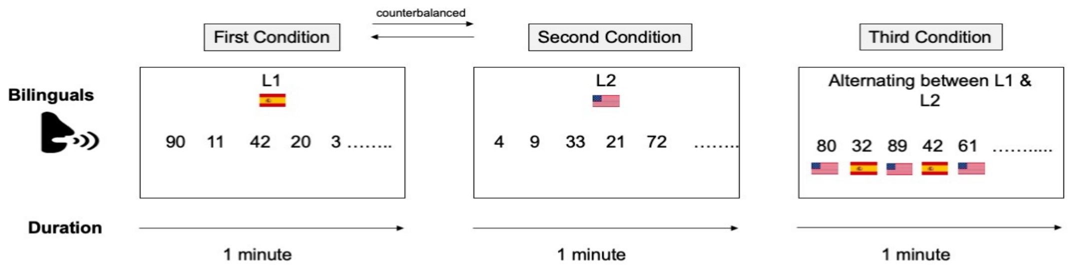
Figure 2

The Procedure for the Digit Fluency Task in Monolinguals

The Digit Fluency Tasks for Bilinguals. Participants were asked to produce as many digits in 1 minute in 3 conditions: 1) in English 2) in their other language, and 3) alternating between English and their other language (Figure 3). The participants were instructed to produce these digits in random order, not to repeat any response twice in any of the conditions, and to be quick. The tasks were recorded in Audacity software for Windows (Version 2.3.2) for later transcription by native speakers of the language. The Arabic-English bilingual researcher transcribed the Arabic samples, Spanish-English research assistants transcribed the Spanish samples, and student volunteers transcribed samples from other languages for partial course credit.

Figure 3

The Procedure for the Digit Fluency Tasks in Bilinguals



Note: The example presented is for Spanish-English bilinguals.

Scoring of this task was based on 1) total items produced, 2) total correct items, 2) the number of repetition errors, 3) the number of sequence errors, 4) the number of failure-to-switch errors in the alternating language condition (e.g., saying two English numbers back to back) and 5) direct translation errors in the alternating condition (e.g., saying *uno* immediately after *one).* These five scores were calculated separately for each 15-second interval.

Results

Performance on the Experimental EF Tasks

The descriptive data from each of the experimental EF tasks are included in Table 2.[1] Two sets of analyses were conducted to examine the effects of language group and mTBI history on the scores of these EF measures. First, separate 2(Language Group: Monolingual vs. Bilingual) × 2(mTBI History: mTBI vs. Healthy Control) analysis of variance (ANOVA) tests were used on the Forward and Backward Digit Spans, Symmetry Span, and accuracy and perseverative errors on the BCST.[2] There was a main effect of mTBI History on the Forward digit Span, $F(1,159) = 4.08$, $p = .045$, $\eta_p^2 = .025$. Participants with a history of mTBI had lower spans ($M = 7.0$) than healthy control participants ($M = 7.5$). However, the main effect of Language Group and its interaction with mTBI History were not statistically significant on the Forward Digit Span. On the other hand, the main effect of Language Group was statistically significant on the BCST accuracy, $F(1,158) = 7.87$, $p = .006$, $\eta_p^2 = .047$. No other statistically significant main effects or interactions were observed on the BCST accuracy, the BCST errors, the Backward Digit Span, nor the Symmetry Span.

---

[1] All statistical analyses were performed using SPSS for Mac, versions 25 & 26.

[2] To overcome the limitation of the study's unbalanced design, all ANOVA, ANCOVA, repeated measures, and mixed designs were implemented using a general linear model (GLM) approach and Type III Sums of Squares, as recommended by (Wickens & Keppel, 2004). Also, due to the sensitivity of unbalanced designs to violations of heterogeneity of variance, the degrees of freedom were corrected using Greenhouse-Geisser estimates whenever a violation was suspected.

Second, mixed-model analysis of covariance (ANCOVA) was used separately on the accuracy and RT of the Flanker task with Language Group and mTBI History as the between-subject variables and Condition (control vs. interference control vs. response inhibition) as the within-subject variable. There was a positive correlation between the Cambridge English test and the accuracy on the response inhibition condition of the Flanker, $r(155) = .338$, $p < .001$; therefore, this objective English proficiency measure was included as a covariate.[3] Mauchly's test of sphericity was significant, $p < .001$, therefore the degrees of freedom were corrected using the Greenhouse-Geisser estimates. On accuracy, there was a main effect of Condition, $F(2, 204.27)= 12.60$, $p<.001$, $\eta_p^2=.077$. Participants were significantly more accurate on the interference control condition ($M = .975$) compared to the control ($M = .958$) and the response inhibition ($M = .953$) conditions of the Flanker. Also, the interaction of Condition and the Cambridge English scores was significant, $F(2, 204.27)= 10.98$, $p < .001$, $\eta_p^2=.067$. No other statistically significant interactions were observed. Similarly, there was a significant main effect of Condition on the RT of the Flanker, $F(2, 226.13) = 6.33$, $p = .005$, $\eta_p^2 = .040$, and a significant interaction of Condition and the Cambridge test, $F(2, 204.27) = 4.03$, $p < .030$, $\eta_p^2=.026$. No other interactions were significant.

[3] There was no correlation between reported English understanding or the Cambridge English test with any of the other EF tasks (p<.05), therefore, English proficiency was not added as a covariate.

Table 2

Means and Standard Deviations for each of the EF Tasks Across Groups

	Monolinguals		Bilinguals	
	Healthy Control (n=24)	mTBI (n=56)	Healthy Control (n=61)	mTBI (n=23)
Digit Forward [a]	7.52 (1.0	6.96 (1.5)	7.54 (1.5)	7.09 (1.4)
Digit Backward [b]	5.86 (1.3)	5.80 (1.4)	6.13 (1.8)	5.57 (2.0)
Symmetry Span [c]	15.04 (5.0)	14.55 (5.4)	16.29 (5.1)	14.74 (6.5)
BCST accuracy [d]	81.37 (5.3)	79.10 (9.3)	77.36 (8.5)	74.18 (12.6)
BCST perseverations	12.25 (4.1)	13.38 (6.1)	14.17 (5.7)	15.50 (8.1)
Flanker control Acc. [e]	97.68 (1.9)	97.25 (26.7)	95.91 (7.4)	92.30 (11.1)
Flanker interference control Acc.	98.10 (1.8)	98.18 (18.3)	96.88 (6.0)	96.95 (2.5)
Flanker response inhibition Acc.	98.89 (0.9)	98.94 (13.2)	93.75 (13.6)	89.87 (18.8)
Flanker control RT	378.49 (29.8)	395.08 (50.8)	381.22 (47.0)	376.33 (49.4)
Flanker interference control RT	398.22 (34.3)	409.71 (54.8)	390.64 (51.2)	408.21 (63.7)
Flanker response inhibition RT	266 (35.4)	271.96 (45.4)	280.77 (74.0)	305.47 (56.8)

[a] Data from one participant was missing for the Forward Digi Span. [b] Data from four participants were missing for the Backward Digi Span. [c] On the Symmetry Span task, three participants had missing data, and 12 participants scored below 75% on the symmetry judgment part of the task. Therefore, the cut-off criteria were adjusted to 73%, and only 4 participants were excluded for this task. [d] Two participants had missing data on the BCST. [e] Two participants had missing Flanker data, and 4 participants were excluded for scoring below 55% accuracy.
Note: All missing data is due to technical issues; hence, they were believed to be missing at random.

Performance on the Zoo Map

Two-factor ANCOVA was performed separately on each of the Zoo Map scores with language group and mTBI history as between-subject factors and the scores on the Cambridge English Test as an English proficiency covariate. The covariate, English proficiency, was significantly related to the number of Rule-breaking Errors on the Zoo

Map, $F(1, 158) = 1.67$, $p = .010$, $\eta_p^2 = .025$, but not to the number of correct places visited on the Map, Other Errors, or time ($p > .01$). The main effect of Language Group was not significant for any of the Zoo Map variables after controlling for English proficiency ($p > .01$). However, the main effect of mTBI History was statistically significant on the number of Rule-breaking Errors, $F(1, 158) = 5.80$, $p = .017$, $\eta_p^2 = .035$, but not to the other variables ($p > .01$; see Table 3 for means and SD).

Table 3

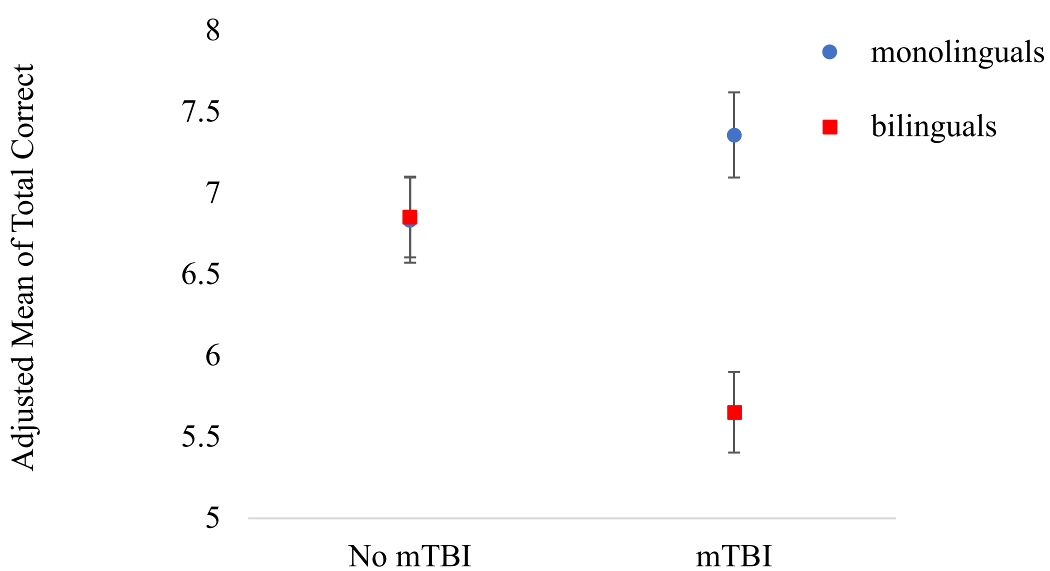
Means, Standard deviation, Adjusted means, and standard errors (for $_{adj}$means) for each of the Zoo Map Variables across the different groups

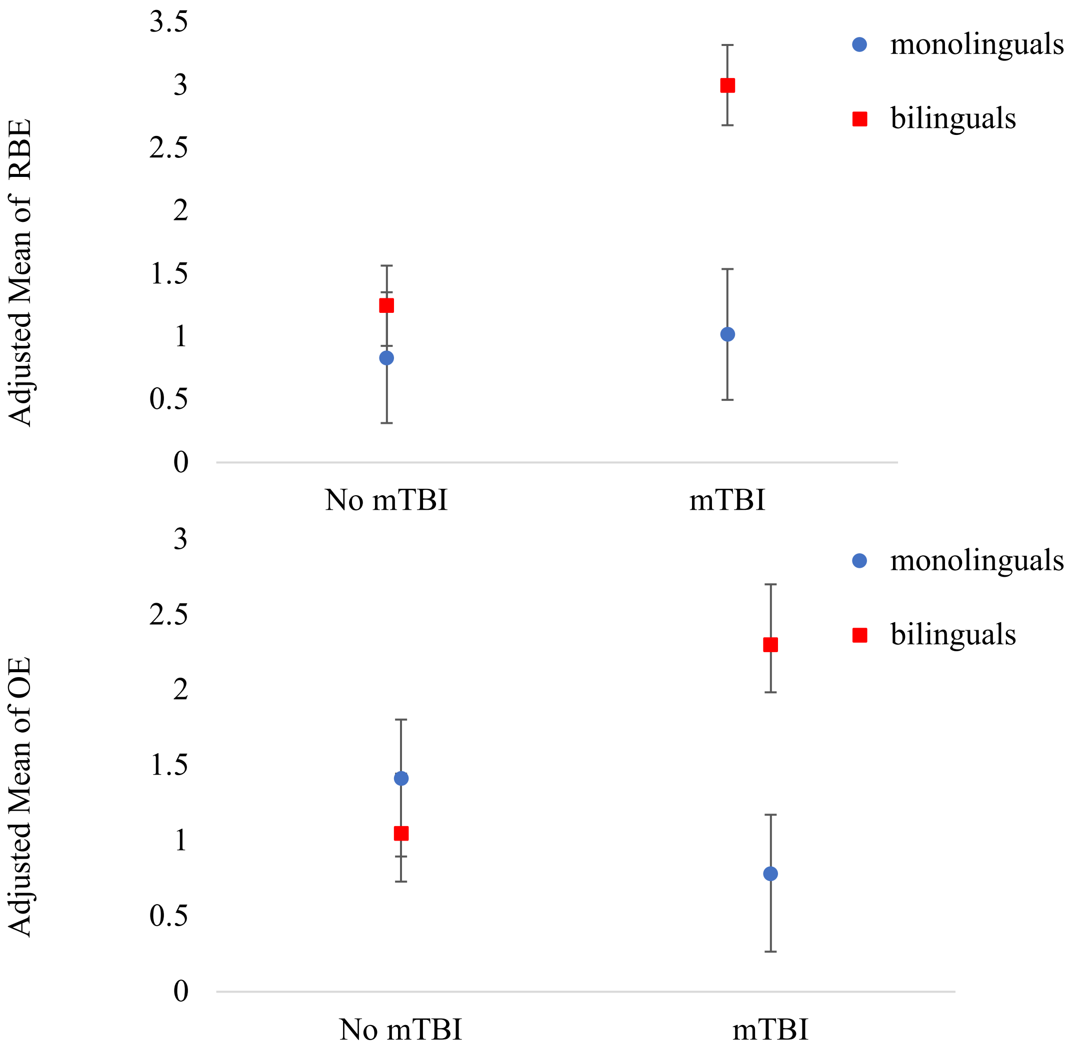
	Monolinguals				Bilinguals			
	Healthy Control (n=24)		mTBI (n=56)		Healthy Control (n=61)		mTBI (n=23)	
	M (SD)	$_{adj}$M (SE)	M (SD)	$_{adj}$M (SE)	M (SD)	$_{adj}$M (SE)	M (SD)	$_{adj}$M (SE)
Time (seconds)	152.4 (81.7)	157.5 (24.0)	140.3 (115.6)	143.53 (16.1)	175.8 (129.1)	170.6 (15.6)	140.7 (101.5)	139.0 (24.1)
Correct places	6.83 (2.1)	6.73 (0.4)	7.36 (1.6)	7.26 (0.3)	6.85 (2.0)	6.96 (0.3)	5.65 (2.2)	5.69 (0.4)
Rule-breaking Errors	0.83 (1.7)	1.04 (0.5)	1.02 (2.2)	1.21 (0.3)	1.25 (2.1)	1.03 (0.3)	3.00 (4.2)	2.93 (0.5)
Omissions	0.08 (0.4)		0.07 (.3)		.38 (.89)		.70 (0.8)	
Intrusions	0.08 (0.3)		0.07 (.5)		.11 (.58)		.22 (0.8)	
Path Errors	0.70 (1.7)		0.89 (1.9)		.77 (1.6)		2.1 (3.1)	
Other Errors	1.42 (2.3)	1.46 (0.4)	0.88 (1.6)	0.84 (0.30	1.05 (1.8)	1.00 (0.3)	2.30 (2.3)	2.29 (0.4)
Transpositions	1.17 (2.3)		0.79 (1.6)		.79 (1.5)		1.70 (1.7)	
Deviation Errors	0.25 (0.4)		0.27 (0.62)		.26 (.48)		0.61 (1.5)	

On the other hand, there was a statistically significant interaction of Language Group with mTBI History on the number of correct places, $F(1, 158) = 7.14$, $p = .008$, $\eta_p^2 = .043$, Rule-breaking Errors, $F(1, 158) = 4.00$, $p = .047$ and Other Errors, $F(1, 158) = 8.25$, $p = .005$, after controlling for English proficiency. A follow-up simple effects analysis with Bonferroni correction revealed statistically significant differences between the mTBI group and the healthy control group within the bilingual group only for the correct places, $p = .002$, $\eta_p^2 = .061$, Rule-breaking Errors, $p = .007$, $\eta_p^2 = .045$, and Other Errors, $p = .003$, $\eta_p^2 = .054$. Bilinguals with mTBI performed significantly worse on all measures of the Zoo Map task than healthy control bilinguals. This discrepancy in performance based on the history of mTBI was not observed among the monolingual group (Figure 4).

Figure 4

Interaction of Language Group and mTBI in the Zoo Map Scores





Note: Interaction of Language Group (monolingual in *blue* and bilingual in *red*) and mTBI History (X-axis) was noted in the correct places visited (top), Rule-Breaking Errors (middle), and Other Errors (bottom) after adjusting for English proficiency. The error bars represent standard error (*SE*).

Performance on the Digit Fluency Tasks

Performance on the Digit Fluency tasks by condition and across groups is presented in Table 4. Three sets of analyses were conducted on these tasks. First, Mann-Whitney tests were conducted separately for monolinguals and bilinguals to compare groups based on mTBI history on the total and total correct items produced for each condition. Second, Mixed-design ANOVAs were used to analyze total correct items between groups across conditions and over time. Third, Mann-Whitney tests were used to analyze the errors in bilinguals based on mTBI history.

Table 4

Total Items Produced, Total Correct, and Percentage of Errors on Each Trial and Condition Across Groups

	Monolinguals		Bilinguals	
	Healthy Control (n=24)	mTBI (n=56)	Healthy Control (n=43)	mTBI (n=13)
L1 Condition [a]				
Total Items Produced	25.38 (5.8)	29.24 (6.6)	39.30 (11.3)	31.46 (6.6)
Total Correct	18.56 (2.4)	20.99 (3.4)	28.95 (7.2)	24.39 (4.0)
Repetition Errors	10.49 (5.8)	11.25 (7.4)	12.00 (9.7)	9.29 (7.4)
Sequence Errors	13.38 (12.0)	13.90 (9.8)	12.40 (13.7)	11.16 (9.7)
L2 Condition				
Total Items Produced			33.19 (7.7)	25.00 (7.2)
Total Correct			26.21 (5.8)	20.69 (6.0)
Repetition Errors			9.64 (8.8)	7.71 (5.7)
Sequence Errors			9.37 (7.8)	6.21 (5.5)
Alternating Condition				
Total Items Produced	20.79 (4.7)	23.91 (5.9)	28.21 (7.5)	20.38 (4.1)
Total Correct	18.83 (4.4)	20.29 (5.3)	22.77 (6.6)	18.38 (5.7)
Repetition Errors	7.17 (6.5)	7.73 (6.8)	5.27 (6.8)	3.60 (4.3)
Sequence Errors	7.05 (10.6)	8.65 (10.8)	7.24 (13.1)	7.28 (11.0)
Direct Translation Errors			5.00 (11.6)	1.04 (2.7)
Failure-to-switch from L1 to L2			2.86 (5.4)	3.43 (4.7)
Failure-to-switch from L2 to L1			1.99 (3.9)	1.00 (3.6)

Note: Errors are expressed in percentages. Data from 28 bilingual participants were excluded for not having the transcription of the other language available. [a] For monolinguals, the odd and the even conditions were collapsed in the L1 condition.

Performance of the mTBI Groups Compared to Healthy Controls. In monolinguals, a Mann-Whitney test indicated that the total items produced in 1 minute collapsed across the blocked odd and even conditions[4] were greater for the mTBI group than for the healthy control group, $U = 917$, $p = .010$. Similarly, the total correct items produced in 1 minute was greater for the monolingual mTBI group than the healthy monolingual controls, $U = 975$, $p = .001$. In the alternating condition, the monolingual mTBI group produced significantly more total items than the healthy control group, $U = 908$, $p = .013$; however, there was no significant difference between the two groups in terms of total correct items, $p < .05$.

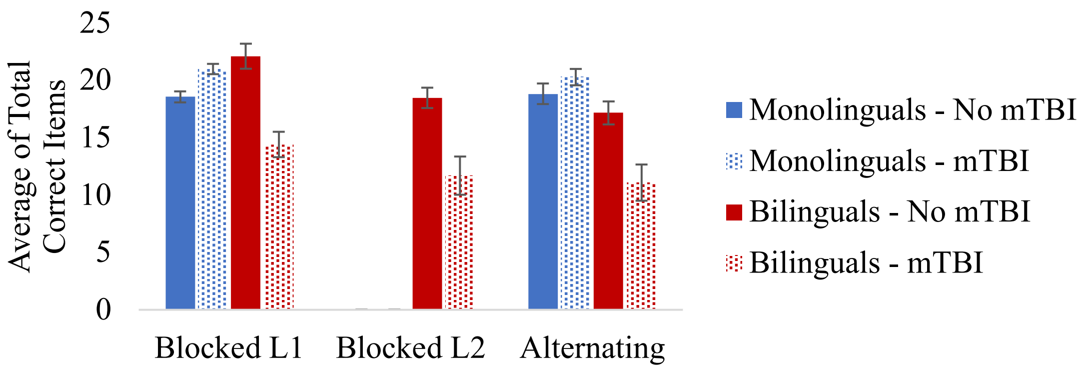
On the contrary, the healthy control bilinguals performed better than the bilingual mTBI group in terms of total items and total correct items produced in 1 minute in all conditions (Figure 5). In the L1 condition, the bilingual healthy control group produced more total items, $U = 159.5$, $p = .020$, and total correct items, $U = 154$, $p = .015$, than the mTBI group. Similarly, in the L2 condition, the bilingual healthy control group produced more total items, $U = 117$, $p = .002$, and total correct items than the mTBI group, $U = 151$ $p = .012$. Lastly, In the alternating condition, the bilingual healthy control group also produced more items and total correct than the mTBI group, $U = 103$, $p =.001$, $U = 172$, $p = .037$, respectively.

---

[4] In monolinguals, there was no reason to believe that performance on the *odd* condition is different from the *even* condition, therefore performance on these two conditions was collapsed (referred to as '*blocked*' hereafter).

Figure 5

Total Correct Items Produced on The Digit Fluency Task Across Conditions and Groups.



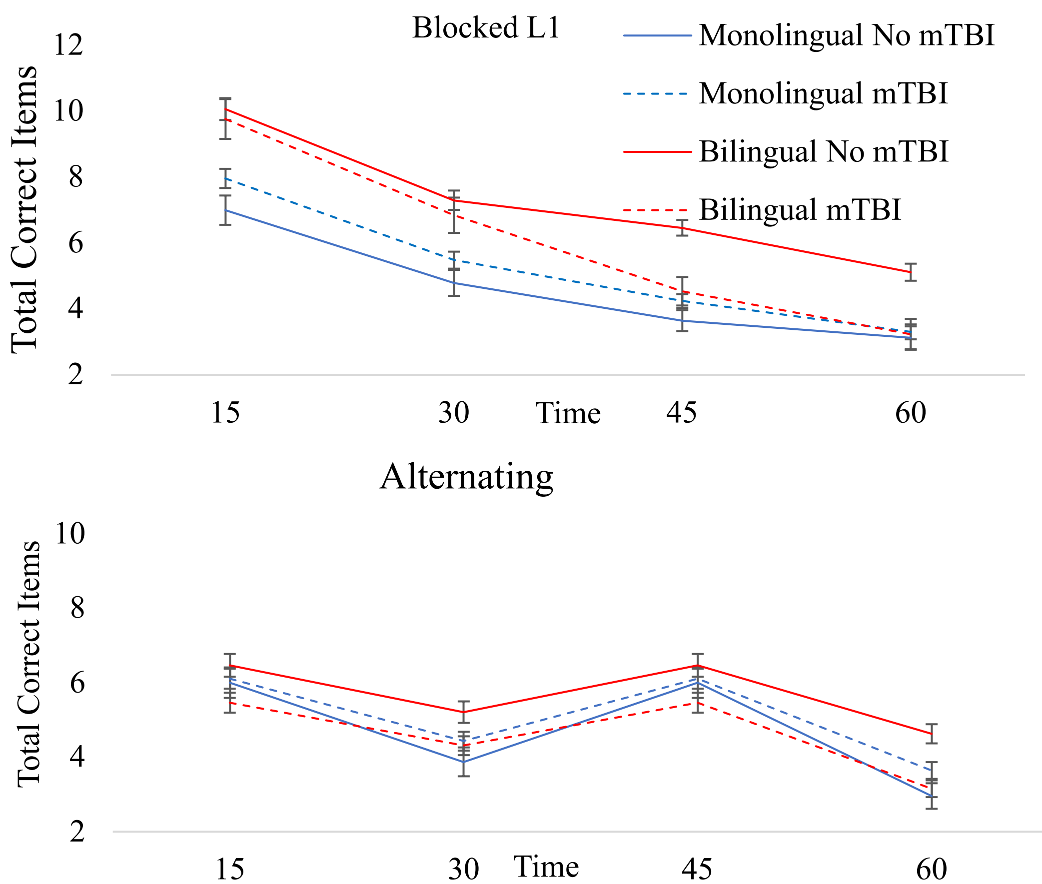
Note: For monolinguals, the odd and the even conditions were collapsed in the Blocked L1 condition.

Performance Over Time Across Conditions and Between Groups. Mixed-design ANOVA was used with 2(Language Group: Monolingual vs. Bilingual) × 2(mTBI History: mTBI vs. Healthy Control) × 2(Condition: Blocked vs. Alternating) × 4(Time: 1st Interval vs. 2nd Interval vs. 3rd Interval vs. 4th Interval) on the total correct items as the dependent variable. Between subjects, there was a significant main effect of Language Group on the total correct items produced, $F(1,132) = 20.56$, $p < .001$, $\eta_p^2=.135$. Also, there was a significant interaction between Language Group and mTBI History, $F(1,132)= 20.56$, $p < .001$, $\eta_p^2 = .093$. A follow-up Bonferroni-corrected pairwise comparisons revealed a significant difference between the mTBI group and the healthy control group among bilinguals only, $p = .002$, $\eta_p^2 = .074$. Bilinguals with mTBI produced overall less correct items compared to healthy controls. Moreover, the main effect of Condition, $F(1,132) = 28.85$, $\eta_p^2 = .179$, and Time, $F(2.4,317.4)= 184.82$, $\eta_p^2 = .583$, on the total correct items was significant, $p < .001$. Also, the interaction of

Condition and Time, $F(2.6,348.9) = 66.45$, $\eta_p^2 = .335$, Condition and Language Group, $F(1,132) = 25.01$, $\eta_p^2 = .159$, and the 3-way interaction of Condition, Time, and Language Group, $F(2.6,348.9)= 4.33$, $\eta_p^2 = .035$, were significant, $P < .05$. Bilinguals produced more total correct items in the Blocked conditions across all time intervals (Figure 6).

Figure 6

Total Correct Items Over Time by Condition and Group

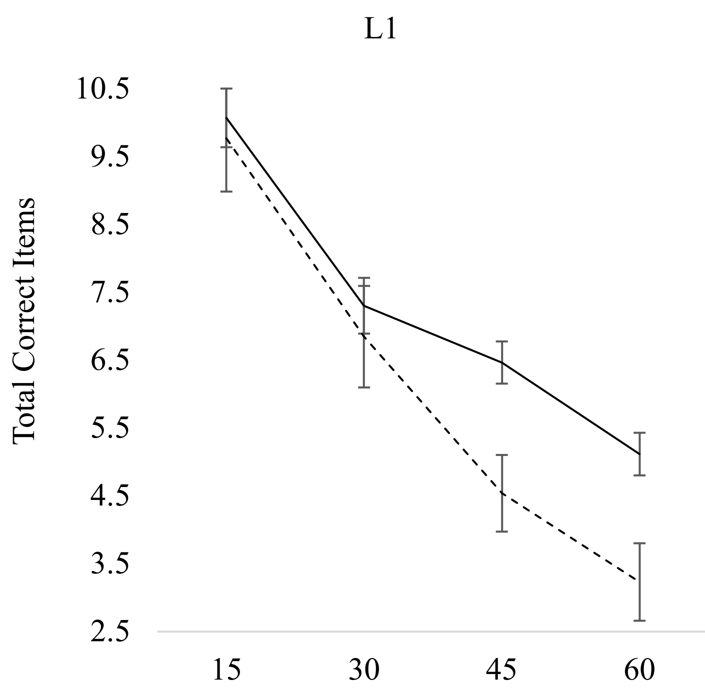


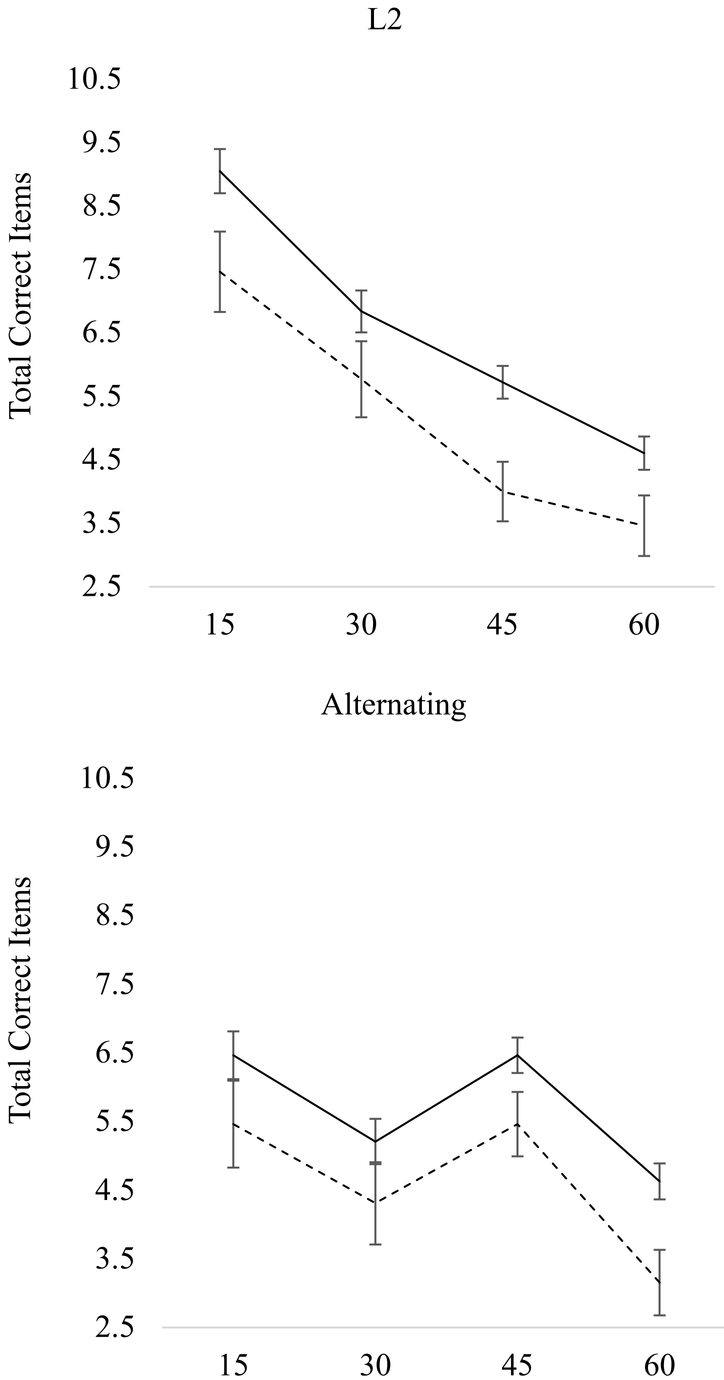
Note. Total Correct Items produced over time in the Blocked L1 condition (top) and the alternating condition (bottom) by Language Group (monolingual in *blue* and bilingual in *red*) and mTBI History (the mTBI group in dotted lines and the healthy control group in solid lines).

To examine bilinguals' performance on the Digit Fluency Tasks, mixed-design ANOVA was used with 2(mTBI History: mTBI vs. Healthy Control) × 3(Condition: L1 vs. L2 vs. Alternating) × 4(Time: 1st Interval vs. 2nd Interval vs. 3rd interval vs. 4th Interval on the total correct items as the dependent variable. As expected, the main effect of mTBI History was significant, $F(1,54) = 9.708$, $p = .003$, $\eta_p^2 = .152$. Bilinguals with a history of mTBI produced less total correct items across all conditions (Figure 7). There was also a significant main effect of Condition, $F(2,108)=15.830$, $\eta_p^2=.227$, and Time, $F(2.5,134.3)=109.030$, $\eta_p^2=.669$, on the total correct items produced, $p<.001$.

Figure 7

Total Correct Items by Condition Based on mTBI History



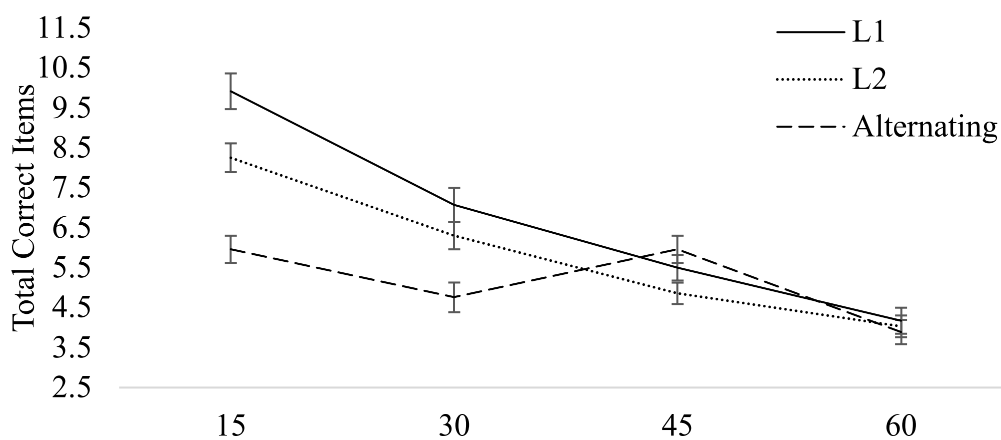


Note. Total Correct Items produced over one minute in L1, L2, and the alternating conditions and by mTBI history (the mTBI group in dotted lines and the healthy control group in solid lines).

Also, the interaction of Time and Condition was significant, $F(4.6,251.5) = 14.01$, $p < .001$, $\eta_p^2 = .206$ (Figure 8). Follow-up Bonferroni-corrected pairwise comparisons revealed that bilingual participants (with and without mTBI history) exhibited a discrepancy in performance between all 3 conditions in the first interval, $p < .001$, $\eta_p^2 =$ 564. In the first 15 seconds, bilinguals produced significantly more total correct items in the L1 condition ($M = 9.9$), followed by L2 ($M = 8.3$), and lastly, the alternating condition ($M = 6.0$). By the second interval, there was a discrepancy only between the first two conditions and the alternating condition; however, no significant difference between L1 and L2 was noted, $p > .05$. By the third interval, bilinguals produced significantly less correct items in the L2 compared to the alternating condition, $p = .018$. By the fourth and last interval, there were no differences between the three conditions, $p > .05$. No other interactions were significant.

Figure 8

Total Items Correct Over Time for Bilinguals Over Time Across Conditions



Analysis of Errors in bilinguals. The proportion of the different types of errors (i.e., repetition, sequence, failure-to-switch, and direct translation) were separately compared between bilinguals with and without mTBI History using Mann-Whitney tests. There was no significant difference in the proportion of errors between the two bilingual groups, $p > .05$. In terms of failure-to-switch errors, there was generally a small number of this type of error in the alternating condition ($M = 1.23, SD = 1.95$). Inspection of the direction of failure-to-switch errors showed that bilinguals failed to switch from L1 to L2 more than failing to switch from L2 to L1 (Table 4); however, that difference did not reach significance, $p > .05$.

Correlation of EFs tasks with the Digit tasks in bilinguals

A correlational analysis was conducted to examine the relationship between measures of EFs and performance on the Digit Fluency tasks in bilinguals. The EF measures included in this analysis were: (1) forward digit span, (2) backward digit span, (3) Symmetry Span, (4) BCST accuracy, (5) BCST perseverative errors, (6) interference control accuracy, (7) interference control RT, (9) response inhibition accuracy, and (10) response inhibition RT. The total items produced and errors on each of the three conditions (L1, L1, and alternating) of the Digit Fluency task were included in the correlation analysis as well.

In the L1 condition, the total items produced in one minute correlated positively with the Forward Digit Span and negatively with the RT on the response inhibition condition of the Flanker, $r(54) = 0.30$, and $r(52) = -0.35$ respectively, $p < .01$).

Bilinguals with higher Forward Digit Spans and who were inhibiting their motor responses quicker on the Flanker produced more items in their L1. Additionally, higher Forward and Backward Digit Spans correlated with more repetition errors in L1, $r(54) = 0.41$, and $r(53) = 0.40$ respectively, $p < .01$). Similarly, the total items produced in the L2 condition of the Digit Fluency task correlated negatively with the RT on the response inhibition condition of the Flanker, $r(52) = -0.30, p < .01$ and the repetition errors correlated with higher Forward and Backward Digit Spans, $r(54) = 0.30$, and $r(53) = 0.34$ respectively, $p < .01$. Also, more repetition errors in L2 correlated significantly with lower accuracy on the interference control condition of the Flanker $r(52) = -0.30$, $p < .05$.

Lastly, the total items produced in the alternating condition correlated positively with the Forward and Backward Digit Spans, $r(54) = 0.30$, and $r(53) = -0.31$, respectively, $p < .05$. The repetition errors on this condition correlated negatively with the accuracy of the interference control condition of the Flanker only, $r(52) = 0.39$, $p < .01$. Direct Translation errors (e.g., saying *uno* immediately after *one*) correlated significantly with the accuracy and RT on the response inhibition condition of the Flanker, $r(52) = -0.40$ *and* $r(52) = 0.38$, respectively, $p < .01$. That is, bilinguals who made more response inhibition errors on the Flanker (i.e., did not inhibit motor responses to the flanking arrows between Xs) made more direct translation errors. Lastly, failure-to-switch errors (i.e., saying two consecutive digits in the same language in the alternating condition) correlated significantly with the Symmetry Span and the accuracy and perseverative errors on the BCST, $r(54) = 0.30$, $r(54) = -0.27$, $r(54) = 0.34$, respectively, $p < .05$. This result indicates that bilinguals who made more errors on the non-verbal working memory and switching tasks made more cross-linguistic errors when alternating between L1 and L2 was required.

Correlation between L1 and L2 Proficiency and The Digit Tasks

A correlational analysis was conducted between the reported L1 and L2 proficiency in understanding and speaking and the total correct items and proportion of errors in the three Digit Fluency conditions. The L1 condition and the alternating condition did not correlate with L1 nor L2 proficiency. The only observed significant correlation was between L2 understanding and the proportion of errors in the L2 condition, $r = -.273$, $p < .05$. Bilinguals who reported higher proficiency in L2 understanding made fewer errors in the L2 condition of the Digit Fluency task.

Case Analysis of the Bilingual mTBI Group

The mTBI bilingual group was vastly heterogeneous in terms of mTBI history and bilingual language experience. As expected, no two participants within this group had identical language and mTBI profiles (see Appendix B for the full language and mTBI profiles). Therefore, this section aims to explore the different mTBI and bilingualism variables and provide a descriptive analysis of their effect on the EF and verbal fluency tasks.

Exploring the mTBI-related Variables. The influence of different mTBI variables on scores from the EF and verbal fluency tasks was explored using two approaches. First, a correlational analysis was conducted between scores from different tasks (e.g., experimental EF, Zoo Map, Digit Fluency tasks) and the following mTBI-related variables: 1) history of diagnosed mTBI, 2) history of repetitive mTBIs, 3) reported persistent symptoms, 4) reported loss of consciousness, 5) years since the last mTBI, and

6) the number of mTBIs.[5] Based on this analysis, there were no correlations between any of these variables and performance on any of the study's tasks. The second approach to exploring mTBI-related variables was to analyze three subgroups of interest descriptively. These three subgroups consisted of those who reported: (1) persistent cognitive or behavioral symptoms, (2) history of repetitive mTBI, and (3) recent mTBI.

Eight participants out of the bilingual mTBI group (34.8%) reported persistent cognitive or behavioral symptoms since their last head injury. The symptoms included memory and attention problems, increased anxiety, sleep disturbances, changes in mood, headaches, and nausea. This subgroup of bilinguals showed lower scores on all measures of EF and fluency tasks compared to the healthy control bilinguals, except for the accuracy of the interference control condition of the Flanker (Table 5). However, the only measure that showed over 1 standard deviation difference from the mean of the bilingual control group was the Rule-breaking Errors on the Zoo Map task (Table 5; see Table 2, 3, and 4 for the healthy control and mTBI group means). On the Digit Fluency task, this subgroup did not show a significant discrepancy in their scores on the 3 conditions (L1, L2, and alternating). That is, this subgroup with persistent symptoms did not perform significantly better on the L1 condition compared to L2 and the alternating condition, a pattern that was observed in the healthy control group.[6]

[5] The first four variables were dichotomous, therefore, a point biserial correlation was used.
[6] Repeated-measures ANOVA on the total correct items with Condition (L1, L2, and alternating) as the within-subject variable was conducted for this subgroup (n=8) and did not show a significant main effect, $p>.05$.

The other group of interest was the bilingual participants who reported a history of repetitive mTBI, which has been associated with long-term cognitive impairments among monolingual college students (Vynorius et al., 2016). There were only two bilingual participants who reported multiple mTBIs. Both participants showed lower working memory spans than the average for the healthy control bilinguals (>1 SD). However, they performed within average on the Zoo Map task and the BCST. Data from the Flanker and the Digit Fluency task were not available for these two participants.

Considering the transient nature of some cognitive symptoms after mTBI that may resolve over time, the third group of interest was bilinguals who reported a recent mTBI. Three bilingual participants experienced a mTBI within a year of the testing date. Their performance was comparable to the healthy control group (Table 5)

Table 5

Descriptive Data for three Subgroups Based on mTBI History.

	Persistent Symptoms (n=8)	Repetitive mTB (n=2)	Recent mTBI (n=3)
Digit Forward	6.8 (1.7)	6.0 (.0)	8.0 (1.0)
Digit Backward	5.6 (1.5)	3.5 (.7)	6.7 (.6)
Symmetry Span	15.3 (5.4)	10.5 (6.4)	15.7 (6.7)
BCST Accuracy	72.5 (15.5)	72.65 (4.4)	80.5 (.8)
BCST Perseverations	17.3 (11.0)	16.41 (.0)	12.8 (1.8)
Flanker Interference control Acc.	0.98 (.0)		0.98 (.0)
Flanker Response inhibition Acc.	0.91 (.2)		0.93 (.1)
Flanker Interference control RT	436.5 (83.4)		400.6 (45.6)
Flanker Response inhibition RT	320.1 (63.9)		231.2 (10.9)
Zoo Map Correct places	6.4 (2.1)	6.5 (2.1)	6.3 (2.1)
Zoo Map RBE	4.0 (6.1)	1.5 (2.1)	1.7 (1.5)
Zoo Map OE	2.5 (3.2)	2 (1.4)	2.0 (1.7)
Digit Fluency L1	22.0 (4.8)		29.0 [a]
Digit Fluency L2	21.0 (5.7)		19.0
Digit Fluency Alternating	17.8 (4.4)		22.0

Note: [a] n=1.

Exploring the bilingualism-related Variables. Similarly, to explore the effect of the different bilingualism variables on the performance on different tasks, a correlational analysis was initially conducted, followed by a descriptive analysis of specific subgroups. The bilingualism-related variables included in the correlational analysis were: 1) speaking English as a second language (ESL), 2) simultaneous bilingualism,[7] 3)

[7] The first two variables were dichotomous.

percentage of L1 daily use, 4) L1 reported proficiency, 5) L2 reported proficiency,[8] 6) Age of L2 acquisition, 7) Number of languages spoken, and 8) the Cambridge English Test score. The only variables that correlated significantly with scores from the EF and Digit Fluency tasks were the ESL and the percentage of L1 daily use variables. Bilinguals with mTBI history who spoke English as a second language were slower on the response inhibition condition of the Flanker, $r(20) = .456$, $p = .043$, and produced more total correct items on the L2 condition of the Digit Fluency task, $r(13) = .753$, $p = .003$. On the other hand, there was a negative correlation between the percentage of L1 daily use and both types of errors on the Zoo Map task, $r(20) = -.456$, $r(20) = -503$, for the Rule-breaking and Other Errors respectively, $p < .05$. Also, bilinguals with mTBI who reported using L1 more than L2 were faster on the interference control condition of the Flanker, $r(18) = -.596$, $p = .009$.

When asked about the percentage of their L1/L2 daily use, bilinguals reported three patterns: (1) using both languages equally on daily bases (dual-language users), (2) using L1 70% of the time or more (frequent L1 users), or (3) using L1 40% of the time or less (frequent L2 users). These three subgroups were explored further, and their descriptive data are provided in Table 6. The performance of the frequent L1 users on the different EF tasks was comparable to the healthy control bilingual group, except for the L2 condition of the Digit Fluency task, where they scored > 1 SD below the mean. Similarly, the dual-language users appeared to perform comparably to the control group

---

[8] L1 and L2 proficiency were measured by calculating the average of the speaking and understanding proficiency for each language.

on all measures, except for the Zoo scores. Bilinguals with mTBI, who were dual-language users, scored over 1 SD below the mean of the control group on all of the Zoo Map scores. On the other hand, the frequent L2 users had a lower Backward digit span, were slower on the interference control condition of the Flanker, made more errors on the Zoo Map, and produced less correct items on the alternating Digit Fluency condition (>1-2 SD) compared to the bilingual control group.

By observing the Digit Fluency performance of these three subgroups of bilinguals with mTBI, an advantage was noted for the dual-language users on all three conditions, although it did not reach statistical significant.[9] In the L1 condition, dual-language users produced 4.3 total correct items on average compared to the frequent L1 users, $d = 1.20$, and the frequent L2 users, $d = 2.68$. Similarly, the dual-language users produced 4 – 8 more correct items in the L2 condition compared to the frequent L2 users, $d = .85$, and the frequent L1 users, $d = 1.35$. Lastly, on the alternating condition, the dual-language users produced 3 – 8 correct items on average compared to the frequent L1, $d = .59$, and L2 users, $d = 1.8$.

[9] Kruskal-Wallis test did not show significant group differences in the total correct items on any of the Digit Fluency conditions, P>.05.

Table 6

Descriptive Data for four Subgroups Based on Language Experience

	ESL (n=12)	Dual-language users (n=5)	Frequent L1 users (n=10)	Frequent L2 users (n=5)
Digit Forward	7.1 (1.6)	7.0 (1.7)	7.0 (1.1)	6.6 (1.5)
Digit Backward	5.2 (2.3)	6.6 (2.1)	5.0 (1.5)	4.2 (1.8)
Symmetry Span	14.4 (6.9)	15.0 (8.8)	14.0 (5.6)	12.8 (7.1)
BCST Accuracy	75.3 (12.4)	81.7 (2.3)	75.1 (11.9)	70.6 (15.9)
BCST Perseverations	15.3 (6.8)	11.8 (.5)	14.8 (10.3)	17.9 (7.5)
Interference control Acc.	0.96 (.02)	0.97 (.03)	0.97 (.03)	0.96 (.03)
Response inhibition Acc.	0.89 (.2)	0.88 (.2)	0.85 (.2)	0.98 (.02)
Interference control RT	430.2 (70.8)	396.9 (39.6)	380.57 (37.3)	493.9 (76.5)
Response inhibition RT	328.3 (54.2)	320.4 (58.8)	284.99 (55.2)	343.2 (43.0)
Zoo Map Correct places	5.0 (2.4)	4.4 (2.0)	6.40 (2.3)	5.6 (2.5)
Zoo Map RBE	4.2 (5.0)	3.4 (3.0)	1.60 (2.2)	4.8 (7.5)
Zoo Map OE	3.0 (2.7)	3 (1.7)	1.30 (1.7)	3.4 (3.8)
Digit Fluency L1	23.0 (3.3)	26 (1.7)	21.75 (4.4)	21.7 (1.5)
Digit Fluency L2	24.7 (4.5)	26.3 (5.7)	18.00 (6.6)	22.3 (3.5)
Digit Fluency Alternating	19.3 (5.6)	22.7 (6.1)	19.50 (4.7)	14.7 (.6)

Note: The sample size for the Digit Fluency task is as follows: ESL n= 7, dual-language users n=3, L1 frequent users n=4, and frequent L2 users n=3.

Discussion

The first aim of this study was to examine the effect of language group (monolingual vs. bilingual) and mTBI history on various experimental and clinical EF measures. The performance of the monolingual and bilingual groups with mTBI history was comparable to the healthy control groups on the experimental tasks, except for the Forward Digit Span. On this task, those with a history of mTBI showed lower working memory spans; however, their digit spans were within the norms reported in the literature (Cowan, 2010; Miller, 1956). The lack of group differences on the experimental tasks was not surprising considering the subtle nature of EF deficits after mTBI that may not be apparent unless under effortful and challenging conditions (Raskin & Mateer, 1999). Interestingly, on these experimental tasks, there was a main effect of language group on the BCST accuracy, indicating better performance by monolinguals. That is, contrary to the reported bilingual advantage on switching tasks (e.g., Garbin et al., 2010; Prior & MacWhinney, 2010), the bilingual group in this study scored lower on the BCST than monolinguals. Such inconsistency in findings is not uncommon in the literature, and others have failed to document any evident advantage by bilinguals on non-verbal switching tasks (Hernández et al., 2013; Paap et al., 2017).

Although bilinguals with mTBI history were not significantly different from the control group on the experimental tasks, they scored lower on the clinical measure of EF. On the Zoo Map task, there was an interaction of mTBI history and language group on all scores reflecting a particular disadvantage for bilinguals with mTBI history on this planning measure. The Zoo Map task requires more than responding rapidly to a flanking arrow or sorting cards; it requires the ability to formulate a plan, keep it active in working memory, and update it as necessary until the task at hand is complete. Therefore, this complex task may have the ability to detect subtle differences in EF that other simpler EF tasks such as the Flanker or BCST do not. However, monolinguals with mTBI did not perform worse than monolingual controls on this task. In addition, they performed significantly better than bilinguals with mTBI on this task. A possible explanation for this finding is that, as expected, the Zoo Map task is verbal nature, and a bilingual disadvantage on verbal tasks is well-documented (e.g., Gollan et al., 2002; Ivanova & Costa, 2008). Another explanation could be that the Zoo Map may require increased verbal thinking abilities due to its complexity, and these abilities may be disproportionately disrupted in bilinguals with mTBI than in monolinguals.

Verbal thinking abilities or *inner speech* serve a crucial role in self-regulation during planning tasks, and any disruption to this inner speech mechanism during EF tasks is known to be detrimental. For example, Wallace et al. (2017) asked 51 adults (no information on their language history) to complete a Tower of London, a planning task that requires moving discs across 3 pegs following specific rules, under two conditions. In the first condition, participants were asked to say one word "*Monday*" to the beat of a metronome at the rate of 1 word per second (articulatory suppression condition). In the other condition, the participants were asked to tap their foot at the same rate (foot-tapping condition). The findings showed significantly worse performance on the Tower of London task under the articulatory suppression condition compared to the foot-tapping one. The authors concluded that verbal thinking abilities are necessary to complete a planning task and interfering with it could impair performance.

There are no experimental studies, to my knowledge, that examined the effects of interfering with verbal thinking on planning abilities in bilinguals. However, Festman et al. (2010) examined EF in neurotypical German-Russian bilinguals and its relationship with the ability to control cross-language interference. The participants completed 4 EF tasks, including the Tower of Hanoi, another planning task that is similar to the Tower of London mentioned above. The authors found that participants who made more errors on the Tower of Hanoi made more language switching errors on a cued picture naming task concluding that the two abilities are related. Therefore, the findings from Festman et al. (2010), Wallace et al. (2007), and the current study warrant further examination of the nature of the discrepancy observed between bilinguals and monolinguals with mTBI on planning tasks. Future studies examining planning and covert verbal thinking abilities in bilinguals might be warranted.

The second aim of this study was to examine group differences in verbal fluency and switching tasks using a digit fluency paradigm. Bilinguals with mTBI performed worse than bilingual control on this task, while monolinguals with mTBI either did not differ from monolingual control or did better. Again, the same pattern emerges where a disadvantage is observed for the bilinguals with mTBI group only. Bilinguals with mTBI produced less correct items in their L1, L2, and when they alternated between their two languages. These findings could suggest that bilinguals with mTBI face unique challenges on verbal fluency measures, with detrimental effects from both the history of mTBI and bilingualism. Reduced verbal fluency after mTBI has been reported in the monolingual research literature (Raskin & Mateer, 1999). In addition, a bilingual disadvantage on verbal fluency tasks has been reported in neurotypical bilinguals (Gollan et al., 2002). Sandoval et al. (2010) attributed this replicable disadvantage on verbal fluency tasks in bilinguals to the cross-language interference and the competition from the two simultaneously active language systems. Therefore, bilinguals with mTBI may constitute a particularly vulnerable population to reduced verbal fluency.

The third aim of this study was to investigate the relationship between the verbal language switching task and other EF tasks in bilinguals. In the alternating condition of the Digit Fluency task, where bilinguals had to switch between languages for each digit, the number of total items produced correlated with reduced RT on the Flanker. That is, those who were faster in controlling their responses on the response inhibition condition of the Flanker produced more items in the language switching task. This is consistent with the Inhibitory Control account in that controlling responses from the non-target language rely on domain-general inhibition (Green, 1998).

In addition, the failure-to-switch errors in this alternating condition of the Digit Fluency task correlated moderately with the accuracy and perseverative errors on the BCST, the non-verbal switching task. The failure-to-switch errors refer to instances where bilinguals did not successfully alternate between languages and produced two consecutive digits in the same language. The correlation of this type of error with other perseverative errors on the card sorting task may suggest that language switching abilities is a function of domain-general switching ability. However, it is important to note that the forced language switching in this task may rarely be experienced outside the laboratory; therefore, examining language switching abilities in an ecologically valid way in future studies is recommended.

Lastly, due to the heterogeneous nature of bilingualism and mTBI, the fourth aim of this study was to explore the different mTBI and bilingualism variables, which yielded a few interesting outcomes. First, about 35% of the participants in the bilinguals with mTBI group reported persistent cognitive or behavioral symptoms, a percentage that may be higher than what has been reported in the monolingual literature (McInnes et al., 2017). This subgroup and the subgroup of bilinguals with repetitive mTBI showed lower scores on different EF tasks including the Digit Spans and the Zoo Map. However, in this sample, bilinguals with relatively recent mTBI did not appear to be different from healthy control or the other subgroups. This could be due to the way recency was defined in this study. While others have described recent mTBI as those within the last 90 days (Belanger et al., 2005), in this study, cases within one year from testing were included.

On the other hand, in terms of the bilingualism-related variables, there were two interesting findings regarding the pattern of daily L1/L2 use in bilinguals with mTBI history. First, dual-language users, who switched between languages frequently and reported equal daily use of L1 and L2, produced more items on the language switching task (i.e., the alternating condition of the Digit Fluency task) than the single-language users. This finding is consistent with the Adaptive Control Theory that suggests that bilinguals in dual-language contexts exert greater demands on the language control processes allowing them to adapt accordingly. Based on this theory, the dual-language users in this study may have performed better on the language switching task due to improved language control shaped by their daily language use patterns.

However, there was an alarming finding for this subgroup of dual-language users with mTBI. This subgroup appeared to score lower than the healthy control bilinguals on the complex EF measure, the Zoo Map. On this task, the discrepancy in scores between healthy bilingual controls and the mTBI group was greater for the dual-language users than for the single-language users. This raises the question of whether the increased demand to control the two languages in the dual-language users consumes the same cognitive resources required to complete the complex planning task. In such a case, the dual-language users may be allocating their cognitive resources to control their languages at the expense of the complex EF task at hand.

Experiment 2

This study aimed to investigate EF and communication abilities in monolinguals and bilinguals with mTBI using ecologically valid scales to identify any subtle deficits that college students with mTBI may have in their everyday life. Using self-reports in assessing EF and communication could provide valuable information about daily challenges in a way that laboratory and clinical measures may not capture. It is hypothesized that at least a subgroup of monolinguals and bilinguals with mTBI history would report more EF and communication challenges than controls; however, bilinguals may experience greater challenges. This is based on the susceptibility of language to EF deficits after mTBI, and bilinguals' greater reliance on EF to control language (Green, 1998).

The second aim was to determine whether bilinguals with mTBI history report more language control difficulties than healthy control. To this end, a bilingual language control questionnaire was designed and its utility as a measure of language control in bilinguals will be explored. It is hypothesized that at least a subgroup of bilinguals with mTBI would report greater challenges in controlling their languages due to the potential detrimental effects of mTBI on the cognitive control processes underlying language control in bilinguals.

Lastly, in this study, bilingualism was viewed as a continuous variable with both monolinguals and bilinguals at different ends of the same continuum. Therefore, the possible moderating effects of second language experience on the relationship between a history of mTBI and EF and language impairments was explored. It was hypothesized that either a linear or a quadratic relationship exists between the bilingual experience and performance on EF and communication measures in participants with a history of mTBI. A linear relationship would suggest that with increased experience in a second language, more demands are placed on the cognitive system underlying language control, making language more susceptible to cross-language errors. However, a quadratic relationship would suggest that unbalanced bilinguals may experience more language control impairments compared to monolinguals and balanced bilinguals (i.e., on the opposite ends of the bilingual experience continuum) after mTBI. Such findings would support the notion that unbalanced bilinguals may require greater inhibition to suppress the non-target L1; therefore, any inhibition deficits due to mTBI would result in greater language production and control errors.

Method

Participants

In this experiment, 107 monolingual and 60 bilingual young adults with and without a history of mTBI were recruited from ASU undergraduate courses. The monolingual participants were native English speakers and reported no-to-limited experience in a second language. On the other hand, the bilingual participants reported speaking English, and at least one other language with varying degrees of proficiency (Table 6). Four participants were excluded; two for reporting a history of learning disability and two for not finishing the online questionnaire. All participants received partial course credit for their participation and provided their informed consent.

Table 7

Demographic, Language, and Head Injury History for Participants in Experiment 2

	Monolinguals (n=105)		Bilinguals (n=58)	
	No mTBI (n=37)	mTBI (n=68)	No mTBI (n=32)	mTBI (n=26)
DEMOGRAPHICS				
Gender (F)[a]	23	33	18	9
Age	18.67 (1.7)	19.13 (1.8)	19.47 (1.4)	19.23 (1.1)
SES [b]	3.59 (1.0)	3.60 (1.0)	2.66 (1.2)	2.77 (1.3)
LANGUAGE HISTORY				
L1 understanding	9.73 (0.6)	9.74 (0.6)	9.31 (1.7)	9.88 (0.3)
L1 speaking	9.76 (0.5)	9.76 (0.5)	8.97 (2.0)	9.58 (0.8)
L1 reading	9.65 (0.7)	9.53 (1.0)	8.31 (2.7)	9.04 (2.4)
L1 writing	9.57 (0.7)	9.38 (0.9)	7.38 (3.3)	8.77 (2.5)
L2 understanding	3.92 (2.4)	2.98 (2.0)	8.25 (1.9)	8.5 (1.9)
L2 speaking	2.72 (1.7)	2.64 (1.6)	7.63 (2.1)	8.32 (1.8)
L2 reading	3.28 (1.6)	2.74 (2.0)	7.50 (2.6)	7.77 (2.6)
L2 writing	2.40 (1.6)	2.06 (1.6)	7.09 (2.7)	7.65 (2.8)
L2 Age of Acquisition			4.19 (3.05)	6.31 (3.9)
Simultaneous bilinguals [a]			23	15
% of L1 use			57.03 (21.8)	62.11 (24.2)
ESL [a]			24	18
Cambridge English Test score			18.84 (5.5)	17.92 (5.9)
Languages other than English [a]				
Spanish	18	43	11	13
Chinese (e.g., Mandarin)	0	0	13	6
mTBI HISTORY				
Total number of mTBIs		2.22 (2.1)		1.81 (1.3)
Number of diagnosed mTBI [a]		1.75 (1.5)		1.3 (0.5)
Years since last mTBI		3.84 (3.5)		4.88 (4.0)
Reported persistent symptoms [a]		25		14
LOC [a]		16		4
Sports-related mTBI [a]		23		16

Procedure and Materials

There were two parts to this study; an online and an in-person language and cognitive testing parts. The monolingual group completed both parts of the study; however, the bilingual group completed the online portion of the study only. The in-person testing was not conducted for the latter group due to the Coronavirus Disease (COVID-19) restrictions.

Part One – The Online Questionnaires

General Questionnaire. All participants completed a 40-item online questionnaire. This questionnaire included demographic, educational, medical history, and language experience questions (Appendix B). The medical history section contained questions about diagnosed or suspected mTBI and the resulting acute or persistent symptoms, if any. The same grouping approach from Experiment 1 was used in this experiment. That is, participants were classified as having no history of mTBI (healthy control) or with a history of diagnosed or suspected mTBI (mTBI group) based on their responses on this questionnaire. In the language experience section, the LEAP-Q (Marian et al., 2007) was used for both monolingual and bilingual participants. Monolinguals were asked to report any experience in a second language such as a limited language exposure to Spanish in high school or during a summer of studying in a foreign country. Asking the monolingual participants to elaborate on their limited second language exposure was an attempt to bridge the gap between monolingual and bilingual research by conceptualizing monolinguals at one end of the language experience spectrum (DeLuca et al., 2019; Grosjean & Li, 2012).

The Dysexecutive Questionnaire (DEX; Wilson et al., 1996). This 20-item self-rating scale was administered electronically to measure signs of everyday EF challenges. Participants were asked to rate statements such as "I have difficulty thinking ahead or planning for the future" on a four-point Likert scale, with 0 referring to *never* and 4 referring to *very often*. Burgess et al. (1998) explored the factor structure of this scale and concluded that scores from this scale loaded on 5 different factors: inhibition, intentionality, executive memory, and positive and negative affect. Therefore, scoring was based on the total composite score and 4 sub-scores from the inhibition, intentionality, memory, and affect (combining both positive and negative) subsections. The highest composite score was 80 indicating the highest level of EF challenges.

La Trobe Communication Questionnaire (LCQ; Douglas et al., 2000). This 30-item questionnaire was designed to evaluate perceived communicative abilities in young adults (Douglas et al., 2000). Each of its 30 items were rated as follows: 1 = "never or rarely", 2 = "sometimes", 3 = "often" and 4= "usually or always". All participants completed this questionnaire about their communication abilities in English. Also, bilinguals reported on their communication abilities in the other language (completed the same 30-item questionnaire regarding the other language). The total score was obtained with 30 being the lowest score possible for each language, indicating no communication difficulties, and 120 as the maximum possible score indicating more severe challenges in communication. In addition, 4 scores were obtained from the following subsections: inhibition, fluency, attention, and task management (as described in Douglas et al., 2007).

Bilingual language control questionnaire (BLCQ). The available questionnaires used to assess communication abilities after neurological deficits do not take into account the bilingual experience. For example, the previously mentioned questionnaire, LCQ, has no questions regarding the patients' second language ability or bilingual control. Therefore, an additional questionnaire was created to allow the bilingual participants in this study to express any challenges they may have in controlling their languages. The first draft of the questionnaire was created based on reported language control symptoms from the literature. These symptoms may include unintentional language switching within and between sentences (Gollan et al., 2017), word-finding difficulties, and accent errors (Ratiu & Azuma, 2017). The questionnaire was modified based on experts' feedback to include 13 items asking about bilingual language control symptoms in English and the other language (see Appendix D). Participants rated the first 10 items based on the frequency of occurrence in their everyday conversations, 1 as "never" and 4 as "always". The last 3 items were open-ended questions asking about any changes in L1, L1, or in controlling the two languages.

Part Two – The In-person Testing (Monolinguals Only)

The monolingual participants completed the following set of experimental and clinical EF measures that were presented in a counterbalanced manner to control for order effect.

Inhibition measures. The *Flanker task* was presented using E-Prime, as described in experiment 1. Performance on this task was measured based on the accuracy (% correct) and the average RT of correct responses on each of the three conditions: (a) Control, (b) Interference Control, and (c) Response Inhibition.

Switching measure. A shortened version of the BCST was administered using PEBL (Mueller, 2013) as described in Experiment 1. Participants were asked to sort 64 virtual cards (instead of 128) based on color, number, or shape. The shortened version of the card sorting task has shown moderate to strong correlations with the full version, and is preferred by clinicians due to its shorter administration time (Strauss et al., 2006). The task was scored based on: (a) accuracy (% of cards correctly sorted), (b) perseverative errors, and (b) non-perseverative errors.

Working memory Measures. Computerized versions of the *digit forward and digit backward span tasks* were administered using PEBL (Mueller, 2013), as described in Experiment 1. In these tasks, the participants were presented a series of single digits at the rate of one number per second and asked to recall the digits by typing them in the same order (digit forward) or reverse order (digit backward). Performance on the tasks is scored as the highest span level successfully completed by the participant, and the maximum possible span is 10. In addition, the modified *Symmetry Span* task was presented using E-Prime software (Foster et al., 2015), as described in Experiment 1. In this task, participants were asked to recall the location of red shaded areas in 4x4 grids while making symmetry judgments (Figure 1). The performance was measured using partial credit score, which reflects the number of correctly recalled items within different trials.

Clinical EF Measure. A subtest of the Functional Assessment of Verbal Reasoning and Executive Strategies (FAVRES; MacDonald, 2005) was used as a complex measure of EF. The FAVRES is an ecologically valid measure of subtle cognitive-communication deficits using realistic tasks (Macdonald & Johnson, 2005). In this study, the *scheduling* task was administered and scored according to the test manual. This scheduling subsection measures the ability to plan, sequence, and prioritize tasks within a specific time frame. Scoring was based on the completion time, accuracy, the provided rationale, and reasoning. The reasoning score was based on a follow-up questions on how the participants completed the task and reached to their solution.

The Digit Fluency Task

Participants were asked to produce as many digits in 1 minute in 3 conditions: 1) odd digits only, 2) even digits only, and 3) alternating between even and odd digits, as described in Experiment 1. The odd and even conditions were then collapsed into one blocked condition. Scoring of this task was based on 1) the total items produced, 2) the total correct items, 3) the number of repetition errors, 4) the number of sequence errors, and 5) the number of failure-to-switch errors in the alternating category (e.g., saying two odd numbers back to back).

Results

The performance of Monolinguals on the EF Tasks Based on mTBI History

First, a Mann-Whitney test was used to compare the mTBI and healthy control groups on the different EF and Digit Fluency tasks. There was no significant difference between the performance of the monolingual mTBI and healthy control groups on any of the measures. Next, a correlational analysis was used to identify any mTBI subgroups who may have exhibited greater difficulty on these different tasks. The scores from the different EF and Digit Fluency tasks were included in the analysis in addition to the following mTBI variables: (1) history of diagnosed mTBI, 2) history of repetitive mTBI, 3) reported persistent symptoms, 4) reported loss of consciousness, and 5) years since the last mTBI. The only variable that correlated with lower EF scores in monolinguals was the history of repetitive mTBI. Monolingual participants who reported experiencing more than one mTBI in the past, were faster, $r(103) = -.201$, $p = .040$, however, less accurate on the FAVRES, $r(103) = .252$, $p = .010$ (see Table 8 for descriptive data).

Table 8

Means and Standard Deviations for the FAVRES Across Monolingual Groups Based on mTBI History

	Healthy Control (n= 37)	mTBI (n=68)	Repetitive mTBI (n= 19)
Time in seconds	917.03 (280)	937.45 (317)	800.87 (261)
Accuracy	4.05 (.74)	4.19 (.92)	3.68 (1.2)
Rational	4.32 (.82)	4.26 (1.18)	4.16 (1.5)
Reasoning	19.47 (2.8)	18.99 (2.8)	18.47 (2.1)

Group Differences in Scale Scores for Monolinguals and Bilinguals

Scores from the different scales used in this study are provided in Table 9. The Kruskal-Wallis nonparametric test was used to compare the 4 groups (healthy control monolinguals, healthy control bilinguals, monolinguals with mTBI, and bilinguals with mTBI) in terms of their reported EF and communication challenges on the DEX and the LCQ-L1. Scores on the DEX were influenced by group membership, $H(3) = 9.054$, $p = .029$. Follow up Mann-Whitney tests with a Bonferroni correction revealed that the only significant difference in DEX scores was between the healthy control monolingual and bilingual groups, $U = -31.56$, $p = .033$. The healthy bilingual control group reported higher EF challenges on the DEX ($M = 33.25$) compared to the healthy monolingual control group ($M = 23.35$). However, there was no significant difference in reported communication challenges in L1 (i.e., LCQ-L1 scores) based on group membership, $p > .05$.

Table 9

Average Scores on the Different Scales across Groups.

	Monolinguals (n=105)		Bilinguals (n=58)	
	No mTBI (n=37)	mTBI (n=68)	No mTBI (n=32)	mTBI (n=26)
BADS DEX [a]	23.35 (12.3)	27.24 (12.5)	33.25 (17.1)	23.54 (13.7)
DEX Inhibition	8.65 (5.1)	9.37 (5.0)	10.31 (5.7)	7.27 (5.3)
DEX Intentionality	6.38 (3.7)	7.19 (4.1)	9.22 (5.4)	6.69 (4.6)
DEX Memory	2.46 (2.1)	3.35 (2.6)	4.66 (3.0)	3.35 (2.4)
DEX Affect	5.81 (3.6)	7.59 (3.8)	8.97 (4.4)	6.31 (3.6)
LCQ-L1	61.46 (10.7)	61.97 (11.2)	65.09 (14.1)	59.46 (12.9)
L1 Inhibition	13 (3.8)	13.25 (4.3)	14.28 (4.4)	12.62 (3.9)
L1 Fluency	9.65 (2.1)	10.01 (2.9)	10.91 (4.0)	9.27 (3.5)
L1 Attention	9.84 (2.8)	9.84 (2.7)	10.22 (3.1)	8.69 (2.7)
L1 Management	17 (2.8)	16.54 (2.8)	16.22 (2.6)	16.69 (3.7)
LCQ-L2			69.16 (13.1)	62.62 (14.0)
L2 Inhibition			15.22 (3.9)	12.96 (3.7)
L2 Fluency			12.13 (3.5)	9.96 (3.5)
L2 Attention			11.06 (3.4)	9.54 (3.4)
L2 Management			16.06 (2.6)	17.04 (3.2)
BLCQ-L1			14.59 (5.0)	13.46 (4.8)
BLCQ-L2			14.47 (4.5)	13.69 (3.8)

Note: Standard deviations are presented in parentheses. Higher scores reflect worse reported symptoms. [a] The highest possible score for each of the DEX subsections is as follows: 28 for inhibition, 20 for intentionality, 12 for memory, and 20 affect. The highest possible score for each of the LCQ subsections is as follows: 32 for inhibition, 20 for fluency, 20 for attention, and 24 for management.

To compare the scores of the LCQ-L2 and the BLCQ between bilinguals based on their mTBI history, Mann-Whitney tests were used. There was no significant difference in the reported communication challenges in L2 and bilingual language control difficulties between the bilinguals with a history of mTBI and the healthy bilingual control, $p > .05$.

Correlation Between Different mTBI Variables and Scale Scores

Pearson's and point-biserial correlational analysis was conducted to examine the relationship between the different mTBI variables and the scores on different scales. The mTBI variables included in this analysis were: (1) mTBI history, (2) history of repetitive mTBI, (3) years since last mTBI, (4) reported persistent symptoms, and (5) reported loss of consciousness. In monolinguals, there was no significant correlation between the DEX and LCQ scores and any of the mTBI variables. On the other hand, in bilinguals, there were significant correlations between scores on the communication and language control scales and mTBI-related *persistent symptoms*. This binary variable identifies a subgroup of participants with mTBI history who reported persistent cognitive or behavioral symptoms since the injury (e.g., memory and attention difficulties, increased anxiety). Although the persistent symptoms variable did not correlate with the DEX in bilinguals, it was the only variable that correlated positively with the scores from all other communication and language control scales (Table 10). Bilinguals with mTBI who reported persistent cognitive or behavioral symptoms since the injury reported more communication challenges in L1, $r_{pb}(24) = .480$, $p = .013$, more communication challenges in L2, $r_{pb}(24) = .588$, $p = .002$, more language control difficulties in L1, $r_{pb}(24) = .450$, $p = .021$, and more language control difficulties in L2, $r_{pb}(24) = .438$, $p = .025$. Also, this indicates that the variability in whether bilinguals with mTBI history were experiencing persistent symptoms accounted for 19% -34% of the variability in the communication and language control scores in both languages.

Table 10

Correlations between the Scores on Different Scales and mTBI Variables Disaggregated by Language Group

	1	2	3	4	5	6	7	8	9	10
1. BADS DEX	—	.682**				.149	-.004	-.127	.202	.054
2. LCQ-L1	.598**	—				.022	.008	-.025	.099	.104
3. LCQ-L2	.711**	.703**	—							
4. BLCQ-L1	.295*	.642**	.388**	—						
5. BLCQ-L2	.578**	.640**	.617**	.496**	—					
6. History of mTBI [a]	-.299*	-.206	-.239	-0.116	-.093	—	.c	.c	.c	.c
7. Repetitive mTBI [a]	-.231	-.211	-.202	0.17	-.079	.c	—	-.31*	.292*	.311**
8. Years since last mTBI	-.031	-.198	.005	-.135	.209	.c	.016	—	-.201	.247
9. Persistent symptoms [a]	.312	.480*	.588**	.450*	.438*	.c	.098	-.179	—	.008
10 LOC [a]	.323	.162	.0	.093	.123	.c	.236	-.183	.181	—

Note. The results for the monolingual group (n=105) are displayed above the diagonal. The results for the bilingual group (n=58) are shown below the diagonal. Variables 7 through 10 include participants with a history of mTBI only (n=68 for monolinguals and n=26 for bilinguals). [a] Binary variable. [c] Cannot be computed because one variable is a subgroup of the other.
* <.05. ** <.001.

Correlation Between DEX and LCQ Scores

Reported EF difficulties on the DEX correlated positively with the reported communication difficulties on the LCQ in L1 for both the monolingual, $r(103) = .682$, and the bilingual group, $r(56) = 598$, $p < .001$ (Table 10). Similarly, the DEX scores correlated positively with the LCQ scores in L2 for bilinguals, $r(56) = 711$, $p < .001$.

Based on these findings, the variability in reported EF challenges on the DEX accounted for 35% of the variability in communication challenges in L1 and 50% in L2 in bilinguals.

The Degree of L2 Experience and DEX and LCQ Scores

Hierarchical multiple regression analyses were conducted to examine whether the EF and communication difficulties could be predicted from the degree of second-language experience or its interaction with mTBI history. The second-language experience here was defined as any exposure to a language other than L1, and it was measured by obtaining an additive score of L1 and L2 self-reported proficiency. This *balance score* was obtained for all participants (n= 163) by adding the average of speaking and understanding proficiency in L1 and L2.[10] After obtaining this score, a separate hierarchical multiple regression analyses were used with this balance score and mTBI history as predictors and scores on the DEX and the LCQ-L1 as the dependent variables. Both mTBI history and the balance score were entered in the first step, followed by the quadratic term of the balance score (x^2) in the second step (Table 11).

[10] According to this L1/L2 balance score, a monolingual with no exposure to a second language who rated his L1 understanding as 10 and speaking as 9 would have a balance score of 9.5. On the other hand, a bilingual who reported maximum proficiency (i.e. 10) on both the speaking and understanding modalities in both languages would have the score of 20.

Table 11

Hierarchical Regression of mTBI History and L2 experience on DEX and LCQ-L1 scores

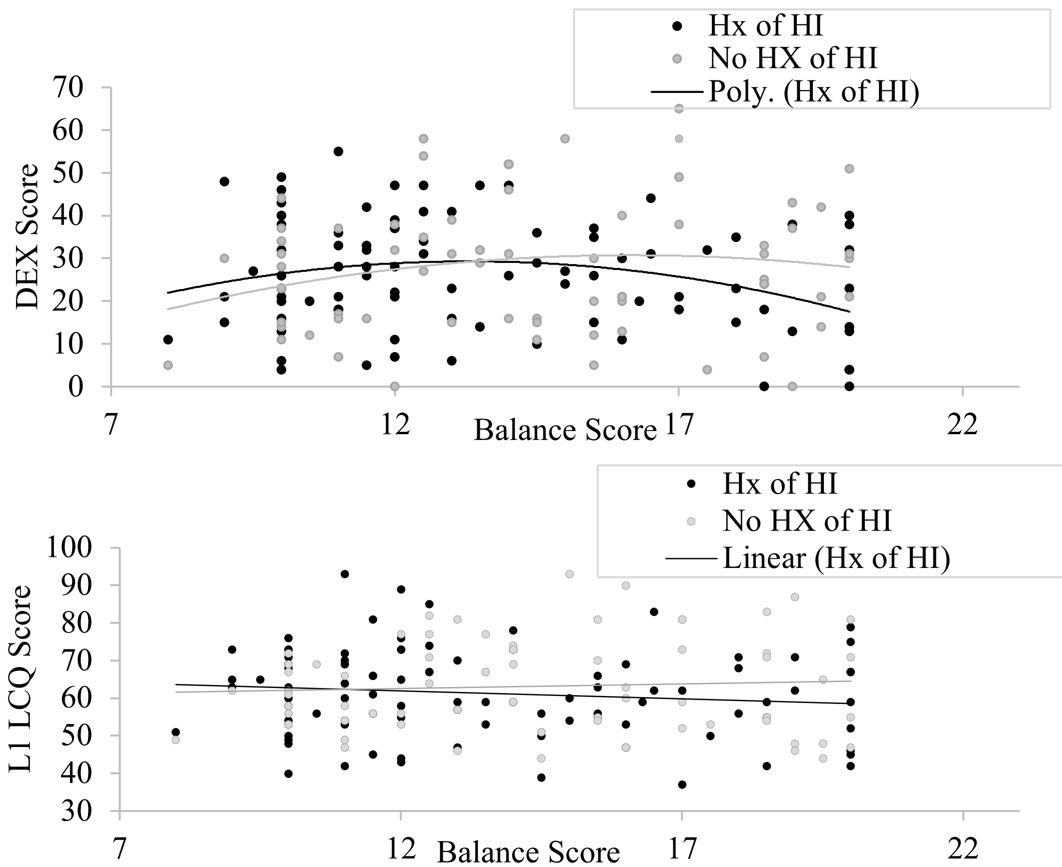
Variables	β	*t*	ΔR^2	ΔF^2
		DEX scores		
Step 1			.005	.374
mTBI History	-.065	-.815		
Balance Score [a]	-.030	-.382		
Step 2			.033	4.585*
mTBI History	-.055	-.702		
Balance Score	.044	.508		
Balance Score^2	-.182	-2.141*		
		LCQ-L1 scores		
Step 1			.224	7.96**
mTBI History	-.145	-1.188		
Balance Score	-.420	-3.447*		
Step 2			.018	1.252
mTBI History	-.139	-1.140		
Balance Score	-.773	-2.284*		
Balance Score^2	.376	1.118		

[a] Centered. * <.05. ** <.001.

The balance score and mTBI history did not predict the DEX scores when they were added in the first step, however, adding the quadratic term for the balance score in the second step contributed significantly to the model and accounted for additional 3% of the variance in the DEX scores (Table 11). This quadratic term was the only significant predictor of DEX scores, β = -.182, $p = .034$. This may suggest a curvilinear relationship between L2 experience and reported EF challenges (Figure 9). Monolinguals and balanced bilinguals (i.e. both ends of the language experience continuum) may report fewer EF challenges compared to the less balanced bilinguals. On the other hand, the model with mTBI history and the balance score significantly predicted LCQ-L1 scores and explained 22% of the variance in LCQ scores. However, only the balance score was a significant predictor in that model, β = -.420, $p = .034$. That is, for each unit increase in the balance score, there was a .42 unit decrease in the reported communication challenges in L1. Adding the quadratic term in the second step did contribute significantly to the model.[11]

Figure 9

The Relationship Between L2 experience and the DEX and LCQ scores based on mTBI History



Note: There was a quadratic relationship between the balance score and the DEX scores (top) and a linear relationship between the balance score and the LCQ-L1 scores (bottom). The interaction between mTBI and the balance score was not significant in predicting any scale scores.

[11] The interactions of Balance Score × mTBI History and Balance Score^2 × mTBI History were probed to predict both DEX and LCQ-L1 scores and did not result in a significant ΔR^2.

Language Proficiency and LCQ & BLCQ Scores in Bilinguals

Separate simple regression analyses were conducted to examine the effect of L1 and L2 proficiency on the reported communication and language control challenges in L1 and L2 (Table 12). L1 proficiency, as measured by the average self-reported speaking and understanding in L1, significantly predicted scores on the LCQ-L2, β = -.327, *p* = .012, and BLCQ- L1, β = -.329, *p* = .012. That is, for every unit increase in L1 proficiency, there was a .33 unit decrease in the reported communication challenges in L2 and language control difficulties in L1. Also, L1 proficiency accounted for 9-10% of the variance in the LCQ-L2 and BLCQ-L1 scores. Similarly, L2 proficiency predicted the scores on the same measures (LCQ-L2 and BLCQ-L1) and explained the same amount of variance (9-10%) in their scores.

Table 12

Separate Simple Regressions with either L1 or L2 Proficiency as Predictors

Variable	β	*F*	*p*	R^2
		L1 Proficiency		
LCQ-L1	-.243	3.512	.066	.059
LCQ-L2	-327	6.695	**.012**	.091
BLCQ-L1	-329	6.813	**.012**	.108
BLCQ-L2	-.121	.826	.367	.015
		L2 Proficiency		
LCQ-L1	-.081	.369	.546	.007
LCQ-L2	-.303	5.673	**.021**	.092
BLCQ-L1	.323	6.535	**.013**	.104
BLCQ-L2	.018	.018	.894	>.000

Analysis of the BLCQ as a Measure of Bilingual Language Control

Reliability. The internal consistency of the BLCQ was evaluated for the entire sample (n=58), and each bilingual group based on mTBI history. Cronbach's alpha (α) was .899 for the entire sample and .914 and .874 for the control and mTBI groups, respectively, indicating good internal consistency (Nunnally and Bernstein, 1994). Also, split-half reliability was obtained by measuring the correlation between the first and second halves of the scale and using the Spearman-Brown (SB) formula to estimate the reliability coefficient. The correlation between the first and second half of the BLCQ was .585 for the entire sample, and the SB coefficient was .738. By groups, the split-half correlations and coefficients were .600, *BS* = .750 for the healthy control group and .553, *BS*=.712 for the mTBI group. Also, the item-total correlation was evaluated to indicate the contribution of each item to internal consistency. The correlation between each item and the full scale was higher for the control group than the mTBI group, however, all were within the acceptable range (> .4; De Vaus, 2004; see Table 13).

Table 13

Item-level Internal Consistency Analysis of the BLCQ

Questionnaire Items	No mTBI M (SD)	No mTBI Item total	No mTBI α	mTBI M (SD)	mTBI Item total	mTBI α
Speaking in English, have you experienced any of the following?						
1. Accidentally switching to your other language (e.g., while talking in English, you find yourself switching to Spanish by mistake)?	2.03 (0.9)	0.56	0.91	1.88 (0.9)	0.62	0.86
2. Using some words from your other language by mistake?	2.09 (0.9)	0.56	0.91	2.04 (1.0)	0.54	0.87
3. Having a hard time thinking of a specific word you were thinking of?	2.47 (1.9)	0.70	0.90	2.19 (0.8)	0.63	0.86
4. Using vague or empty words "e.g., the thing, you know what I mean" instead of the right word?	2.44 (1.1)	0.81	0.90	2 (1.0)	0.58	0.86
5. Any changes in your rate of speech (e.g., speaking faster or slower)?	2.5 (1.0)	0.74	0.90	2.27 (0.8)	0.41	0.87
6. Any changes in your English accent?	2.03 (0.9)	0.57	0.91	2 (1.0)	0.44	0.87
Speaking in your other language, have you experienced any of the following:						
7. Accidentally switching to English (e.g., while talking in your other language, you find yourself switching to English by mistake)?	2.72 (0.9)	0.66	0.91	2.5 (0.9)	0.70	0.86
8. Using some English words by mistake?	2.81 (0.8)	0.57	0.91	2.58 (0.9)	0.58	0.86
9. Having a hard time thinking of a specific word you were thinking of?	2.69 (1.0)	0.54	0.91	2.65 (0.8)	0.65	0.86
10. Using vague or empty words "e.g., la cosa, ¿sabes lo que quiero decir?" instead of the right word?	2.53 (1.0)	0.68	0.91	2.35 (1.0)	0.68	0.86
11. Any changes in your rate of speech (e.g., speaking faster or slower)?	2.44 (1.0)	0.73	0.90	2.54 (1.0)	0.58	0.86
12. Any changes in your accent?	2.38 (1.0)	0.69	0.91	2.15 (1.1)	0.42	0.87

Note. No significant mean difference between the two groups on any of the scale items, $p > .05$. Item-total refers to the correlation of the item to the full scale. α refers to Cronbach's alpha of the scale when that item is deleted.

Construct Validity. This type of validity is concerned with how well the scale is *in-tune* with the theoretical construct it measures, and how well the scale correlates with other measures of the same construct (DeVellis, 2016). In this case, the BLCQ was designed to measure bilingual language control after neurological deficits. To date, no available scales are measuring the same construct; therefore, validity was evaluated by examining the correlation of the BLCQ with conceptually related constructs such as EF and communication abilities. The BLCQ correlated moderately with the DEX, $r(56) = .492$, LCQ-L1, $r(56) = .740$, and LCQ-L2, $r(56) = .570$, $p < .001$. The DEX scores showed a higher positive correlation with the L2 subsection of the BLCQ compared to the L1 subsection (Table 14).

Qualitative Analysis. The BLCQ contains 3 open-ended questions where participants were asked to elaborate and give examples of any noticeable changes in L1, L2, or in controlling the two languages since the head injury. The answers fell into 3 categories: rate of speech, word-finding, and language switching difficulties (see Table 14 for details).

Table 14

Qualitative Data from the Open-ended Questions of the BLCQ

Theme	Freq.	Describing changes in L1	Describing changes in L2
Rate of Speech	2	Participant 27: "I speak slower." Participant 48: "[I] began to speak either at a slower rate or a quicker rate than before."	
Word Finding Difficulties	5	Participant 21: "Harder to think of words in Spanish [L1]."	Participant 27: "It [has] been more difficult to remember words as I rarely use it anymore." Participant 28: "[I] had trouble remembering certain words." Participant 29: "[I] forgot some words while talking with someone." Participant 48: "I began to lose parts of the spoken language."
		Describing changes in controlling the two languages	
Switching between languages	4	Participant 21: "I have a little more difficulty when changing from one language to another." Participant 27: "Whenever I try to speak the limited Spanish I know, I [will] always start speaking Hebrew. However, when I speak English or Hebrew, I do [not] get them mixed up." Participant 47: "I [have] always had this issue of mixing up my two languages." Participant 45: "[O]nly when I speak in Spanish[,] I sometimes say things in English."	

Discussion

In this study, monolingual and bilingual young adults completed a full language history questionnaire and self-rated EF and communication scales, the DEX and the LCQ, respectively. In addition, bilinguals completed the LCQ regarding communication abilities in their second language as well as a newly designed scale aimed to measure bilingual language control difficulties in everyday conversations.

The first aim of the current study was to examine EF and communication abilities in monolinguals and bilinguals using these ecologically valid scales, and to identify any group differences based on mTBI history. Based on the scores from the DEX and the LCQ, participants with mTBI history did not report greater challenges compared to healthy controls. However, healthy control bilinguals reported significantly more EF challenges on the DEX than healthy control monolinguals. This finding is consistent with studies reporting a bilingual disadvantage on clinical measures of EF (Gollan et al., 2002; Ratiu & Azuma, 2019) and extends it to self-perceived EF difficulties. In their study, Ratiu and Azuma (2019) reported that 20% of their healthy control bilingual sample scored below the cut-off criteria for monolingual norms on the FAVRES, a clinical measure of EF. Therefore, these authors cautioned against using the same cut-off criteria from monolingual norms in bilinguals as it may overestimate EF deficits. Thus, the DEX and LCQ scores from the healthy control bilinguals in the current study could be useful for clinicians working with bilinguals with TBI who may use these scales regularly.

Although no significant group differences were observed on the DEX and the LCQ based on mTBI history, we have hypothesized that increased EF and communication challenges may only be present in a subgroup of participants with mTBI.

Therefore, the group differences analysis was followed up by a correlational analysis between the DEX and LCQ scores and the different mTBI-related variables. These variables included: repetitive mTBI history, years since the last mTBI, reported a loss of consciousness, and reported persistent symptoms. The latter was the only mTBI variable that correlated positively with increased challenges in communication abilities in bilinguals. Bilinguals who reported persistent cognitive or behavioral symptoms, such as memory and attention difficulties, sleep disturbances, and increased anxiety, also reported increased communication challenges in their L1 and L2. However, this correlation was not observed in monolinguals, where no group differences were observed based on mTBI history, nor did any of the mTBI variables correlate with scores from the DEX or LCQ.

The second aim was to determine whether bilinguals with mTBI history experience more language control difficulties in everyday conversation than healthy control. In previous research, bilingual language control has been studied under experimental laboratory conditions. However, findings from these laboratory tasks may not explain the nature of errors occurring in everyday conversations. Therefore, a 13-item bilingual language control questionnaire was designed to allow bilingual participants to report any self-perceived language control challenges. This scale showed good internal consistency and good construct validity by showing moderate correlations with the DEX and LCQ scores.

Again, there were no group differences between bilinguals with and without mTBI. However, the subgroup of bilinguals with mTBI with persistent cognitive or behavioral symptoms reported more language control challenges in their L1, based on the follow up correlational analysis. In addition, some bilinguals with mTBI qualitatively described their language control challenges. For example, describing the changes in language control since the injury, one participant said: "[w]henever I try to speak the limited Spanish I know, I [will] always start speaking Hebrew. However, when I speak English or Hebrew, I do [not] get them mixed up.". These findings may suggest that bilinguals may experience changes in their ability to control their languages after mTBI, at least in those with long-lasting cognitive or behavioral symptoms. This is consistent with other studies reporting language control difficulties in bilingual clinical populations (e.g., Calabria et al., 2014).

To explore the last aim, bilingualism was conceptualized as a continuous variable with monolinguals and bilinguals at opposite ends of a continuum. Taking this into account, we explored the possible moderating effects of second language experience on the relationship between a history of mTBI and EF and communication difficulties. It was hypothesized that either a linear or a quadratic moderating relationship exists between the second language experience and scores on the DEX and LCQ in participants with a history of mTBI. Second language experience was obtained by calculating an additive score of L1 and L2 proficiency for both monolinguals and bilinguals (balance score).

Contrary to our hypothesis, second language experience did not show a moderating effect on the relationship between mTBI history and DEX and LCQ scores. That is, there was no interaction between the balance score and the binary mTBI history variable in predicting DEX and LCQ scores. However, a quadratic relationship between the balance score and the DEX scores was observed. This finding suggests that unbalanced bilinguals may experience more EF challenges compared to monolinguals and balanced bilinguals (i.e., on the opposite ends of the bilingual experience continuum). However, this curvilinear relationship is present in both the mTBI and healthy control groups. Such findings may support the notion that unbalanced bilinguals experience greater cross-language interference and require greater inhibition to suppress the non-target language. Therefore, this constant cross-language interference may be consuming inhibitory resources and resulting in greater EF challenges in everyday life.

General Discussion

A battery of experimental, clinical, and self-rating measures was used to evaluate EF, communication, and language control in monolinguals and bilinguals with and without a history of mTBI. This study aimed to examine the cognitive-communication abilities in bilinguals with mTBI, and the relationship between language control impairments and domain-general EF.

In the first experiment, the bilingual participants showed particular vulnerability to EF deficits compared to monolinguals with mTBI. However, those deficits were only evident in complex EF measures, not on simple measures assessing isolated EF such as the Flanker. The verbal nature of the Zoo Map task may be behind the discrepancy in performance between monolingual and bilingual participants with mTBI. This explanation is consistent with findings from neurotypical bilinguals showing a disadvantage on verbal clinical tasks (e.g., Gollan, 2002). However, such discrepancies in these verbal measures were not observed between the healthy control monolinguals and bilinguals in this study.

Therefore, another possible explanation of these findings involves the nature of language processing and control in bilinguals and how it may be disrupted due to mTBI. Bilinguals who have two concurrently active languages may require top-down processes such as inhibition (Green, 1998) to control the two languages. This mechanism may be ongoing while planning and solving complex EF tasks even when the two languages are not used overtly. In such a case, bilinguals with mTBI may be consuming the same cognitive resources needed to complete the EF tasks to control the two covertly used languages.

A similar pattern emerged on the verbal fluency task, where bilinguals with mTBI were significantly less fluent than healthy bilinguals, while monolinguals did not differ in fluency based on mTBI history. Bilinguals were also less fluent in their second language than their first, regardless of the mTBI history. A bilingual disadvantage on verbal fluency tasks has been reported in neurotypical bilinguals and attributed to the competition from the two simultaneously active language systems. In addition, the negative impact of TBI on verbal fluency in monolinguals is well established. Therefore, findings from the current study highlight the unique challenges faced by bilinguals with mTBI on verbal fluency measures, with detrimental effects from both the history of mTBI and bilingualism.

Bilingual language control was examined using an experimental language switching task (i.e., the alternating condition of the Digit Fluency task) in Experiment 1 and a newly designed self-rating scale (i.e., BLCQ) in Experiment 2. On the experimental task, bilinguals with mTBI produced less correct items when forced to switch between their languages than the healthy control bilinguals suggesting increased difficulty switching between languages. On the other hand, using the self-rating scale in Experiment 2, only those who reported persistent cognitive or behavioral symptoms after their mTBI reported difficulties in bilingual language control, as evident by their scores on the BLCQ. These findings suggest that bilingual language control impairments may emerge after mTBI in bilinguals resulting in difficulty switching between languages. Those language control impairments could be observed on experimental tasks and experienced in everyday conversations as reported by participants. Therefore, it is important to assess bilingual language control in bilinguals when evaluating cognitive-communication abilities after TBI. To date, there are no available clinical measures of bilingual language control; however, the BLCQ is a promising tool to measure perceived language control challenges in bilinguals.

One of the aims of this study was to investigate the relationship between bilingual language control and EF. This aim was examined in Experiment 1 using the experimental Digit Fluency and EF tasks and Experiment 2 using the self-rating scales (the BLCQ & the DEX). Language control errors characterized by direct translations and failure-to-switch errors on the alternating condition of the Digit Fluency task correlated with performance on the response inhibition, non-verbal switching, and complex working memory tasks. Similarly, reported language control challenges in everyday conversations correlated with everyday EF difficulties in Experiment 2. This may suggest that controlling and switching between two languages is a function of domain-general EF. These findings have important clinical implications as information from non-verbal EF tasks may provide some insight into bilinguals' ability to control their languages.

Additionally, bilinguals may experience increased communication challenges following mTBI compared to monolinguals. In Experiment 2, around 30% of the bilingual participants with mTBI history reported persistent cognitive or behavioral symptoms, and this subgroup reported more communication challenges (in both L1 and L2), a finding that was not observed in monolinguals. This finding suggests that bilinguals may continue to have long-term symptoms affecting communication in their first and second languages. These challenges in communication could be due to the impact of mTBI on cognitive control processes such as working memory, switching, & inhibition.

Limitations & Future Directions

The current study examined EF, communication, and language control in bilinguals from widely diverse backgrounds. There were at least 20 different language combinations (e.g., Spanish-English, English-Arabic, Chinese-English). In addition, the participants were from different social and cultural backgrounds, including international students from over 12 countries. These cultural and linguistic variables and their impact on EF and language measures were not explored in the current study. In previous studies, performance on some of the EF measures used in this study (e.g., Digit Span tasks) has been impacted by cultural differences. For example, Hedden et al. (2002) reported higher Digi Spans in a group of participants from China compared to a group from America and concluded that it might be due to the linguistic and cultural differences between the two groups. Therefore, exploring these cultural and linguistic variables is important in future studies.

Moreover, future research should take into consideration the heterogeneous nature of both the bilingual experience and mTBI history. The bilingual experience differs along numerous dimensions, such as the age of acquisition, language use, proficiency, language combination, and language context. Similarly, the history of brain injury can be diverse in terms of time since the injury, the number of injuries, concomitant symptoms, etc. Therefore, neither bilingualism nor mTBI history should be regarded as categorical variables. A research methodology that considers these confounding variables using a multivariate approach may come closer to disentangling the differences in cognitive-communication abilities in bilinguals with TBI.

References

Abutalebi, J., Della Rosa, P. A., Green, D. W., Hernandez, M., Scifo, P., Keim, R., Cappa, S. F., & Costa, A. (2011). Bilingualism tunes the anterior cingulate cortex for conflict monitoring. *Cerebral cortex, 22*(9), 2076-2086.

Abutalebi, J., & Green, D. (2007). Bilingual language production: The neurocognition of language representation and control. *Journal of Neurolinguistics, 20*(3), 242-275. https://doi.org/https://doi.org/10.1016/j.jneuroling.2006.10.003

Abutalebi, J., & Green, D. (2016). Neuroimaging of language control in bilinguals: neural adaptation and reserve. *Bilingualism: Language and Cognition, 19*(4), 689-698.

Abutalebi, J., Miozzo, A., & Cappa, S. F. (2000). Do subcortical structures control 'language selection'in polyglots? Evidence from pathological language mixing. *Neurocase, 6*(1), 51-56.

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.

Adrover-Roig, D., Galparsoro-Izagirre, N., Marcotte, K., Ferré, P., Wilson, M. A., & Inés Ansaldo, A. (2011). Impaired L1 and executive control after left basal ganglia damage in a bilingual Basque–Spanish person with aphasia. *Clinical Linguistics & Phonetics, 25*(6-7), 480-498.

Alvarez, J. A., & Emory, E. (2006). Executive function and the frontal lobes: a meta-analytic review. *Neuropsychology review, 16*(1), 17-42.

Anderson, P. (2002). Assessment and Development of Executive Function (EF) During Childhood [Article]. *Child Neuropsychology, 8*(2), 71. http://search.ebscohost.com/login.aspx?direct=true&db=aph&AN=9382714&site=ehost-live

Anderson, V., Jacobs, R., & Anderson, P. J. (2010). *Executive functions and the frontal lobes: A lifespan perspective*. Psychology Press.

Ardila, A. (2008). On the evolutionary origins of executive functions. *Brain and Cognition, 68*(1), 92-99. https://doi.org/https://doi.org/10.1016/j.bandc.2008.03.003

Aron, A. R., Robbins, T. W., & Poldrack, R. A. (2004). Inhibition and the right inferior frontal cortex. *Trends in Cognitive Sciences, 8*(4), 170-177. https://doi.org/10.1016/j.tics.2004.02.010

Banich, M., & Depue, B. E. (2015). Recent advances in understanding neural systems that support inhibitory control. *Current Opinion in Behavioral Sciences, 1*, 17-22.

Barkley, R. A. (2012). *Executive functions: What they are, how they work, and why they evolved*. Guilford Press.

Barrow, I. M., Hough, M., Rastatter, M. P., Walker, M., Holbert, D., & Rotondo, M. F. (2003). Can within-category naming identify subtle cognitive deficits in the mild traumatic brain-injured patient? *Journal of Trauma and Acute Care Surgery, 54*(5), 888-897.

Belanger, H. G., Curtiss, G., Demery, J. A., Lebowitz, B. K., & Vanderploeg, R. D. (2005). Factors moderating neuropsychological outcomes following mild traumatic brain injury: A meta-analysis. *Journal of the International Neuropsychological Society, 11*(3), 215-227. https://doi.org/10.1017/s1355617705050277

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

Blumenfeld, H. K., & Marian, V. (2014). Cognitive control in bilinguals: Advantages in Stimulus–Stimulus inhibition. *17*(03), 610-629. https://doi.org/10.1017/s1366728913000564

Branzi, F. M., Della Rosa, P. A., Canini, M., Costa, A., & Abutalebi, J. (2015). Language control in bilinguals: monitoring and response selection. *Cerebral cortex, 26*(6), 2367-2380.

Burgess, P. W., Alderman, N., Evans, J., Emslie, H., & Wilson, B. A. (1998). The ecological validity of tests of executive function. *Journal of the International Neuropsychological Society, 4*(6), 547-558.

Calabria, M., Costa, A., W. Green, D., & Abutalebi, J. (2018). *Neural basis of bilingual language control*. https://doi.org/10.1111/nyas.13879

Calabria, M., Marne, P., Romero-Pinel, L., Juncadella, M., & Costa, A. (2014). Losing control of your languages: A case study. *Cognitive neuropsychology, 31*(3), 266-286.

Cicerone, K. D., Dahlberg, C., Kalmar, K., Langenbahn, D. M., Malec, J. F., Bergquist, T. F., Felicetti, T., Giacino, J. T., Harley, J. P., Harrington, D. E., Herzog, J., Kneipp, S., Laatsch, L., & Morse, P. A. (2000). Evidence-based cognitive rehabilitation: Recommendations for clinical practice. *Archives of Physical Medicine and Rehabilitation, 81*(12), 1596-1615. https://doi.org/10.1053/apmr.2000.19240

Cipolotti, L., Spanò, B., Healy, C., Tudor-Sfetea, C., Chan, E., White, M., Biondo, F., Duncan, J., Shallice, T., & Bozzali, M. (2016). Inhibition processes are dissociable and lateralized in human prefrontal cortex. *Neuropsychologia, 93*, 1-12. https://doi.org/https://doi.org/10.1016/j.neuropsychologia.2016.09.018

Coderre, E. L., Smith, J. F., Van Heuven, W. J., & Horwitz, B. (2016). The functional overlap of executive control and language processing in bilinguals. *Bilingualism: Language and Cognition, 19*(3), 471-488.

Constantinidou, F., & Kennedy, M. (2017). Traumatic brain injury in adults. *Aphasia and related neurogenic communication disorders*, 421-450.

Constantinidou, F., Wertheimer, J. C., Tsanadis, J., Evans, C., & Paul, D. R. (2012). Assessment of executive functioning in brain injury: Collaboration between speech-language pathology and neuropsychology for an integrative neuropsychological perspective. *Brain Injury, 26*(13-14), 1549-1563. https://doi.org/10.3109/02699052.2012.698786

Conway, A. R., Kane, M. J., Bunting, M. F., Hambrick, D. Z., Wilhelm, O., & Engle, R. W. (2005). Working memory span tasks: A methodological review and user's guide. *Psychon Bull Rev, 12*(5), 769-786.

Cowan, N. (2010). The Magical Mystery Four: How is Working Memory Capacity Limited, and Why? *Current Directions in Psychological Science, 19*(1), 51-57. https://doi.org/10.1177/0963721409359277

Davidson, M. C., Amso, D., Anderson, L. C., & Diamond, A. (2006). Development of cognitive control and executive functions from 4 to 13 years: Evidence from manipulations of memory, inhibition, and task switching. *Neuropsychologia, 44*(11), 2037-2078. https://doi.org/10.1016/j.neuropsychologia.2006.02.006

Delis, D. C., Kaplan, E., & Kramer, J. H. (2001). *D-Kefs: Delis-Kaplan Executive Function System*. Pearson.

DeLuca, V., Rothman, J., Bialystok, E., & Pliatsikas, C. (2019). Redefining bilingualism as a spectrum of experiences that differentially affects brain structure and function. *Proceedings of the National Academy of Sciences, 116*(15), 7565-7574.

Derrfuss, J., Brass, M., Neumann, J., & Von Cramon, D. Y. (2005). Involvement of the inferior frontal junction in cognitive control: Meta-analyses of switching and Stroop studies. *Human Brain Mapping, 25*(1), 22-34. https://doi.org/10.1002/hbm.20127

DeVellis, R. F. (2016). *Scale development: Theory and applications* (Vol. 26). Sage publications.

Diamond, A. (2013). Executive functions. *Annual review of psychology, 64*, 135-168.

Diamond, A. (2016). Why improving and assessing executive functions early in life is critical. *Executive function in preschool-age children: Integrating measurement, neurodevelopment, and translational research*, 11-43.

Douglas, J. M., Bracy, C. A., & Snow, P. C. (2007). Exploring the factor structure of the La Trobe Communication Questionnaire: Insights into the nature of communication deficits following traumatic brain injury. *Aphasiology, 21*(12), 1181-1194. https://doi.org/10.1080/02687030600980950

Douglas, J. M., O'Flaherty, C. A., & Snow, P. C. (2000). Measuring perception of communicative ability: the development and evaluation of the La Trobe communication questionnaire. *Aphasiology, 14*(3), 251-268. https://doi.org/10.1080/026870300401469

Eagle, D. M., Bari, A., & Robbins, T. W. (2008). The neuropsychopharmacology of action inhibition: cross-species translation of the stop-signal and go/no-go tasks.

Psychopharmacology, 199(3), 439-456. https://doi.org/10.1007/s00213-008-1127-6

Eriksen, C. W. (1995). The flankers task and response competition: A useful tool for investigating a variety of cognitive problems. *Visual Cognition, 2*(2-3), 101-118. https://doi.org/10.1080/13506289508401726

Fabbro, F., Skrap, M., & Aglioti, S. (2000). Pathological switching between languages after frontal lesions in a bilingual patient. *Journal of Neurology, Neurosurgery & Psychiatry, 68*(5), 650-652.

Fabbro, F., Tavano, A., Corti, S., Bresolin, N., De Fabritiis, P., & Borgatti, R. (2004). Long-term neuropsychological deficits after cerebellar infarctions in two young adult twins. *Neuropsychologia, 42*(4), 536-545. https://doi.org/https://doi.org/10.1016/j.neuropsychologia.2003.09.006

Festman, J., Rodriguez-Fornells, A., & Münte, T. F. (2010). Individual differences in control of language interference in late bilinguals are mainly related to general executive abilities. *Behavioral and Brain Functions, 6*(1), 5. https://doi.org/10.1186/1744-9081-6-5

Foster, J. L., Shipstead, Z., Harrison, T. L., Hicks, K. L., Redick, T. S., & Engle, R. W. (2015). Shortened complex span tasks can reliably measure working memory capacity. *Memory & cognition, 43*(2), 226-236.

Friedman, N. P., & Miyake, A. (2004). The relations among inhibition and interference control functions: a latent-variable analysis. *Journal of Experimental Psychology: General, 133*(1), 101.

Friedman, N. P., & Miyake, A. (2017). Unity and diversity of executive functions: Individual differences as a window on cognitive structure. *Cortex, 86*, 186-204.

Garbin, G., Sanjuan, A., Forn, C., Bustamante, J. C., Rodriguez-Pujadas, A., Belloch, V., Hernandez, M., Costa, A., & Ávila, C. (2010). Bridging language and attention: Brain basis of the impact of bilingualism on cognitive control. *NeuroImage, 53*(4), 1272-1278. https://doi.org/http://dx.doi.org/10.1016/j.neuroimage.2010.05.078

Gilbert, S. J., & Shallice, T. (2002). Task Switching: A PDP Model. *Cognitive Psychology, 44*(3), 297-337. https://doi.org/https://doi.org/10.1006/cogp.2001.0770

Gollan, T. H., Montoya, R. I., & Bonanni, M. P. (2005). Proper names get stuck on bilingual and monolingual speakers' tip of the tongue equally often. *Neuropsychology, 19*(3), 278.

Gollan, T. H., Montoya, R. I., & Werner, G. A. (2002). Semantic and Letter Fluency in Spanish-English Bilinguals. *Neuropsychology, 16*(4), 562-576. http://login.ezproxy1.lib.asu.edu/login?url=https://search.proquest.com/docview/85569487?accountid=4485

Gollan, T. H., Stasenko, A., Li, C., & Salmon, D. P. (2017). Bilingual language intrusions and other speech errors in Alzheimer's disease. *Brain and Cognition, 118*, 27-44. https://doi.org/https://doi.org/10.1016/j.bandc.2017.07.007

Gray, T., & Kiran, S. (2016). The relationship between language control and cognitive control in bilingual aphasia. *Bilingualism: Language and Cognition, 19*(3), 433-452.

Green, D. W. (1998). Mental control of the bilingual lexico-semantic system. *Bilingualism: Language and Cognition, 1*. https://doi.org/10.1017/s1366728998000133

Green, D. W., & Abutalebi, J. (2013). Language control in bilinguals: The adaptive control hypothesis. *Journal of Cognitive Psychology, 25*(5), 515-530. https://doi.org/10.1080/20445911.2013.796377

Green, D. W., Grogan, A., Crinion, J., Ali, N., Sutton, C., & Price, C. J. (2010). Language control and parallel recovery of language in individuals with aphasia. *Aphasiology, 24*(2), 188-209. https://doi.org/10.1080/02687030902958316

Grosjean, F., & Li, P. (2012). *The psycholinguistics of bilingualism*. John Wiley & Sons.

Hedden, T., Park, D. C., Nisbett, R., Ji, L.-J., Jing, Q., & Jiao, S. (2002). Cultural variation in verbal versus spatial neuropsychological function across the life span. *Neuropsychology, 16*(1), 65.

Hernandez, A. E. (2009). Language switching in the bilingual brain: What's next? *Brain and Language, 109*(2), 133-140. https://doi.org/https://doi.org/10.1016/j.bandl.2008.12.005

Hernández, M., Martin, C. D., Barceló, F., & Costa, A. (2013). Where is the bilingual advantage in task-switching? *Journal of Memory and Language, 69*(3), 257-276.

Heyder, K., Suchan, B., & Daum, I. (2004). Cortico-subcortical contributions to executive control. *Acta Psychologica, 115*(2-3), 271-289.

Hough, M. S. (2008). Word retrieval failure episodes after traumatic brain injury. *Aphasiology, 22*(6), 644-654. https://doi.org/10.1080/02687030701541024

Ivanova, I., & Costa, A. (2008). Does bilingualism hamper lexical access in speech production? *Acta Psychologica, 127*(2), 277-288.

Jurado, M. B., & Rosselli, M. (2007). The elusive nature of executive functions: a review of our current understanding. *Neuropsychology review, 17*(3), 213-233.

Koch, I., Gade, M., Schuch, S., & Philipp, A. M. (2010). The role of inhibition in task switching: A review. *Psychonomic Bulletin & Review, 17*(1), 1-14. https://doi.org/10.3758/PBR.17.1.1

Lezak, M., Howieson, D., & Loring, D. W. (2004). *Neuropsychological Assessment*. Oxford University Press.

Lezak, M. D. (2004). *Neuropsychological assessment*. Oxford University Press, USA.

Luk, G., Green, D. W., Abutalebi, J., & Grady, C. (2012). Cognitive control for language switching in bilinguals: A quantitative meta-analysis of functional neuroimaging studies. *Language and cognitive processes, 27*(10), 1479-1488.

MacDonald, S. (2005). Functional assessment of verbal reasoning and executive strategies. *Guelph, Ontario: CCD Publishing*.

Macdonald, S., & Johnson, C. J. (2005). Assessment of subtle cognitive-communication deficits following acquired brain injury: A normative study of the Functional

Assessment of Verbal Reasoning and Executive Strategies (FAVRES). *Brain Injury, 19*(11), 895-902. https://doi.org/10.1080/02699050400004294

Malec, J. F., Brown, A. W., Leibson, C. L., Flaada, J. T., Mandrekar, J. N., Diehl, N. N., & Perkins, P. K. (2007). The mayo classification system for traumatic brain injury severity. *J Neurotrauma, 24*(9), 1417-1424. https://doi.org/10.1089/neu.2006.0245

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.

McInnes, K., Friesen, C. L., Mackenzie, D. E., Westwood, D. A., & Boe, S. G. (2017). Mild Traumatic Brain Injury (mTBI) and chronic cognitive impairment: A scoping review. *PLoS ONE, 12*(4), e0174847. https://doi.org/10.1371/journal.pone.0174847

Miller, E. K., & Cohen, J. D. (2001). An integrative theory of prefrontal cortex function. *Annual review of neuroscience, 24*(1), 167-202.

Miller, G. A. (1956). The magical number seven, plus or minus two: Some limits on our capacity for processing information. *Psychological Review, 63*(2), 81.

Miyake, A., Emerson, M., & Friedman, N. (2000). Assessment of Executive Functions in Clinical Settings: Problems and Recommendations. *Seminars in Speech and Language, 21*(2), 169-183.

Miyake, A., Friedman, N. P., Emerson, M. J., Witzki, A. H., Howerter, A., & Wager, T. D. (2000). The unity and diversity of executive functions and their contributions to complex "frontal lobe" tasks: A latent variable analysis. *Cognitive Psychology, 41*(1), 49-100.

Monsell, S. (2003). Task switching. *Trends in Cognitive Sciences, 7*(3), 134-140.

Monsell, S., Yeung, N., & Azuma, R. (2000). Reconfiguration of task-set: Is it easier to switch to the weaker task? *Psychological Research, 63*(3-4), 250-264.

Mueller, S. T. (2013). The Psychology Experiment Building Language (Version 0.14) [Software]. Available from http://pebl.sourceforge.net.

Murdoch, B. E., & Theodoros, D. G. (2001). *Traumatic brain injury: Associated speech, language, and swallowing disorders*. Cengage Learning.

Norris, G., & Tate, R. L. (2000). The Behavioural Assessment of the Dysexecutive Syndrome (BADS): Ecological, Concurrent and Construct Validity. *Neuropsychological Rehabilitation, 10*(1), 33-45. https://doi.org/10.1080/096020100389282

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.

Paap, K. R., Myuz, H. A., Anders, R. T., Bockelman, M. F., Mikulinsky, R., & Sawi, O. M. (2017). No compelling evidence for a bilingual advantage in switching or that frequent language switching reduces switch cost. *Journal of Cognitive Psychology, 29*(2), 89-112.

Peters, G. J., David, C. N., Marcus, M. D., & Smith, D. M. (2013). The medial prefrontal cortex is critical for memory retrieval and resolving interference. *Learning & Memory, 20*(4), 201-209. https://doi.org/10.1101/lm.029249.112

Prior, A., & MacWhinney, B. (2010). A bilingual advantage in task switching. *Bilingualism: Language and Cognition, 13*(02), 253-262.

Rabinowitz, A. R., & Levin, H. S. (2014). Cognitive Sequelae of Traumatic Brain Injury. *Psychiatric Clinics of North America, 37*(1), 1-11. https://doi.org/10.1016/j.psc.2013.11.004

Raskin, S. A., & Mateer, C. A. (1999). *Neuropsychological management of mild traumatic brain injury*. Oxford University Press.

Ratiu, I., & Azuma, T. (2015). Working memory capacity: is there a bilingual advantage? *Journal of Cognitive Psychology, 27*(1), 1-11.

Ratiu, I., & Azuma, T. (2017). Language control in bilingual adults with and without history of mild traumatic brain injury. *Brain and Language, 166*, 29-39. https://doi.org/http://dx.doi.org/10.1016/j.bandl.2016.12.004

Ratiu, I., & Azuma, T. (2019). Assessment of executive function in bilingual adults with history of mild traumatic brain injury. *Brain Impairment*, 1-15. https://doi.org/10.1017/brimp.2019.17

Rogers, R. D., & Monsell, S. (1995). Costs of a predictible switch between simple cognitive tasks. *Journal of Experimental Psychology: General, 124*(2), 207.

Sandoval, T. C., Gollan, T. H., Ferreira, V. S., & Salmon, D. P. (2010). What causes the bilingual disadvantage in verbal fluency? The dual-task analogy. *Bilingualism: Language and Cognition, 13*(02), 231-252.

Scherf, K. S., Sweeney, J. A., & Luna, B. (2006). Brain basis of developmental change in visuospatial working memory. *Journal of Cognitive Neuroscience, 18*(7), 1045-1058.

Strauss, E., Sherman, E. M., & Spreen, O. (2006). *A compendium of neuropsychological tests: Administration, norms, and commentary*. American Chemical Society.

Stuss, D. T., & Alexander, M. P. (2000). Executive functions and the frontal lobes: a conceptual view [journal article]. *Psychological Research, 63*(3), 289-298. https://doi.org/10.1007/s004269900007

Turkstra, L. S., & Byom, L. J. (2010). Executive Functions and Communication in Adolescents. *The ASHA Leader, 15*(15), 8-11. https://doi.org/10.1044/leader.FTR1.15152010.8

Van den Noort, M., Struys, E., Bosch, P., Jaswetz, L., Perriard, B., Yeo, S., Barisch, P., Vermeire, K., Lee, S.-H., & Lim, S. (2019). Does the bilingual advantage in cognitive control exist and if so, what are its modulating factors? A systematic review. *Behavioral Sciences, 9*(3), 27.

Videsott, G., Herrnberger, B., Hoenig, K., Schilly, E., Grothe, J., Wiater, W., Spitzer, M., & Kiefer, M. (2010). Speaking in multiple languages: Neural correlates of language proficiency in multilingual word production. *Brain and Language, 113*(3), 103-112.

Vynorius, K. C., Paquin, A. M., & Seichepine, D. R. (2016). Lifetime Multiple Mild Traumatic Brain Injuries Are Associated with Cognitive and Mood Symptoms in Young Healthy College Students. *Frontiers in Neurology, 7*. https://doi.org/10.3389/fneur.2016.00188

Wallace, G. L., Peng, C. S., & Williams, D. (2017). Interfering With Inner Speech Selectively Disrupts Problem Solving and Is Linked With Real-World Executive Functioning. *Journal of Speech, Language, and Hearing Research, 60*(12), 3456-3460. https://doi.org/doi:10.1044/2017_JSLHR-S-16-0376

Wickens, T. D., & Keppel, G. (2004). *Design and analysis: A researcher's handbook*. Pearson Prentice-Hall.

Wilson, B. A., Alderman, N., Burgess, P. W., Emslie, H., & Evans, J. J. (1996). *BADS: Behavioural assessment of the dysexecutive syndrome*. Pearson.

Wylie, G., & Allport, A. (2000). Task switching and the measurement of "switch costs". *Psychological Research, 63*(3-4), 212-233.

Yeates, K. O., Levin, H. S., & Ponsford, J. (2017). The Neuropsychology of Traumatic Brain Injury: Looking Back, Peering Ahead. *Journal of the International Neuropsychological Society, 23*(9-10), 806-817. https://doi.org/10.1017/s1355617717000686

Zelazo, P. D. (2015). Executive function: Reflection, iterative reprocessing, complexity, and the developing brain. *Developmental Review, 38*, 55-68.

APPENDIX A

INSTITUTIONAL REVIEW BOARD APPROVAL

APPROVAL: MODIFICATION

Tamiko Azuma
CHS: Health Solutions, College of
480/965-9455
TAMIKO.AZUMA@asu.edu

Dear Tamiko Azuma:

On 2/12/2020 the ASU IRB reviewed the following protocol:

Type of Review:	Modification / Update
Title:	Cognitive Performance in Bilingual Adults with and without History of Mild Traumatic Brain Injury
Investigator:	Tamiko Azuma
IRB ID:	STUDY00005712
Funding:	None
Grant Title:	None
Grant ID:	None
Documents Reviewed:	None

The IRB approved the modification.

When consent is appropriate, you must use final, watermarked versions available under the "Documents" tab in ERA-IRB.

In conducting this protocol you are required to follow the requirements listed in the INVESTIGATOR MANUAL (HRP-103).

Sincerely,

IRB Administrator

cc: Halah Alateeq
Celeste Moreno-Campoy
Alexandra Bizzarri
Halah Alateeq

APPENDIX B

MTBI AND BILINGUAL LANGUAGE PROFILES FOR THE BILINGUAL GROUP WITH M

	mTBI History							Language History							
	Diag.	Susp.	LOC	Years	#	Pres. Symp.	>1	Language	ESL	Sim.	L2 AoA	% L1 Use	L1 Prof.	L2 Prof.	CET
516		+		7	1			Chinese	+	+	7	40	8	5.5	14
527	+				1			Spanish			12	70	10	7.5	21
536		+		3	1			Vietnamese		+	3	75	8.5	6.5	20
555	+				1			Spanish	+	+	4	50	10	10	21
572	+		+		1			Spanish	+		6	50	9.5	6.5	19
574		+													10
594		+		1	1			ASL		+	2	75	10	7	24
602	+	+		4	3		+	French		+		90	10	2.5	23
604		+		6	2		+	German	+	+	4	25	9	7.5	20
612		+		15	1			Chinese	+	+	1	50	8.5	9	24
625		+	+	1	1			Japanese			14	90	10	5	24
632		+		8	1			Japanese			16	90	10	7	22
647	+		+		1										24
650		+		1	1	+	+	Spanish							24
656		+		19	1			Arabic	+	+	12	25	9.5	7.5	16
667		+		4	1			Chinese	+	+	15	75	9	6	15
518	+				1	+		Spanish	+		12	90	10	8.5	15
531	+		+		1	+		Hungarian	+		16	50	9	9	20
550		+		5	1	+		ASL			16	75	10	7.5	22
565		+				+		Hindi	+	+	2	10	10	10	20
575	+				1	+		Vietnamese		+	3	75	10	8.5	19
580		+				+		Chinese	+		8	50	6.5	4	7
607	+				1	+		Spanish	+	+	1	25	6.5	8.5	18

Note: History of diagnosed mTBI (diag.). History of suspected mTBI (susp.). Reported loss of consciousness after mTBI (LOC). Years since last mTBI (years). The number of mTBIs (#). Reported persistent cognitive or behavioral symptoms (pres. Symp.). History of repetitive mTBI (>1). Languages used other than English (language). Simultaneous bilinguals (sim.). Age of L2 acquisitions (L2 AoA). Percentage of L1 daily use (%L1 use). The average of L1 speaking and understanding proficiency (L1 prof). The average of L2 speaking and understanding proficiency (L2 prof.). Scores on the Cambridge English Test (CET).

APPENDIX C

GENERAL QUESTIONNAIRE

The General Questionnaire

(It will be sent to participants as a Google Form. The following is the content of the questionnaire).

Age: _______
Gender: ___ Male ___ Female ____ non-binary
Race: Multiple choices
Are you Hispanic? ____ Yes ___No

If you have vision problems, please describe them. If you do not, type "none."

____

If you have a hearing loss, please describe it. If you do not, type "none."

____

Have you been diagnosed (by a doctor or a specialist) with any of the following conditions (select all that apply):
____Post-traumatic Stress Disorder
____Depression
____Attention Deficit Hyperactivity Disorders (ADHD)
____Learning Disability
____Autism/Asperger's
____Stroke/Aneurysm
____Dyslexia/dysgraphia (Difficulty reading or writing)

Do you take medications for specific medical conditions? If yes, please list the medications and why you take them.

____

Have you ever been DIAGNOSED with a concussion or head injury? (Have you had a head injury and saw a doctor and/or went to the hospital)
____ Yes ___No

How many concussions/head injuries have you been diagnosed with? Please give your age for each.

____

How did you get the concussion/head injury? (Check all that apply)
_____Sports or recreational accident (e.g., soccer, biking)
_____Motor vehicle accident
_____Assault
_____Fall that was not sports-related
_____Explosion or blast

_____Blow to the head (something hit your head)
_____ Other: __________

Please describe what happened with each injury and your symptoms.

____

If you lost consciousness, how long were you unconscious?

____

Please select all symptoms you IMMEDIATELY had right after your concussion/head injury:
____Memory Problems (i.e. you cannot remember things)
____Attention Difficulties (i.e. distracted, cannot concentrate)
____Increased Anxiety (i.e. feeling stressed, anxious, worried)
____Headaches
____Difficulty Sleeping
____Changes in Mood
____ Other: _________

Please select all symptoms you feel you STILL experience as a result of your concussion/head injury:
____Memory Problems (i.e. you cannot remember things)
____Attention Difficulties (i.e. distracted, cannot concentrate)
____Increased Anxiety (i.e. feeling stressed, anxious, worried)
____Headaches
____Difficulty Sleeping
____Changes in Mood
____ Other: _________

Do you think that you have ever had an UNDIAGNOSED concussion or head injury? (Have you had a head injury and did not go to the hospital or see a doctor)
____ Yes ___No

How many concussions/head injuries you believe you have had? Please give your AGE for each.

____

What were the circumstances of the suspected concussion/head injury? (Select all that apply) Please describe what happened with each injury and your symptoms.
_____Sports or recreational accident (e.g., soccer, biking)
_____Motor vehicle accident
_____Assault
_____Fall that was not sports-related
_____Explosion or blast
_____Blow to the head (something hit your head)

_____ Other: __________

If you lost consciousness, how long were you unconscious?

____

Please select all symptoms you IMMEDIATELY experienced as a result of your suspected concussion/head injury:
____Memory Problems (i.e. you cannot remember things)
____Attention Difficulties (i.e. distracted, cannot concentrate)
____Increased Anxiety (i.e. feeling stressed, anxious, worried)
____Headaches
____Difficulty Sleeping
____Changes in Mood
____ Other: _________

Please select all symptoms you feel you STILL experience as a result of your suspected concussion/head injury:
____Memory Problems (i.e. you cannot remember things)
____Attention Difficulties (i.e. distracted, cannot concentrate)
____Increased Anxiety (i.e. feeling stressed, anxious, worried)
____Headaches
____Difficulty Sleeping
____Changes in Mood
____ Other: _________

EDUCATIONAL HISTORY
How many semesters have you completed in college?

Are you an International Student?
____ Yes ___No

INTERNATIONAL STUDENTS
What country are you from?

____

What city are you from?

____

Where did you grow up?

When you started at ASU, was it your first time in the U.S.?

How long have you lived in the U.S.?

____

How many years did you formally study English in school? (How many years did you take English classes?)

____

Which test of the following have you taken before?
_____TOEFL _______IELTS ______PTE
Approximately, what was your score on the TOEFL, IELTS, or PTE test?

____

BILINGUAL QUESTIONNAIRE
How many languages do you speak?

What is the FIRST language you spoke?

What is the SECOND language you spoke?

Did you learn these languages simultaneously (at the same time when you were a kid)?
____ Yes ___No

Which language do you consider yourself MORE FLUENT in?

On a typical day, what percentage of time do you use English? (e.g. speak, listen, and read in English)
___0 ____10 ____20 ____30 ____40 ____50 ____60 ____70 ____80 _____90 ____100

On average, what percentage of time do you use your OTHER language?
___0 ____10 ____20 ____30 ____40 ____50 ____60 ____70 ____80 _____90 ____100

How well do you SPEAK English?
___1 ____2 ____3 ____4 ____5 ____6 ____7 ____8 ____9 _____10

How well can you WRITE in English?
___1 ____2 ____3 ____4 ____5 ____6 ____7 ____8 ____9 _____10

How well do you UNDERSTAND spoken English?
___1 ____2 ____3 ____4 ____5 ____6 ____7 ____8 ____9 _____10

How well do you READ written English?
___1 ____2 ____3 ____4 ____5 ____6 ____7 ____8 ____9 _____10

How much of a foreign accent do you think you have in English?
___1 ____2 ____3 ____4 ____5 ____6 ____7 ____8 ____9 _____10

How often do others identify you as a non-native English speaker based on your accent?
___1 ____2 ____3 ____4 ____5 ____6 ____7 ____8 ____9 _____10

How old were you when you began learning English?

____

How old were you when you began reading in English?

____

How well do you SPEAK your other language?
___1 ____2 ____3 ____4 ____5 ____6 ____7 ____8 ____9 _____10

How well can you WRITE in your other language?
___1 ____2 ____3 ____4 ____5 ____6 ____7 ____8 ____9 _____10

How well do you UNDERSTAND speech spoken to you in your other language?
___1 ____2 ____3 ____4 ____5 ____6 ____7 ____8 ____9 _____10

How well can you READ and understand material written in your other language?
___1 ____2 ____3 ____4 ____5 ____6 ____7 ____8 ____9 _____10

How old were you when you began learning this language?

____

How old were you when you began reading in this language?

____

If you would like to find out about participating in our other studies on memory, attention, and learning, please enter your email address below.

____