Bilingualism's Influence on Perceptual Learning of Word Decoding and Flicker Fusion

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Abstract

Language acquisition is a unique human trait that has evolved into the most efficient communication system known. Individuals with normal linguistic physical structures who are exposed to speech acquire language in an almost effortless manner during early development. Individuals who learn to speak one language are referred to as monolinguals. Individuals exposed to multiple languages on a regular basis learn to speak those languages and are referred to as bilingual or multilingual. Research evidence strongly supports the view that the process of learning more than one language, imbues the speaker with enhanced ability in processing a variety of perceptual learning and cognitive tasks. Here we present evidence that bilinguals possess greater ability than monolinguals to process flicker and non-linguistic symbol decoding, two perceptual learning tasks associated with enhanced executive function, that have not been studied in this population before. Implications of these findings for generalization to improved cognitive function in applied areas, such as reading, are discussed.

Keywords: language development, bilingualism, cognition, perceptual learning, brain plasticity

1. Introduction

Balanced-proficient *bilingualism* is defined as the ability to speak two languages at a high level of oral comprehension and production mastery. Of course, bilingualism in signed language also occurs. Those in the process of acquiring, but not yet fully fluent in a second spoken or signed language, are known as *emergent bilinguals* (Garcia and Náñez, 2011). Individuals who speak (or sign) one language are known as *monolinguals*. For the purpose of the current study, we focused on individuals' oral/spoken linguistic abilities.

Speech is a complex cognitive and sociocultural communication system possessed only by humans. (Garcia and Náñez, 2011; Náñez, 2010; Pinker, 1995; Shriver, 2001) Quoting Pinker (1995) "Possessing a language is the quintessentially human trait: all normal humans speak, no nonhuman animal does." (p. 135). Learning to speak involves acquisition and mastery of a symbolic linguistic system with letters, words, and word combinations utilized to represent objects, events, and thought processes.

From this perspective, it seems logical that increases in cognitive abilities and intelligence (powerful brain; efficient brain circuits – information processors) go hand-in-hand with development of the physical structures (mouth and larynx) required for speech and language acquisition (Eliot, 1999). Other researchers believe that language and brain development constitute an interactive communication process. For example, according to Shaffer and Kipp (2010), "...language acquisition is clearly a holistic process intertwined with the child's cognitive and social development and the child's social and cultural life." (p. 424) With regards to bilingual language acquisition, during the process of brain and language development evolution, individuals at the boundaries of cultures with different languages effortlessly acquired the ability to speak the languages they were exposed to. For example, it is known that human newborns are universal language learners, who respond to the native sounds of any language they hear.

Soon after birth however, the infant brain begins to ‘filter out’ sounds native to non-exposed languages, and to ‘filter in’ sounds of the languages they continue to experience. (Saffran and Thieesen, 2003; Werker and Desjardins, 1995).

The current paper focuses on bilingualism as it relates to perceptual learning and cognition. Undoubtedly, bilingualism is a desirable sociocultural outcome. However, there is disagreement regarding the bilingual acquisition process, for example, what is the “best” way to learn a second language? (Simultaneously [at the same time during early development] or sequentially [master one language first and acquire a second language later in development]). Also, there has been much debate historically as to whether bilingual development “interferes” with language mastery (decoding and encoding) or other higher-order cognitive information processing abilities. There is a significant body of literature showing that in the process of learning two languages simultaneously, learning "Language One" (L1) does not impede acquisition of "Language Two" (L2) during the bilingual acquisition process. (see Garcia and Náñez, 2011 for a detailed discussion of research that effectively debunks the L1 – L2 impedance hypothesis and other ‘bilingualism myths’). For excellent reviews of earlier bilingualism and cognition research see Cummins, (1976); Hakuta and Diaz, (1984); and Peal and Lambert, (1962). From their reviews, these researchers concluded, that a significant problem with early bilingualism studies was lack of scientific methodological rigor. They also noted common design flaws, such as disregard for participants’ bilingual proficiency and balance.

There is now a large body of evidence supporting the theory that balanced, proficient bilinguals outperform monolinguals on various measures of intelligence and demonstrate greater cognitive information processing flexibility (e.g. Bialystok, 2005) on tasks requiring problem solving skills (Náñez, Padilla, & Máez, 1992). For example, bilinguals show evidence of increased ability to ignore non-central, task-irrelevant information (clutter) and focus on central, task-relevant (target) information an indicator of increased executive function.

The research cited above indicates that there is a positive correlation between a variety of cognitive tasks and bilingualism. In fact, a number of early studies proposed that bilingualism is related to increased performance on simple and complex information processing tasks (Durán & Enright, 1983; Náñez, Padilla, & Máez, 1992; Náñez & Padilla, 1993). There is also evidence from early studies that reaction time is correlated with certain cognitive linguistic measures. For example, RT has been shown to correlate with cognitive uncertainty (Hick, 1952; Jensen & Munro, 1979; Jensen, 1980, 1982), short-term memory digit-span tasks (Sternberg, 1966; Vernon & Jensen, 1984) and long-term memory sentence verification tasks (Vernon, 1983; Vernon & Jensen, 1984). However, there is a paucity of research examining the relationship between bilingualism and performance on low-level perceptual learning tasks and how this may relate to processing of high-order cognitive tasks. Thus, the current study was designed to initiate examination of whether plasticity in low-level perceptual learning tasks (directional motion detection and flicker fusion) is enhanced in bilinguals relative to monolinguals. The possibility that improved motion detection and flicker processing function to strengthen broader brain systems, e.g. dorsal and ventral visual networks and whether strengthening of these networks generalizes to elicit plasticity in processing of complex cognitive tasks, such as reading comprehension and retention is also discussed.

The current study specifically explored the relationship between bilingualism, critical flicker fusion and a nonlinguistic, psychophysical measure of word decoding called the “C Test,” two lower-level visual perception learning tasks related to cognitive ability. Critical flicker fusion (CFF) is the lowest level of continuous flicker (measured in Hz) that is perceived as a steady source of light. The ability to resolve visual modulation (flicker) has been shown to be limited by timing constraints of the primary visual system (Wells, Bernstein, Scott, Bennett, & Mendelson, 2001). There is evidence supporting the relationship between CFF threshold and cortical processing capacity (Seitz, Náñez, Holloway, & Watanabe, 2005). For example, lesion studies in non-human primates indicate that CFF rates are limited by processing in the magnocellular visual pathway (Merigan, Byrne, & Maunsell, 1991; Schiller, Logothetis, & Charles, 1991) and in the occipital lobe (Halstead, 1947; Mishkin & Weiskrantz, 1959). Yet, given that the central dorsal system processes not only flicker, but contrast, motion, and other visual perceptual stimuli as well, this brings into question whether other perceptual learning tasks might also be processed within this neural network. There is strong evidence that this is the case.

Research to date has shown that bilingualism is related to an increase in processing of some higher-order abilities that involve executive function control, for example, the relationship between bilingualism and print biliteracy (Bialystok, 1977), bilingualism and attentional control (Bialystok, 1979), bilingualism and metalinguistic ability (Bialystok, 2001), bilingualism and cognitive control on the Simon perceptual processing task (Bialystok et al. 2005; Bialystok et al., 2004), bilingualism and phonology (Bialystok, Mujumder, & Martin, 2003).

From such findings, we propose that the benefits of experiencing the environmental learning process that results in bilingualism may influence brain plasticity/malleability involved with lower-level information processing and cognition. For example, research shows that bilinguals exhibited increased functional (Kim et al., 1997) and structural (Mechelli et al., 2004) brain plasticity. This raises the question of whether strengthening neural networks involved in bilingual functional and structural changes (Kim et al., 1997; Mechelli et al., 2004) by mastering two languages, translates into increased ability to process other language-based cognitive abilities, mainly, reading comprehension?

Before engaging this question, we first describe a visual perceptual process that has been demonstrated to produce changes in brain function (plasticity/malleability) in monolinguals. Specifically, research has shown that repeated presentation of a low-level (area V1) directional dot motion identification task results in significant performance improvement on the task (Watanabe, Náñez, & Sasaki, 2001; Watanabe, Náñez, et al., 2002; 2010; Seitz & Watanabe, 2009). Repeated pairing of the dot motion task with a flicker fusion task (involving mid-level [areas V4/MT+] visual processing) resulted in enhanced flicker processing threshold. Presenting successive trials of the flicker task without the paired motion task did not alter participants' flicker threshold. Training that increases motion detection and CFF (Seitz, Náñez, Holloway, & Watanabe, 2005) has in turn been shown to be associated with improved processing of the C Test, which involves identifying the cardinal direction of the opening in a letter C stimulus (Holloway, Náñez, & Seitz, 2013; Zhou, Náñez, Zimmerman, Holloway, Seitz, 2016; Holloway 2016) and increased performance on a word and non-word decoding task, two orthographic tasks that are processed in the Occipital lobe There is recent data suggesting that training in tasks that engage progressively higher brain processing mechanisms may be related to a high-order cognitive function, namely increased reading ability in monolinguals. If this turns out to be the case, the findings may have positive implication for increasing reading speed and comprehension in monolingual normal slow readers and in clinical cases such as dyslexia among that population. (Deveau, Lovcik, & Seitz, 2014).

Research to date has shown that bilinguals, as a whole, tend to out-perform monolinguals on a variety of perceptual and cognitive tasks. The current study explores whether this observed outcome is also found for bilingual processing of CFF and the C Test, two perceptual tasks that to our knowledge have not be studied with bilinguals before.

2. Methods

2.1 Participants

Written Informed consent was obtained from all participants, and this study conformed to the tenants of the Declaration of Helsinki for the ethical treatment of human subjects (2013). Twenty participants (14 females), ages 18-43 years, were recruited from a university-level Introduction to Statistics class and received academic extra credit for their participation. Demographics were collected through administration of a participant questionnaire. Ten of the participants self-reported being English-only speakers (monolingual group) and 10 reported being Spanish-English speakers (bilingual group). Eight of the participants in the latter group self-identified as Hispanic. Given that the participants were high intellectually functioning individuals, evidenced by their successful enrollment in upper division university courses, self-report was accepted as an indicator of bilingual proficiency.

To ensure that the visual stimuli seen clearly, all participants were required to have normal or corrected-to-normal vision of at least 20/40 (measured on-site with a Snellen chart and protocol). All participants were naive as to the purpose of the experiment.

2.2 Measures and Procedure

A Macular Pigment Densitometer (Wooten, Hammond, and Snodderly, 1999) was used to measure critical flicker fusion (CFF) which was calculated psychophysically by measuring each participant's sensitivity to light that flickered between a black background and a green circle (peak wavelength = 550 nm at 1.5 cd/m2 presented at one degree of visual angle).

The room was dimly lit (1.5 cd/m2), and lighting conditions were constant across measures. The method of limits was used to determine threshold values with targets presented six times. The experimenter adjusted the rate of modulation, and the participant was unable to see either the control box or the researcher's actions. CFF was defined as the mean frequency (measured in Hz) at which the participant could no longer detect flicker in the stimulus (three trials) and the frequency at which the participant reported that the flicker recommenced (three trials).

A psychophysical non-linguistic decoding measure (the C Test) was obtained using a computer program that consisted of Landolt C targets randomly presented at one of four cardinal orientations, at three radial distances from a focal point, for eight compass directions, in a circular pattern. Participants responded by pressing the arrow key on a keyboard that matched the direction the target (opening in the C) was facing on given trial. Percentage correct was assessed over five blocks of 96 trials each for a total of 480 trials. This psychophysical test is non-linguistic, it is more akin to novel shape recognition than it is to reading, yet, it still requires the visual system to assess the direction of the opening in a manner similar to letter and word decoding (e.g., differentiating b and d based on the direction of the hump) and has been shown to be highly correlated with verbal word decoding measures (see Holloway, Náñez, and Seitz, 2013). Bilinguals were then compared to monolinguals on their ability to modulate fickler and their accuracy at decoding the Landolt C target openings.

3. Results

The average bilingual CFF threshold (M = 21.4, SD = 2.14) was significantly higher, $t(18) = 2.28$, $p<.05$, $d = 2.05$, $r^2 = 0.27$ than that of the monolinguals (M = 19, SD = 2.39). The effect size, as measured with a Cohen's d statistic, was moderate, with 27% of the variance between the groups attributable to bilingualism (see Figure 1).

In the nonlinguistic decoding task, Stimuli were presented on a computer screen at three "distances" from the focal point on the retina. The bilingual participants performed significantly better as a group than the monolinguals on this task, $F(1,54) = 8.26$, $p<.01$, $\eta^2 = .11$. Performance for both groups was equal when the target location was the furthest distance from the focus point of gaze (i.e., both groups had difficulty perceiving the target when it was most peripheral within the visual field, i.e., when the clarity of the display was weakest). As seen in Figure 2, beyond the farthest presentation from the focus point, the two groups increased performance at different rates. Performance only increased slightly in the monolinguals as the distance between the stimuli and the fixation point decreased. Alternatively, bilingual performance increased across distance, representing a clear advantage of the bilinguals on this task.

Overall the bilinguals' performance in the Landolt C task was significantly better compared to the monolinguals, $t(58)=2.69$, $p<0.01$, $d=0.69$, $r^2=0.11$ (Figure 3). The effect size, as measured with Cohen's d, was large and 11 percent of the difference between these groups is attributable to bilingualism.

4. Discussion

Previous research has revealed a positive correlation between directional motion detection, flicker processing, and word decoding in monolinguals. Here we show evidence that bilinguals' flicker processing is significantly greater than that of monolinguals. The literature shows that CFFT is related to cognitive ability in monolinguals. The bilinguals' enhanced CFFT levels relative to the monolinguals**,** indicates that the cortical exercise involved in the process of multiple language acquisition is associated with cognitive processing in bilinguals. The relative advantage in flicker processing by bilinguals observed in our study is a novel finding. On the surface, this finding appears to be somewhat surprising, however, as discussed above, there is considerable research evidence showing that bilinguals out-perform monolinguals on a variety of simple nonlinguistic perceptual processing tasks. (e.g., Náñez, Padilla, and Máez, 1992; Bialystok et al., 2005). The current findings demonstrate yet another functional cognitive advantage related to the bilingualism acquisition process.

A potential weakness of this study is that bilingual proficiency was established through participant self-report. Although this method has been used by other bilingualism researchers (Restrepo, personal communication 2016), the current findings would be strengthened through administration of an objective bilingual proficiency measure.

Overall, our review of the literature and the findings reported here contribute to a filling-in of the mosaic constituting the relationship between bilingualism, perceptual learning, brain plasticity, and cognition. Research systematically shows that training on a low-level visual processing task, such as a shape recognition task, that consistently pairs directional dot motion with a central task requiring concentration, increases motion perception performance (Watanabe, Nanez & Sasaki, 2001; Watanabe, et.al, 2002; 2010).

In turn, improved directional dot motion detection is correlated with increased flicker fusion threshold, mediated in the central dorsal visual stream, a higher-level of the visual cortex than area V1. Further, plasticity on these two tasks (dot motion and CFF) has been demonstrated to be related to increased word decoding ability, one of several functions processed in the Parietal lobe. Proficient word decoding is an indicator of orthographic processing strength that serves as an indicator of text processing ability involved in reading speed and comprehension. (Holloway, Náñez, and Seitz, 2013).

Deficits in orthographic processing have been shown to negatively impact reading abilities that are evidenced in dyslexia. Given accumulating evidence for the relationship between language and perceptual learning, the intriguing question arises regarding whether problems in learning e.g., reading deficits, may involve reduced executive function that may affect performance on higher-order visual cognitive processes?

Our future research will continue to explore whether monolinguals exposed to a comprehensive perceptual learning paradigm that includes motion detection, CFF, Landolt C, word decoding, and visual acuity training will exhibit greater improvement on higher-order cognitive tasks, such as reading comprehension than monolingual controls with no training or controls exposed to traditional reading improvement methods. Our research will also expand to include exploration of whether our perceptual learning paradigm will result in greater plasticity on higher-order cognitive tasks (e.g. reading comprehension and retention of reading content) than monolinguals.

We will also continue to seek clarification for how the process occurs. Further fertile ground for future research is examination of functional and or structural plasticity in brain structures related to bilingualism. For example, using MEG technology, Bialystok et al's. (2005) reported, "Correlations between activated regions and reaction times, however, showed that the two bilingual groups demonstrated faster reaction times with greater activity in superior and middle temporal, cingulate, and superior and inferior frontal regions, largely in the left hemisphere. The monolinguals demonstrated faster reaction times with activation in middle frontal regions. The interpretation is that the management of two language systems led to systematic changes in frontal executive functions." (p. 40) Recently, Kim, Lee, and Cho, (2015) showed that differences in processing of Simon-type perceptual conflict tasks involve differences in cognitive control processes. Kim, Lee and Cho conclude: "Although many related issues still require investigation, these results help clarify the mechanism underlying cognitive control, and contribute to building a concrete and comprehensive architecture of cognitive control." (p. 60) Kim, Lee, and Cho's research participants were likely Korean language monolinguals (language abilities were not reported). If this is the case, their findings show that high cognitive control is related to increased performance on Simon tasks in monolinguals. Is there evidence that bilinguals may enjoy benefits in cognitive control beyond those experienced by monolinguals? This is strongly suggested by Bialystok et al.'s (2005) findings, demonstrating an existing interactive relationship between processing conflict in a visual perceptual task (Simon) and higher-order cognitive processing (increased executive function) among their bilingual vs. monolingual research participants**.**

5. Conclusion

Research evidence to date points to the strong possibility that observed cognitive advantages exhibited by bilinguals relative to monolinguals, are related to improved executive function resulting from their (bilinguals'/multilinguals') acquired cognitive capabilities associated with the ecological experience of mastering multiple language systems. Our on-going research along with the work of other investigators in this area, should serve to significantly increase research-based knowledge of how early perceptual learning processes interact to affect higher-level cognitive abilities.

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Appendix A

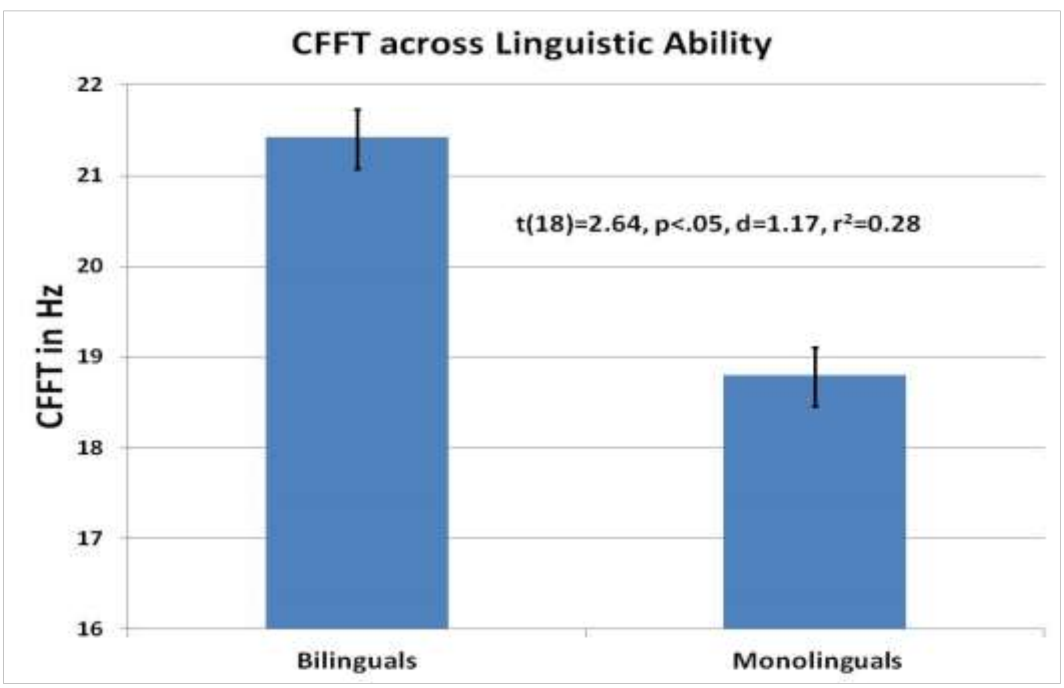

Figure 1. Critical Flicker Fusion Threshold Means (Hz), Bilinguals vs Monolinguals.

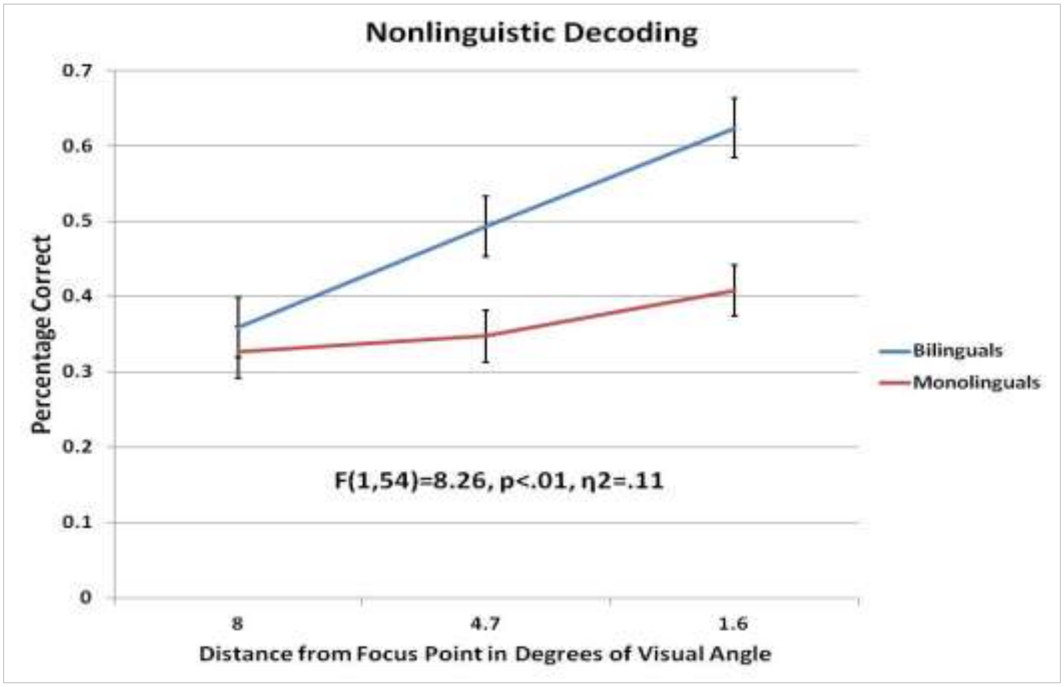

Figure 2. Nonlinguistic Word Decoding across Distance from Focus Point, Bilinguals vs Monolinguals.

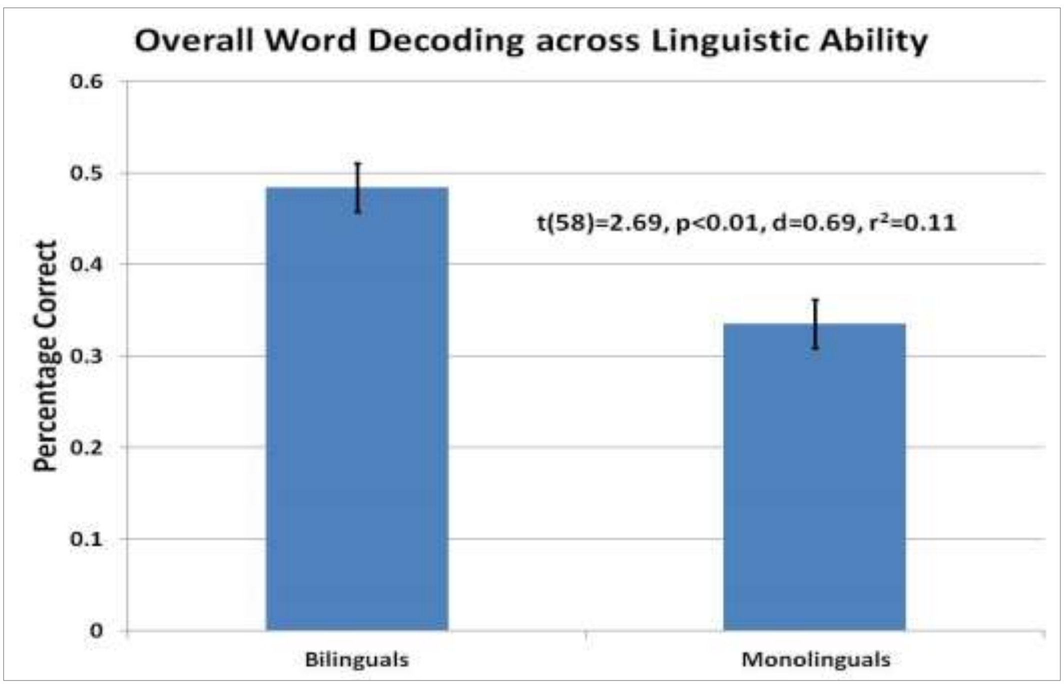

Figure 3. Overall Nonlinguistic Word Decoding Performance, Bilinguals vs Monolinguals.