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Does language context impact the neural correlates of executive control in monolingual and multilingual young adults?

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ABSTRACT

Some previous studies have shown that creating a language context in which words from both languages are interspersed into a flanker task improves executive control performance for bilinguals, but these studies have produced inconsistent results. The studies have used different versions of the task and not included monolinguals, limiting generalization. Here, English-Chinese multilinguals and English monolinguals performed a flanker task while EEG was recorded. There were three language context blocks – English, Chinese, or both – and participants were instructed to ignore the interspersed words. Multilinguals displayed faster flanker RTs and earlier P2 and N2 waveforms than monolinguals. There was also a significant correlation between the P2/N2 latency and reaction times, connecting these waveforms to behavior. Finally, P2 amplitude differed between groups in the mixed context, and language context impacted P3 amplitude for monolinguals but not multilinguals. These results are interpreted in terms of language context effects on monolingual executive function processing and possible difference in bilingual experience between current participants and those in previous studies.

1. Introduction

Language processing in multilinguals is characterized by continuous conflict induced by language co-activation (Kroll et al., 2015). To successfully resolve this ongoing conflict during both comprehension (Marian & Spivey, 2003; Thierry & Wu, 2007) and production (Poarch & Van Hell, 2012a; Sullivan et al., 2018), a language control mechanism is required (Kroll & Bialystok, 2013). The cognitive mechanism that multilinguals draw on for language control is most likely the domain-general executive function network (Abutalebi & Green, 2008; Bialystok, 2017), a system responsible for control of effortful processing (Botvinick et al., 2001; Diamond, 2013; Engle, 2002). The claim from bilingualism is that the ongoing use of this system to resolve language conflict leads to modifications in executive function network more broadly (Bialystok, 2017). Accordingly, multilinguals have been shown to outperform monolinguals on various executive function tasks (e.g., Bialystok et al., 2004; Bialystok et al., 2014; Blumenfeld & Marian, 2011; Chung-Fat-Yim et al., 2019; Coderre et al., 2013; Comishen & Bialystok, 2020; Costa et al., 2008; Kapa & Colombo, 2013; Krizman et al., 2012; Poarch & Van Hell, 2012b; Poarch & Bialystok, 2015; Salvatierra & Rosselli, 2010), all of which recruit domain-general executive functioning (review by Antoniou, 2019; meta-analyses by Grundy, 2020; Grundy & Timmer, 2017). Nonetheless, other studies show no difference in performance between monolinguals and multilinguals on such tasks (Antón et al., 2014, Dick et al., 2019; Duñabeitia et al., 2014; Paap & Greenberg, 2013), and meta-analyses have challenged the view that the effect of multilingualism on executive function is reliable (Donnelly et al., 2019; Lehtonen et al., 2018). How can these contradictory results be reconciled?

Given the multi-faceted experiences that make up multilingualism (DeLuca et al., 2019a), its non-categorical nature (Luk & Bialystok, 2013; Surrain, & Luk, 2019), and its variability across the lifespan (Anderson et al., 2020), some researchers have attempted to resolve these contradictory results by moving beyond assessing whether executive function differs between groups of multilinguals and monolinguals in general (Poarch & Krott, 2019) and identifying aspects of bilingual experience that may be decisive in producing these effects. Several such factors have been identified, including age of second-language acquisition (Yang et al., 2016), second-language proficiency (Khare et al., 2013; Luque & Morgan-Short, 2021; Surrain & Luk, 2019; Xie & Pisano, 2019),

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second-language immersion (DeLuca et al., 2019b), language dominance (Yamasaki et al., 2018), and frequency of language switching (Soveri et al., 2011).

Another approach is to consider the linguistic and social context in which multilingual language use takes place. The most influential model in this regard is the Adaptive Control Hypothesis (Green & Abutalebi, 2013). The model distinguishes among three prototypical language usage contexts: single-language, in which each language is used separately (e.g., home vs. work); dual-language, in which different languages are used in the same context but with different individuals; and dense code-switching, in which multilinguals freely switch between languages with interlocutors who are also multilingual. Each of these interactional contexts is assumed to pose different processing demands on the system that controls language selection (see discussion in Green & Wei, 2014; Green, 2018).

Variations in language contexts have also been identified by Gullifer and colleagues as crucial for the representation and control of language in general. Gullifer and Titone (2020a) characterized social diversity in multilinguals' interactional contexts using the construct of language entropy to provide a fine-grained description of differences in individual language experience in bilingual populations (Gullifer et al. 2018; Titone et al., 2017). They found that increased diversity in bilingual usage and exposure was associated with greater engagement of proactive control in the AX-CPT task (Gullifer & Titone, 2020b). Proactive control in this task is required when attending to goal-relevant cues while anticipating possible targets and adjusting proactive and reactive control to determine whether the target appeared.

Because of the cognitive demands associated with different interactional language contexts, the impact of multilingualism on individual speakers will depend on their linguistic experiences (Beatty-Martínez et al., 2020; Ooi et al., 2018; Pot et al., 2018). Moreover, some multilinguals will experience only one such context in daily life, while others will do so in a variety of these contexts, obviating simple correspondences between multilingual experience and cognitive outcome. The linguistic context has even been reported to affect the cognitive profile of monolinguals who are learning a new language; monolinguals in linguistically diverse environments (Southern California) showed functional brain responses to learning a new language that were more similar to bilinguals than to those from monolinguals in linguistically homogeneous environments (Pennsylvania) (Bice & Kroll, 2019). Participants completed Finnish vocabulary lessons and comprehension tests while EEG was recorded. At the behavioral level, neither group learned the vowel harmony pattern that is unique in Finnish, but the late anterior positivity in the electrophysiological data showed that monolinguals from Southern California could distinguish between real Finnish words and vowel harmony violations while those from Pennsylvania could not. Therefore, context as determined by the expectation for the use of each language is an important factor for both monolinguals and multilinguals.

These studies show that differences in the contexts of language use impact control processes, not only for bilinguals but also to some extent for monolinguals. Previous studies investigating the effect of context on bilingual performance have used two approaches: (1) compare participants from contextually different environments or (2) induce changes in language contexts within an experimental task. For the first approach, contexts of language use in daily life have shown to differentially influence performance in cognitive tasks (Beatty-Martínez et al., 2020; Gullifer et al., 2018; Hartanto & Yang, 2016; Ooi et al., 2018; Pot et al., 2018; see Kroll et al., 2018, for review). For example, bilinguals who used their languages in a dual-language context had smaller switch costs on a task-switching-paradigm than bilinguals who used their languages in a single-language context (Hartanto & Yang, 2016). Similarly, Ooi et al. (2018) found that bilinguals from Singapore, where language-switching pervades daily life, were more efficient at resolving conflict between incongruent and congruent trials on the Attention Networks Task than bilinguals from Edinburgh, who predominantly use their languages in single-language contexts.

For the second approach, language context has been manipulated by inducing incidental language processing to simulate different language contexts. In the first study to use this approach, Wu and Thierry (2013) had Welsh-English bilinguals perform a flanker task while EEG was recorded. Their study included three language context blocks – English, Welsh, and mixed-language – that were created by inserting high frequency words intermittently between flanker trials. In the English-context and Welsh-context blocks, the inserted words were exclusively in English or Welsh, but in the mixed-language block, Welsh and English words were randomly intermixed, corresponding approximately to single-language and dual-language contexts respectively (Green & Abutalebi, 2013). Participants were instructed to respond to the flanker trials and to ignore the words. There were no differences in reaction times across context blocks, but the mixed-language block led to fewer errors than the single-language blocks. In addition, the P3 amplitude of the incongruent trials was smaller in the mixed-language block than in either of the single-language blocks. The central-parietal P3 peaks between 300 and 600 ms post-stimulus onset and serves as an index of attentional resources necessary for stimulus categorization (Neuhaus et al., 2010; Polich, 2007). On the flanker task, the P3 is larger in amplitude for incongruent than congruent trials (Frühholz et al., 2011). The authors interpreted the P3 findings as suggesting that the mixed-language context improved executive functioning by reducing the attentional resources necessary to perform conflict trials.

Three subsequent studies have used this approach to manipulate language context, but unlike the study by Wu and Thierry (2013), participants were required to make an overt response to the interspersed words, drawing attention to the linguistic information. The details of these studies are summarized in Table 1. Using a picture-word matching task as the context manipulation, Jiao et al. (2019) had Chinese-English bilinguals report whether the label (written word for Experiment 1 and auditory word for Experiment 2) and the picture matched in three language context blocks: Chinese, English, and mixed-language. In both experiments, the overall RTs on the flanker task were significantly faster in the mixed-language block, implying that language control processes in reading and auditory comprehension facilitated executive functioning. A follow-up ERP study by Jiao, Liu, et al. (2020) using the same paradigm as Experiment 2 of Jiao et al. (2019) found that the mixed-language block produced shorter RTs than the Chinese block, but not the English block, partially replicating the results of the previous study. At the electrophysiological level, there was a larger N2 amplitude but smaller P3 amplitude for the mixed language block than the single language blocks, similar to the P3 finding from Wu and Thierry (2013). The N2 is a stimulus-locked negative deflection that occurs between 200 and 350 ms at fronto-central electrode sites and is thought to reflect conflict monitoring (van Veen & Carter, 2002; Yeung et al., 2004; Yeung & Cohen, 2006) and attentional control processes (Tillman & Wiens, 2011; Bartholow et al., 2005), such that a larger amplitude indicates more resources allocated to process conflict (i.e., larger for incongruent than congruent trials).

These ERP findings were replicated with Chinese-English bilinguals naming pictures in either Chinese (Chinese-context), English (English-context), or both languages (mixed-language context) by Jiao, Grundy, et al. (2020). In addition to the N2 and P3, the authors observed a smaller late positive component (LPC) for the mixed-language block than the single-language blocks. The LPC, a sustained positivity beginning around 400 and 500 ms at medial and posterior sites (Friedman & Johnson, 2000), has been associated with trial-by-trial conflict adaptation processes (Larson et al., 2009). As in the study by Wu and Thierry (2013), Jiao, Grundy, et al. (2020) found no effect of language context on reaction time to the flanker task.

The results from these studies differed in some respects but converged on two main findings. First, if there were RT differences in the flanker task, it was to demonstrate faster responses in the mixed block than in the single blocks. Second, ERP results in general indicated less

Table 1
Summary of Language Context Studies.

Studies	Participants	Language Context Manipulation	Behavioral Findings	ERP Findings
Wu & Thierry (2013)	18 Welsh-English balanced bilinguals	Words embedded "Ignore words"	**ACC:** C > I Mixed block: I errors reduced **RT:** I > C	**P3 (500–700 ms) Amplitude:** I > C Mixed block: reduced amplitude for I trials
Jiao et al. (2019)	Exp 1 29 Chinese-English unbalanced bilinguals	Picture-word matching	**ACC:** C > I **RT:** I > C Mixed block: Overall faster RTs	No ERP measures
	Exp 2 28 Chinese-English unbalanced bilinguals	Auditory picture-word matching task	**ACC:** Marginal congruency effect **RT:** I > C Mixed block: Overall faster RTs	
Jiao, Grundy, et al. (2020)	22 Chinese-English unbalanced bilinguals	Picture matching	**ACC:** C > I **RT:** I > C	**N2 (250–350 ms) Amplitude:** I > C Mixed block: larger amplitude than others **P3 (350–500 ms) Amplitude:** Mixed block: smaller amplitude than others **LPC (500–700 ms) Amplitude:** I > C Mixed block: smaller amplitude than others
Jiao, Liu, et al. (2020)	23 Chinese-English unbalanced bilinguals	Auditory picture-word matching task	**ACC:** C > I **RT:** I > C Mixed block: faster RTs than Chinese block but not English block	**N2 (250–350 ms) Amplitude:** Mixed block: larger amplitude for I trials than in Chinese block; no difference for C trials. **N2 (200–250 ms) Latency:** I > C in mixed block **P3 (350–500 ms) Amplitude:** Mixed block: smaller amplitude than others

Note. ACC = Accuracy; C = Congruent; I = Incongruent; RT: Reaction Time.

allocation of attention in the mixed block than in the single blocks. Together, these studies demonstrate that multilinguals performing a task in a context designed to resemble a dual-language situation showed more efficient executive control than when they performed the same task in contexts that were more monolingual.

These studies demonstrate that manipulations in language context show effects in either behavioral or electrophysiological outcomes for participants performing an executive function task. However, all the participants in these studies were multilingual so it is not clear that it was their bilingual status rather than some task feature that was responsible for the effects. The issue is important because of evidence described above indicating that monolinguals are also sensitive to context manipulations. In addition, the existing studies on language context indicate different outcomes from behavioral and electrophysiological measures, so these too need to be evaluated in a single design (see Table 1). Including behavioral and electrophysiological data, monolingual and multilingual participants, and language context manipulations in the same design may contribute to a more detailed understanding of the nature and conditions under which bilingualism affects nonverbal cognitive performance.

The present study implemented Wu and Thierry's (2013) paradigm with English monolinguals and Chinese-English multilinguals while EEG was recorded. Language context was manipulated by substituting the Welsh words from Wu and Thierry's modified flanker task paradigm with high-frequency Chinese words to create three language contexts: single-language English, single-language Chinese, and mixed-language. Following previous research with this task, the behavioral prediction was that multilinguals will perform faster than monolinguals on both congruent and incongruent trials (e.g., Costa et al., 2009; Emmorey et al., 2008, summary in Hilchey & Klein, 2011). However, following the results of Jiao et al. (2019), it was expected that this difference would be largest in the mixed language context block. Note that previous studies with this paradigm did not include a monolingual group so this prediction has not been tested.

Regarding ERP, following previous research (reviewed in Grundy et al., 2017a), the prediction was that multilinguals will show an overall earlier N2 and P3 in conjunction with a larger N2 but smaller P3 than the monolinguals. The earlier onset of N2 and P3 will indicate that multilinguals are faster than monolinguals at discriminating relevant from irrelevant information and use fewer attentional resources to recognize the relevant information. These differences were expected to be amplified in the mixed-language context.

Although previous studies using this paradigm have not analyzed frontal P2 waveforms, it has been observed in ERP studies of the flanker task (Kałamała et al., 2018; Korsch et al., 2016). The P2 is an early positive deflection that occurs between 150 and 275 ms post-stimulus onset and indexes selective attention (Luck & Hillyard, 1994; Potts, 2004) or change detection (Capizzi et al., 2016). Therefore, the prediction was that multilinguals will show earlier and smaller P2 than monolinguals, again with greatest group differences in the mixed-language context.

2. Method

2.1. Participants

The sample included 26 English monolingual (15 males/11 females), 26 Chinese-English bilingual (English plus Cantonese or Mandarin; 8 males/18 females), and 21 Chinese-English trilingual (English plus Cantonese and Mandarin; 10 males/11 females) young adults between the ages of 18 and 33 years (M = 20.78 years, SD = 3.36). Preliminary analyses showed no significant difference in task performance between bilinguals and trilinguals (cf. Chung-Fat-Yim et al., 2020; Poarch & Van Hell, 2012b; Poarch & Bialystok, 2015), so the groups were collapsed in further analyses. Participants were recruited through the Undergraduate Research Participant Pool (URPP) and posters at York University in Toronto, Canada. All participants were right-handed with no history of head injuries or neurological disorders. Participants recruited through URPP were compensated with academic credits and those recruited through posters received $20 for their time. The study was approved by the university's research ethics board. All participants were tested in our lab at York University.

2.2. Materials

2.2.1. Language and social background questionnaire (LSBQ; Anderson et al., 2018)

The LSBQ was used to assess participants' language use patterns and level of multilingualism. Participants answered demographic questions, such as age, years of education, handedness, each parent's level of education, languages spoken on a daily basis, and the contexts in which each language is spoken. Participants were asked to list all languages they know in order of fluency together with age and place of acquisition. They also rated their usage and proficiency of English and all non-English languages. Level of fluency in speaking, listening, reading, and writing for each language relative to a native speaker was assessed on a scale from 0 "Non-native like" to 100 "Native like" by drawing a vertical line on the page.

2.2.2. Peabody picture vocabulary Test – III (PPVT-III; Dunn & Dunn, 1997)

PPVT-III is a measure of English receptive vocabulary. Items are grouped into sets of 12 trials such that each set increases in difficulty. For each trial, four black-and-white line drawings and an auditory word were presented simultaneously, and participants chose the picture that best described the word. Testing discontinued when 8 or more errors were made within a set. Raw scores were converted to standardized scores using an age-corrected norm table with a mean of 100 and standard deviation of 15.

2.2.3. Kaufman brief intelligence Test – II (KBIT-2; Kaufman & Kaufman, 2004)

KBIT-2 is an individually administered measure of verbal and non-verbal intelligence but only the non-verbal subtest (Matrices subtest) was employed. The Matrices subtest assesses the ability to solve new problems, perceive relationships, and complete visual analogies. On each trial, participants were shown either 2 × 2 or 3 × 3 array of pictures or abstract designs along with six tiles that contained one missing element. Participants must select the tile to complete the pattern. Scores were transformed into standard scores with a mean of 100 and a standard deviation of 15.

2.2.4. Chinese reading proficiency measure

The Chinese reading proficiency measure was administered to ensure that multilingual participants had basic reading competency in Chinese. Participants in the multilingual group were given a sheet of paper that contained a list of 20 high frequency Chinese words written in simplified characters and asked to write the English translation for each word. The words were selected from the short and long versions of the Chinese Character Recognition Test by Gottardo et al. (2001).

2.2.5. EEG modified flanker task (Wu & Thierry, 2013)

An adapted version of Wu and Thierry's modified flanker task was programmed in E-Prime 2.0 (Psychology Software Tools, Pittsburgh, PA) and presented on a 17-inch computer monitor that was located 50 cm away from the participant. Five white arrows were displayed horizontally on a black background in the center of the screen. The central target arrow pointed either in the same direction (congruent condition; ← ← ← ← ←) or in the opposite direction (incongruent condition; ← ← → ← ←) as the surrounding arrows. Participants were required to press the left or right mouse key using the corresponding index finger as quickly as possible to indicate the direction of the central target arrow.

Each trial began with a fixation cross presented on the screen for 500 ms, followed by a blank screen for 200 ms, and then the stimulus appeared and stayed on the screen until the participant made a response or a maximum of 1500 ms had elapsed (Fig. 1). A jittered inter-trial interval of 500 ms, 1000 ms, or 1500 ms was used so the occurrence of the stimulus was less predictable.

The three language context blocks (English single-language block, Chinese single-language block, and Chinese-English mixed-language block) were counterbalanced across participants. The flanker task in each block consisted of 45 congruent and 45 incongruent trials and therefore included 90 interspersed words. The words were presented in pseudorandom order between flanker trials in each block (90 English words in the English single-language block, 90 Chinese words in the Chinese single-language block, and 45 English and 45 Chinese words randomly in the Chinese-English mixed-language block). All words were high frequency and non-cognates. English words were chosen from the CELEX lexical database (Baayen et al., 1996). Chinese words were chosen from a database provided by Yan Jing Wu with lexical frequencies and concreteness ratings. Because Mandarin is generally written in simplified characters and Cantonese in traditional characters, all the words selected were written the same in both systems. Short breaks were provided between blocks. Behavioral (accuracy and mean RTs) as well as electroencephalogram data were obtained.

2.3. Procedure

Following informed consent, participants were administered the following questionnaires and tasks in a fixed order: LSBQ, modified flanker task, KBIT-2, PPVT, and Chinese reading proficiency (multilingual group only). The language tasks were administered after the flanker task to prevent biasing participants towards a specific language context.

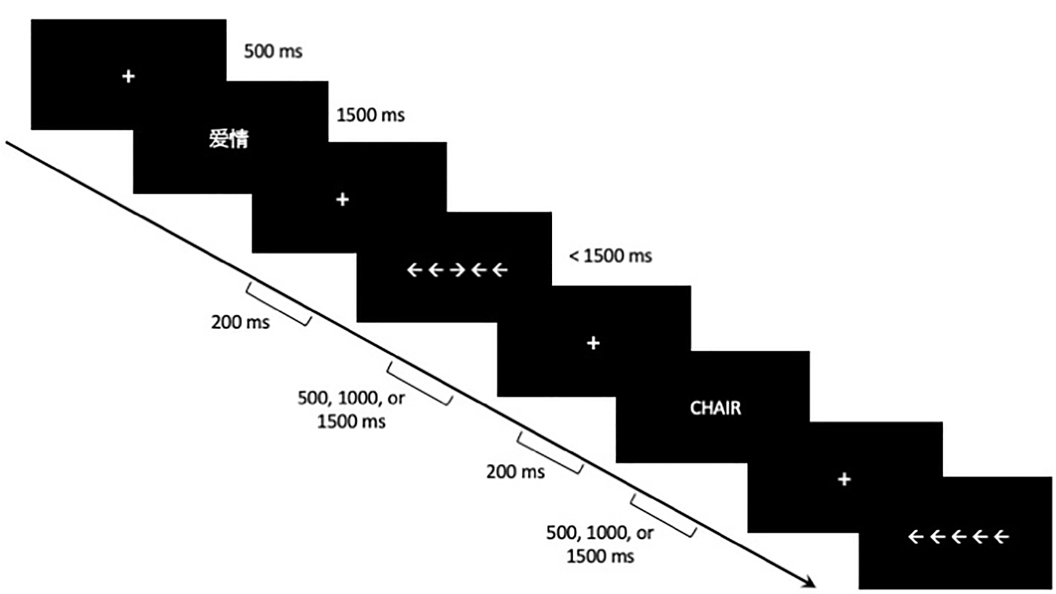

Fig. 1. Trial sequence of the flanker task in the mixed-language block.

For the electroencephalography (EEG) component, the experimenter explained each step while the cap and electrodes were placed on the participant's head. Because artifacts caused from eye or muscle activity can obscure brain activity, leading to misrepresentation of the resulting data (Coles & Rugg, 1995), once connected to the system, participants were shown how their eye blinks and muscle tension interfered with their EEG signal in an attempt to keep artifacts to a minimum. The testing session was approximately 2 h long. Participants were debriefed about the purpose of the study at the end of the testing session.

2.3.1. Electroencephalogram (EEG) recording

The EEG was continuously recorded at a sampling rate of 512 Hz from 64 Ag/Ag-CI active electrodes that followed the International 10–20 electrode system (Jasper, 1958) using BioSemi ActiveTwo system (Amsterdam, Netherlands; www.biosemi.com). Six additional electrodes were used: four eye electrodes (one below each eye and one just lateral to the outer canthi of each eye), and two electrodes placed on the left and right mastoids. Impedances were maintained below 20 kΩ.

Off-line pre-processing was conducted using EEGLAB (version 10.2.2.4b; Delorme & Makeig, 2004) and ERPLAB (version 4.0.3.1, Lopez-Calderon & Luck, 2014) toolboxes in MATLAB (version 8.0, The MathWork Inc., Natick, MA, R2012b). The EEG recording was filtered offline using a band-pass filter of 0.01–60 Hz, as recommended by Tanner et al. (2015) for the high-pass filter and re-referenced to the average of both mastoids. The signal was baseline-corrected and segmented into epochs of −200 ms of pre-stimulus activity to 800 ms of post-stimulus activity. Prior to artifact detection, noisy channels were interpolated and a simple voltage threshold of 400 μV was used to detect and remove trials with drift and/or high frequency noise. On average, 1.28 channels were interpolated and 1.19% of trials across all participants were removed from the simple voltage 400 μV threshold. Ocular and muscle artifacts were detected and removed using Independent Component Analysis (ICA; Makeig et al., 1996). ICA has been found to be a valid method in preserving the brain activity of interest while separating eye artifacts out of the signal (Mennes et al., 2010). Accordingly, components indicative of an eye movement or eye blink were removed from the data. Finally, a 150 μV simple voltage threshold was applied after ICA to eliminate any remaining trials with ocular artifacts (1.76% of trials removed across all participants). For each participant, individual ERPs were generated by electrode site, condition, and language context. Participants for whom more than 20% of their data was excluded or provided data that were more than three standard deviations below or above the group mean were removed from the analyses. Hence, the final sample consisted of 24 monolinguals and 42 multilinguals.

3. Results

3.1. Background measures

Mean scores for the background measures are presented in Table 2. There were no group differences on combined maternal and paternal level of education, $F < 1$. Multilinguals scored significantly lower than monolinguals on the PPVT, $F(1,65) = 31.62$, $p < .001$, $\eta_p^2 = 0.33$ (cf., Bialystok & Luk, 2012), but significantly higher than monolinguals on the K-BIT, $F(1,65) = 17.18$, $p < .001$, $\eta_p^2 = 0.21$.

3.2. Behavioral results

Because the groups differed in background measures for PPVT and K-BIT scores, correlations were conducted to examine the relation between these scores and performance on the flanker task. There was no correlation between overall RTs in each block and PPVT, $r = 0.08$, $p = .51$, or between overall accuracy in each block and PPVT, $r = 0.12$, $p = .32$. However, there was a small but significant negative correlation between RT and K-BIT scores, $r = -0.25$, $p = .048$, and between accuracy and K-BIT scores, $r = 0.28$, $p = .024$. Therefore, K-BIT scores were used as a covariate when analyzing RT and accuracy.

Table 2
Mean values for demographic and background measures (SD) by language group.

N	Monolingual N = 24	Multilingual N = 42
Age in years	19.21 (1.96)	21.79 (3.69)
Gender	14 males, 10 females	16 males, 26 females
Parents' Education	2.92 (1.14)	2.76 (1.12)
PPVT	103.29 (11.40)	76.14 (21.97)
K-BIT	92.04 (11.03)	106.14 (14.41)
Chinese Reading Proficiency (out of 1)	.	0.93 (0.050)
English (out of 100)		
Speaking	100.00 (0.00)	76.25 (17.97)
Understanding	100.00 (0.00)	77.67 (17.08)
Reading	100.00 (0.00)	75.77 (18.13)
Writing	100.00 (0.00)	69.46 (20.39)
L2: Cantonese or Mandarin (out of 100)		
Speaking	.	92.56 (11.56)
Understanding	.	93.63 (11.35)
Reading	.	86.37 (18.48)
Writing	.	73.32 (32.20)

Note. Maternal level of education was measured on a 5-point Likert scale (1 = no high school diploma, 2 = high school graduate, 3 = some college or college diploma, 4 = bachelor's degree, 5 = graduate or professional degree).

Mean accuracy scores are presented in Table 3. Accuracy was near ceiling with means greater than 95% across all conditions for both groups. A 3-way ANCOVA controlling for K-BIT scores on accuracy for Group, Context, and Congruency showed a main effect of Congruency, $F(1,63) = 14.91$, $p < .001$, $\eta_p^2 = 0.19$, with higher accuracy for congruent than incongruent trials. No other main effects or interactions reached significance, $ps > 0.063$.

The LS means for RT by group, context, and congruency are presented in Fig. 2. A 3-way ANCOVA controlling for K-BIT scores on correct RTs for Group, Context, and Congruency showed a main effect of Congruency, $F(1,63) = 12.99$, $p < .001$, $\eta_p^2 = 0.17$, in which participants were faster to respond to congruent trials than incongruent trials. There was also a main effect of Group, $F(1,63) = 5.04$, $p = .028$, $\eta_p^2 = 0.074$, indicating multilinguals were faster than monolinguals. No other main effects or interactions reached significance, all $ps > 0.079$.

3.3. EEG results

Mean amplitude and peak latency for the P2, N2, and P3 waveforms are reported in Table 4. The P2 and N2 waveforms were analyzed by taking the average waveform recorded at electrodes F1, Fz, F2, FC1, FCz, and FC2 across participants. The P300 waveform was analyzed by taking the average waveform recorded at electrodes P1, Pz, P2, PO3, POz, and PO4 across participants. Time windows of 175–275 ms, 225–350 ms, and 375–475 ms were used to analyze the P2, N2, and P3 components, respectively. These electrodes and time windows were selected based on visual inspection of the data and previous literature on these

Table 3
Accuracy (SD) on the flanker task by language context and group.

Context	Congruency	Monolingual	Multilingual
English	Congruent	99.91 (0.45)	99.95 (0.34)
	Incongruent	96.20 (8.14)	95.61 (4.77)
Chinese	Congruent	99.72 (0.75)	98.62 (7.88)
	Incongruent	96.11 (6.82)	95.03 (8.61)
English/Chinese	Congruent	99.72 (1.00)	99.89 (0.48)
	Incongruent	97.22 (3.89)	96.09 (5.70)

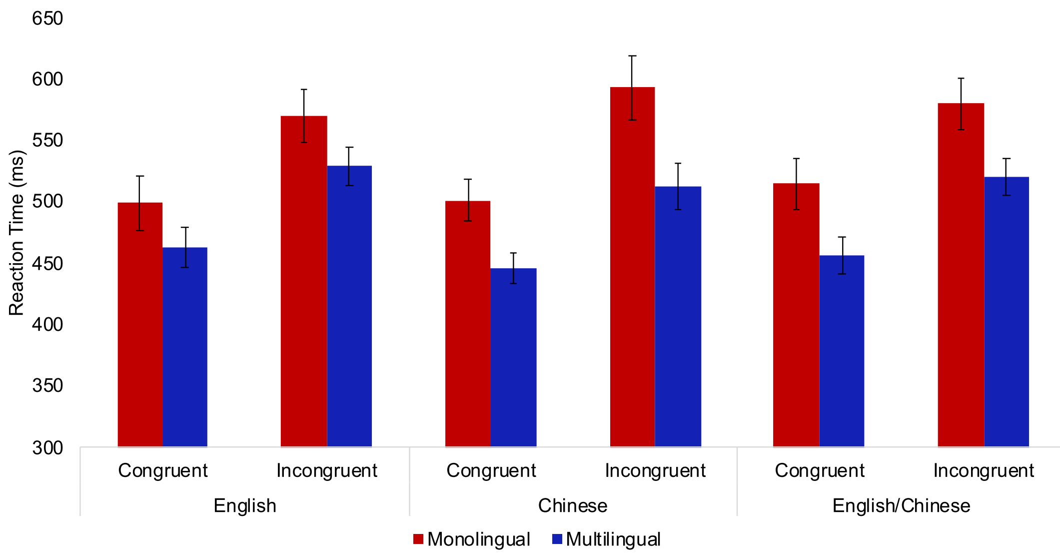

Fig. 2. LS Means for RT (standard errors) on the flanker task by language context, congruency, and group.

Table 4
Mean amplitude and peak latency (SD) of the P2, N2, and P3 waveforms.

			Mean Amplitude (μV)		Peak Latency (ms)	
Component	Context	Congruency	Monolingual	Multilingual	Monolingual	Multilingual
P2	English	Congruent	6.81 (4.16)	5.38 (3.29)	248 (15)	201 (16)
		Incongruent	6.89 (4.13)	4.92 (3.66)	252 (17)	201 (14)
	Chinese	Congruent	6.25 (3.72)	5.66 (3.73)	252 (16)	198 (14)
		Incongruent	6.01 (3.46)	5.30 (3.43)	247 (15)	203 (14)
	English/Chinese	Congruent	6.48 (3.48)	4.89 (3.57)	244 (16)	201 (14)
		Incongruent	7.03 (3.17)	4.98 (3.75)	248 (18)	202 (14)
N2	English	Congruent	4.67 (3.91)	4.51 (4.20)	321 (20)	262 (23)
		Incongruent	4.13 (3.29)	4.26 (4.31)	326 (20)	266 (21)
	Chinese	Congruent	4.72 (3.68)	4.72 (4.53)	319 (18)	261 (23)
		Incongruent	3.86 (2.96)	4.41 (4.01)	318 (19)	261 (18)
	English/Chinese	Congruent	4.40 (3.42)	4.79 (3.96)	317 (20)	266 (20)
		Incongruent	4.73 (2.88)	3.85 (4.47)	318 (20)	259 (22)
P3	English	Congruent	10.33 (5.03)	10.43 (5.84)	422 (29)	416 (30)
		Incongruent	9.63 (4.15)	10.18 (6.30)	427 (30)	435 (26)
	Chinese	Congruent	11.08 (4.15)	10.18 (5.36)	418 (34)	410 (27)
		Incongruent	11.06 (4.51)	10.52 (5.90)	437 (26)	431 (28)
	English/Chinese	Congruent	11.52 (4.64)	10.67 (5.69)	414 (30)	414 (28)
		Incongruent	11.29 (3.72)	10.14 (5.67)	435 (23)	435 (28)

components (Botvinick et al., 2001; Johnson, 1986; Polich, 2012), previous language context studies (Jiao, Liu, et al., 2020; Wu & Thierry, 2013), and a recent study examining the effects of bilingualism on executive control that also used the flanker task (Botezatu et al., 2021).

Mean amplitude of the P2, shown in Fig. 3, was analyzed using a 3-way ANOVA for Group, Context, and Congruency. There were no main effects but there was a significant interaction of Group and Context, $F(2,128) = 3.02$, $p = .05$, $\eta_p^2 = 0.05$. Follow-up analyses indicated there were no group differences in mean amplitude for the Chinese context, $F(1,64) = 0.55$, $p = .46$, or English context, $F(1,64) = 3.47$, $p = .07$. For the English/Chinese mixed context, the monolingual group ($M = 6.75$ μV, $SE = 0.67$) had a significantly larger amplitude than the multilingual group ($M = 4.94$ μV, $SE = 0.56$), $F(1,64) = 4.41$, $p = .04$, $\eta_p^2 = 0.06$. Another way of examining the Group and Context interaction is to compare each level of language context separately for the monolingual and multilingual groups. There was no significant effect of language context for the monolingual group, $F(2,46) = 1.98$, $p = .15$, or the multilingual group, $F(2,82) = 1.43$, $p = .25$. No other effects or interactions were significant, all $ps > 0.10$.

The analysis of peak latency for the P2 revealed a main effect of Group, $F(1,64) = 269.51$, $p < .001$, $\eta_p^2 = 0.81$, indicating the P2 waveform occurred earlier for the multilingual group ($M = 201$ ms, $SE = 3$) than the monolingual group ($M = 248$ ms, $SE = 2$). No other main effects or interactions were significant, all $ps > 0.10$. Furthermore, the correlation between P2 latency and RT was significant, $r(64) = 0.29$, $p = .02$, indicating that earlier P2 peak latencies were associated with faster reaction times.

For mean amplitude of the N2, there was no effect of Group, Context, or Congruency, or interaction effects, all $ps > 0.15$. A similar ANOVA for peak latency revealed a main effect of Group, $F(1,64) = 225.09$, $p < .001$, $\eta_p^2 = 0.78$, indicating an earlier N2 for the multilingual group ($M = 262$ ms, $SE = 4$) than the monolingual group ($M = 300$ ms, $SE = 3$). No other main effects or interactions were significant, all $ps > 0.09$. The correlation between N2 latency and RT was significant, $r(64) = 0.44$, $p < .001$, indicating that earlier N2 peak latencies were associated with faster reaction times.

Mean waveforms by group and context for P3 are presented in Fig. 4. A 3-way ANOVA for Group, Context, and Congruency on P3 mean amplitude revealed a significant interaction of Group and Context, $F(2,128) = 2.94$, $p = .05$, $\eta_p^2 = 0.04$. There was a main effect of Context

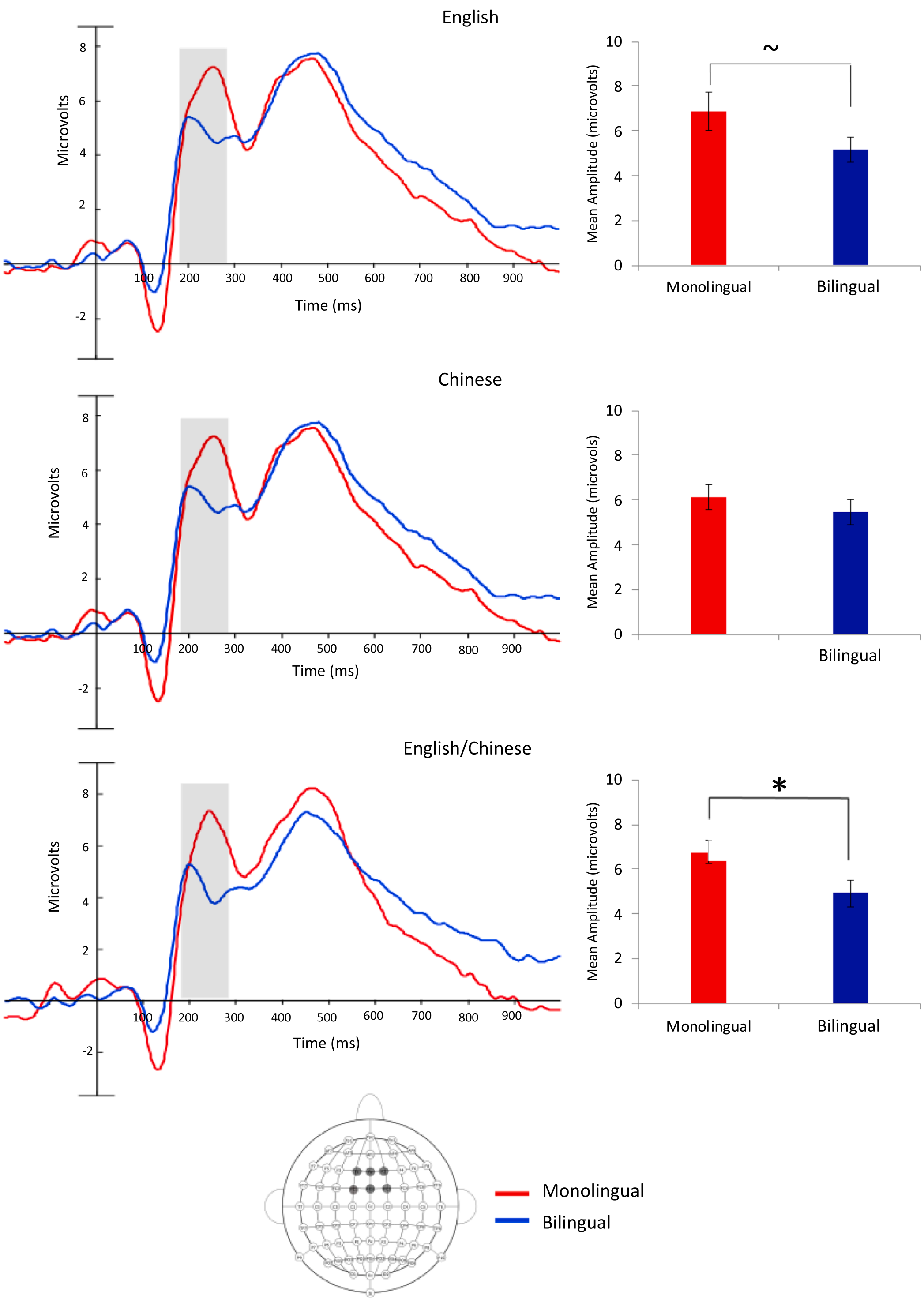

Fig. 3. Grand average P2 waveforms (175–275 ms) from the monolingual and multilingual groups presented by English, Chinese, and English/Chinese contexts (left panel). The average mean amplitudes (standard errors) of the P2 by group and language context (right panel). $*p < .05$, $\sim p < .07$.

for the monolingual group, $F(2,46) = 4.09$, $p = .02$, $\eta_p^2 = 0.15$, but not the multilingual group, $F < 1$. The monolingual group had a larger amplitude for the mixed ($M = 11.40$ μV, $SE = 0.85$) than the English context ($M = 9.98$ μV, $SE = 0.93$), $F(1,23) = 7.71$, $p = .01$, $\eta_p^2 = 0.25$, but no difference between either the English and Chinese ($M = 11.07$ μV, $SE = 0.87$) contexts, $F(1,23) = 4.70$, $p = .12$, or the Chinese and mixed contexts, $F < 1$. Another way of examining the Group and Context interaction is to compare the monolingual and multilingual groups across each level of context. There was no significant difference in language group performance across any of the contexts, *F*s < 1. No other main effects and interactions were significant, all *ps* > 0.09.

Finally, a similar ANOVA for P3 peak latency revealed a main effect of Congruency, $F(1,64) = 42.88$, $p < .01$, $\eta_p^2 = 0.40$, indicating the P3 waveform occurred earlier on congruent ($M = 415$ ms, $SE = 4$) than incongruent ($M = 433$ ms, $SE = 3$) trials for all participants. No other main effects or interactions were significant, all *ps* > 0.25.

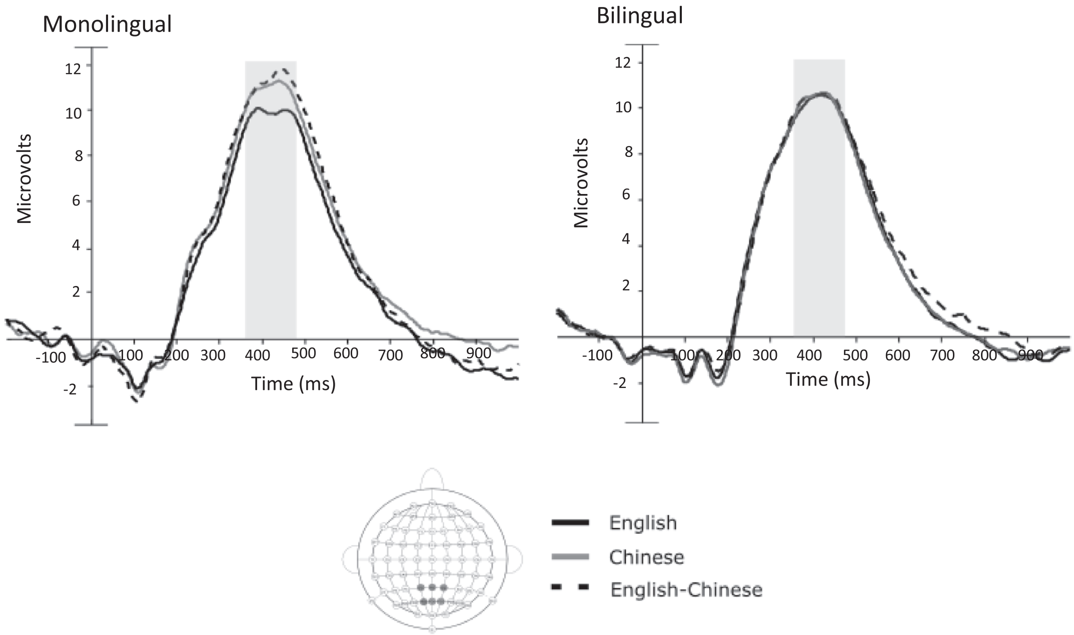

Fig. 4. Grand average P3 waveforms (375–475 ms) of the monolinguals (left panel) and multilinguals (right panel) presented by language context: English (black), Chinese (grey), and English/Chinese contexts (dashed).

4. Discussion

The current study examined the role of language context on executive control in English monolinguals and English-Chinese multilinguals. Behaviorally, multilinguals were faster than monolinguals on both congruent and incongruent trials of the flanker task, but in contrast to previous studies, language context did not modulate performance for multilinguals. The electrophysiological data revealed that multilinguals were faster than monolinguals to attend to and evaluate the stimulus as indexed by the earlier onset of the P2 and N2 components for multilinguals. Contrary to the predictions, however, language context impacted P3 amplitude for the monolingual group but not the multilingual group. The monolingual group had a larger P3 amplitude for the mixed-language context than single-language English context, indicating they required more resources for the mixed-language context, whereas for multilinguals, the P3 amplitude was similar across all three contexts. Thus, the mixed-language context was more distracting for the monolinguals than the English context, but not for the multilinguals.

The behavioral evidence from previous studies using this paradigm only included bilinguals but showed mixed results. In some studies, there was an effect of context on reaction time (Jiao et al., 2019; Jiao, Liu, et al., 2020) and in others there was no such effect (Jiao, Grundy, et al., 2020; Wu & Thierry, 2013). Hence, the language context manipulation used in this paradigm may have a less reliable impact on behavioral measures than it does on electrophysiological ones. This difference in sensitivity to capturing processing differences between language groups is consistent with previous research reporting no behavioral group differences but significant differences in ERP waveforms (e.g., Grundy & Bialystok, 2018; Grundy et al., 2017b; Kousaie & Phillips, 2012).

In the three previous studies that recorded ERP, the results showed an effect of congruency on amplitude for at least some of the waveforms (see Table 1). However, in the present study there were no congruency effects found for P2, N2, or P3 amplitudes. There was, however, an effect of congruency in P3 latency in which the waveform began earlier for congruent than incongruent trials. Why were the present results different from those of previous studies?

The paradigm used here was the one created by Wu and Thierry (2013). Their main result was reduced amplitude for incongruent trials on the P3 in the mixed block compared to the single block conditions, an effect not replicated in the present study. However, the time window Wu and Thierry reported this effect was 500–700 ms, which is an unusually late window for P3. It is possible that this time window was chosen to accommodate the P3 latency difference between congruent and incongruent trials. Furthermore, the reaction times in their study were very long (~625 ms), so this slower processing may have pushed the waveform to a later window. It is noteworthy that Jiao, Grundy, et al. (2020) analyzed the same time window of 500–700 ms and reported a similar effect to Wu and Thierry, namely a smaller amplitude for incongruent trials, but they interpreted it as an LPC. LPC is thought to index conflict adaptation processes – a plausible by-product of their task design. Closer examination of the graphs presented by Wu and Thierry suggest that their time window primarily captures the second half of the P3 waveform and that an earlier window, beginning at 375 ms, would still show a reduced amplitude for the mixed block but be more commensurate with other studies.

In the studies by Jiao and colleagues, every trial required a response to the interposed linguistic stimuli, whereas in the present study using the Wu and Thierry paradigm, participants were instructed to ignore the words when performing the flanker task. The need to respond to the words may reduce the demands on the flanker task since participants had sufficient time to disengage from each flanker trial. Typical flanker paradigms present conflict and non-conflict trials successively that are separated by relatively short interstimulus intervals (ISIs). In the current study, the ISI (500, 1000, or 1500 ms) between stimulus presentation and the fixation cross for the next trial was quite long in order to limit carryover effects from seeing the word onto the flanker trials. Moreover, the fixation cross remained on the screen for 500 ms and the words for 1500 ms. Jiao, Grundy, et al. (2020) and Jiao, Liu, et al. (2020) found an effect of congruency in all contexts for the N2, P3, and LPC. This is possibly because participants were required to make a language response on every trial, a requirement that may have increased the cognitive load on the conflict monitoring system and level of alertness.

Despite these disparities with some results from previous studies, the current results help clarify how context affects performance of multilinguals on nonverbal tasks. For both the behavioral measures of reaction time and latency measures for P2 and N2 waveforms, multilinguals were faster to respond and deploy attention than monolinguals. These differences were found as main effects and not as an interaction with congruency as reported in previous studies. These group differences in P2 and N2 latency are consistent with the ability of multilinguals to deploy selective attention earlier than monolinguals leading to faster reaction times across all conditions, as previously shown in the Bilingual Anterior-Posterior Subcortical Shift framework (Grundy et al., 2017a). These findings demonstrate that fluency in a second language leads to a more efficient strategy, specifically, one that involves devoting attentional resources earlier at the initial stages of processing (i.e., N2 and P2 time windows).

Although previous language context studies did not analyze the P2, the present data revealed group differences on this component. A study by Kałamała et al. (2018) pointed to the P2 as a more promising index of conflict resolution in a flanker task than the N2 component which is more typically used. Consistent with this notion, the present study found a significant effect of language group on P2 amplitude, showing larger amplitude for monolinguals than multilinguals in the mixed Chinese-English block. One interpretation is that the mixed block required greater involvement of selective attention for the monolinguals because the mixed language block was more distracting than the single blocks and required more attentional resources to ignore that distraction.

This interpretation is consistent with research by Olguin and colleagues (Olguin et al., 2018; Olguin et al., 2019). Using a dichotic listening task, Olguin et al. (2019) had Spanish-English and Dutch-English bilinguals listen to a narrative in their native language while ignoring competing information in the other ear. The information presented to the unattended ear was either a story in their native language (Spanish or Dutch), a story in an unknown language (Serbian), or nonverbal noise (musical rain). The electrophysiological data revealed no difference in neural encoding across all interference conditions. In contrast, a study with English monolinguals performing the same task found that attentional encoding was modulated by the type of interference (Olguin et al., 2018); competing information from their native language led to the strongest neural encoding of the attended and unattended streams, interference from the unknown language was next, and nonverbal noise created the least distraction. The authors interpreted these findings in terms of the more efficient attentional control system in bilinguals that led to enhanced processes of selective attention. Put another way, the language interference was more distracting for monolinguals than for bilinguals.

In the present study, there was an interaction between language context and group such that context modified P3 amplitude for the monolingual group but had no effect for the multilinguals. Specifically, for the monolinguals, the P3 amplitude was larger in the mixed block than the English block, with the Chinese block not different from either. The English block is the most familiar for the monolinguals and yielded the smallest amplitude, consistent with the lowest demands on attention, yet there was no significant increase in amplitude for the Chinese block despite the language being unfamiliar. It was only when the two languages were combined that the P3 amplitude increased for the monolinguals, pointing to the variation in the intervening words and not their specific properties. In other words, monolinguals were distracted by the intervening stimuli that randomly mixed two language systems together and were thus upregulating attention for the mixed-language context (and to some degree for the Chinese context as well despite not reaching statistical significance). In contrast, the intermixing of two systems did not increase the distraction for multilinguals.

Finally, it is possible that differences in the way the two languages were used by the bilingual participants in the Wu and Thierry (2013) study and the current study reflect different patterns of language use by these groups. The specific experiences in interactional contexts and the cognitive demands inherent in these contexts have been shown to modulate the cognitive impact of using multiple languages in daily life (e.g., Beatty-Martínez et al., 2020; Pot et al., 2018). Wu and Thierry (2013) indicated that their participants used Welsh and English on a daily basis both at home and at university, so according to the Adaptive Control Hypothesis (Green & Abutalebi, 2013), they would be considered dual-language context bilinguals. In contrast, the Chinese-English multilinguals in the present study were immersed in an anglophone environment, attending an English-speaking university, and likely using Mandarin or Cantonese largely at home, making them single-language context bilinguals. Similarly, differences in the language use context for bilinguals in Toronto and Montreal may be responsible for different outcomes regarding the relevant aspect of use that is associated with cognitive outcomes. In Toronto, which is primarily a single language situation, greater use of the non-English language at home is associated with better outcomes on executive function tasks (Anderson et al., 2018) whereas in Montreal, which is closer to a dense code-switching context, more complex and varied social use contexts is associated with better outcomes on executive function tasks (Gullifer & Titone, 2020b). These individual differences in bilingual use experiences may fine-tune or regulate the precise modifications that bilingualism has on cognitive and brain outcomes.

5. Conclusions

The purpose of the present study was to investigate previously reported effects showing that manipulation of the language context in a nonverbal flanker task modified the attentional resources recruited by bilingual participants. Subsequent research with the paradigm confirmed aspects of the original results but diverged in other respects. The present study contributes to the discussion in two primary ways.

First, the inclusion of a monolingual group helped to specify the effect of the paradigm and the response to it by bilingual participants. In the original study, Wu and Thierry (2013) argued that the presence of both languages in the mixed condition mentally placed the bilingual participants in a mode characterized by a dual-language context and that similarity enhanced their performance, presumably through more efficient allocation of attentional resources. The present study did not replicate those results; instead, it was the monolingual group whose performance was most impacted by the language context manipulation. The mixed language condition required greater resource allocation by monolinguals, presumably because the mixed languages were more distracting and required greater effort to ignore. This interpretation is in line with evidence from Bice and Kroll (2019) discussed earlier showing that language context impacts monolinguals, although in different ways than it does bilinguals.

Second, although the language context manipulation did not affect performance in multilinguals, there were nonetheless reliable effects of flanker task performance. The behavioral results demonstrated significantly faster performance by multilinguals than monolinguals for both congruent and incongruent trials. Similarly, ERP results showed multilinguals had an earlier N2 and P3 than monolinguals corroborating the interpretation of more efficient performance on this task by multilinguals. These language group differences in ERP outcomes reflect unique cognitive processing for each group in response to this task; specifically, changes in the language context had no effect on performance by multilinguals but elicited changes in resource recruitment for monolinguals. Only the monolinguals needed to recruit additional resources to perform in the mixed language context.

Although the current results did not show significant language context effects for multilinguals, this does not mean that language context is irrelevant to bilingual processing. Rather, the effect is likely more complex than could be captured in that manipulation and depends as well on the nature of language interaction experienced by the participants. Future studies, therefore, should consider the nuanced relationship between individuals and their language environment and the implication of this relationship on the recruitment and deployment of attentional resources on cognitive tasks.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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