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Bilingualism Alters the Neural Correlates of Sustained Attention

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The present study examined whether monolingual and bilingual language experience—including first and second language proficiency, exposure, and age of acquisition—modify the neural mechanisms of attention during nonverbal sound discrimination. English monolinguals and Korean–English bilinguals performed an auditory two-stimulus oddball task while their electroencephalogram was recorded. Participants heard a series of two different tones (high-pitch tone vs. low-pitch tone), one of which occurred less frequently (deviant trials) than the other (standard trials), and were asked to mentally count the number of infrequent tones. We found that in the early time window, bilinguals had larger amplitudes than monolinguals in response to both standard and deviant trials, suggesting that bilinguals initially increased attention to identify which of the two tones they heard. In the later time window, however, bilinguals had a smaller event-related potential (ERP) effect (deviant minus standard trials) relative to monolinguals, suggesting that bilinguals used fewer cognitive resources for the infrequent stimuli at later stages of processing. Furthermore, across the entire sample, increased exposure to the native language led to larger early, middle, and late ERP effects. These results suggest that native language exposure shapes perceptual processes involved in detection and monitoring. Knowing more than one language may alter sustained attentional processes, with implications for perception and learning.

What is the significance of this article for the general public?
This study examined the effect of bilingualism on the neural correlates of sustained attention, which is necessary for learning and completing day-to-day activities. Our results provide neural evidence that speaking multiple languages shapes the way nonverbal sounds are processed.

Keywords: bilingualism, sustained attention, event-related potentials, auditory oddball paradigm

Supplemental materials: https://doi.org/10.1037/tps0000373.supp

Attention is a necessary component when concentrating on a task such as reading a book (sustained attention), shifting attention from one activity to another such as when cooking a meal (alternating attention), and processing multiple pieces of information simultaneously such as when driving a car (divided attention). Attention plays an important role in language processing.

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For example, listeners must direct attention to the speech stream from conversational partners, while ignoring competing auditory input from the environment (de Diego-Balaguer et al., 2016; Kurland, 2011). However, attention is a limited resource, one that could be deployed more efficiently by capitalizing on life experiences that are known to impact attention and executive function. One such experience that has been shown to influence attentional processes is bilingualism (Bialystok & Craik, 2022; Chung-Fat-Yim et al., 2022). An array of attentional processes is recruited during bilingual language processing. For example, bilinguals need to focus on the target language (sustained attention), select the target language from the nontarget language(s) (selective attention), and switch from one language to the other language (alternating attention; see Chung-Fat-Yim et al., 2022; Dong & Li, 2020 for reviews). Bilinguals are constantly navigating competition between languages and need to direct their attention to the representations in the intended language.

Depending on the socio-linguistic context, bilinguals sometimes use only one language over extended periods of time in one environment (e.g., French at home) and the other language in another environment (e.g., English at work; refer to the single-language context from the adaptive control hypothesis by Green & Abutalebi, 2013). According to Green and Abutalebi (2013), "in the single-language context, the demand is to ensure efficient suppression of the nontarget language over extended periods of time" (p. 524). Yet, few studies have examined how ongoing immersion experience in single-language contexts may modify the neural correlates of *sustained* attention, which is the ability to focus on a task for an extended duration (DeGangi & Porges, 1990; Langner & Eickhoff, 2013). Difficulties in sustained attention can lead to greater interference from irrelevant information and the inability to adapt to environmental demands (DeGangi & Porges, 1990; Ko et al., 2017). Additionally, bilingualism is a multidimensional construct along noncategorical continuums. Bilinguals are exposed to and become proficient in each of their languages to varying degrees. Second language proficiency has been shown to modulate inhibitory control (Dash & Kar, 2020) and executive control (Jiao et al., 2019), whereas second language exposure has been shown to impact proactive control (Gullifer & Titone, 2021). Due to the multifaceted nature of bilingualism and variability in bilingual language experience (Marian, 2023), the present study examines which first- and second-language factors influence the neural correlates associated with sustained attention.

Previous research suggests early exposure to multiple languages influences auditory processing and sound perception. For example, 9-month-old bilingual infants can detect a musical violin pitch contrast, whereas monolingual infants cannot (Liu & Kager, 2017). The authors speculated that the bilingual infants' heightened ability to discriminate musical tones may be due to their complex linguistic environment. In adults, the literature on speech sound discrimination has been mixed, with similar performance between monolinguals and bilinguals in quiet environments (e.g., Bsharat-Maalouf & Karawani, 2022), but poorer speech perception observed among bilinguals in many noisy environments (e.g., Tabri et al., 2011; Weiss & Dempsey, 2008), although not always (Filippi et al., 2012). When bilinguals experience difficulty perceiving speech in noise, this may be due to less frequent exposure to each language compared to monolinguals (Schmidtke, 2016), as proposed by the frequency lag hypothesis (Gollan et al., 2008).

Sustained Attention and Bilingualism

Speech sound discrimination involves early attentional processes like sustained attention. Though limited, studies examining the effect of bilingualism on the sustained attention to response task (SART; Bialystok et al., 2008) and test of everyday attention task (TEA; Bak et al., 2014; Vega-Mendoza et al., 2015), both measures of sustained attention, have yielded null results between language groups.[1] Compared to studies

[1] The SART requires participants to make a motor response to frequent stimuli (Digits 1–9) and withholding a response to an infrequent stimulus (Digit 3). Carter et al. (2013) explained that because participants are withholding a response to an infrequent stimulus, the SART places high demands on other cognitive processes like response inhibition and motor control/planning, and does not necessarily measure sustained attention. The elevator counting subtest from the TEA requires participants to count the number of simple tones of the same pitch and duration presented at irregular intervals. To the best of our knowledge, only one EEG study (Avirame et al., 2022) has used the Elevator Counting task to measure sustained attention, making it difficult to determine which ERP components to focus on. For these reasons, we did not use the SART or the TEA to measure sustained attention.

with children and older adults, effects of bilingualism on cognitive control are less consistently observed in young adults (Bialystok & Craik, 2022). In the young adult group, this finding is not surprising given that young adults are performing at their peak efficiency (Bialystok, 2006). Due to the lack of variability in performance of young adults, bilingualism is less likely to impact their performance on cognitive control tasks. Although traditional analyses on behavioral measures provide a good description of overall performance, they lack the sensitivity to capture important underlying cognitive processes that occur between the time a stimulus is presented and the execution of a response (i.e., perception vs. discrimination, bottom-up vs. top-down processing, and resource allocation). Time-sensitive methodologies provide rich temporal information with millisecond precision regarding the time course of cognitive processes, even in the absence of behavioral differences (Rugg & Coles, 1995). For this reason, utilizing a high-temporal-resolution methodology, such as event-related potentials (ERPs), is advantageous because ERPs capture the timing of many aspects of attention and perception, including cognitive processes that are manifested covertly (Luck, 2014). The present study examines whether young adult monolinguals and bilinguals differ in the time course of sustained attention.

In ERP studies, one task that is commonly used to measure sustained attention is the oddball task (Squires et al., 1975). In this task, participants are presented with a sequence of two different stimuli, one of which occurs more frequently (standard trials) than the other (deviant trials). Deviant trials elicit a larger P3 amplitude post-stimulus onset around 300–450 ms at frontal to parietal sites compared to standard trials (Segalowitz & Barnes, 1993; Squires et al., 1975). In addition to the P3 component, the N1 and N2 components (Grimm & Escera, 2012) are typically larger in amplitude for deviant than standard trials. The mismatch negativity (MMN) (derived by taking the difference in amplitude between the deviant and standard trials) peaks between 100 and 250 ms poststimulus onset at fronto-central electrode sites and has been proposed to occur at the preattentive stages of stimulus discrimination (Näätänen & Alho, 1995). While the N1 and N2/MMN can vary in amplitude depending on the physical properties of the stimulus, the P3 serves as an index of cognitive control and resource allocation. Lastly, the late negativity (LN), which typically follows the MMN, is a negative deflection thought to serve as an index of attention reorientation (Schröger & Wolff, 1998).

Previous electrophysiological studies on auditory discrimination in bilingual adults have focused primarily on the neural indices of nonnative speech perception (e.g., García & Froud, 2018; Winkler et al., 1999). Very few studies have looked at neural differences between monolinguals and bilinguals in auditory processing to nonspeech sounds. Ortiz-Mantilla et al. (2010) compared English monolinguals and early Spanish–English bilinguals who acquired English before the age of 10 on an auditory oddball paradigm, which consisted of one complex tone as the standard trial and four complex tones varying in duration and fundamental frequency as deviant trials. In another variation of the auditory oddball task, Datta et al. (2020) had English monolinguals and early Spanish–English bilinguals identify an infrequent high tone interspersed among vowels and an infrequent low tone. While early bilinguals had a significantly larger LN amplitude compared to monolinguals in the study by Datta et al. (2020), there were no significant differences in LN, MMN, P3a amplitudes or latencies between early bilinguals and monolinguals in the study by Ortiz-Mantilla et al. (2010). The discrepant findings may be due to differences in the auditory stimuli used in each study (verbal vs. nonverbal). Because bilinguals are exposed to each of their languages less frequently than monolinguals (Gollan et al., 2008), bilinguals generally take longer than monolinguals to name pictures on lexical retrieval tasks (e.g., Gollan et al., 2007; Ivanova & Costa, 2008). Therefore, bilinguals may have required more effort to re-orient attention toward the target in the study by Datta and colleagues because the auditory input included linguistic information. While both studies included nonverbal tones as the target, the task demands were large as participants had to either detect a complex tone among other tones (Ortiz-Mantilla et al., 2010) or a pure tone among vowels (Datta et al., 2020), which may have recruited additional attentional processes beyond sustained attention. The current study uses nonverbal tones as the target and nontarget stimuli by having participants identify a high-pitch tone from a low-pitch tone or vice versa.

The Current Study

Bilingualism is a complex and heterogenous construct due to the many factors that influence what it means to be a bilingual speaker (Luk & Bialystok, 2013), such as age of first (L1) and second language (L2) acquisition, proficiency, and exposure. In recent years, research on the neurocognitive effects of bilingualism has shifted from asking whether or not differences between monolinguals and bilinguals exist toward examining which aspects of language experience shape the mind and brain (DeLuca, 2019). There is now a greater appreciation for the diversity in first- and second-language experience. For example, duration of L2 use predicts brain function (e.g., DeLuca et al., 2019), L2 proficiency predicts executive control performance (e.g., Gallo et al., 2021, 2022), and usage of the nonsocietal language at home and in society predicts brain connectivity at rest (Soares et al., 2021). However, in the studies reviewed above, composite measures of proficiency and exposure were used, focusing mainly on the L2. The present study takes a more nuanced approach by examining proficiency in speaking and understanding (instead of average proficiency) and exposure to family, friends, radio, and TV (instead of average exposure) on the neural correlates of sustained attention. To the best of our knowledge, no study to date has looked at how variability in L1 and L2 experiences influences sustained attention. By studying the complexity associated with bilingualism, we gain a better understanding of how language experience may lead to neural plasticity.

The current study examined whether language experience modifies the neural correlates of sustained attention when discriminating nonverbal tones. English monolingual and early Korean–English bilingual young adults completed an auditory oddball task while their electroencephalogram (EEG) was recorded. Korean–English bilinguals were recruited because both Korean and English are nontonal languages. Previous EEG studies on sustained attention focused primarily on Spanish–English bilinguals (Datta et al., 2020; Ortiz-Mantilla et al., 2010). We aimed to examine whether the effect of bilingualism on nonspeech processing would generalize to another group of bilingual speakers who are fluent in nontonal languages. Based on the findings by Datta et al. (2020), we predicted that bilinguals would have a larger LN amplitude than monolinguals. Due to the bilinguals' increased efficiency in attentional and cognitive control when processing conflicting information (see Bialystok & Craik, 2022 for a review), we predicted that bilinguals would have a smaller P3 amplitude than monolinguals. In addition, because the oddball paradigm in the present study required participants to mentally count the number of deviant trials (less frequent tones), we predicted that working memory would be positively associated with the P3 amplitude. Lastly, we predicted that L2 factors would impact the neural correlates of sustained attention at early and late time windows.

Method

Participants

Twenty-six English monolinguals ($M_{\text{age}} =$ 22.52, $SD_{\text{age}} = 5.60$) and 23 Korean–English bilinguals ($M_{\text{age}} = 21.62$, $SD_{\text{age}} = 6.79$) were recruited through posters around campus. Based on the results of a power analysis in G*Power (Faul et al., 2007) with an effect size of Cohen's $d = 0.65$ (Datta et al., 2020), $\alpha = .05$, and power = .85, the minimum number of participants required for this study is 24.[2]

In the bilingual group, the ages of acquisition for Korean and English were 0.82 ($SD = 1.31$) and 5.62 ($SD = 2.69$), respectively. Nine of the bilingual participants reported some knowledge of a third language. This subset of participants spent an average of 2.78% of their daily time exposed to a third language ($SD = 4.41$). Furthermore, these participants acquired their third language at a mean age of 15.22 years ($SD = 1.39$) and rated their average proficiency across speaking, understanding, and reading in this language at 3.07 on a scale of 0–10 ($SD = 1.86$). No significant differences in ERP

[2] To determine whether our current sample size ($n = 39$) can detect the effect size with power of .85, we ran two power analyses. The sensitivity power analysis yielded an effect size f of 0.25 (Cohen's $d = 0.50$), which represents a "medium" effect. We also ran a post hoc power analysis to compute achieved power. With an effect size $f = 0.40$, $n =$ 39, and $\alpha = .05$, the achieved power is .998, which is larger than a power of .85.

amplitudes were observed between bilinguals who did and did not have some knowledge of a third language,[3] consistent with previous electrophysiological findings (Chung-Fat-Yim et al., 2021). Therefore, the bilingual participants who did and did not have some knowledge of a third language were combined into one group in the analyses. Monolinguals reported either none or minimal exposure to a second language (i.e., 10% or less daily exposure in a second language). All participants were right-handed (Edinburgh Handedness Inventory; Oldfield, 1971), had normal or corrected-to-normal vision, no hearing, learning, or language disabilities, and no prior history of any neurological disorders. At the start of the experiment, participants provided their consent to participate in the study, which was approved by the local Institutional Review Board. Five Korean–English bilinguals and five English monolinguals were excluded due to poor EEG quality or because too few trials remained after artifact rejection and exclusion of incorrect trials (< 30 trials/condition). The final sample consisted of 21 monolinguals and 18 bilinguals. Table 1 includes a summary of the demographic and language background information for each group. Participants were matched on age, years of formal education, and nonverbal reasoning (as measured by the NIH Toolbox Cognition Battery Fluid and Crystallized Cognition composite scores; Zelazo et al., 2013), $ps > .21$.

Materials

Language Experience and Proficiency Questionnaire (LEAP-Q; Marian et al., 2007)

The LEAP-Q was used to assess each participant's linguistic background. Participants listed the languages they spoke in order of acquisition and dominance. For each language, they rated their proficiency level in speaking, understanding, and reading from 0 (*none*) to 10 (*perfect*) and the age at which they acquired each language. In addition, participants rated the extent to which they were exposed to each language when interacting with friends, family, reading, TV, and radio on a scale from 0 (*never*) to 10 (*always*).

NIH Toolbox Cognition Battery (Zelazo et al., 2013)

The NIH Toolbox Cognition Battery consists of brief tests, each assessing a different cognitive domain (executive functioning, memory, language, and processing speed). A detailed description of each test can be found in Zelazo et al. (2013) and Weintraub et al. (2013). Raw scores were fully corrected and averaged to compute composite scores in fluid cognition and crystallized cognition (Akshoomoff et al., 2013). The NIH Toolbox Cognition Battery has high test–retest reliability, convergent validity, and discriminant validity (Akshoomoff et al., 2013; Weintraub et al., 2013).

Oddball Task (Squires et al., 1975)

An auditory two-stimulus oddball task was used to measure sustained attention. In two separate blocks, participants heard a series of low-pitch (1,000 Hz) or high-pitch (1,500 Hz) tones, one of which appeared only 20% of the time. In the first block, participants heard the low-pitch tone as the standard trial and the high-pitch tone as the deviant trial or vice versa. In the second block, participants heard the high-pitch tone as the standard tone and low-pitch tone as the deviant tone or vice versa. The order of which tone was presented as the deviant tone in the first block was counterbalanced across participants. The duration of each tone was 100 ms. Tones were separated by an interstimulus interval of 1,500 ms and played from two audio speakers positioned on each side of the monitor. Participants completed 15 practice trials and 300 experimental trials (240 standard trials and 60 deviant trials) and were instructed to mentally count the number of deviant trials. To minimize eye movements, a fixation cross remained on the screen for the duration of the task.

Procedure

For the EEG component, the experimenter explained each step of the testing protocol as the electrode cap and electrodes were placed on the participant's head. Because ocular and motor artifacts can obscure brain activity, once connected to the system, participants were shown how eye

[3] Repeated-measures ANOVAs with trial type (standard and deviant) and electrode sites (C3, Cz, C4, CP1, CP2, P3, Pz, and P4) as within-subject factors, and language experience (some third language, no third language) as the between-subject factor on the mean amplitudes of the early, middle, and late components revealed no effect of language experience, all $ps > .18$.

Table 1
Participant Background Information by Language Group

	Monolinguals	Bilinguals	*p*
Age	22.19 (3.60)	21.71 (3.08)	.66
Gender	6 males, 15 females	3 males, 14 females	
Years of education	15.89 (3.46)	14.66 (1.89)	.21
L1 proficiency in understanding (/10)	9.71 (0.64)	9.06 (0.90)	.017
L1 proficiency in speaking (/10)	9.67 (0.66)	9.00 (1.00)	.026
L1 age of acquisition	0.024 (0.11)	0.82 (1.33)	.025
L1 exposure family (/10)	9.63 (1.17)	6.76 (3.09)	.002
L1 exposure friends (/10)	9.84 (0.50)	5.65 (3.16)	<.001
L1 exposure radio (/10)	8.74 (1.41)	5.12 (3.31)	<.001
L1 exposure TV (/10)	9.63 (0.76)	4.94 (3.40)	<.001
L1 exposure (%)	98.14 (3.12)	36.47 (23.50)	<.001
L2 proficiency in understanding (/10)[a]	2.92 (1.75)	9.12 (1.05)	<.001
L2 proficiency in speaking (/10)[a]	2.69 (1.25)	8.88 (1.41)	<.001
L2 age of acquisition[a]	11.79 (4.04)	5.62 (2.41)	<.001
L2 exposure family (/10)[a]	0.38 (1.16)	2.35 (2.91)	.016
L2 exposure friends (/10)[a]	0.29 (0.64)	7.71 (2.20)	<.001
L2 exposure radio (/10)[a]	1.40 (1.71)	5.47 (2.88)	<.001
L2 exposure TV (/10)[a]	0.80 (1.14)	5.94 (2.77)	<.001
L2 exposure (%)[a]	1.86 (3.12)	61.41 (24.33)	<.001
Crystallized cognition composite score	115.47 (16.24)	113.80 (15.82)	.74
Fluid cognition composite score	122.74 (25.54)	126.77 (12.85)	.55
Cognitive function composite score	132.68 (23.34)	136.60 (12.56)	.53

Note. Proficiency in understanding and speaking (/10) is rated on a scale from 0 = *none* to 10 = *perfect*. Exposure (/10) is the extent to which the participant is exposed to each language in each context on a scale from 0 = *never* to 10 = *always*. Exposure refers to the average percentage of time currently exposed to the language. L1 = first language; L2 = second language.
[a] Twelve out of 21 monolinguals listed a second language.

blinks and muscle tension interfered with the EEG signal. This biofeedback step was completed to ensure that the number of artifacts was kept to a minimum. Participants were then administered the oddball task, which was programmed in MATLAB (MathWork Inc., Natick, MA, United States, 2013) via PsychToolbox 3.0 (Brainard, 1997) and presented on a 22-in. monitor. Data from the oddball task, NIH Toolbox Cognition Battery, and LEAP-Q were collected as part of a larger experimental session that was 3 to 4 hours long (see Chen et al., 2017). The oddball task was the third EEG task administered to participants. At the end of the experiment, participants were debriefed about the purpose of the study and compensated monetarily for their time.

EEG Acquisition and Processing

The EEG was continuously recorded at a sampling rate of 500 Hz with a bandpass filter of 0.01–100 Hz from 30 Ag/AgCl active electrodes (Brain Vision antiCHamp and PyCorder, Brain Vision LLC) and placed according to the international 10–20 electrode system (Jasper, 1958). Two additional electrodes were placed on the participant's face, one below the left eye and the other on the outer canthus of the right eye to measure vertical and horizontal electrooculogram, respectively. Electrodes were referenced online to the left mastoid and impedances were maintained below 15 kΩ.

Offline preprocessing was conducted using EEGLAB (v.10.2.2.4b; Delorme & Makeig, 2004) and ERPLAB (v.4.0.3.1; Lopez-Calderon & Luck, 2014) toolboxes in MATLAB (v.8.2, MathWorks Inc., Natick, MA, United States, 2013). Ocular artifacts were detected and removed using independent component analysis (Makeig et al., 1996). Components indicative of eye movements, eye blink, and motor activity were removed from the data. The EEG signal was then filtered offline using a bandpass filter of 0.05–70 Hz and rereferenced to the average mastoids. The signal was baseline-corrected and segmented into epochs of −200 ms of prestimulus activity to 800 ms of poststimulus activity. Epochs with amplitudes

$\pm$120 microvolts in any channel were discarded. Participants for whom more than 30 trials of their data per condition were removed during artifact rejection were excluded from the analyses (see "Participants" section above). Monolinguals (standard trials: 85.65%; deviant trials: 78.45%) and bilinguals (standard trials: 83.15%; deviant trials: 76.32%) did not differ in the percentage of trials included in the ERP analyses, *p*s $> .96$. Individual ERPs were generated by electrode site and trial type for each participant. Accuracy on the oddball task was at ceiling across participants and was not analyzed further due to a lack of variability.

Results

The region of interests, time windows, and ERP components were selected based on visual inspection of the data and previous auditory oddball studies (e.g., Picton, 1992; Squires et al., 1975). The early, middle, and late ERP component analyses of variance (ANOVAs) consisted of within-subject factors, trial type (standard and deviant) and electrode site (C3, Cz, C4, CP1, CP2, P3, Pz, and P4), and between-subjects factor, language group (monolingual and bilingual). The electrode sites were selected because they elicited the largest difference in amplitude between standard and deviant trials. A Greenhouse–Geisser correction was applied to variables with more than one degree of freedom in the numerator, and all pairwise comparisons were adjusted using Bonferroni corrections. The early, middle, and late ERP waveforms were analyzed by taking the average waveform recorded across all participants at each electrode site. The mean ERP waveforms for representative electrode Cz by language group and trial type are plotted in Figure 1A.

L1 and L2 factors of interest from the LEAP-Q included age of acquisition, proficiency in speaking, proficiency in understanding, exposure to friends, exposure to family, exposure to TV, and exposure to radio. To examine which linguistic factors predicted sustained attention, correlations were conducted across the entire sample between each ERP effect, each L1 factor, and each NIH Toolbox Cognition Battery score (Table S1 in the online supplemental materials). We also conducted correlations by group. For the bilingual group, correlations were conducted between each ERP effect, each L1 and L2 factor, and each NIH Toolbox Cognition Battery score (Table S2 in the online supplemental materials). For the monolingual group, correlations were conducted between each ERP effect, each L1 factor, and each NIH Toolbox Cognition Battery score (Table S3 in the online supplemental materials).

Early ERP Component (380–420 ms)

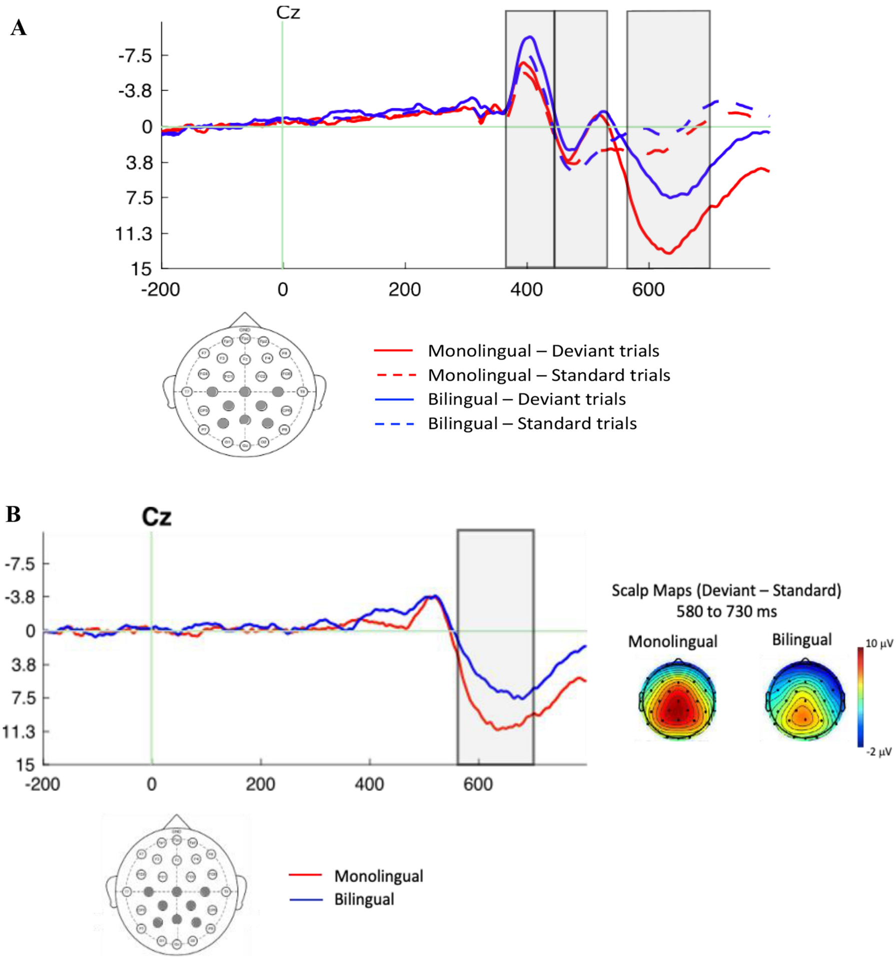
Mean amplitude analyses revealed an effect of trial type, $F(1, 37) = 26.05$, $p < .001$, $\eta_p^2 = 0.41$, language group, $F(1, 37) = 4.42$, $p = .042$, $\eta_p^2 = 0.11$, but no interaction, $F(1, 37) = 1.82$, $p = .19$, $\eta_p^2 = 0.047$. Deviant trials ($M = -5.66$ µV, $SE = 0.36$) elicited a more negative early ERP amplitude than standard trials ($M = -4.38$ µV, $SE = 0.36$). Bilinguals ($M = -5.72$ µV, $SE = 0.49$) had an overall larger early ERP amplitude than monolinguals ($M = -4.32$ µV, $SE = 0.45$). Correlations across the entire sample revealed that the early ERP effect (deviant minus standard trials) increased with greater L1 exposure through family, $r(36) = .33$, $p = .048$, 95% CI [0.00, 0.60], and marginally increased with greater L1 exposure to TV, $r(36) = .32$, $p = .058$, [−0.01, 0.59]. The early ERP effect did not correlate with L1 proficiency, L1 exposure through friends, L1 exposure to radio, or scores from the NIH Toolbox Cognition Battery, all *p*s $> .096$. Among monolinguals, correlations between the early ERP effect and L1 factors of proficiency, acquisition, and exposure were not significant, *p*s $> .089$. Similar results were found in the bilingual group for both L1 and L2 factors, *p*s $> .15$.

Middle ERP Component (420–520 ms)

The mean amplitude analysis yielded an effect of trial type, $F(1, 37) = 28.69$, $p < .001$, $\eta_p^2 = 0.44$. Deviant trials ($M = -0.88$ µV, $SE = 0.45$) elicited a more negative middle ERP amplitude than standard trials ($M = 0.91$ µV, $SE = 0.33$). The effect of language group and the trial type by language group interaction were not significant, *p*s $> .24$. Across the entire sample, the middle ERP effect (deviant minus standard trials) correlated positively with L1 exposure through friends, $r(36) = .35$, $p = .039$, 95% CI [0.02, 0.61], and TV, $r(36) = .38$, $p = .022$,

Figure 1

Grand-Averaged ERPs and Scalp Maps



Note. (A) Grand-averaged ERPs of representative electrode Cz for the deviant (full line) and standard (dashed line) trials of the monolingual group and bilingual group. The gray shaded areas represent the early, middle, and late time-windows, respectively. (B) The late ERP difference waves and scalp maps by language group. ERP difference waves (deviant minus standard trials) for the monolingual group and bilingual group. Grand average scalp maps of the difference waves by language group between 580 and 730 ms. ERP = event-related potential. See the online article for the color version of this figure.

[0.06, 0.63]. The middle ERP effect was marginally positively associated with L1 exposure through radio, $r(36) = .32$, 95% CI [−0.01, 0.58], $p = .060$, but did not correlate with L1 proficiency ratings nor the scores from the NIH Toolbox Cognition Battery, $ps > .13$.

In the bilingual group, the middle ERP effect was positively associated with L1 exposure through TV, $r(17) = .57$, $p = .016$, 95% CI [0.13, 0.83], marginally positively associated with L1 exposure through friends, $r(17) = .45$, $p = .067$, [0.77, −0.034], but marginally negatively associated with L1 average proficiency, $r(17) = -.46$, $p = .061$, [0.022, −0.77]. The middle ERP effect was not associated with any of the other factors in the bilingual group, $ps > .082$, nor with any of the factors in the monolingual group, $ps > .57$.

Late ERP Component (580–730 ms)

The mean amplitude analysis yielded an effect of language group, $F(1, 37) = 11.48$, $p = .002$, $\eta_p^2 = 0.24$, trial type, $F(1, 37) = 135.16$, $p < .001$, $\eta_p^2 = 0.79$, and its interaction, $F(1, 37) = 5.75$, $p = .022$, $\eta_p^2 = 0.14$. To breakdown the language group by trial type interaction, separate ANOVAs by language group were conducted. The effect of trial type was significant in both groups, monolingual: $F(1, 20) = 90.95$, $p < .001$, $\eta_p^2 = 0.82$; bilingual: $F(1, 17) = 49.51$, $p < .001$, $\eta_p^2 = 0.74$. Another way to examine the interaction is to compare monolinguals and bilinguals on each trial type. Monolinguals and bilinguals were significantly different from each other on both deviant trials, $F(1, 38) = 9.78$, $p = .003$, and standard trials, $F(1, 38) = 9.50$, $p = .004$. Given that the magnitude of the effect looked visually different between language groups, we computed a difference wave in the late time window. The monolinguals ($M = 8.73$ μV, $SE = 0.81$) had a significantly larger difference wave than bilinguals ($M = 5.80$ μV, $SE = 0.88$), $F(1, 37) = 6.01$, $p = .019$, $\eta_p^2 = 0.14$ (Figure 1B).

Across the entire sample, the late ERP effect (deviant minus standard trials) correlated negatively with L1 age of acquisition $r(38) = -.35$, $p = .031$, 95% CI [−0.60, −0.035], and positively with L1 exposure to radio, $r(36) = .34$, $p = .042$, [0.01, 0.60], list sorting working memory scores, $r(39) = .33$, $p = .042$, [0.58, 0.01], and marginally with L1 exposure to TV, $r(36) = .32$, $p = .059$, [−0.01, 0.59]. The late ERP effect did not correlate with L1 exposure through friends or family and the remaining NIH Toolbox Cognition Battery scores, $ps > .12$. In the bilingual group, the late ERP effect did not correlate with any of the L1 or L2 factors, $ps > .11$. In the monolingual group, the late ERP effect did not correlate with any of the L1 factors, $ps > .17$.

Discussion

The present study investigated the neural underpinnings of sustained attention between monolinguals and bilinguals. Compared to monolinguals, bilinguals initially used more attentional resources to detect the infrequent tone, but then used fewer resources for the infrequent tone at later stages of processing. In the bilingual group, L1 factors were positively associated with the middle ERP effect. Additionally, bilinguals who were better at ignoring irrelevant information on the flanker task also used fewer attentional resources to discriminate between frequent and infrequent tones in the late time window. In contrast, none of the brain-behavior correlations were significant in the monolingual group. Our findings demonstrate that variability in language experiences and cognitive abilities can influence sustained attention in adulthood. By examining the variance that exists in language experiences and cognitive abilities, we gain a better understanding of the cognitive architecture of the brain as well as the dynamic relationship between language and cognition (Fricke et al., 2019).

In the present study, the difference waves by language group presented in Figure 1B revealed that bilinguals had a smaller ERP effect compared to monolinguals in the late time window. Consistent with the findings by Datta et al. (2020), early Korean–English bilinguals in our sample did not differ from English monolinguals in the earlier time window. Datta and colleagues found that the LN component was larger in amplitude for early Spanish–English bilinguals compared to English monolinguals. In contrast to the findings by Datta et al. (2020), we observed a smaller difference in amplitude between trial types in the later time window for bilinguals than monolinguals. This difference in findings may stem from the task. In Datta et al.'s study, participants were presented with nonverbal tones embedded in a stream of vowels. Because bilinguals simultaneously activate both language systems (Kroll et al., 2012), processing nonverbal tones in the context of speech may have increased the LN amplitude in the study by Datta et al. (2020).

The shift from needing more resources early on to needing fewer later in the time course may be because bilinguals are front-loading the detection process. As bilinguals had a smaller late ERP difference wave than monolinguals, this would suggest that bilinguals did not need to increase attentional resources to evaluate their response. Our findings coincide with functional neuroimaging studies demonstrating that bilinguals are better at filtering out irrelevant information (Abutalebi et al., 2012; Bartolotti et al., 2017). Abutalebi et al. (2012) examined the link between regions associated with language control and those associated with more general instances of control in monolinguals and highly proficient bilinguals. On the flanker task, a measure of cognitive control, bilinguals showed less activity in the dorsal anterior cingulate cortex than monolinguals, a brain region important for conflict monitoring and detection. The authors interpreted the difference in activation in terms of the bilingual group being more efficient in adapting to conflict.

Across the entire sample, we found that increased exposure to the native language led to larger early and middle ERP effects. Exposure to the L1 may aid in detecting differences at the perceptual level. Interestingly, when correlations were conducted separately by language group, L1 (but not L2) exposure and proficiency factors correlated with the middle and late ERP effects in the bilingual group. At the time of testing, all bilingual participants were living in the United States and immersed in an anglophone environment. The bilinguals in our sample were likely exposed to their L2 (i.e., English) more frequently than their L1 (i.e., Korean). In the bilingual group, the percentage of time currently exposed to each language was higher in L2 than L1. L1 may have a larger impact on sustained attention than L2 because in order for bilinguals to prevent native language attrition in an L2-dominant environment, they need to maintain their L1. Future studies will need to examine the link between language dominance, exposure, and nonspeech sound discrimination in bilinguals. In contrast, none of the L1 acquisition, proficiency, and exposure factors correlated with the ERP components in the monolingual group.

Limitations and Future Directions

The timings of the ERP components in the present study are later than what are traditionally observed for the oddball task. For this reason, we are reluctant to label each peak and attribute it to a particular cognitive process. Considering that the oddball task was the third EEG experiment administered, it is possible that after spending 3 hours connected to the EEG system and completing other cognitively demanding EEG tasks, participants may have experienced mental fatigue. Prior research has shown that mental fatigue affects the neural correlates of visual selective attention (Faber et al., 2012) and response inhibition (Guo et al., 2018). For example, mental fatigue decreases the P3 amplitude and increases the N2 latency when performing a Go/No-go task (Kato et al., 2009). Furthermore, Boksem et al. (2005) observed that the difference in amplitude between relevant and irrelevant stimuli is reduced on selective attention tasks due to mental fatigue. Similar effects of mental fatigue may be at play in the present study for the oddball task, which required a great deal of vigilance and concentration from the participants. For this reason, we focus instead on comparing the electrophysiological patterns between language groups, under the assumption that attentional components may have shifted in latency and/or decreased in amplitude due to mental fatigue.

The present findings point to two lines of future research inquiry. First, although the present study increases our understanding of how language experience shapes the neural correlates of sustained attention, it is restricted to Korean–English bilinguals. To increase the generalizability of our findings to other bilingual speakers, future research will need to investigate sustained attention in participants from diverse linguistic backgrounds, including those who are fluent in other nontonal languages. Another potential direction for future research could be to investigate whether the impact of multilingualism on sustained attention is limited to the auditory domain. If similar electrophysiological findings between language groups are observed on the *visual* oddball task, this would provide evidence that the effect of language experience on cognitive function may be domain-general.

Conclusions

In sum, studies on bilingualism and sustained attention have focused primarily on behavioral measures. More sophisticated outcome measures and neural evidence point to enhanced processing of attention in bilinguals relative to monolinguals. Our study demonstrates that native language experience influences the way bilinguals perceive and process nonverbal tones. Specifically, exposure to the native language, while immersed in the second language, increases bilinguals' ability to discriminate between frequent and infrequent tones. Knowing more than one language may facilitate discrimination because bilinguals attend more to infrequent auditory information than monolinguals. This may increase bilinguals' sensitivity to new information in their environment. Attention is essential for our everyday lives because it allows us to "tune out" unnecessary information and instead focus our energy on which events in our environment need to be attended to, a process that is important for our survival. We conclude that early experience speaking multiple languages changes how bilinguals process acoustic input from nonspeech sounds.

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