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Individual differences in main idea identification: An EEG study of monolinguals and bilinguals with dyslexia

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Abstract

Individuals differ in a range of processes related to reading comprehension, including working memory capacity, decoding skills, inference making and main idea identification. In this exploratory study, we examined evoked potential N400 amplitude during reading comprehension tasks and focused on identifying the main idea in the text, modulated by working memory capacity. Participants included monolinguals or bilinguals who were either typical readers (n = 33) or had been diagnosed with dyslexia (n = 19). Analyses revealed significant group differences for main idea conditions. Participants with dyslexia showed greater N400 amplitude than typical readers, particularly in the right hemisphere, when the main idea was in the last position in the paragraph. There were no significant differences in performance between bilinguals and monolinguals, which does not support the idea of a cognitive advantage for bilingualism. It was noteworthy that, if they had dyslexia, they were similarly negatively impacted by their reading disability. Findings highlight the processing advantages typical readers have relative to dyslexia.

Highlights

- We examined right and left cerebral hemisphere N400 amplitude during tasks involving language comprehension, working memory and main idea identification.
- Our sample included four groups, including bilingualism and dyslexia. Participants with dyslexia showed greater N400 amplitude overall.
- There were no associations between working memory capacity and N400 amplitude.
- Greater right N400 amplitude was observed overall, suggesting that this hemisphere is more prone to detect language violations than the left.
- There does not appear to be a cognitive advantage to being bilingual.

1. Introduction

The literature in the area of individual differences in reading comprehension shows that readers differ in terms of a range of processes, such as working memory capacity (WMC) (e.g., Alptekin & Erçetin, 2011; Martin, 2021; Tomitch, 2003), the use of prior knowledge (e.g., Bilikozen & Akyel, 2014; Kendeou & Van Den Broek, 2007), the use of strategies (e.g., Sparks, 2012; Veenman, 2015), inference making (e.g., Gillioz et al., 2012; Perez et al., 2020), vocabulary (e.g., Nagy & Scott, 2000; Sidek & Rahim, 2015), decoding (Hulme & Snowling, 2016) and main idea identification (e.g., Elashhab, 2013; Stevens et al., 2019), among others. Here we focus on the ability to identify the main idea in a text, modulated by two specific conditions: being a monolingual or a bilingual and being a typical reader or a reader with dyslexia.

Extracting main ideas from texts is a complex cognitive activity that demands mental effort from the individual and is one of the most important reading skills to master, particularly when the main idea is not explicitly stated as a topic sentence and the reader must make inferences in order to construct it. Highly proficient readers identify more accurately the central ideas in a text and, consequently, they can construct a more adequate mental representation of the text's content than less proficient readers (Tomitch, 2003; Williams, 1988; Winograd, 1984). Individuals with dyslexia have more difficulties in extracting main ideas from texts than typical readers (Kirby et al., 2008), presumably because of difficulties both with decoding and with making inferences when the main idea is not explicitly stated in the text. Understanding the main idea is understudied relative to other aspects of language research, particularly regarding cognitive neuroscience. Most of the experimental research involving individuals with dyslexia focuses on lower-level processes in reading, investigating word decoding (matching and recoding) (Gagné et al., 1993). Therefore, the present exploratory study may signal a possible direction for future research by looking at a higher-level process, namely main idea identification, which involves inferential comprehension or semantic integration.

1.1. Language comprehension and the brain

Reading comprehension is arguably the goal in literacy. Comprehension refers to "any information about events, relations and so on that the reader adds to the information that is explicitly presented" in discourse (van Den Broek et al., 1995, p. 353). It depends on the integration of cognitive processes (see Rapp et al., 2007) and linguistic skills (Cain et al., 2004). The right hemisphere (RH), including the cerebellum, is involved in most of these aspects, including verb generation, semantic processing, sentence processing and verbal fluency (Geva et al., 2021). Some even claim that the RH plays a stronger role than the left in tasks with higher comprehension demands (Silagi et al., 2015). Making and generating inferences about text is also an important part of reading comprehension, and both cerebral hemispheres appear to contribute (Baretta et al., 2009). In the RH, the inferior and middle temporal sulcus, inferior frontal gyrus and inferior parietal areas are particularly involved (Mason & Just, 2004).

1.2. Language comprehension, main idea extraction and EEG

The mental effort in main idea extraction can be captured by electroencephalogram (EEG) and event-related potential (ERP) techniques, specifically the N400 ERP component. The N400 is a large negative deflection wave that begins around 200–300 ms after the presentation of visual or auditory stimuli and peaks around 400 ms after stimulus onset (range 200–500 ms) and is maximal over the centro-parietal electrode regions. It is involved in the detection of semantic outliers and integration of lexical information (Kutas & Federmeier, 2011; Lau et al., 2008).

The N400 was first discovered in a sentence processing study that looked at ambiguous or unexpected words (Kutas & Hillyard, 1980). The N400 had a greater amplitude to semantic violation such as "he spread the warm bread with socks," the word "socks" eliciting a greater N400 response in comparison to the word "butter." Subsequent studies have shown that the N400 is related to lexical and semantic processing of information (for reviews, see Kutas & Federmeier, 2011; Lau et al., 2008) as well as language comprehension (see Baretta et al., 2012). As the N400 component is involved in semantic integration between words and phrases (Friederici, 2011), reduced N400 responses have been demonstrated by readers with lower working memory span who have more difficulties in integrating elaborative inferences and comprehending sentences into a coherent text (St. George, 1995).

In an EEG study investigating global expectancy in short paragraphs, St George et al. (1994) observed larger RH N400s for untitled paragraphs than for titled ones, suggesting that the lack of explicit global coherence pointers (e.g., titles and textual markers) in a text can affect the N400 component, indicating a more demanding reading situation for readers. In a follow-up study, St George et al. (1999) confirmed these findings by using functional magnetic resonance imaging (fMRI), verifying more RH activation for untitled than for titled paragraphs, located specifically in the middle temporal sulcus. More brain activation for untitled paragraphs was also observed in both right and left hemispheres in the inferior temporal sulcus. In an fMRI study with L1 participants (native speakers of English), Tomitch et al. (2008) found that, in the left temporal region, more activation was exhibited when the main idea was displayed in the last position in the paragraph (a more demanding reading situation) than when it appeared in the first position. Though the right temporal region did not show more activation for the main idea in the last position, it was more active for the main ideas than for the supporting ones, suggesting that the RH recognized the main ideas, regardless of their position in the text.

1.3. Bilingualism and dyslexia

Dyslexia is a neurobiological reading disorder characterized "by an unexpected difficulty in reading in children and adults who otherwise possess the intelligence and motivation considered necessary for accurate and fluent reading" (Shaywitz & Shaywitz, 2005, p. 1301). In general, the specific difficulties are related to some form of phonological coding, where the graphemic input (visual) is not adequately coded as phonemic (sound), hampering access to the meaning of the word in memory.

In relation to its neural representation, neuroimaging studies indicate that dyslexia would be connected to an impairment in activation of posterior cerebral circuits in the LH, including the angular gyrus (a temporo-parietal region, important in the mapping of graphemic input into phonological structures of the linguistic system) (Park et al., 2012; Shaywitz & Shaywitz, 2005), as well as an occipito-temporal region (Richlan, 2012; Shaywitz & Shaywitz, 2005), responsible for the automatic recognition of words, the *visual word form area* (Dehaene et al., 2002). Another important finding relates to an indication of a greater involvement of the RH in dyslexia, as a possible way to compensate for a failure in activation of the relevant homologue areas in the LH (Park et al., 2012; Shaywitz & Shaywitz, 2005; Waldie et al., 2013). This finding is important in the present study, since bilinguals have also been found to present greater RH activation during language tasks (e.g., Bailer & Tomitch, 2020; Waldie et al., 2012; Badzakova-Trajkov et al., 2008).

Although the number of studies worldwide on bilingual dyslexia is increasing, many of them are behavioral and findings need replication (Bonifacci et al., 2017; Dulude, 2012). Further investigation is also required on how dyslexia and bilingualism interact (do Amaral & de Azevedo, 2021). As reviewed by Waldie et al. (2020), there may be a cognitive advantage to being bilingual due to the need for language switching – a cognitively demanding executive task involving working memory (Bialystok, 2011; Olulade et al., 2015). If so, bilingual individuals should show better performance on a WM test and be better at extracting a central idea from text than monolinguals. Perhaps the advantage could extend to bilinguals with dyslexia. This is in line with a study by Vender et al. (2021). While bilingualism did not provide an advantage for morphological processing, the authors concluded that it also did not disadvantage individuals with dyslexia across tasks, i.e., while not significant, bilingual individuals with dyslexia were able to generate more plural nouns from non-words compared to monolingual individuals with dyslexia (Vender et al., 2021).

Together, these findings indicate that more research is needed into the complex relations between bilingualism and neurodiversity (do Amaral & de Azevedo, 2021). To this end, the main objective of the present study was to examine N400 amplitude, particularly in the right hemisphere, during a reading comprehension task, specifically main idea identification (first and last paragraph presentation) in L1 (monolingual) and L2 (bilingual) typical readers and those with dyslexia. In order to shed some light on the bilingual advantage discussion in the literature, we measured participants' working memory (WM) capacity. WM is involved in the construction of the semantic representation of the text by providing the necessary resources for activating and using knowledge in inference generation (Belke, 2008; Ericsson & Kintsch, 1995; Just & Carpenter, 1992; Martin, 2021), which is an important process in main idea identification. Based on previous research on WM, we predicted that processing the two conditions (MI First; MI Last) would be modulated by working memory capacity, so the further the pronoun (in the first sentence) from the actual referent (MI last), the more resources from WM are necessary to maintain the verbatim sentences or phrases in WM until the resolution comes in the last sentence.

The role of WM in predicting reading comprehension is more complicated in bilinguals. Babayiğit et al. (2022) suggest that, despite the advantage of bilingualism in cognitive domains such as WM and cognitive inhibition, bilingual readers have lower performance in reading comprehension compared to their monolingual peers due to their usually smaller vocabulary size in the second language (L2). Nonetheless, psychometric studies with bilinguals show a clear relationship between WMC and reading comprehension. For example, Alptekin and Erçetin (2010), in studying the effect of L1 and L2 working memory capacity on literal and inferential comprehension in Turkish–English speaking adults, found no differences between L1 and L2 storage capacity. They found that L2 working memory is related to inferential comprehension but not literal comprehension. These findings have been replicated in a recent study by de Azevedo et al. (2022) with Brazilian adult speakers of English as L2 and are in line with Just and Carpenter (1992), who advocate that an effect of WMC will be seen on tasks of moderate difficulty but not on easy tasks.

2. Method

2.1. Participants and general procedure

The initial pool of participants included 54 individuals, but two control participants were excluded from the EEG analysis because they were on SSRI medication (which may have interfered with the results). A total of 52 participants took part in the study: (i) 14 typical monolinguals-TM (native English speakers); (ii) 19 typical bilinguals-TB (English as an L2); (iii) 13 monolinguals with dyslexia (MD) (native English speakers); and (iv) 6 bilinguals with dyslexia (BD). The TB group included 9 native speakers of Brazilian Portuguese, 2 speakers of Spanish, 2 speakers of German, 2 speakers of French, 2 speakers of Chinese, 1 speaker of Norwegian and 1 speaker of Persian. The 19 TB learned English after the age of 6 and were all living in Auckland-NZ during the time of data collection, studying and/or working. The BD group comprised of 3 native speakers of Dutch who learned English after the age of 6 and 3 native speakers of Hindi, Malay and Tamil, respectively, having learned English before the age of 6. From the 19 participants with dyslexia (PD), 12 were female, and from the 33 typical individuals, 20 were female. All participants had normal or corrected-to-normal vision. Participants were recruited via adverts posted at The University of Auckland, via Facebook advertising and a local newspaper (East & Bays Courier). As reported in Tomitch et al (2022), recruiting was kept open for a period of 10 months, due to difficulty in finding bilinguals with dyslexia, a limitation that is common in this area, with many studies including no more than four participants (e.g., de Azevedo, 2016; Dimililer & Istek, 2018; Park et al., 2012; Valdois et al., 2014).

Exclusion criteria for the participants with dyslexia included any psychiatric disorders or being on any psychoactive medications. For participants in the typical group, the exclusion criteria included personal or family history of neurological or psychiatric disorders, hearing deficits and pharmacological treatment. One individual from the group with dyslexia reported taking medication for anxiety, depression and insomnia in the past, but was not on medication during the EEG assessment.

The present study focuses on EEG data collected as part of a larger research endeavor (including qualitative and quantitative studies and both behavioral and brain data) to test the bilingual advantage theory. We ran two language proficiency tests to compare the performance of typical bilinguals and bilinguals with dyslexia: an oral proficiency test in L2 (Oral Narrative Task-ONT) and a reading comprehension test (TOEFL – Test of English as a Foreign Language). The Oral Narrative Task assessed lexical, grammatical and syntactic choices, as well as those related to text organization (cohesion and coherence). The measures were analyzed in terms of accuracy, complexity and fluency. None of the comparisons for the ONT reached statistical significance. The mean for accuracy for typical bilinguals was 72.24 (SD = 23.39), and 88.36 (SD = 14.60) for bilinguals with dyslexia. The average score for complexity was 2.24 (SD = 0.52) and 2.57 (SD = 0.27) for typical bilinguals and bilinguals with dyslexia, respectively. Also, two measures of fluency including speech rate unpruned (SRU) and speech rate pruned (SRP) were used in the study. The mean of these measures for bilinguals with dyslexia (SRU = 155.58, SRP = 151.55) did not differ statistically from typical bilinguals (SRU = 129.07, SRP = 124.12). The same pattern of results was found for the reading comprehension measure used (TOEFL), where differences between groups were not statistically different. For the TOEFL, the mean of correct answers to questions for monolinguals with dyslexia was 8.84 (SD = 2.11), for typical bilinguals was 7.09 (SD = 2.53), and for bilinguals with dyslexia was 8.16 (SD = 2.99). Taken together, the typical bilinguals and bilinguals with dyslexia had a similar performance in both oral language proficiency and reading comprehension proficiency.

Participants in the groups with dyslexia reported having received a clinical diagnosis of dyslexia during childhood, from a clinical psychologist or a pediatrician, in their mother tongue. Furthermore, one of the researchers completed The Letter-Word Identification (LWI) and the Word Attack skills (WAS), part of the Woodcock–Johnson test, for the group with dyslexia. Participants were asked to read aloud a list of real words in the LWI subtest and a list of nonwords in the WAS test. No significant statistical differences were found for any of the groups for the means of the LWI subset: 30.23 for monolinguals with dyslexia and 30.16 for bilinguals with dyslexia. A similar pattern of results was found for the means of the WAS subtest: 33.69 for monolinguals with dyslexia and 35.66 for bilinguals with dyslexia. Results demonstrated that both monolingual and bilingual adults with dyslexia exhibited a similar performance in the lower-level process of word identification.

All participants answered a demographic questionnaire. As reported in Tomitch et al. (2023), a 11-item non-standardized questionnaire was sent to potential participants which sought the following information: (1) highest education; (2) age of dyslexia diagnosis; (3) therapy received; (4) reading difficulties faced when

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diagnosed; (5) reading difficulties faced at the time of data collection; (6) impact of dyslexia on academic reading; (7) impact of dyslexia on reading habits; (8) comorbidities; (9) psychoactive medication; (10) mother tongue and (11) additional languages spoken and age of second language acquisition. The protocol has been described in Tomitch et al. (2023).

Written informed consent was obtained from each participant. All procedures used were approved by the University of Auckland Human Participants Ethics Committee (Ref. #021103).

2.2. Working memory capacity measure

The Operation-Word Span test (Turner & Engle, 1989) was used to measure WMC. The task is based on Daneman and Carpenter's (1980) Reading Span Test (RST) and it is considered a complex measure of WMC since it tackles both its processing and storage functions. In the RST, participants read an increasing set of sentences aloud while trying to maintain each sentence's last word in memory for recall at the end of each group. In the Operation-Word Span (OSPAN), participants solved 42 simple math problems (instead of reading unrelated sentences) presented to them on a computer screen, as they tried to maintain an increasing number of dissyllabic words in memory for subsequent recall in each set (3 sets of 2 math operations (MO) + 2 words to be recalled; 3 sets of 3 MO + 3 words to be recalled; 3 sets of 4 MO + 4 words to be recalled; 3 sets of 5 MO + 5 words to be recalled) (e.g., Set of 3: (9×3) – 3 = 24? **Forget;** 11 – (4 ÷ 1) + 1 = 4? **Dining;** 12 – (10 ÷ 1) – 1 = 9? **Listen).** A practice session was added so that participants would become acquainted with the procedure. For Turner and Engle (1989), the OSPAN is a general measure of WMC which is independent of the task being performed, i.e., the test should be able to predict performance whether the task being performed is reading-related or not.

Data from the OSPAN were analyzed both in a strict and in a lenient way. For the strict scoring, to count as *correct* the word would have to be recalled in the same order as in the presentation, whereas the lenient scoring counted all recalled words as correct, independent of the order in which participants mentioned them. In addition, for the recalled words to be computed, the participant needed 50% correct for the math results.

2.3. Electroencephalography recording

EEG recordings were conducted in an electrically shielded room (IAC Noise Lock Acoustic – Model 1375, Hampshire, the United Kingdom) using 128-channel Ag/AgCl electrode nets (Electrical Geodesics Inc., Eugene, Oregon, USA). EEG was recorded continuously (1000-Hz sample rate; 0.1–100 Hz analogue bandpass) with Electrical Geodesics Inc. amplifiers (300-MΩ input impedance). Electrode impedances were kept below 40 kΩ, an acceptable level for this system (Ferree et al., 2001). Common vertex (Cz) was used as a reference during recording and then re-referenced to the mastoid electrodes offline.

2.4. Stimuli and experimental design

The Main ideas experiment design consisted of 14 paragraphs split into 3 sentences each (see Appendix for a sample paragraph used as stimuli). Seven paragraphs presented the main idea first (MI first) and seven presented the main idea last (MI last). In order to avoid text effects, all paragraphs were presented with the MI first and MI last, but no participant read the same paragraph twice. In the MI first condition, the first sentence (coded sentence 1) portrayed the gist of the paragraph, and the second (coded sentence 2) and third (coded sentence 3) sentences provided supporting arguments to reinforce the main idea presented in sentence one. For the MI last condition, the first and second sentences (coded sentences 4 and 5) were the supporting sentences for the last sentence, which contained the main idea (coded sentence 6). Therefore, the MI last condition was much more demanding than the MI first condition, since the topic and main idea of the paragraph only appeared in the last sentence. The two supporting sentences, which came at the beginning of this paragraph, seemed extremely vague and challenging for comprehension. They contained cataphoric (or forward) reference, that is, the use of a pronoun (e.g., this; it; they; she; he), which was only resolved in the last sentence of the paragraph, when the referent (topic) appeared (See Appendix for a sample paragraph). The point was to compare how the different groups of monolinguals with dyslexia, bilinguals with dyslexia, typical monolinguals and typical bilinguals processed the paragraphs when the main idea came first (control/less demanding) versus in the last position (more demanding). As mentioned before, we also investigated whether processing would be modulated by working memory capacity, so the further the pronoun is from the actual referent (MI last), the more resources from WM are necessary to maintain the verbatim sentences or phrases. This type of manipulation of sentences and/or specific words has been used in many other studies in the area of language comprehension (St George et al., 1999; Tomitch et al., 2008, among many others). The paragraphs used in this study were those used in Tomitch et al. (2008), and they all depicted general knowledge topics (e.g., Sigmund Freud, Abraham Lincoln, Marilyn Monroe, Eiffel Tower, olive oil, singing whales). Two practice paragraphs were used to familiarize participants with the procedure.

2.5. EEG procedure and data analysis

For the EEG presentation, it was important to prevent ocular artifacts, so each sentence was presented word by word for participants to read, rather than presenting the whole sentence on screen creating vertical and horizontal motion. Rapid serial visual presentation (RSVP) is a common way to present sentences in EEG and fMRI paradigms (Tomitch et al., 2008). In the present study, each word was presented on screen for a duration of 300 ms, then the screen automatically moved on to the next word. The ISI between each word was 1000 ms. Although we understand that this is about 3 times longer than normal reading outside the lab situation, this was necessary to ensure that the EEG signal from each word was not contaminated by the neural response from previous or following words. The EEG sessions were counterbalanced, so that half the subjects were presented with trials that began with the main idea first and the other half with the main idea presented last. At the end of each paragraph, participants responded to a true (press 1) or false (press 2) statement about the main idea presented in the paragraph. Participants were seated 57 cm away from the screen to ensure 1° of visual acuity.

The EEG files were segmented into 600 ms epochs (including a 100 ms pre-stimulus baseline) during which ocular artefacts were corrected (Jervis et al., 1985). Trials with channels marked as bad according to EGIs algorithms were dropped from the averaging process, and 98% of trials remained for analysis from each group. ERPs from individual participants were combined to produce grand-averaged ERPs for each condition. Grand averaged data were

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digitally filtered with a zero-phase-shift 3-pole Butterworth filter (0.1–30 Hz; Alarcon et al., 2000) and then re-referenced to mastoid electrodes offline.

The current study focused on the N400 component as this component is thought to reflect semantic processing. For statistical analysis, electrode clusters of interest for the N400 component (Calloway & Perfetti, 2017) were selected by combining all 52 participants' data for the main idea sentences (First and Last) and the supporting sentences (SS first and SS last). For the supporting sentences conditions, which there were two of each for MI first paragraphs and MI last paragraphs, these were combined, as there were no differences between them. The resultant grand averaged topographic map was used to select symmetrical clusters of electrodes over centro-parietal areas (Delogu et al., 2019; Kutas & Federmeier, 2011) as shown in Figure 1, which showed the greatest difference in mean amplitude between the main idea sentences (MI1 and MI6) and the supporting sentence conditions (SS2, SS3, SS4, SS5) (Left hemisphere electrodes: 31, 37, 42, 47, 52, 53, 54, 59, 60, 61; Right hemisphere electrodes 78, 79, 80, 85, 86, 87, 91, 92, 93, 98). These were then averaged across channels to measure the main ideas versus supporting sentences waveforms. A time window for the N400 was determined based on the full-width half max of the difference waveform of the combined group for each hemisphere. Statistical analyses were performed on the area under the curve. Data were screened for homogeneity, and any violations of sphericity were corrected using the Greenhouse–Geisser correction.

2.6. Data analysis

Behavioral data (e.g., response time in milliseconds) for the monolingual and bilingual participants were analyzed by a mixed ANOVA, with Group (Monolingual, Bilingual) as a between-groups factor and Main Idea (MI) (First, Last) as a within-subjects factor. Data for the Typical Participants (TP) and the Participants with Dyslexia (PD) were analyzed in a mixed ANOVA, with Group (TP, PD) as a between-groups factor and MI (First, Last) as a within-subjects factor.

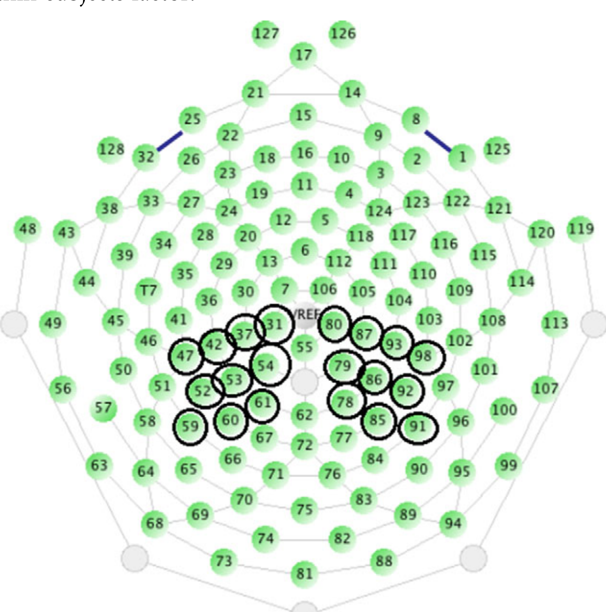

Figure 1. 128 channel head map showing the symmetrical cluster locations of the electrodes used for the N400 component analyses.

2.7. ERP group analyses

Pearson correlations were run to investigate the strength of the relationships between the N400 amplitudes for each group in each of the Main idea conditions (First, Last) and the OSPAN. The aim was to see whether working memory capacity correlated with any of the main idea sentence conditions.

To investigate the role of the cerebral hemispheres in language comprehension, a mixed ANOVA looking at Hemisphere (Left Hemisphere [LH], Right Hemisphere [RH]) by paragraph type (MI First, MI Last) was run for the N400 time window.

A split-plot ANOVA on the mean amplitude values of the N400 time window was analyzed, with Group (Monolingual; Bilingual) as the between-subjects variable and Hemisphere (Left hemisphere, Right hemisphere) and MI Position (First; Last) by Type (Main idea sentence; Supporting sentence) as the within-subjects variables. To investigate Typical readers and those with Dyslexia, a Group (TP, PD) by Hemisphere (LH, RH) by MI Position (First; Last) by Type (Main idea sentence; Supporting sentence) mixed ANOVA on the mean amplitude values of the N400 time window was run on the data.

Statistical analyses were conducted in 25.0 IBM SPSS Statistics and significance was given at a p-value of .05. Simple effects tests conducted on all significant interactions used a *Bonferroni* correction to the alpha level.

3. Results

Table 1 shows the demographic information of the total 54 participants as well as of each of the four groups. The Group (2) X Main Idea (2) ANOVA on response times revealed a significant main effect for Group (F (1, 50) = 4.24, p = 0.045, $\eta\rho^2$ = 0.08), indicating that the Monolingual group (M = 6984.23 SE = 601.57) had faster reaction times than the Bilingual group (M = 8771.61, SE = 625.18) when responding true or false to the main idea. There was no significant main effect of Main Idea (F (1,50) = 3.38, p = n.s., $\eta\rho^2$ = 0.06). No significant interactions were found.

The Group (Typical, Dyslexia) X Main Idea (2) ANOVA on reaction times revealed no significant main effects of Group (F (1, 50) = 276.91, p = n.s.) or for Main Idea (F (1,50) = 3.19, p = n.s.), nor was there a significant interaction effect (F (1, 50) = 0.019, p = n.s.).

3.1. Working memory capacity and N400 amplitudes in main idea identification

As shown in Table 2, the only significant difference in relation to the working memory task (OSPAN) performance was that between typical monolinguals (TM) and monolinguals with dyslexia (MD), with TM performing better than MD in the OSPAN in relation to both strict and lenient scoring. No other pair of group means was statistically significant.

As shown in Table 3, the OSPAN did not significantly correlate with any of the Main idea conditions across the groups, suggesting that working memory load did not influence the N400 amplitudes for the paragraph conditions. The Main Idea conditions were moderately to highly positively correlated with each other for the TM, TB and the MD, but no significant correlation was found between the Main idea conditions for the BD group.

In the absence of a correlation between the N400 amplitudes for each of the four groups in each of the Main Idea conditions (First, Last) and the Operation-Word Span test (OSPAN), and due to the

Table 1. Sociodemographic characteristics of the sample

	Total sample	Typical monolingual	Typical bilingual	Monolinguals with dyslexia	Bilinguals with dyslexia
	N = 54	*N* = 15	*N* = 20	*N* = 13	*N* = 6
Age [M (SD)]	28.9 (07.4)	26.2 (06.4)	30.3 (6.1)	31.5 (10.1)	25.8 (4.6)
Gender [*n*, (%)]					
Male	18.0 (33.3)	06.0 (40.0)	07.0 (35)	02.0 (15.4)	03.0 (50)
Female	36.0 (66.7)	09.0 (60.0)	13.0 (65)	11.0 (84.6)	03.0 (50)
Education [*n*, (%)]					
Secondary	19.0 (35.2)	08.0 (53.3)	06.0 (30)	03.0 (23.1)	02.0 (33.3)
Tertiary	35.0 (64.8)	07.0 (46.7)	14.0 (70)	10.0 (76.9)	04.0 (66.7)

Note: No statistical differences between groups. ANOVA was conducted for continuous variable, Chi^2 test for categorical variables.

Table 2. Mean differences (SD in parentheses) in working memory between groups

Outcomes M (SD), p-value	Group comparison			
	Typical monolingual (*n* = 15) versus Typical bilingual (*n* = 20)	Monolingual dyslexia (*n* = 13) versus bilingual dyslexia (*n* = 6)	Typical monolingual (*n* = 15) versus monolingual dyslexia (*n* = 13)	Typical bilingual (*n* = 20) versus bilingual dyslexia (*n* = 6)
OSPAN strict	TM: 30.4 (4.4)	MD: 23.7 (5.6)	TM: 30.4 (4.4)	TB: 28.3 (4.7)
	TB: 28.3 (4.7)	BD: 27.2 (3.6)	DM: 23.7 (5.6)	DB: 27.2 (3.6)
	p = .19	*p* = .19	***p* = .001**	*p* = .46
OSPAN lenient	TM: 32.4 (4.4)	MD: 28.1 (5.1)	TM: 32.4 (4.4)	TB: 30.9 (4.4)
	TB: 30.9 (4.4)	BD: 29.8 (4.1)	DM: 28.1 (5.1)	DB: 29.8 (4.1)
	p = .31	*p* = .47	***p* = .02**	*p* = .72

Note: OSPAN = The Operation-Word Span Test. TM = Typical Monolinguals; TB = Typical Bilinguals; MD = Monolinguals with Dyslexia; BD = Bilinguals with Dyslexia.

Table 3. Correlation matrix for the N400 in the Main Idea (MI) sentence conditions and working memory task (OSPAN) for the four groups – Typical Monolinguals, Typical Bilinguals, Monolinguals with Dyslexia and Bilinguals with Dyslexia

Group	Variable	1	2	3	4
Typical monolinguals	1. MI first	1			
	2. MI last	0.663**	1		
	3. Ospan strict	0.066	−0.054	1	
	4. Ospan lenient	−0.014	−0.176	0.931**	1
Typical bilinguals	1. MI First	1			
	2. MI last	0.839**	1		
	3. Ospan strict	−0.314	−0.256	1	
	4. Ospan lenient	−0.105	−0.007	0.894**	1
Monolinguals with dyslexia	1. MI first	1			
	2. MI last	0.721**	1		
	3. Ospan strict	−0.471	−0.468	1	
	4. Ospan lenient	−0.367	−0.413	0.915**	1
Bilinguals with dyslexia	1. MI first	1			
	2. MI last	0.685	1		
	3. Ospan strict	−0.382	−0.54	1	
	4. Ospan lenient	−0.386	−0.249	0.917*	1

**.Correlation is significant at the 0.01 level (2-tailed).
*Correlation is significant at the 0.05 level (2-tailed).

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Table 4. Correlation matrix for Main Idea sentence conditions and working memory task (OSPAN) for the two groups – monolinguals and bilinguals

Group	Variable	1	2	3	4	5	6
Monolingual group (TM + MD)	1. Idea first	1					
	2. Idea first SS	.698**	1				
	3. Idea last	.393*	.634**	1			
	4. Idea last SS	.544**	.697**	.666**	1		
	5. OSPAN strict	−.131	.059	−.146	−.064	1	
	6. OSPAN lenient	−.179	.041	−.210	−.134	.925**	1
Bilingual group (TB + MD)	1. Idea first	1					
	2. Idea first SS	.620**	1				
	3. Idea last	.501*	.881**	1			
	4. Idea last SS	.459*	.747**	.732**	1		
	5. OSPAN strict	−.268	−.158	−.085	−.166	1	
	6. OSPAN lenient	−.142	−.086	.078	−.144	.897**	1

**Correlation is significant at the 0.01 level (2-tailed).
*Correlation is significant at the 0.05 level (2-tailed).

low number of participants, we collapsed the data from all monolinguals (typical and with dyslexia-TM + MD) and bilinguals (typical and with dyslexia-TB + BD). As shown in Table 4, there were no significant correlations between the main idea sentence conditions' amplitudes and the OSPAN scores. Both groups showed significant positive correlations for the sentence types. Similarly, a significant positive correlation was found for the OSPAN strict scores and the OSPAN lenient scores, but it did not reach significance.

3.2. Cerebral hemispheres and main idea identification

In the first analysis, data from the N400s from the three sentences in each paragraph type were combined. A significant main effect of Hemisphere was found ($F(1, 51) = 23.89$, $p < 0.001$, $\eta\rho^2 = 0.32$). The LH ($M = 0.16$, SE = 0.07) was more positive in amplitude compared to the RH ($M = -0.11$, SE = 0.06). A significant main effect for paragraph type was not found ($F(1, 51) = 2.38$, p = n.s.). As shown in Figure 2 a significant two-way Hemisphere X Main Idea interaction was found ($F(1, 51) = 6.31$, $p < 0.015$, $\eta\rho^2 = 0.11$). For the paragraphs with MI first, a significant difference was found between hemispheres ($p < 0.001$) whereby the LH ($M = 0.22$, SE = 0.07) had a greater positive amplitude (reduced N400) than the RH ($M = -0.10$, SE = 0.07). For paragraphs with MI last, a significant difference ($p < 0.001$) between hemispheres was found, whereby the LH ($M = 0.10$, SE = 0.07) had a positive amplitude compared to the RH ($M = -0.12$, SE = 0.06). In the LH, a significant difference was found between the paragraphs with MI first ($M = 0.22$, SE =0.07) and the MI last ($M = 0.10$, SE = 0.07, $p = 0.032$). There were no differences for the RH.

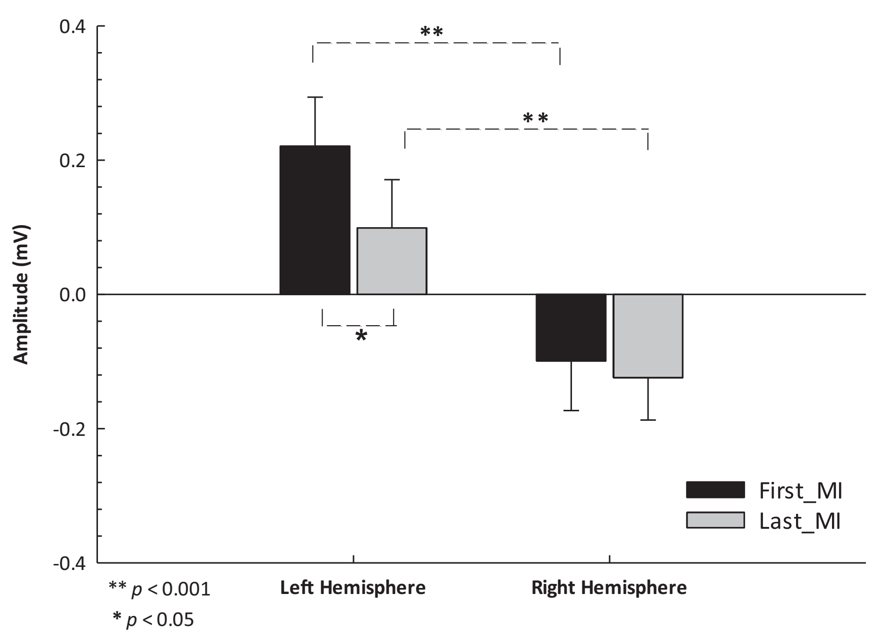

Figure 2. Average N400 amplitude, showing the Hemisphere x Main idea interaction. Significance indicated by *.

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3.3. Combined Monolingual L1 and Bilingual L2 readers when the main idea is presented first

The ANOVA revealed a significant main effect of Hemisphere (F (1, 50) = 24.22, p < 0.001, $\eta\rho^2$ = 0.33), with the LH (M = 0.16, SE = 0.07) more positive in amplitude (reduced N400) compared to the RH (M = −0.12, SE = 0.06). There was no main effect of Group, Sentence Type or Position.

The Hemisphere by Position interaction (F (1, 50) = 6.11, p = 0.017, $\eta\rho^2$ = 0.11) and the Position by Type interaction (F (1, 50) = 4.17, p = 0.046, $\eta\rho^2$ = 0.08) were significant. The Hemisphere by Position by Type interaction was also significant (F (1, 50) = 4.28, p = 0.044, $\eta\rho^2$ = 0.08).

As shown in Figure 3, simple effects tests showed numerous significant P400 amplitude differences: (1) between the LH (M = 0.29, SE = 0.07) and the RH (M = −0.07, SE = 0.08) in the first Position for the main idea Sentence type; (2) between the LH (M = 0.15, SE = 0.09) and the RH (M = −0.14, SE = 0.08) in the first Position for the supporting Sentence Type; (3) between the LH (M = 0.04, SE = 0.09) and the RH (M = −0.15, SE = 0.08) in the last Position for the main idea Sentence type; (4) between the LH (M = 0.16, SE =0.06) and the RH (M = −0.10, SE = 0.06) in the last Position for the supporting Sentence Type; (5) between the first Position (M = 0.29, SE = 0.07) and the last Position (M = 0.04, SE = 0.09) for the main idea Sentence Type in the LH; (6) between the main idea sentence Type (M = 0.29, SE = 0.07) and the supporting sentence Type (M = 0.15, SE = 0.09) for the first Position in the LH.

3.4. Typical readers and readers with dyslexia where the main idea is presented first

The ANOVA revealed a significant main effect for Hemisphere (F (1, 50) = 24.18), p < .001, $\eta\rho^2$ = .33), with the overall amplitude being more negative over the RH (M = −0.17, SE = 0.07) than the overall amplitude of the LH (M = 0.14, SE = 0.07). No other main effects were significant.

Significant Hemisphere by Position (F (1, 50) = 7.91, p = .007, $\eta\rho^2$ = 0.14) and Position by Type (F (1, 50) = 6.60, p = .013, $\eta\rho^2$ = 0.12) interactions were found. A significant Group by Position by Type interaction was also found (F (1, 50) = 4.02, p = 0.050, $\eta\rho^2$ = 0.07). As shown in Figure 4 a significant Group difference was only found between the Typical group (M = 0.14, SE = 0.10) and the group with Dyslexia (M = −0.23, SE = 0.12) for the supporting sentence type when it was in the first position (p = 0.021). A Position difference was found for the main idea sentence type for the group with Dyslexia (p = 0.050). The main idea sentence was negative in amplitude when it was in the Last Position (M = −0.20, SE = 0.13), whereas it was positive in amplitude when presented in the First Position (M = 0.06, SE = 0.11). A difference was found between the main idea sentence type (M = 0.06, SE = 0.10) and the supporting sentence type (M = −0.23, SE = 0.12) when the main idea was positioned first for the group with Dyslexia (p = 0.004).

A significant three-way interaction of Hemisphere by Position by Type was found (F (1, 50) = 4.13, p = 0.047, $\eta\rho^2$ = 0.08). As shown in Figure 5 a significant difference was found between the LH (M = 0.30, SE =0.08) and the RH (M = −0.09, SE = 0.080) in the first position for the main idea sentence type (p < .001). A difference was also found between the LH (M = 0.11, SE =0.09) and the RH (M = −0.19, SE = 0.09) in the first position for the supporting sentences Type (p < .001). A difference was found between the LH (M = 0.02, SE =0.08) and RH (M = −0.18, SE = 0.08) for the Last Position for the main idea sentence type (p = .004). A significant Position difference was shown for the main idea sentence type in the LH (p = 0.004). The First position (M = 0.29, SE = 0.08) had a greater positive amplitude compared to the Last Position (M = 0.02, SE = 0.09) main idea sentence.

Simple effects tests also revealed a significant type difference between the main idea (M = 0.29, SE = 0.08) and the supporting sentence (M = 0.11, SE = 0.09) type for the first position in the LH (p = .005).

4. Discussion

The aim of the present study was to examine N400 amplitude, in both the right and left cerebral hemispheres, during tasks involving language comprehension, working memory and main idea

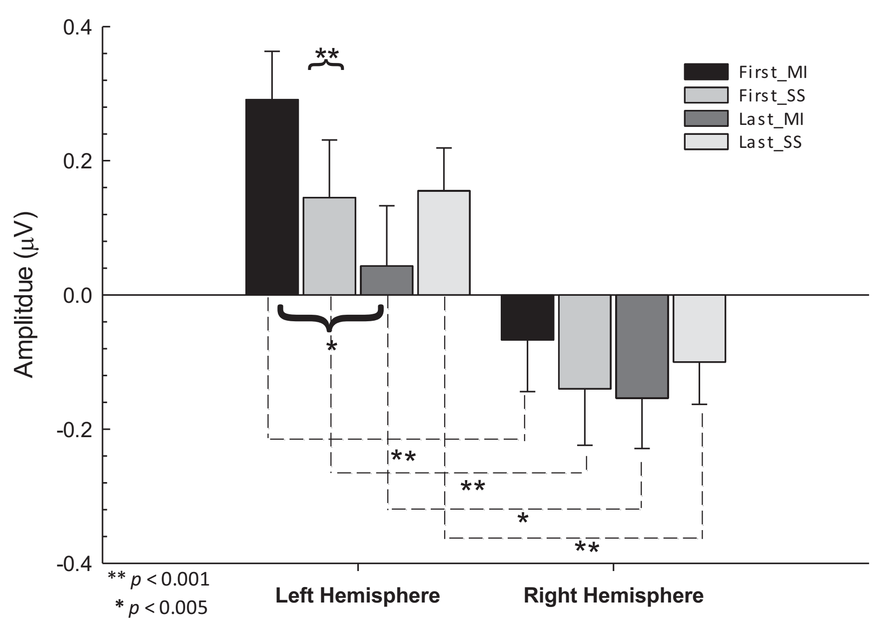

Figure 3. Average N400 amplitude, showing the Hemisphere by Position by Type interaction. Significance indicated by *.

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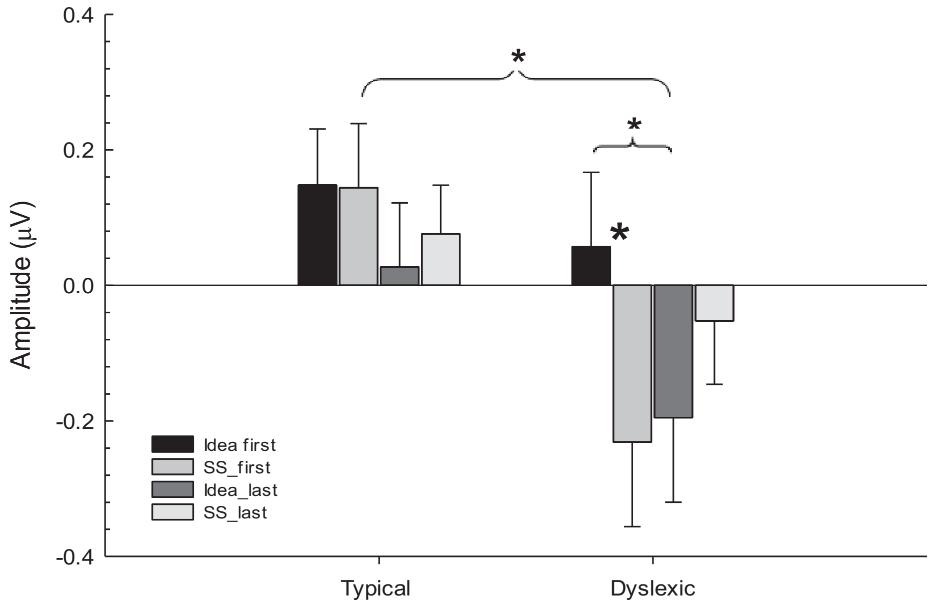

Figure 4. Average N400 amplitude, showing the Group by Position by Type interaction. Significance indicated by *.

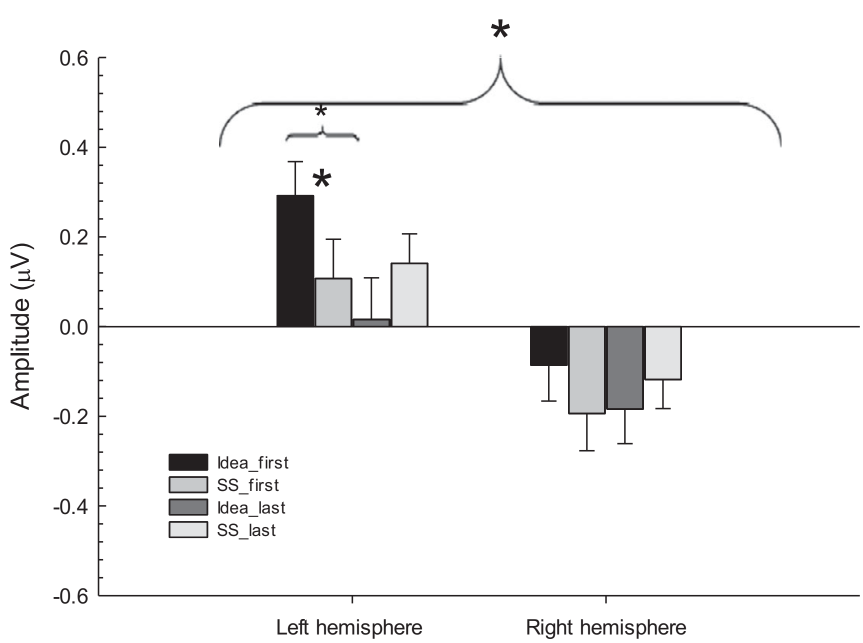

Figure 5. Average N400 amplitude, showing the Hemisphere by Position by Type interaction. Significance indicated by *.

identification in monolingual adults and bilingual typical readers and those with dyslexia. We expected greater N400 amplitude when the main idea of the paragraph was displayed in the last position relative to when it appeared in the first position, as this is a more cognitively demanding reading situation (Tomitch et al., 2008). We sought to determine if the right hemisphere plays a stronger role than the left in a task such as the OSPAN, and when the main idea is presented last in the paragraph, due to the high comprehension demands of the tasks. We also assessed whether there is a cognitive advantage to being bilingual (Bialystok, 2011; Olulade et al., 2015).

Overall, our preliminary findings showed no significant associations between working memory capacity and N400 amplitudes across the four groups (TM, TB, MD, BD). Preliminary analyses also revealed that the right hemisphere was less positive in amplitude (i.e., greater N400) compared to the left hemisphere overall, and main idea identification generally involved bilateral cerebral processing. Importantly, group N400 amplitude differences were found in the expected direction between typical readers and adults with dyslexia under two conditions: when the supporting sentence was in first position in the paragraph and when the main idea was in the last position (both more cognitively demanding). This means that individuals with dyslexia, irrespective of being monolinguals or bilinguals, are more affected by semantic violations resulting from the position of the main idea in the text than typical ones.

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4.1. Main idea identification and working memory

Regarding the relations between working memory and N400 amplitude in main idea identification, our analyses revealed no significant correlations between OSPAN scores and the amplitudes for the MI conditions (first or last) across the four groups (TM, TB, MD, BD). These findings remained consistent when we combined the groups into typical readers and those with dyslexia. We expected to see differences at least between the performance of typical monolinguals (who had higher OSPAN scores) and monolinguals with dyslexia (who had lower OSPAN scores), but this was not the case.

Our results indicate that the working memory load in the two conditions (MI first and MI last) did not exceed the resource supply at hand (Just & Carpenter, 1992) for both typical participants and those with dyslexia (monolingual or bilingual), and even when the two first presented sentences were ambiguous and they had to wait for the topic to come as the MI in the last sentence of the paragraph. According to Just and Carpenter (1992), differences in the performance of college students of differing WMC are best seen when the task at hand is difficult, which does not seem to have been the case for our participants. As noted earlier, in a recent study by de Azevedo et al. (2022), differences between high and low spans were only seen in a reading task which demanded inferential comprehension but not in a task involving only literal comprehension of the text, findings which are supported by Alptekin and Erçetin (2010). Furthermore, in a review of neuroimaging studies, Abutalebi (2008) shows that the involvement of brain areas linked to executive functions lessens as proficiency in the L2 gets higher, which we believe to be a possible explanation for the lack of results related to WMC in our study. The fact that the amplitudes for the Main Idea conditions (first and last) did not correlate with each other significantly for bilinguals with dyslexia, whereas significant correlations were found for the other groups (TM; TB; MD), show that BD's neural activity diverged from the other groups, possibly being affected by their dyslexia condition, since they were all very proficient in the L2-English.

4.2. Cerebral laterality and main idea identification

As to the involvement of the right hemisphere (RH) in main idea identification, our results bring evidence of its participation in specific situations and confirm the participation of the left hemisphere (LH) during language processing. Overall, the RH showed increased amplitude compared to the LH for the N400 component, corroborating previous studies in relation to the RH being more prone to detect language violations (Kutas & Federmeier, 2011; Lau et al., 2008), which in the present study involves the extremely vague MI last paragraphs. Furthermore, the paragraphs with MI first yielded higher positive amplitude (reduced N400) than those with MI last in the LH: no such difference was found between MI first and MI last for the RH, where the amplitude was negative in the two conditions. A larger N400 for MI last may be an indication that more work was going on in the LH than in the RH in trying to integrate the ambiguous supporting sentences until the MI came as the last sentence in the paragraph. The reduced N400 for the MI first in the LH, on the other hand, points to a possible ease of integration processes connecting supporting sentences into the foundation that was laid by the MI presented first in the paragraph (Gernsbacher, 1997).

These findings are consistent with earlier studies, where upcoming words supported by the context of the sentence induce more reduced N400s than unexpected or incongruent words (Calloway & Perfetti, 2017; Kutas & Federmeier, 2011; Lau et al., 2008). On the other hand, when the MI was presented last, the LH was more involved than the RH. In line with Tomitch et al. (2008) the fact that there was no difference in the N400 amplitudes between MI first and MI last in the RH indicates that it was able to recognize the main idea, irrespective of its presentation being first or last in the paragraph.

4.3. Bilingualism, cognitive advantage and main idea identification

Concerning the neural activity of L1 (monolingual) and L2 (bilingual) readers, both typical and with dyslexia, during the reading of paragraphs where the main idea is presented first as opposed to last position in the paragraph, our results showed no significant main effect of group, with monolinguals and bilinguals presenting similar amplitudes for the N400 component overall. Our findings do not support the bilingual advantage theory, which advocates for a possible enhancement of the executive control system in bilinguals because of having to constantly deal with two language systems (Bialystok, 2011). In fact, research shows that the bilingual advantage issue has not been resolved yet. In a systematic review of 46 original studies, Van den Noort et al. (2019) found that although 54.3% (the majority) supported the theory, among the remaining studies, 28.3% exhibited mixed results and 17.4% did not support the theory at all. Inconsistent results were also found in another systematic review by Giovannoli et al. (2020).

In relation to the results for typical versus participants with dyslexia, a significant group difference was only found between the typical readers and those with Dyslexia, particularly in the RH, for the supporting sentence type, when it was in first position in the paragraph. This confirms our expectations since this condition was vague and ambiguous and expectedly more demanding for participants with dyslexia. Similarly, a position difference was found for the main idea sentence type for the group with dyslexia, which showed increased amplitude, particularly in the RH, when it was in the last position, but decreased amplitude when presented in the first position. These results were also expected, since having the main idea last in the paragraph is more cognitively demanding (paragraph understanding is often delayed until its presentation, after two ambiguous and vague supporting sentences). Importantly, our findings show that only those with dyslexia were affected by this condition. The fact that participants with dyslexia showed greater N400 amplitude than typical readers, particularly in the right hemisphere, when the main idea was in the last position in the paragraph, and when the supporting sentence type was in first position, finds support in our earlier research on hemispheric specialization for reading in dyslexia. In our earlier work, we have found a right hemisphere advantage for processing written words in English in EEG (Waldie et al., 2012) and fMRI (Waldie et al., 2012, 2017) studies. Since generally the right hemisphere is a simultaneous processor of stimuli (and is not therefore specialized for language), we explain any group differences in cerebral laterality as a compensatory system (due to faulty left hemisphere processing). We understand that, due to our small sample, especially of bilinguals, our results should be interpreted with caution. However, we would like to suggest that the best explanation for the mechanism underlying group differences between the dyslexia and non-dyslexia groups is based on compensatory activity of the right hemisphere during reading tasks, including the present task of finding the main idea in text. As the right hemisphere is not specialized for sequential stimuli processing, some of the reading deficits seen by the adults with dyslexia in our sample are likely due to this.

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In relation to the behavioral reaction time data, the monolingual group (including both typical readers and those with dyslexia) had faster reaction times overall compared to the bilingual group when responding true or false for the main idea sentences. This may indicate greater processing demands for the bilingual group in comparison to monolinguals, irrespective of having dyslexia or not. These results support other studies in the literature (Andreou et al., 2021; Tomitch et al., 2023) but do not support the idea that bilingual individuals have a processing advantage over monolinguals.

4.4. Limitations of the study

The results from the present study should be interpreted with caution due to several limitations. First, our sample size was small, especially in relation to the bilinguals with dyslexia. For this reason, comparing the data groups Typical Bilinguals ($N = 15$) to Bilinguals with Dyslexia ($N = 6$) was not feasible due to the sample size concerns. Even if we added the Monolinguals with Dyslexia group to the Bilingual group, we would not be able to address this or properly investigate this factor. Given the fact that sample sizes of each group were uneven, we decided to look at combined data to prevent conflation of the p-value score. By combining groups Monolinguals compared to Bilinguals, and Typical compared to those with Dyslexia participants overall, we were still attempting to investigate whether the main ideas paradigm could be looked at from a bilingual advantage perspective. This line of investigation is a starting point and future research should look to address these issues. Second, we suspect that a relatively high SES might have played a role in our results. We advertised the call for participants in and around the university campus, in a local newspaper and in social media. However, the fact that most of our recruited participants were from in and around the university campus means that they most likely came from privileged backgrounds, thus preventing us from seeing differences between groups. Research has shown that high SES, measured by family income, occupation and education level, leads to learners' better academic achievement (Chen et al., 2018). High SES generally relates to more support, opportunities and resources from families to learners. In a previous study (Tomitch et al., 2023), we found that participants with dyslexia worked harder than neurotypical participants, using various coping strategies to obtain academic success.

5. Conclusions

The present study showed no significant correlations between working memory capacity, as measured by the OSPAN, and N400 amplitudes across the four groups, indicating that the two conditions (Main Idea first or last) did not exceed the available cognitive resources for any of the four groups. Our preliminary analyses also revealed greater N400 amplitude for the right hemisphere, corroborating previous findings that the RH is more prone to detect language violations than the LH. Also meaningful is our finding that the RH appears to recognize the main idea, irrespective of its position in the paragraph.

Importantly, participants with dyslexia showed greater N400 amplitude than typical ones when the supporting sentence was in first position in the paragraph and when the main idea was in the last position (both more cognitively demanding). For bilinguals with dyslexia, the pattern of EEG activity for the Main Idea conditions (first and last) diverged from the other groups, suggesting that although they were all very proficient in the L2-English, their dyslexia condition might have influenced processing. Since both hemispheres are involved in processing difficult language concepts, requiring both sequential and simultaneous information, this processing would have been more effortful and compensatory systems would likely be needed (Waldie et al., 2013). Larger sample sizes will be needed in future work to corroborate our findings.

Data availability statement. The data that support the findings of this study are promptly available upon request to the first author at ledatomitch@gmail.com.

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Competing interests. The authors declare none.

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A. Appendix

A.1. Sample paragraph

Main idea first.

Languages depend on their environment to survive, and survival is defined by economic might, military muscle and cultural prestige.

When they die out, it is for reasons analogous to those that cause the extinction of plant and animal species.

They are consumed by predators, deprived of their natural habitats or displaced by more successful competitors.

Main idea last.

When they die out, it is for reasons analogous to those that cause the extinction of plant and animal species.

They are consumed by predators, deprived of their natural habitats or displaced by more successful competitors.

Languages depend on their environment to survive, and survival is defined by economic might, military muscle and cultural prestige.

The survival of a language, just like that of an animal or a plant, depends on its environment. True (Press 1) or false (Press 2)?