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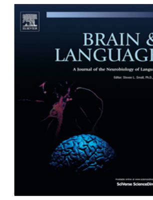

Language control in bilingual adults with and without history of mild traumatic brain injury

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ABSTRACT

Adults with a history of traumatic brain injury often show deficits in executive functioning (EF), including the ability to inhibit, switch, and attend to tasks. These abilities are critical for language processing in bilinguals. This study examined the effect of mild traumatic brain injury (mTBI) on EF and language processing in bilinguals using behavioral and eye-tracking measures. Twenty-two bilinguals with a history of mTBI and twenty healthy control bilinguals were administered executive function and language processing tasks. Bilinguals with a history of mTBI showed deficits in specific EFs and had higher rates of language processing errors than healthy control bilinguals. Additionally, individuals with a history of mTBI have different patterns of eye movements during reading than healthy control bilinguals. These data suggest that language processing deficits are related to underlying EF abilities. The findings provide important information regarding specific EF and language control deficits in bilinguals with a history mTBI.

1. Introduction

Approximately 1.4 million individuals sustain a mild traumatic brain injury (mTBI) in the U.S. every year (Faul, Xu, Wald, & Coronado, 2010; Langlois, Rutland-Brown, & Thomas, 2004). The most common cortical areas affected by mTBI are the prefrontal and temporal lobes (e.g., Lipton et al., 2009; Strangman et al., 2010; Zhang et al., 2010). Sensitive neuroimaging techniques (e.g., diffusion tensor imaging) have revealed diffuse axonal injuries following mTBI which are related to executive dysfunction (e.g., Leunissen et al., 2014; Lipton et al., 2009; Shenton et al., 2012; Sorg et al., 2013). Monolingual individuals, who experience a TBI affecting the prefrontal cortex, commonly show deficits in one or more executive functions, such as the ability mentally shift their attention between tasks, hold multiple items in memory, and suppress interference from distractors (e.g., Eslinger, Grattan, & Geder, 1995; Hunt, Turner, Polatajko, Bottari, & Dawson, 2013; Kennedy et al., 2008; Miyake et al., 2000). Executive function (EF) refers to a set of cognitive processes responsible for the complex control of thoughts and actions. Individuals rely on EF when inhibiting interference from distracting stimuli, suppressing prepotent responses, switching attention between multiple tasks, planning and organizing a sequence of events, reasoning, problem solving, and holding multiple task relevant goals in working memory (e.g., Garner, 2009; Miyake et al., 2000). Bilingual individuals rely on EF to efficiently manage or control their languages (e.g., Green & Abutalebi, 2013); however, it is not known how mTBI impacts these abilities. The present study examined the impact of mTBI on bilingual EF and language control and attempted to identify individuals who may be at greater risk for deficits following mTBI.

1.1. Traumatic brain injury

Traumatic brain injury can impact multiple EFs. In a systematic review, Dimoska-Di Marco, McDonald, Kelly, Tate, and Johnstone (2011) reported significant differences between TBI patients and healthy controls in response inhibition tasks (e.g., go/no-go tasks), but not in interference inhibition tasks (e.g., Stroop). The authors concluded that TBI can cause deficits in the withholding of manual responses (see also Swick, Honzel, Larsen, Ashley, & Justus, 2012). It was further proposed that response inhibition deficits may underlie the more pronounced disinhibition observed in patients with moderate to severe TBI (e.g., Kim, 2002; Ylvisaker, Turkstra, & Coelho, 2005).

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Traumatic brain injury can also detrimentally affect the ability to switch attention between tasks. Caeyenberghs et al. (2014) observed individuals with TBI and healthy controls as they performed switching tasks. Compared to healthy controls, individuals with a history of TBI were slower and less accurate, and showed a greater switching cost (i.e., alternating between two different trial types versus repeating the same trial type). Additionally, MRI scans of the TBI participants showed that task performance was related to decreased brain network connectivity. The authors concluded that TBI affects task-switching ability and that ability is directly related to underlying efficiency in neural processing. The authors proposed that subtle task switching deficits are related to behavioral inflexibility that is commonly observed in individuals with TBI.

Terry et al. (2012) examined working memory performance following mTBI. Participants with mTBI and healthy controls completed the operation span task, a complex working memory task (Turner & Engle, 1989). Participants were shown a two-step math equation to verify and an item to remember. Terry et al. found that patients with mTBI performed significantly worse compared with healthy controls. Individuals with mTBI also perform worse than healthy controls on another working memory task, the n-back task (e.g., Dean & Sterr, 2013; Slovarp, Azuma, & LaPointe, 2012). However, individuals with mTBI do not show deficits on simple span memory tasks (e.g., Anderson & Knight, 2010; Ozen, Skinner, & Fernandes, 2010). In simple span tasks, such as a digit span task, participants are required to simply repeat a short list of items. The pattern of preserved simple span memory and impaired complex working memory in individuals with mTBI indicates a specific deficit in the ability to hold multiple items in memory in the face of distraction.

1.2. Bilingual language processing

Because of these EF impairments, bilinguals with a history of TBI are likely to also manifest language processing deficits. For bilinguals, lexical items in both languages are constantly active (e.g., Duñabeitia, Perea, & Carreiras, 2010; Illes et al., 1999; Spivey & Marian, 1999). Studies have shown that a bilingual's languages are integrated and lexical items across languages are coactivated for both orthographic items (e.g., Duñabeitia, Perea, & Carreiras, 2010; Libben & Titone, 2009) and auditory items (e.g., Marian & Spivey, 2003; Spivey & Marian, 1999). Because bilinguals successfully communicate without making constant cross-language intrusions, they likely recruit cognitive mechanisms to control cross-language competition. These cognitive mechanisms may be domain general in nature (i.e., not specific to language) (e.g., Garbin et al., 2010). Green and Abutalebi (2013) proposed that bilinguals use multiple adaptive control mechanisms to resolve the conflict between competing language activations, referred to as *language control*. Language control allows bilinguals to effectively communicate in one language without intrusion from the other. Multiple control processes are responsible for language control in different linguistic contexts, such as goal maintenance, interference control, salient cue detection, and selective response inhibition. The degree to which each process is recruited depends on the demands of the linguistic context.

Processing in both languages is associated with activation in overlapping regions associated with language production and comprehension: the left inferior frontal gyrus, the left dorsolateral prefrontal gyrus, superior temporal gyrus, and the left supplementary motor area (e.g., Illes et al., 1999; Marian, Spivey, & Hirsch, 2003; Zou et al., 2012). Additionally, bilinguals use multiple neural regions in language control, including the prefrontal cortex, anterior cingulate cortex, inferior parietal lobule, and the basal ganglia (e.g., Abutalebi et al., 2008; Crinion et al., 2006; Lehtonen et al., 2005; Mechelli et al., 2004). The prefrontal cortex is involved in selecting the appropriate language and inhibiting the non-target language (Abutalebi, 2008). The prefrontal cortex and the anterior cingulate cortex are active during language translations and language switching (e.g., Abutalebi et al., 2008; Hernandez, 2009). The inferior parietal lobule may be involved in articulatory planning and word production and is associated with processing in the less dominant language and language switching (e.g., Mechelli et al., 2004). The caudate nucleus plays a role in monitoring the language in use and in detecting language switching (e.g., Abutalebi, 2008; Crinion et al., 2006), while the basal ganglia is involved in the suppression of competing responses (e.g., Lehtonen et al., 2005). Damage to any of these regions could potentially result in language processing and language control deficits in bilinguals. To date, no studies have specifically investigated the impact of traumatic brain injury on bilingual executive control or bilingual language processing.

Nearly all research on cognitive deficits associated with TBI is based on monolingual populations or populations in which linguistic background is not specified. Yet, minority populations, such as Hispanics experience higher rates of TBI compared to non-minority groups (Cooper, Tabaddor, & Hauser, 1993) and have a worse prognosis post injury than non-minority groups (e.g., Arango-Lasprilla et al., 2007; Jimenez et al., 2013).

Some studies have shown that cognitive decline and disorders affect language processing in bilingual speakers (e.g., Gollan, Sandoval, & Salmon, 2011; Marrero, Golden, & Espe-Pfeifer, 2002). Patients who have aphasia as the result of a stroke can show impairments in one or in both languages and the degree of recovery for each language can vary widely (e.g., Lorenzen & Murray, 2008; Marrero et al., 2002). Both languages can be affected similarly and recover in parallel, or one language may be less affected and recover more quickly, regardless of language dominance. Additionally, the ability to switch languages may be impaired, particularly if there is a frontal lobe lesion (e.g., Fabbro, 2001; Mariën, Abutalebi, Engelborghs, & De Deyn, 2005). Thus, neurological impairment can impact a bilingual's ability to communicate in both languages and their ability to effectively control their languages.

Cognitive decline due to normal healthy aging may also impact language control and executive function in bilinguals. Gollan et al. (2011) administered the flanker task and verbal fluency task to healthy young and older Spanish-English bilinguals. In the flanker task, participants indicate the direction of a central target arrow while inhibiting distracting incongruent arrows that flank it. Older bilinguals performed significantly poorer on the flanker task than younger bilinguals, suggesting reduced inhibition abilities. Additionally, older bilinguals were more likely to make cross-language errors during the verbal fluency task (e.g., producing 'pulpo' instead of 'octopus'). Critically, there was a significant relationship between flanker task errors and cross-language errors for older bilingual adults: As inhibitory ability declined, language control abilities also declined (reflected in more cross-language errors).

While there are currently no studies directly investigating the impact of mTBI on executive function and language control in bilinguals, there is evidence showing that neurological impairment and cognitive decline can result in EF and language control deficits (e.g., Gollan et al., 2011; Lorenzen & Murray, 2008; Marrero et al., 2002). Following a TBI, bilinguals will likely experience difficulty switching between languages, translating information from one language into another, and/or greater difficulty retrieving words in one language compared to the other.

1.3. Present study

The current study had three aims: (1) to examine the performance of bilinguals with mTBI and healthy bilinguals on EF and language control tasks; (2) to examine whether eye-movement