Sublexical speech perception and attention networks in bilingual adults who stutter: a behavioral and electrophysiological study.

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Abstract

Purpose – Several studies show that adults who stutter have deficient auditory perception and attentional control. Moreover, these studies tend to focus on monolinguals, whereas both stuttering and bilingualism seem to have implications for these processes. This study aimed (1) to compare sublexical speech perception and nonlinguistic, nonauditory attention networks between bilingual adults who stutter (BAWS) and who do not stutter (BANS) and (2) to explore to which extent second language (L2) proficiency influences these processes.

Method – Thirteen BAWS and thirteen BANS were enrolled in an electrophysiological protocol using an inattentive (MMN) and an attentive auditory oddball paradigm (P300) containing a phonemic contrast (place of articulation). The Attention Network Test (ANT) was administered as a behavioral measure of attentional control.

Results – (1) The amplitude and onset latency of the MMN and P300 effect did not differ between BAWS and BANS, but BAWS did not show a typical differentiation between standard and deviant syllables as measured by the P2. Behaviorally, BAWS displayed a less efficient alerting network and executive attention network. (2) L2 proficiency had no significant effect on sublexical speech perception, but was negatively associated with executive attention in BAWS.

Conclusions – These results suggest that BAWS display difficulties in maintaining an alert state and inhibiting irrelevant and selecting relevant information, rather than selecting information from sensory input. In sensory processing, BAWS showed an atypical pattern compared to BANS, but no disparities in phoneme discrimination, or categorization, regardless of an inattentive or attentive listening mode. Lastly, L2 proficiency influenced nonlinguistic, nonauditory attention in BAWS, emphasizing the need for more comprehensive research on bilingual profiles in people who stutter.

Key Words

Speech perception – attention networks – bilingualism – Mismatch Negativity (MMN) – P300

1. Introduction

Developmental stuttering is a complex and multifactorial condition, with its underlying mechanisms remaining still not fully understood. Current models of stuttering generally propose that multiple factors contribute to its development and persistence, including linguistic, motor, emotional, cognitive, and sensory processes (see Bloodstein et al., 2021). This study focuses on two of these factors, auditory speech perception and attention, which have been shown to differ in adults who stutter (AWS) compared to nonstuttering adults (ANS) (auditory perception: e.g., Beal et al., 2010; Chang et al., 2008; Chang et al., 2009; Foundas et al., 2001; Halag-Milo et al., 2016; Kikuchi et al., 2011; Kikuchi et al., 2017) (attention: e.g., Bosshardt, 2002; Doneva, 2020; Eichorn et al., 2016; Eichorn et al., 2019; Vasiç & Wijnen, 2005). However, while most of these studies have focused on monolingual individuals, research suggests that bilinguals allocate their attentional resources more efficiently (Bialystok, 2025). This enhanced efficiency not only affects nonauditory processing (Adesope et al., 2010; Antoniou, 2019; Bialystok, 2010) but also fine-tunes auditory processing (Dastgerdi et al., 2023; Giroud et al., 2020; Krizman et al., 2012; Krizman et al., 2014; Kumar et al., 2020; Spinu et al., 2023). Notably, the effects of bilingualism are thought to be most pronounced when the attention system is under strain (Bialystok & Craik, 2022), which may be particularly relevant for individuals who stutter. To address this knowledge gap, the current study investigates auditory speech perception and attention in bilingual adults who stutter (BAWS), using behavioral and electrophysiological measures to examine both nonauditory, nonlinguistic attention networks and pre-attentive and attention-driven auditory processing. These key concepts and their interrelations are further elaborated in the following sections.

1.1 The interplay of auditory and attentional mechanisms in stuttering

Auditory speech perception is not a purely sensory process, but it also relies heavily on higher-order cognitive processes, such as attention, which influences how auditory information is processed through all stages of auditory processing. Attention allows individuals to achieve and maintain a state of readiness to respond to environmental stimuli (alerting or sustained attention), select information from auditory input (orienting or selective attention), and focus on relevant input while inhibiting irrelevant and competing stimuli (executive attention) (Posner & Petersen, 1990). Auditory and attentional processes are not only essential for general speech perception, but also for speech development, by supporting the formation of stable internal models for speech sounds. These models enable the translation between motor commands and their sensory consequences. Inverse internal models, used by the feedforward system, convert the expected sensory outcomes into motor commands needed to achieve them. Forward internal models, used by the feedback system, convert motor commands into predicted sensory consequences and compare them to incoming feedback (Hickok et al., 2011). During speech development, these models are refined through auditory-motor integration. The auditory system plays a crucial role in this refinement through processing external speech, monitoring self-produced speech, and interacting with the motor cortex (Civier et al., 2010; Tourville & Guenther, 2011). Attention further enhances this refinement by optimizing the encoding of rapidly presented auditory cues and selecting relevant speech cues from complex auditory input (Conboy et al., 2008).

In people who stutter, however, the internal models for speech sounds may be unstable or insufficiently activated due to errors in acquiring and updating sensory-motor mappings, possibly arising from deficiencies in auditory processing and/or attention (Max et al., 2004). Unstable inverse models may then generate inaccurate feedforward commands, increasing reliance on feedback-based corrections. Disrupted forward models may produce faulty sensory predictions, potentially triggering erroneous error signals. This leads to both increased production errors and impaired error correction, reducing speech stability and limiting effective feedforward motor control (Bradshaw et al., 2021; Chang & Guenther, 2019; Max & Daliri, 2019; Max et al., 2004).

Indeed, growing evidence suggests that AWS experience deficiencies in both auditory and attention processing. Regarding audition, behavioral and neuroimaging studies reveal structural anomalies in auditory-motor regions (Beal et al., 2007; Chang et al., 2008; Foundas et al., 2001), altered brain activation during speech perception (Chang et al., 2009; Halag-Milo et al., 2016; Kikuchi et al., 2017), and deficiencies in accessing phoneme representations (Bakhtiar et al., 2021; Neef et al., 2012; Phillips & Myers, 2024; Shao et al., 2022). For nonauditory attention, AWS show reduced performance in tasks requiring selective attention and inhibitory control (Aydoğuş & Tunçer, 2025; Doneva et al., 2018; Hennessey et al., 2014). Moreover, dual-task or divided attention paradigms often reveal greater performance costs for AWS compared to ANS (Bosshardt, 2002; Eichorn et al., 2016; Eichorn et al., 2019; Vasiç & Wijnen, 2005) (for a meta-analysis, see Doneva, 2020). Evidence on auditory attention is more limited but points in a similar direction. For instance, Poormohammad et al. (2023) reported lower auditory focused attention in AWS, as indexed by slower response times to auditory targets in the Integrated Visual and Auditory Continuous Performance Test. However, because auditory and attentional processes are closely intertwined, it remains unclear whether the deficits observed in AWS primarily reflect domain-specific auditory deficits, attentional difficulties, or their interaction. As a result, attentional deficits may be misinterpreted as central auditory processing deficits, and vice versa (Price & Moncrieff, 2021).

1.2 The role of attention in bilingualism

Attention has been explored as a factor influencing sensory processing, not only in AWS but also in bilinguals, who regularly use at least two languages in their daily lives (Grosjean, 2010). Bilingualism is frequently associated with cognitive advantages in both verbal and nonverbal tasks involving cognitive flexibility, working memory, inhibition, and selective attention (Adesope et al., 2010; Antoniou, 2019; Bialystok, 2010). This so-called bilingual advantage is thought to arise from the continuous need to manage and switch between languages, suppress interference from the nontarget language, and adapt to varying linguistic contexts (van den Noort et al., 2019). However, the extent and consistency of this advantage remain debated, with some studies challenging bilingual effects on executive control tasks (Paap & Greenberg, 2013; Van der Linden et al., 2018). Addressing these inconsistencies, Bialystok and colleagues argued that the cognitive effects of bilingualism do not arise from a direct transfer of inhibition control between linguistic and nonlinguistic domains, but from the adaptation of attention networks to the bilingual environment. In this environment, continuous language management strengthens and enhances the flexibility of attention selection mechanisms. Unlike transfer, where learned skills generalize to nonpracticed domains, adaption refines selection mechanisms, enhancing efficiency across linguistic and cognitive tasks, rather than increasing overall attentional resources. Consequently, bilingualism would optimize attentional resource allocation based on the task demands and individual control abilities (Bialystok, 2024, 2025; Bialystok & Craik, 2022). This view is supported by neuroimaging studies showing that bilinguals exhibit reduced neural activation compared to monolinguals when performing executive tasks, suggesting they require fewer attentional resources to achieve similar behavioral outcomes. Additionally, behavioral research has shown that bilinguals tend to outperform monolinguals on tasks that place higher demands on attentional control (Abutalebi et al., 2012; Bialystok & Craik, 2022; Comishen & Bialystok, 2021; Gold et al., 2013).

This enhanced efficiency in attentional control may explain why bilingualism is also associated with auditory processing advantages. Research suggests that bilinguals outperform monolinguals in nonlinguistic auditory tasks, such as temporal and spectral processing (Kumar et al., 2020), tone detection in noise (Krizman et al., 2012), and auditory sensory memory

(Spinu et al., 2023). Additionally, higher second language proficiency is associated with improved dichotic and temporal pattern processing (Dastgerdi et al., 2023; Giroud et al., 2020). In the linguistic domain, bilinguals exhibit more precise neural encoding of speech sounds, particularly in noisy environments, suggesting heightened early sensory processing and greater stability in brainstem and cortical responses to speech sounds. Furthermore, these auditory processing advantages are positively correlated with attentional control and language proficiency, reinforcing the idea that bilingualism strengthens both sensory and cognitive mechanisms (Krizman et al., 2012; Krizman et al., 2014).

1.3 The interplay between attention, bilingualism, and stuttering

The interplay between bilingualism, attention, and auditory processing is particularly relevant for AWS, as it may influence how these individuals allocate attentional resources across nonlinguistic and linguistic domains. However, the cognitive effects of bilingualism in AWS remain a relatively underexplored area. While there is limited research directly examining this relationship, insights can be drawn from separate findings on bilingual individuals who do not stutter (BANS) and monolingual people who stutter (MAWS). As outlined in Section 1.1, MAWS typically show less efficient auditory speech perception and attention processing compared to monolingual people who do not stutter. In contrast, the adaptation hypothesis (Bialystok, 2024, 2025) suggests that in BANS, frequent engagement of the selective attention system through bilingual language experience would enhance its efficiency over time. Consequently, if BAWS have underlying attentional difficulties, the cognitive demands of bilingualism could either support the development of compensatory attention mechanisms or impose additional strain on the system.

To our knowledge, no published studies investigated auditory (attention) processing in BAWS. For nonlinguistic, nonauditory attention, one recent study examined attention networks in BAWS (Aslan et al., 2024). The authors found no significant differences between BAWS and BANS across alerting, orienting, and executive attention networks as measured by the Attention Network Test. The authors suggested that bilingualism may mitigate attentional difficulties typically associated with stuttering. However, since the groups were not matched on factors such as education level, the findings may reflect broader group differences (Gómez-Pérez & Ostrosky-Solís, 2006). Further support for a potential compensatory effect of bilingualism comes from two studies by Kornisch et al. (2017a, 2017b), which focused on executive functioning in BAWS. In a selective identification task (Kornisch et al., 2017b), bilingual participants, regardless of stuttering, showed faster reaction times and fewer errors than monolinguals, while no differences emerged between BAWS and BANS. Similarly, in a dual-task paradigm (Kornisch et al., 2017a), BAWS and BANS again performed comparably, and both groups outperformed MAWS, further supporting the hypothesis that bilingualism may offset deficits in executive functioning typically seen in stuttering (Doneva, 2020).

1.4 The added value of event-related potentials

Although behavioral and neuroimaging studies have provided valuable insights into auditory perception, they may lack the sensitivity to detect whether atypical processing in (B)AWS during speech perception arises from sensory and/or cognitive differences (Kaganovich et al., 2010; Moein et al., 2022). In contrast, neurophysiological investigation such as the event-related potential (ERP) technique allows insight into the neural processing of a well-defined stimulus in the order of milliseconds. Consequently, it provides excellent temporal resolution across the different processing stages, going from early sensory to higher-level cognitive processing (Luck, 2014). In particular, the Mismatch Negativity (MMN; Näätänen et al., 1978) and the P300 (Sutton et al., 1965) have been studied concerning pure-tone and speech sound discrimination (Näätänen et al., 2012) ánd categorization (Kok, 2001), respectively. A commonly used task for eliciting the MMN and P300 components is an auditory oddball paradigm, which involves the random presentation of frequent standard stimuli and infrequent deviant stimuli. The MMN is typically generated independently of voluntary attentional allocation to stimuli, while the generation of the P300 component requires active attention to the stimuli. Because of the difference in attentional resources required to elicit the MMN and P300 (i.e., involuntary versus active attentional engagement), both are of particular interest in research investigating auditory speech perception in BAWS. By comparing active and passive tasks with the same stimuli, it is possible to investigate both categorical processing in the auditory system arising from automatic, pre-attentive grouping mechanisms compared to active attentional engagement (Bidelman & Walker, 2017).

The MMN (Näätänen et al., 1978) is a pre-attentive negative deflection between 160 and 220 ms after stimulus presentation, which can be elicited in the auditory modality. This component has a fronto-central midline scalp maximum when a deviant stimulus is presented in a sequence of repetitive stimuli. The MMN is associated with inattentive and preconscious deviance detection and discrimination (Näätänen et al., 2007). One ERP study investigating the MMN with speech sounds has revealed that AWS show atypical auditory processing in response to vowel changes (AWS; Corbera et al., 2005). Corbera et al. (2005) revealed enhanced left mastoidal MMN amplitudes in response to phonemic contrasts in AWS, which suggests atypical speech sound representations within the region of the left auditory cortex. Additionally, this study revealed that the enhanced MMN amplitude correlated positively with self-reported speech fluency.

The P300 (i.e., P3b Sutton et al., 1965) is a positive deflection of the cortical response to a deviant stimulus in a classical attentive oddball paradigm. This deflection has its onset approximately 300 ms post-stimulus with a parietal scalp maximum (Polich, 2007). This component has been thought to reflect working memory, context updating, stimulus classification and categorization, as well as attentional resource allocation (Linden, 2005; Polich, 2007). P300 research has shown auditory categorization and attention allocation in response to tonal stimuli (Hampton & Weber-Fox, 2008; Moein et al., 2022; Morgan et al., 1997; Sassi et al., 2011) to be atypical in terms of amplitude, latency, and scalp distribution in AWS compared to ANS. However, studies investigating the P300 in response to linguistic stimuli are scarce. Valentine (2019) found no group differences for the perception of a place of articulation and voice onset time (VOT) contrast but observed no leftward laterality of the P300 amplitude in AWS, which was present in ANS.

The P300 reflects cognitive processes in auditory stimulus categorization. Preceding this component, the P1-N1-P2 complex represents early auditory sensory processing (Alain & Tremblay, 2007). This complex, elicited by both standard and deviant sounds, consists of overlapping components - P1, N1, and P2 - peaking at approximately 50 ms, 100 ms, and 180 ms after stimulus onset (Han, 2010). In phoneme perception, these components are linked to phoneme detection and decoding of spectrotemporal features (Martin et al., 2014). Research on the P1-N1-P2 components using listening tasks in AWS is scarce. Using tone bursts, Prestes et al. (2017) found longer latencies of the N1 in AWS, suggesting slower auditory processing, though no group differences in the N1-P2 measures emerged. Similarly, Hampton and Weber-Fox (2008) reported no group differences in the N1 and P2 during tonal oddball tasks. In contrast, Liotti et al. (2010) observed a reduced N1 amplitude over right inferior temporo-occipital scalp regions in AWS during passive vowel listening, linking this to atypical right hemisphere motor-auditory activation and timing in stuttering.

Although studies examining the impact of bilingualism on MMN and P300 in auditory oddball tasks are limited, especially those not specifically targeting non-native language contrasts, emerging evidence suggests that these components are sensitive to bilingual experience. For example, De Letter et al. (2021) found that MMN and P300 responses were influenced by second language experience in individuals recovering from aphasia. Similarly, tonal oddball paradigms indicate that L2 experience can modulate both MMN and P300 responses (Chung-Fat-Yim et al., 2023). Early sensory components of auditory processing, such as the P1–N1–P2 complex, have also been associated with bilingualism, often exhibiting shorter latencies in bilinguals compared to monolinguals (Hajimohammadi & Heidari, 2025). Although limited, these findings suggest that bilingual experience may enhance both sensory and cognitive aspects of auditory processing.

1.5 Research aims and hypotheses

Given the well-documented effects of bilingualism across domains, it is essential to explore how BAWS allocate attention in both auditory and nonauditory contexts (Kornisch, 2021). Prior findings (Aslan et al., 2024; Kornisch et al., 2017a, 2017b) suggest that bilingualism may support attentional control in AWS, although this relationship is complex and not yet fully understood. In the present study, rather than relying on a binary bilingual-monolingual distinction, which can introduce confounds related to education, socioeconomic status, and cultural background (De Houwer, 2022), our study adopts a continuous approach. This approach examines variability in L2 proficiency within the bilingual groups. This allows us to assess how gradations in one aspect of the bilingual experience relate to attentional and auditory processing, without making broad claims based on categorical group membership.

The present study investigates the perceptual aspects of stuttering in bilingual adults through inattentive and attentive auditory speech perception tasks at the sublexical level. Specifically, it compares BAWS and BANS in terms of the MMN (inattentive listening), P1-N1-P2 (attentive listening), and P300 (attentive listening) components, focusing on mean amplitude and onset latency. Additionally, the attention networks as proposed by Posner and Petersen (1990) (alerting, orienting, and executive attention) are compared between BAWS and BANS. These networks are assessed using the Attention Network Test (ANT; Fan et al., 2002), measuring attention independently of audition and language. The behavioral ANT task has been widely used to assess attentional control in bilinguals (e.g., Aslan et al., 2024; Costa et al., 2008; Tao et al., 2011), due to its nonlinguistic design and ability to isolate distinct attentional subsystems. Further, this study examines whether one aspect of the bilingual profile – second language proficiency (i.e., the degree of skill in speaking, listening, reading, and writing in each language (Werle et al., 2020)) – affects the measured outcomes. The following research questions were formulated:

RQ 1: Do BAWS and BANS differ in sublexical speech perception and does this difference depend on the listening mode (inattentive vs. attentive)?

Hypothesis: We predict no group differences in the inattentive MMN component, as (1) it reflects automatic auditory perception (Näätänen et al., 2012; Näätänen et al., 2007) and (2) Corbera et al. (2005) found no between-group differences in the frontocentral MMN. In contrast, for the attentive listening condition, we expect BAWS and BANS to differ in the P300, since this component is linked to active attentional resource allocation and working memory updating in response to task-relevant changes (Polich, 2007). Following Liotti et al. (2010), being the only study using speech stimuli in individuals who stutter, we also predict between-group differences in the early sensory N1 or P2 components.

RQ 2: Do BAWS and BANS differ in terms of nonlinguistic, nonauditory attention networks?

Hypothesis: We hypothesize that BAWS will show reduced efficiency in executive attention compared to BANS. This prediction is based on prior findings of attentional control differences in individuals who stutter (for a meta-analysis, see Doneva, 2020). While the literature on BAWS is limited, we expect that stuttering-related attentional challenges may persist even in bilinguals, particularly in tasks requiring conflict resolution (i.e., executive attention).

RQ 3: Does second language proficiency influence sublexical speech perception and nonlinguistic attention networks in BANS and BAWS?

Hypothesis: We predict that higher L2 proficiency will be associated with more efficient attentive sublexical speech perception and enhanced performance on attention network tasks, particularly in BAWS. Namely, we expect an interaction between the participant groups and L2 proficiency, such that bilingual proficiency may partially compensate for attentional and auditory processing differences in BAWS, potentially reducing the magnitude of group differences. This is grounded in evidence that bilingual experience can enhance attentional control and auditory discrimination (e.g., Bialystok & Craik, 2022; Costa et al., 2008; Krizman et al., 2014).

2. Method

2.1 Participants

Fourteen BAWS were initially recruited for this study. One participant was excluded due to heavy sweating during the EEG recording, resulting in a final sample of thirteen BAWS included in the analyses. All BAWS were Dutch first language (L1) speakers and this group had a mean age of 26.9 years (*SD* = 7.71; range 19 – 45 years). They were recruited by licensed speech therapists with a special interest in stuttering and followed stuttering therapy at the moment of testing. For each of the thirteen BAWS, a bilingual adult participant who does not stutter (BANS) was matched for gender, age (± 3 years), education level (International Standard Classification of Education; 2011), second language, and hand preference. Handedness (left ≤ -8; right ≥ 8) was defined using the Dutch Handedness Inventory (DHI; Van Strien, 1992). Thirteen BANS were recruited and all were included in the final analyses. The matched individuals had a mean age of 26.5 years (*SD* = 7.52; range 19 – 45 years). None of the BANS reported a history of stuttering nor did they have a stuttering close family member. Both BAWS and BANS reported no pronounced hearing impairment, no history of neurogenic language or speech disorders, apart from stuttering in the BAWS, and no developmental disorders. In addition, all participants had normal or corrected vision and did not suffer from any psychiatric disorders at the time of investigation.

All participants had English (n = 11 BAWS; n = 11 BANS) or French (n = 2 BAWS; n = 2 BANS) as a second language (L2) in addition to their L1 language. L2 proficiency varied within a continuum ranging from moderate to advanced as determined by the LexTALE (Brysbaert, 2013; Lemhöfer & Broersma, 2012). All BAWS and BANS were sequential, unbalanced bilinguals who learned English and/or French in an educational context from the age of 12 and 10, respectively and used their L2 in a professional or recreational context on a weekly basis. The study was approved by the Ethics Committee of (anonymized information) and all participants declared their written informed consent prior to the experiment. **Table 1** presents an overview of the participant demographics.

2.2 Experimental procedure

Data were collected in a single two-hour session, including 30 minutes for head preparation and breaks. First, the anamnesis was administered, which took 10 minutes. Next, the handedness questionnaire (2 minutes), two LexTALE tasks (10 minutes), sublexical perception EEG tasks (15 minutes), and Attention Network Test (15 minutes) were administered in counterbalanced order. The attentive perception task never preceded the inattentive perception task. Speech samples were collected at the end of the session, taking 10 minutes.

2.2.1 Behavioral assessment

Language proficiency – First, to assess self-reported L2 proficiency, participants scored themselves on oral and written production and comprehension on an 11-point Likert scale (0 = no proficiency, 10 = high proficiency). Second, standardized L2 proficiency was assessed using either the English LexTALE (Lemhöfer & Broersma, 2012) or the French LexTALE (Brysbaert, 2013). In this lexical decision task, participants were presented with a sequence of existing words of varying difficulty and pseudowords. For each item, they were instructed to indicate whether the item existed or not in the target language. The English LexTALE consisted of 60 items visually presented in columns: 40 real English words (e.g., hurricane, moonlit) and 20 English-looking pseudowords (e.g., purrage, crumper). The French LexTALE, adapted from the English version, contained 84 items: 56 real French words (e.g., fourmi, crayon) and 28 French-looking pseudowords (e.g., détume, prioche). Both LexTALEs follow the same principles, using a range of high- to low-frequency words and orthographically legal, pronounceable pseudowords. Real words were phonotactically valid and meaningful and pseudowords were constructed by altering existing words or recombining morphemes. The test was not time-limited, but both tests took approximately 5 minutes to complete. LexTALE scores were computed using the formula that accounts for the unequal proportion of words to non-words across the language version: score (%) = ((Number of words correct ÷ total words) * 100 + (Number of pseudowords correct ÷ total pseudowords) * 100) ÷ 2 (Brysbaert, 2013; Lemhöfer & Broersma, 2012).

The English LexTALE scores have been shown to correlate strongly with established language proficiency measures, such as the Quick Placement Test (QPT), particularly in Dutch L1 speakers. Specifically, the English LexTALE demonstrated a Pearson correlation of 0.63 ($p < .01$) with QPT scores, and 0.75 ($p < .001$) with combined translation tasks (L1-to-L2 and L2-to-L1), supporting its validity as a proxy for L2 vocabulary knowledge (Lemhöfer & Broersma, 2012). To our knowledge, no validation studies are currently available for the French version of LexTALE. Brysbaert (2013) reports a high internal reliability (Cronbach's alpha = 0.96) of the French version in his study.

The standardized and self-reported L2 proficiency scores for each matched pair of BAWS and BANS can be found in **Table 2**.

Stuttering severity – Stuttering severity was assessed in BAWS during reading and spontaneous speech production, which were both video recorded (Sony HDR-CX130E). Both speech samples were collected exclusively in Dutch, as the study did not aim to investigate cross-linguistic differences in stuttering characteristics. Participants were instructed to read aloud a Dutch phonetically balanced text containing 183 syllables (The North Wind and the Sun; International Phonetic Association, 1974). To elicit semi-spontaneous speech, participants were asked to respond for one minute to each of eight open-ended questions (Eichorn et al., 2016). The questions were presented in sets of three, allowing participants to choose topics based on their interests. The first of the eight trials was excluded, and the next 450 consecutive syllables were transcribed and analyzed. Using the Stuttering Severity Instrument – Fourth Edition (SSI-4; Riley, 2009), the percentage of stuttered speech (%SS) and stuttering severity were calculated based on the reading task and the spontaneous speaking task. The mean percentage of stuttered syllables was 3.8 (*SD* = 2.39). The mean duration and physical concomitants scale scores were 6.2 (*SD* = 2.76) and 5.5 (*SD* = 3.07), respectively. The stuttered speech of five BAWS was classified as very mild, five as mild, one as moderate, and two as severe. For every stuttering participant, the overt stuttering characteristics can be found in **Table 3.**

Attention networks – The efficiency of three attention networks (alerting, orienting, and executive attention) was examined in BAWS and BANS using the nonlinguistic, nonauditory Attention Network Test (ANT; Fan et al., 2002). During the ANT, a row of five arrows, each of which was directed to the left or right, was visually presented on a laptop screen. Participants were instructed to indicate as quickly and accurately as possible in which direction the middle arrow was pointing with a keyboard press response (left or right). Each trial started with a fixation cross in the center of the screen with a variable duration of 400 to 1600 ms. A visual cue, which could take four forms, was then shown for 100 ms: (1) no cue, (2) a double cue where an asterisk was shown above and below the fixation cross, (3) a central cue, where an asterisk was presented at the position of the fixation cross, and (4) a spatial cue, where an asterisk was shown at the position where the next target stimulus would appear, either above or below the fixation cross. Following another fixation cross lasting 400 ms, the target stimulus, consisting of a middle arrow surrounded by two arrows at each side, was shown. The surrounding arrows (flankers) were positioned in the same (congruent condition) or opposite (incongruent condition) direction of the central arrow or were completely absent (neutral condition). Each cue and condition had a probability of 0.25 and 0.33, respectively. The target was presented for a duration of 1700 ms or until the participant gave a button press response. Finally, another fixation cross appeared with a variable duration time amounting to the difference between the following parameters: 3500 ms – response time – duration of the first fixation cue. As such, each trial had a total duration of 4000 ms. For a visual representation of the ANT procedure, we refer to Fan et al. (2002).

In a total of three experimental blocks comprising 48 trials each, each condition was represented equally in a randomized order. The actual experiment was preceded by a practice block, where feedback was given after every trial. Reaction time (RT) of the correct button presses constituted the outcome measure for the ANT data analysis (Fan et al., 2002; Simonis et al., 2020). The mean RT over the three experimental blocks was calculated for the neutral, congruent, and incongruent conditions separately, in combination with each type of cue (three targets x four cues). As described by Fan et al. (2002), three parameters were computed to assess the efficiency of the attention networks: (1) alerting network = mean $RT_{\text{no cue}}$ – mean $RT_{\text{double cue}}$ (2) orienting network = mean $RT_{\text{central cue}}$ – mean $RT_{\text{spatial cue}}$ (3) executive attention = mean $RT_{\text{incongruent target}}$ – mean $RT_{\text{congruent target}}$. A high score on alerting and orienting was considered to indicate high efficiency in both networks due to the presentation of a cue and a spatial cue, respectively. A high score on executive attention was considered to indicate reduced efficiency due to more interference from the incongruent flanker arrows (Eggers et al., 2012; Fan et al., 2002). Participants were seated at a 60 cm distance from the screen.

2.2.2 Electrophysiological assessment

EEG recording – The EEG was recorded in a dimly lit room at (anonymized information) in the morning or early afternoon. The recording of the EEG data was done using the BrainVision recorder software (BrainVision Recorder, Vers. 1.20.0802, Brain Products GmbH, Gilching, Germany). According to the international 10/20 system, an EEG cap (EasyCap, Brain Products, Germany) with 32 electrodes was placed. Using an electrolyte gel (Abralyt 2000), it was attempted to keep the electrode impedances below 10 kΩ. The online electrode and ground electrode were FCz and AFz, respectively.

Stimuli – Two auditory oddball tasks containing a phonemic contrast, developed and standardized by the BrainComm research group (Aerts et al., 2013), were presented through E-Prime 3.0 (Psychology Software Tools) during EEG recording. More specifically, the paradigms were an inattentive oddball task (MMN), in which attention was directed away from the auditory stimuli, and an attentive oddball task (P300), in which participants directed their attention to the stimuli. All participants were tested by an experienced researcher in their L1 language (Dutch). In both paradigms, the standard /bə/ and deviant stimulus /gə/ (different in terms of articulation place) were randomly presented with probabilities of 0.80

and 0.20, respectively, out of a total of 750 (MMN) and 150 (P300) trials. The stimuli had a duration of 250 ms and were presented binaurally at a level of 70 dB using ER 1 insert earphones (Etymotic Research). The interstimulus interval (ISI) was 500 ms for the MMN task and 2000 ms for the P300 task. In the inattentive MMN task, participants were seated at a 60 cm distance from a laptop screen, asked to watch a cartoon and ignore the auditory stimuli. In the P300 task, subjects were instructed to press a button when they noticed the deviant stimulus /gə/ while looking at the fixation cross in the middle of the screen. A practice block preceded the experimental trials (P300) to ensure that the task instruction was well understood. The overview of the tasks can be found in **Figure 1**.

ERP analysis – Using BrainVision Analyzer 2.1 (BrainVision Analyzer, Version 2.1, Brain Products GmbH, Gilching, Germany), analyses for both paradigms were performed in the same way. First, for seven people in each participant group, a bad electrode channel Oz was eliminated. For the P300 paradigm, the practice block was additionally removed. The EEG data were filtered using a high-pass filter of 0.3 Hz, a low-pass filter of 30 Hz, and a notch filter of 50 Hz. Next, eye blinks, horizontal eye movements, and muscle artifacts were removed using independent component analysis (ICA). After the ICA, the eliminated channels were interpolated and a new reference was applied for further analyses, namely the average of the mastoid electrodes (TP9 and TP10). Subsequently, the responses elicited by the standard stimulus and the deviant stimulus were segmented separately. For the MMN, this was done in a time window of 600 ms (100 ms pre-stimulus onset to 500 ms post-stimulus onset). For the P300, time windows of 1500 ms (300 pre-onset to 1200 ms post-onset) were chosen. Baseline correction was then applied with a prestimulus window of 100 ms and 300 ms for the MMN and P300 paradigms, respectively. Artifact rejection was automatically applied with the following settings: maximum gradient criterion of 75 μV, minimum-maximum amplitude criterion of 100 μV, maximum difference criterion of 150 μV, and low activity criterion of 0.5 μV for 100 ms. Responses to the standard stimulus and deviant stimulus were averaged separately (standard wave and deviant wave). Within each condition (standard and deviant), at least 75% of the original trials had to be included in the mean ERPs to comprise the participant. Due to excessive sweating, one of the original 14 BAWS was excluded based on this criterion. **Table 4** provides an overview of the mean number of included trials for both the MMN and P300 paradigms for BANS and BAWS separately. For the P300 task, both trials with an accurate and inaccurate button press response were included. For each participant group, a grand average difference wave (between the responses to the deviant minus the standard stimuli) was calculated for both the MMN and the P300 effect.

Data extraction – Numerical data extraction was performed on the difference waves for the inattentive MMN and the attentive P300 task. The MMN and P300 time windows were chosen based on (1) the collapsed localizers approach using the scalp distribution of the grand averages across all participants and conditions (Luck & Gaspelin, 2017) and (2) earlier research implementing these paradigms (Aerts et al., 2013; Cocquyt et al., 2021). For the MMN, the average amplitude of six frontocentral electrode positions (F3, Fz, F4, C3, Cz, and C4) was calculated in the time window 100-300 ms. The average of three parietal electrode positions (P3, Pz, and P4) was calculated for the P300 in the time window 300-700 ms. The mean amplitudes of the sensory P1, N1, and P2 were calculated for the standard and deviant waves within component-specific time windows between 60-100 ms (P1), 100-180 ms (N1), and 180-300 ms (P2). For these three components, the average of six frontocentral electrode positions (F3, Fz, F4, C3, Cz, and C4) was used (Aerts et al., 2013; Cocquyt et al., 2022; Giaquinto et al., 2007).

To determine the onset latencies of the ERP components, signed fractional area latencies (Hansen & Hillyard, 1980; Luck, 2014) were determined. The onset latency of the MMN was determined using the 20% fractional area latencies (Newman et al., 2012; Willems et al., 2008) of the frontal (F3, Fz, F4) and central (C3, Cz, C4) electrode positions. For the P300, the 20% fractional area latency was calculated for the parietal electrode positions (P3, Pz, P4) (Aerts et al., 2013; Cocquyt et al., 2021). The onset latency of the sensory components (N1 and P2) was measured as the 50% signed fractional area latency (Kiesel et al., 2008). Latency values were extracted on central (C3, Cz, C4) (N1) or frontal (F3, Fz, F4) (P2) electrodes. For the P1, no positive values could be found in the time window. Due to this large number of missing values, the latencies for the P1 were not calculated.

2.3 Statistical analysis

An overview of the included variables and their relation to each research question can be found in **Table 5**. Statistical analyses were performed in Jamovi, using the GAMLj3 module (version 2.5; the jamovi project, 2024) with a significance level of α = 0.05. Prior to the statistical analyses, extreme outliers ($z > 3.29$) were identified using z-scores, following Field (2013), and were corrected by adjusting the raw values to correspond to a z-score of 3.29. No outliers were corrected for the MMN data, while one outlier was adjusted for two participants per group in the P300 data and three participants per group in the ANT data. For the linear mixed models, the Restricted Maximum Likelihood method was used and in all models, the L2 proficiency scores were mean centered. When significant main or interaction effects were observed, post-hoc comparisons were conducted and corrected for multiple comparisons using the False Discovery Rate (FDR; Benjamini-Hochberg) procedure. Families of comparisons were defined separately for each ERP component and the attention networks: MMN (amplitude, onset latency), P1–N1–P2 (amplitude, onset latency), P300 (amplitude, onset latency), and attention networks (alerting, orienting, executive attention). The number of post-hoc comparisons within each family is reported in the Results. For an overview of the models used for each analyses, we refer to the **Appendix**.

2.3.1 Group differences in inattentive and attentive sublexical speech perception

For the inattentive listening condition, between-group differences in the **MMN** effect (i.e., difference wave) were analyzed using general linear models (LMs), with either *mean amplitude* or *onset latency* as the dependent variable, participant group (BANS vs. BAWS) as fixed factor, and the standardized and self-reported L2 proficiency as covariates, including their interactions with group.

For the attentive listening condition, **P1, N1, and P2** responses to standard and deviant waves were analyzed using LMMs, conducted separately for *mean amplitude* and *onset latency*. Each model included participant group as between-subject fixed factor, stimulus type (standard vs. deviant) as within-subject fixed factor, L2 proficiency scores as covariates with their interactions with group, and participant intercept as random effect. Group differences in either the *mean amplitude* or *onset latency* of the **P300** effect (i.e., difference wave) were analyzed using LMs, with participant group as between-subjects fixed factor, and L2 proficiency scores as covariates including their interactions with group.

2.3.2 Group differences in nonlinguistic nonauditory attention networks

Inaccurate trials were excluded from all attention network analyses. Separate LMs were used to examine between-group differences in each attention network (RT), with either *alerting*, *orienting* or *executive attention* as dependent variable, participant group as fixed factor, and L2 proficiency scores as covariates including their interaction with group.

2.3.3 Influence of second language proficiency on sublexical speech perception and attention networks

For models in Sections 2.3.1 and 2.3.2 where L2 proficiency showed a significant effect on the dependent variable, post-hoc linear regression analyses were conducted to estimate the effect within each group separately (BAWS and BANS), given the observed group differences in LexTALE scores.

3. Results

3.1 Group differences in inattentive and attentive sublexical speech perception

3.2.1 Inattentive sublexical speech perception (MMN effect)

Amplitude & onset latency – The LM analyses did not show differences in the mean amplitude and onset latency of the MMN effect between the participant groups (BAWS vs. BANS), after accounting for the L2 covariates. The statistical results on the MMN are summarized in **Table 6**, and the MMN effect for BAWS and BANS is depicted in **Figure 2**.

3.2.2 Attentive sublexical speech perception (P1-N1-P2 complex and P300 effect)

Amplitude & onset latency – The LMMs and LM revealed no significant differences between BAWS and BANS in the mean amplitude and onset latency of the P1, N1, and P2 standard and deviant waves, and the P300 effect after accounting for L2 proficiency. For both participant groups, P1 and N1 mean amplitudes and onset latencies did not differ between standard and deviant stimuli. However, the P2 component was 1.79 µV (95% *CI* [0.94 – 2.64]; $p_{FDR} < .001$) larger in response to the standard compared to deviant stimuli ($F(1, 24) = 18.94$; $p < .001$). Additionally, this effect was moderated by the participant group, as a significant stimulus type by group interaction was found ($F(1, 24) = 4.80$; $p = .038$). This indicated that the amplitude difference between deviant and standard stimuli was driven by BANS (mean difference: -2.69 µV; $t(24) = -4.627$; $p_{FDR} < .001$), as BAWS did not show this effect. Post-hoc comparisons for significant effects were FDR-corrected across three comparisons *(stimulus type* and *group × stimulus type).* **Tables 7 and 8** provide a summary of the LMs and LMMs on the P1-N1-P2 and the P300 amplitude and latency. **Figure 3** visualizes the P300 effect for both participant groups separately.

3.2 Group differences in the nonlinguistic, nonauditory attention networks

Attention networks – For *alerting*, the LM indicated a significant effect of participant group (F(1, 25) = 3.67; p = .047). The average RT of BAWS was 21.4 ms higher (95% CI [-1.8 – 42.9]; p_{FDR} = .047) than BANS. No between-group differences were observed for *orienting*. For *executive attention*, the LM revealed that the average RT score of BAWS was 30.8 ms higher (95% CI [9.4 – 51.1]; p_{FDR} = .014) compared to BANS (F(1, 25) = 9.11; p = .007), when accounted for standardized and self-reported L2 proficiency. Post-hoc comparisons for significant effects were FDR-corrected across all four contrasts in the attention network family (see Section 3.3). The attention networks for both groups are illustrated in **Figure 4**. **Table 9** summarizes the results of the LMs for the three attention networks. Mean RTs for the attention networks of both groups can be consulted in **Table 10**.

3.3 Influence of second language proficiency on sublexical speech perception and attention networks

The covariates included in the analyses reported in Sections 3.1 and 3.2 did not show a significant main effects of L2 proficiency or interaction effects between L2 proficiency and the participant groups on sublexical speech perception, nor on the alerting or orienting networks. However, the LM for executive attention revealed a significant relationship with the standardized L2 proficiency measure (F(1, 25) = 1.62; p = .037). Post-hoc linear regression confirmed that higher standardized L2 proficiency scores were associated with lower executive network efficiency (i.e., higher RTs) (standardized: F(1, 11) = 9.85; p_{FDR} = .014) in BAWS, but not in BANS. These contrasts were included in the same FDR-corrected attention network family (three comparisons in total: *participant group* in alerting, *participant group* and *standardized L2* in executive attention).

4. Discussion

The present study investigated the influence of second language proficiency on speech perception and attention networks in BAWS and BANS. Additionally, it examined sublexical speech perception differences between BAWS and BANS, and whether these potential differences depend on the listening mode (inattentive vs. attentive). Lastly, the study assessed the representation of nonlinguistic, nonauditory attention networks (alerting, orienting, and executive attention; Posner & Petersen, 1990) in BAWS compared to BANS. To this end, thirteen BAWS and thirteen BANS performed two auditory presented phoneme discrimination and categorization (place of articulation) paradigms, eliciting the MMN, P1-N1-P2, and P300 ERPs. At the behavioral level, the attention networks were assessed using the Attention Network Test.

Results indicated that standardized second language proficiency in BAWS influenced their executive attention network, but did not influence sublexical speech perception or the alerting and orienting networks. Furthermore, BAWS and BANS did not differ in terms of inattentive and attentive sublexical speech perception, as measured by the MMN, P1, N1, and P300. However, BAWS did not show an amplitude differentiation between the deviant and standard P2, in contrast to BANS. Moreover, while both groups showed similar orienting network efficiency, BAWS demonstrated lower efficiency in the alerting and executive attention networks compared to BANS.

4.1 Sublexical speech perception does not differ between BAWS and BANS

Both groups displayed a similar MMN effect over frontocentral electrode positions, suggesting unimpaired efficiency of the sound discrimination accuracy, auditory sensory memory, and mismatch detection in BAWS. This involves both the mismatch detection between (1) the speech sound prediction based on the frequently presented standard stimulus (Garrido et al., 2009) and (2) the language-specific long-term memory traces (Näätänen et al., 2012) on the one hand and the deviant phoneme contrast on the other. This finding aligns with Corbera et al. (2005), who found no group differences in the MMN amplitude and onset latency for vowel contrasts at frontocentral electrode positions.

As for the attentive listening mode, the present findings indicate that BAWS and BANS exhibit similar early sensory encoding of speech sounds (i.e., phoneme detection and decoding spectrotemporal features), as measured by the P1-N1. This contradicts previous studies suggesting early sensory processing deficits in AWS during speech production and planning (Beal et al., 2010; Daliri & Max, 2018; Toyomura et al., 2020), but aligns with studies examining between-group differences in tonal and speech sound perception (Beal et al., 2010; Hampton & Weber-Fox, 2008). However, although no between-group differences emerged in the P1-N1-P2 complex for standard and deviant stimuli, BAWS showed no differentiation between the two stimulus types during later processing, particularly in the P2 response. In contrast, BANS exhibited the typical P2 differentiation, which has also been observed in the young normative data group performing this task (Criel et al., 2023). Given that the P2 is associated with early attentional recruitment, early stimulus evaluation, and predictive processing, the lack of differentiation in BAWS may indicate disruptions in sensory prediction and diminished sensitivity to stimulus change (Brown et al., 2002; Crowley & Colrain, 2004).

In the later stimulus processing time frame, a visual inspection of the P300 suggested reduced neural activation in BAWS compared to BANS. However, both groups revealed statistically similar voluntary attention processing for updating stimulus representations in working memory (Context updating hypothesis; (Luck & Kappenman, 2012; Polich, 2007). This aligns with Valentine (2019), who found no group differences in the P300 amplitude and latency elicited by a PoA contrast. However, the authors reported a reduced leftward asymmetry of this ERP component in BAWS, which was not observed in the current study. The present electrophysiological results contrast with behavioral research suggesting diminished attentive speech discrimination abilities in AWS (Neef et al., 2012; Shao et al., 2022) and the limited evidence from existing P300 studies (Valentine, 2019). Several methodological factors may account for these discrepancies. First, the contrast distance, contrast type, and task used may not have been sensitive enough to identify speech perception deficits in AWS (Shao et al., 2022). The PoA phoneme contrast in the current study contained a larger step distance (natural class-based measure; Frisch, 1996) compared to the voice-onset time (VOT) continua used by (Neef et al., 2012), who found discrimination differences between ANS and AWS. Moreover, this discrepancy may be also attributable to the contrast type rather than the distance. Valentine (2019) found no group differences for PoA perception but noted a lack of leftward P300 amplitude laterality elicited by the VOT contrast in AWS. This suggests that the highly variable and transient acoustic features of VOT (Möttönen et al., 2012) might be more sensitive to subtle auditory processing differences in AWS, supporting the notion that stuttering is a timing disorder, with AWS exhibiting deficits in auditory temporal processing (Beal et al., 2010; Devaraju et al., 2020; Farazi et al., 2023; Howell et al., 2000; Lotfi et al., 2020; Valame & Kekade, 2014). Further, perception measures were obtained in a silent listening task, unlike the backward masking task used by Shao et al. (2022), which disrupts sensory processing of the target stimulus and complicates mapping sensory information to phonological representations (Shao et al., 2022). The authors revealed AWS to show lower auditory performance during backward masking compared to less demanding tasks (Bakhtiar et al., 2021).

4.2 Nonlinguistic, nonauditory executive attention, but not alerting and orienting differs between BAWS and BANS

In addition to sublexical speech perception, between-group differences in nonlinguistic, nonauditory attention networks were examined. Both BAWS and BANS exhibited faster RTs for double cues and spatial cues compared to no cues (i.e., alerting) and central cues (i.e., orienting), respectively. Incongruent flankers increased RTs compared to congruent flankers (i.e., executive attention), consistent with previous studies (Fan et al., 2002; Simonis et al., 2020) confirming the task's validity in both participant groups. No between-group differences emerged in the orienting network, indicating that both groups are equally efficient at selecting information from sensory inputs. This finding aligns with Aslan et al. (2024) who used the ANT to compare the attention networks of 12 BAWS and 12 BANS. In contrast, significant between-group differences were found in the alerting network. BAWS exhibited a smaller RT decrease in response to double cues compared to no cues, suggesting a diminished efficiency in achieving and maintaining a state of readiness. Regarding executive attention, both correct and incorrect responses are activated during incongruent trials, requiring attention-based inhibition of the incorrect response, and slowing responses (Eggers et al., 2012; Fan et al., 2002). This RT increase in response to incongruent trials was larger in BAWS compared to BANS, suggesting difficulties in inhibiting irrelevant and selecting relevant information (Fan et al., 2002; Posner & Petersen, 1990).

The inefficiencies in alerting and executive attention network align with previous findings of differences in alerting and inhibitory control (overlapping with the executive control network) between AWS and ANS (Doneva et al., 2018; Liu et al., 2014), as well as reports of negative correlations between stuttering severity and network efficiency (Haitani & Kumano, 2016). Given the substantial executive control required for speech production (WEAVER++; Levelt et al., 1999; Roelofs, 1997, 2008), these results further underscore the potential association of stuttering with less efficient executive attention and alerting. If AWS experience general deficits in executive attention, they may encounter challenges to efficiently allocate resources across the speech production system, shifting attention resources from one level of production to another (Roelofs & Piai, 2011). Moreover, one model linking attention and stuttering, the Vicious Circle Hypothesis (VCH; Vasić & Wijnen, 2005), proposes that AWS invest a disproportionate amount of attentional resources in speech monitoring, due to a hypervigilant system that detects even minor speech deviations – typically unnoticed by ANS – triggering excessive error-repair attempts that paradoxically disrupt fluency (Lickley et al., 2005; Vasiç & Wijnen, 2005). Hypervigilance is associated with the alerting network (Fan et al., 2005; Posner & Rothbart, 2007), which ensures readiness to detect high-priority signals. However, while VHC suggests hypervigilance in speech monitoring, the current findings indicate that this presumed hypervigilance does not translate into a general heightened alertness to external stimuli regardless of speech. Instead, excessive vigilance toward speech-related errors may divert attentional resources away from general alerting processes, making AWS less able to respond flexibly to external cues, even during non-speech tasks. However, this hypothesis should be examined in future research, investigating whether this imbalance of inefficient general alerting but presumed excessive speech-specific monitoring contributes to overt stuttering characteristics.

Interestingly, the one previous study examining the three attention networks in BAWS (Aslan et al., 2024) found no differences in alerting and executive attention efficiency between BAWS and BANS, as measured by the ANT, which made the authors suggest a bilingual advantage in BAWS. In the study of Aslan et al., the executive attention efficiency of BANS was similar to the present study, but BAWS had lower RTs (M = 95.4 m; SD = 23.65) than in the current study (M = 117.0 ms; SD = 26.31). While both studies had similar demographic characteristics (age, gender, L1 and L2, and L2 proficiency), the differences in RTs could be attributed to other variations in language profiles. Although L2 proficiency was similar between both studies, other language profile aspects might explain these differences. For example, Aslan et al.'s participants were multilingual with high proficiency in a third and fourth language, which might have influenced the multilingual advantage they observed in BAWS. Previous research suggested that the bilingual effect may be more pronounced in the early stages of new language learning (Kieseier, 2021). Consequently, third and fourth languages might exert a stronger impact due to primarily reliance on cortical processing and high-level cognitive control (de Bruin, 2019). This hypothesis is supported by findings that late bilinguals exhibit greater executive attention advantages than early bilinguals (Tao et al., 2011). Moreover, other features of the bilingual profile, such as language dominance, current language use, code-switching frequency, language proficiency, and age of acquisition (Chung-Fat-Yim et al., 2022) might explain why BAWS in this study did not experience the same bilingual advantage toward executive attention as the BAWS in Aslan et al. (2024). However, further research is needed to empirically validate this hypothesis.

4.3 Influence of second language proficiency on attention, but not on sublexical speech perception

Standardized and self-reported L2 proficiency were hypothesized to be associated with more efficient sublexical speech perception. No such effect was observed in the current study, which may be attributed to the relatively low cognitive demands of the tasks used. Both the discrimination task (requiring passive listening) and the categorization task (requiring a simple button press upon detecting a deviant stimulus) might have placed minimal demands on attentional control. Prior research suggests that cognitive advantages associated with bilingualism are most likely to emerge under conditions of increased task complexity and attentional load (Bialystok & Craik, 2022; Kuipers & Westphal, 2021). When tasks are too simple, especially for young, neurotypical, and highly educated adults who are already at a peak in cognitive functioning, the potential benefits of bilingualism may be masked by ceiling effects or insufficient task sensitivity (Bialystok, 2021). Thus, the absence of a relationship between L2 proficiency and sublexical speech perception may reflect a mismatch between the cognitive demands of the task and the level of attentional control in our young, highly-educated participant sample.

Similar to sublexical speech perception, it was hypothesized that higher L2 proficiency would be associated with more efficient attention processing, particularly in the executive attention network. This hypothesis was based on prior studies linking higher L2 proficiency to improved executive attention in BANS (Khare et al., 2013; Rosselli et al., 2016). These studies revealed that higher L2 proficiency correlates with higher accuracy, faster reaction times, and reduced performance differences between congruent and incongruent trials (Yamasaki et al., 2018). Additionally, bilingualism is thought to have the strongest cognitive effect in populations with less effective control functions in general (Bialystok, 2024, 2025; Bialystok & Craik, 2022). Lastly, Kornisch et al. (2017) suggested a bilingual advantage in BAWS compared to MAWS in a dual-task paradigm. In this study, 40 bilingual and 40 monolingual adults, including equal numbers of individuals who stuttered, performed a selective identification task. Objects were presented simultaneously in both visual fields, with an arrow in the center indicating which item to select. Participants then identified the correct word on the following screen. Although no significant differences were found between bilinguals who stuttered and those who did not, bilingual participants - regardless of stuttering - responded more quickly and made fewer errors than monolinguals.

An interaction between the participant groups and the L2 proficiency scores was not established. However, within the stuttering group, BAWS with higher L2 proficiencies showed less efficient executive attention relative to the less proficient

BAWS. Given that BAWS differed from BANS in executive attention (see supra 4.2), a straightforward interpretation might be that acquiring a higher proficiency in an L2 places additional cognitive demands on an already vulnerable attention system due to stuttering. However, several factors warrant consideration before drawing this conclusion. First, in the current study, although not statistically significant, a similar negative trend between L2 proficiency and executive attention efficiency was observed in BANS, which may have contributed to the absence of significant interaction effects. This finding in BANS has also been reported by Kalia et al. (2014), where higher L2 proficiency in late bilinguals correlated with lower inhibitory control. Notably, bilinguals as a group still outperformed monolinguals on inhibition tasks, suggesting that factors beyond proficiency such as language use, language similarity, and age of L2 acquisition (Yamasaki et al., 2018), might drive bilingual advantages in executive attention. A second consideration is the rather small sample size (n = 13) limiting the generalizability of this finding.

4.4 Clinical implications

The current findings support a more comprehensive understanding of stuttering in bilingual adults, emphasizing the role of higher-order cognitive processes, and particularly attentional functioning alongside the motor, emotion, sensory, and language components of stuttering. Specifically, the observed inefficiencies in the alerting and executive attention networks in BAWS suggest that some individuals may face challenges to allocate cognitive resources effectively, especially under increased attentional demands. These findings have several implications for clinical practice. First, they underscore the value of including (executive) attention-related assessments, such as standardized questionnaires (e.g., Test of Everyday Attention (Robertson et al., 1996), Comprehensive Executive Function Inventory for Adults (Naglieri & Goldstein, 2014) or BRIEF-A (Roth et al., 2005)) into the comprehensive evaluation of stuttering, particularly when attentional difficulties are suspected. Such assessments can inform more tailored treatment planning, by including adjustments to task complexity and consideration of attentional shift or load during both direct and indirect stuttering treatment. Further, the study provides further rationale for integrating attention-targeting interventions, such as mindfulness-based interventions or nonlinguistic, attentional training methods as complementary components to the chosen treatment approach. Mindfulness training, for example, aims to enhance self-regulation of attention through present-focused awareness and by cultivating a non-judgmental, open, and curious attitude toward internal experiences. Such interventions have been linked to improvements in attentional control, emotional regulation, and sensorimotor integration in stuttering (Beilby et al., 2012; Boyle, 2011; Harley, 2018). In terms of nonlinguistic attentional training, a study of Nejati et al. (2013) showed that the 15 CWS following their Neurocognitive Joyful Attentive Training program showed improved attentional abilities and less speech dysfluencies after participation. However, the specific cognitive processes targeted by the training are not fully specified in the study, and to our knowledge, this type of intervention has not yet been explored in adults who stutter. Lastly, given the distinct cognitive-linguistic demands faced by bilingual individuals, clinicians could consider key elements of the bilingual profile (e.g., language dominance, proficiency, age of acquisition, and code-switching frequency) when tailoring interventions. Notably, it may be worthwhile to investigate whether and when bilingual language use itself can function as a natural form of attentional training (Poarch & Bialystok, 2015). While attentional training represents a promising direction for clinical application, further research is needed to clarify its long-term effects and determine its impact on the overall quality of life and fluency in (bilingual) adults who stutter.

4.5 Limitations and directions for future research

This study adds to the existing literature on inattentive and attentive speech perception in BAWS, and the influence of L2 proficiency thereupon, by studying the MMN, P300, and the auditory sensory P1-N1-P2 complex. Its added value lies in (1) including L2 proficiency as a continuous variable, (2) evaluating the interaction between stuttering and L2 proficiency, and (3) considering multiple relevant ERP parameters, including mean amplitude and onset latency. Nevertheless, a few limitations need to be addressed, among which are the rather limited sample size and variation regarding L2 proficiency and stuttering severity. Including more participants whose L2 is average and on the boundaries of the continuum (i.e., towards monolingual or balanced bilingual), as well as more variation in the stuttering profiles will enhance statistical power, allowing for more robust statements about the predictive value of L2 proficiency and stuttering on sublexical speech perception and attention networks. Second, a caveat of this study is that L2 proficiency was assessed solely through the LexTALE vocabulary test and self-report. Incorporating additional measures, such as verbal fluency or naming tasks, or assessments such as the MINT (Garcia & Gollan, 2022) or Oxford Quick Placement Test (QPT, 2001) would provide a more comprehensive assessment of participant's actual proficiency. Further, the study only focused on L2 proficiency. Given that bilingualism exists on a continuum with no clear cut-off from monolingualism (Bialystok, 2021; Sanches de Oliveira & Bullock Oliveira, 2022) and considering monolingualism is no longer the norm, a multifactorial continuum approach to examine the effects of different bilingual language profiles is needed (Dash et al., 2022). Incorporating extra descriptives on the participant's bilingual profile, including language history, function, dominance, and age of acquisition will enhance the understanding of the specific aspects influencing auditory perception and attentional control. Third, the present study targeted phonemic articulation place contrasts, omitting exploration of other phonetic consonant features such as articulation manner and voicing. While this focus was influenced by previous research indicating its significance in triggering the MMN and P300 (Aerts et al., 2013), a more comprehensive investigation including various consonant and vowel contrasts and pre-phonemic features (e.g., Jansson-Verkasalo et al., 2014) is recommended for future studies. Further, analyses were confined to mean amplitude and onset latency, limiting insights into the underlying functional networks involved. Future studies employing source localization could better map neural generators and identify lateralization patterns associated with stuttering, particularly given previous indications of compensatory right-lateralized brain activity in AWS (Fox et al., 2000; Preibisch et al., 2003). Finally, stuttering severity was descriptively mapped using the SSI-4 based on a reading and spontaneous speech. However, this instrument has some limitations regarding reliability, the estimation of physical concomitants (Davidow, 2021), and it does not provide information about the variability of the stuttering from situation-to-situation or day-to-day. Moreover, stuttering is often linked to higher anxiety, social anxiety, and depression (Craig & Tran, 2014), which can influence attention networks (Moriya, 2018) and may have affected the performance of BAWS. Additionally, some individuals who stutter exhibit ADHD-like traits (Alm & Risberg, 2007), and while our study did not assess ADHD directly, attentional characteristics associated with ADHD could have influenced ANT performance. In sum, future research should consider cognitive-emotional factors using measurements such as the Unhelpful Thoughts and Beliefs About Stuttering (UTBAS) scales (Iverach et al., 2016) or the Overall Assessment of the Speaker's Experience of Stuttering-Adult (OASES-A-R; Tichenor & Yaruss, 2024) and include attention screenings such as the ASRS (Kessler et al., 2005) in attention studies in AWS.

6. Conclusion

The current study highlights the effect of stuttering on nonlinguistic, nonauditory alerting and executive attention. Whereas BAWS display difficulties in attaining and maintaining an alert state and in inhibiting irrelevant while selecting relevant information compared to BANS, they do not exhibit issues in selecting information from visual sensory input. Further, BAWS show no difficulties in phoneme discrimination and categorization. However, early sensory processing appears atypical in BAWS, as they fail to show the typical differentiation pattern between the two stimuli presented. Additionally, while high L2 proficiency does not seem to impact sublexical speech perception, it was negatively associated with executive attention in BAWS.

Beyond its theoretical contributions, the present study has practical implications for therapeutic approaches to stuttering. Given the observed attentional differences in BAWS, attentional training therapies may hold promise for improving attentional control. Previous research (e.g., Nejati et al., 2013) has demonstrated that interventions targeting sustained and selective attention can enhance attentional performance and lead to improvements in speech fluency in children and adolescents. Future research should explore the potential benefits of such interventions for BAWS, particularly concerning the interplay between bilingualism, attention, and fluency. Moreover, given that the present study focused solely on L2 proficiency, future work should consider additional aspects of the bilingual language profile to further clarify the role of bilingualism in attentional control and speech fluency.

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Disclosure of conflict of interest

None of the authors reported any conflict of interest.

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Data availability statement

The participants of this study did not give their written consent for their data to be shared publicly. Due to this, raw data cannot be made available.

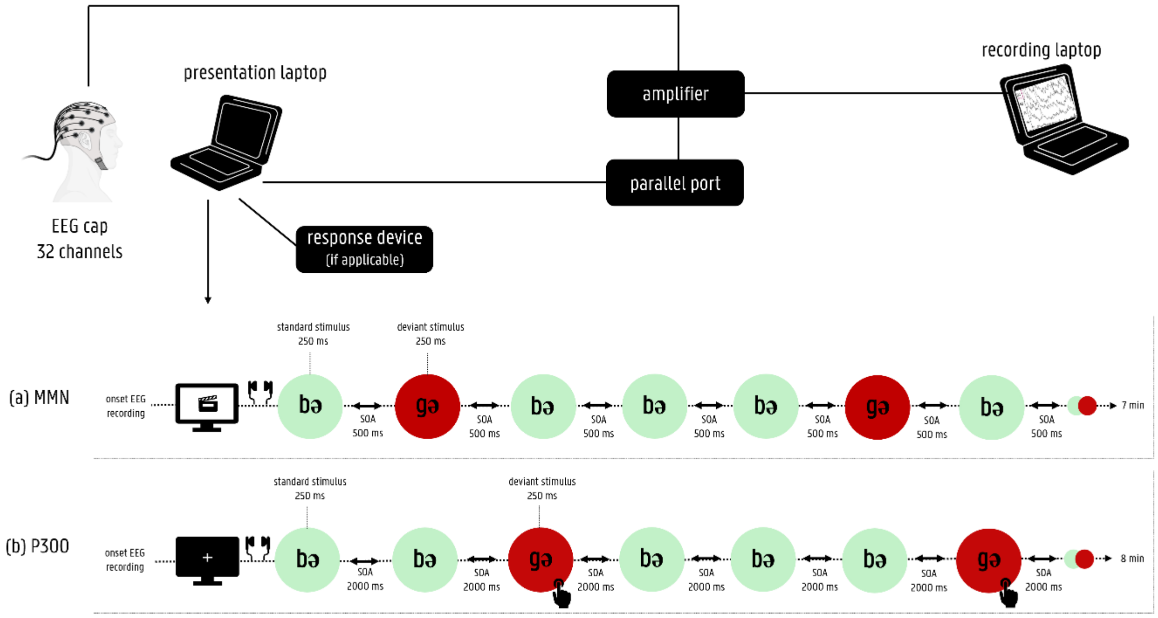
Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work the author(s) used Microsoft 365 Copilot in order to improve writing and readability. After using this tool/service, the author(s) reviewed and edited the content as needed and take(s) full responsibility for the content of the publication.

Figures

Figure 1

Recording set-up and task overview of the inattentive phoneme discrimination task (MMN) and the attentive phoneme categorization task (P300).



Note. (a) Participants watched a 7-minute silent movie while 600 standard stimuli (80% of the time) and 150 deviant stimuli (20% of the time) were presented with a 500 ms speech-onset-asynchrony (SOA). No response was required. **(b)** Participants looked at a fixation cross while 100 standard stimuli (80% of the time) and 50 deviant stimuli (20% of the time) were presented with a 2000 ms speech-onset-asynchrony (SOA). They were asked to press a button when they heard the deviant stimulus. Continuous EEG was recorded, with markers placed at stimulus onsets.

Figure 2

MMN grand average difference waves for BAWS (n = 13) and BANS (n = 13) elicited in response to standard and deviant phonemes (place of articulation contrast) at electrode positions Fz and Cz.

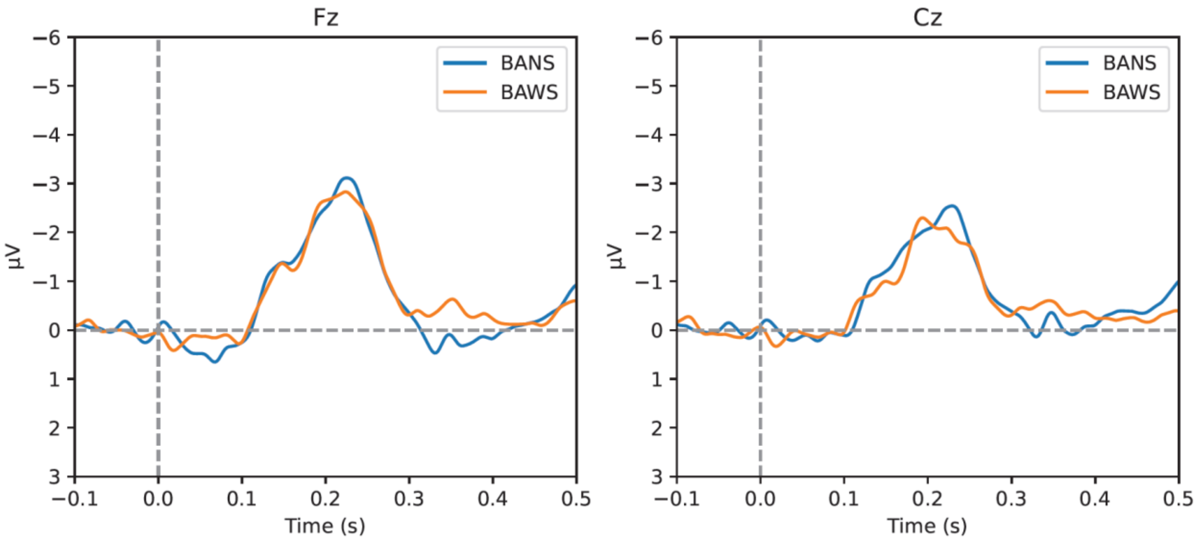


Figure 3

P300 grand average difference waves for BAWS (n = 13) and BANS (n = 13) elicited in response to standard and deviant phonemes (place of articulation contrast) at electrode position Pz.

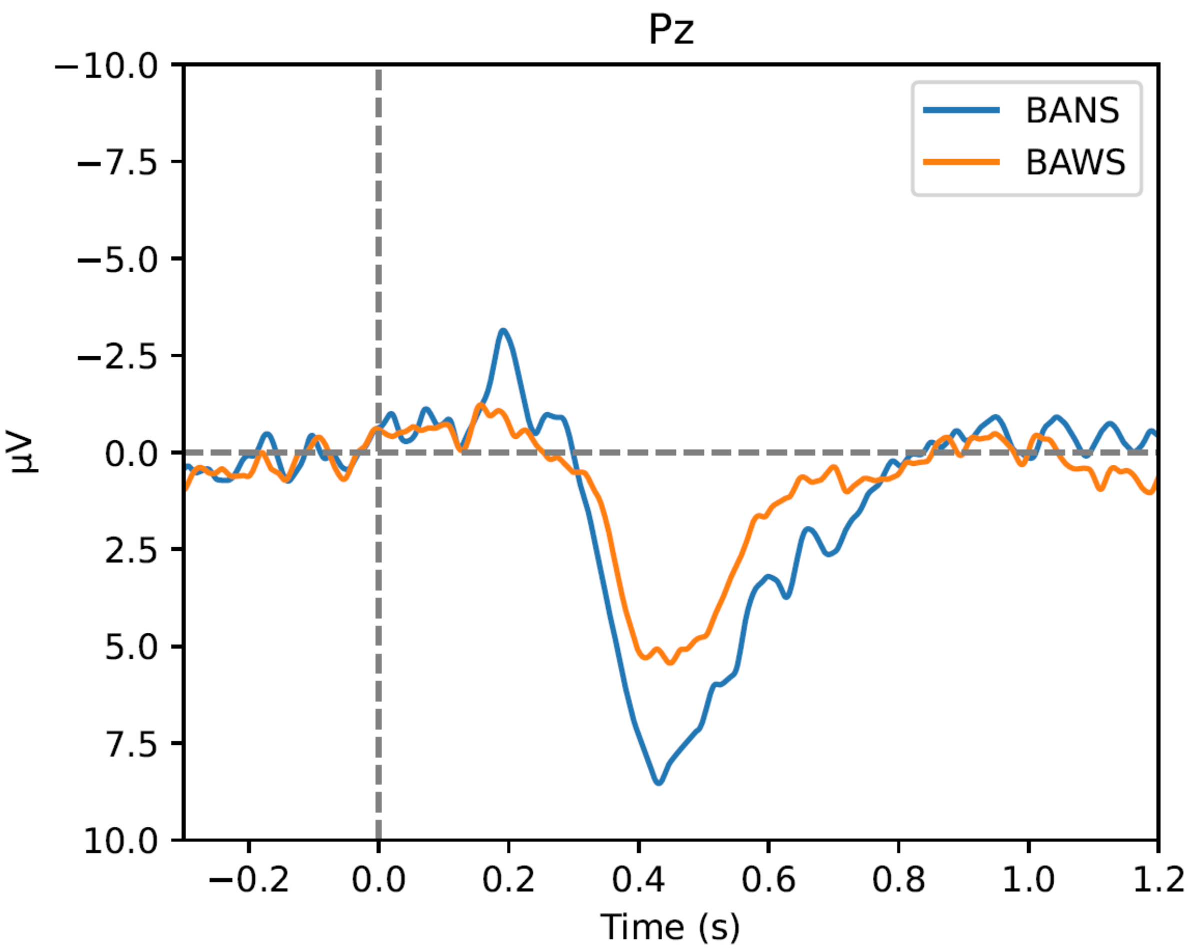
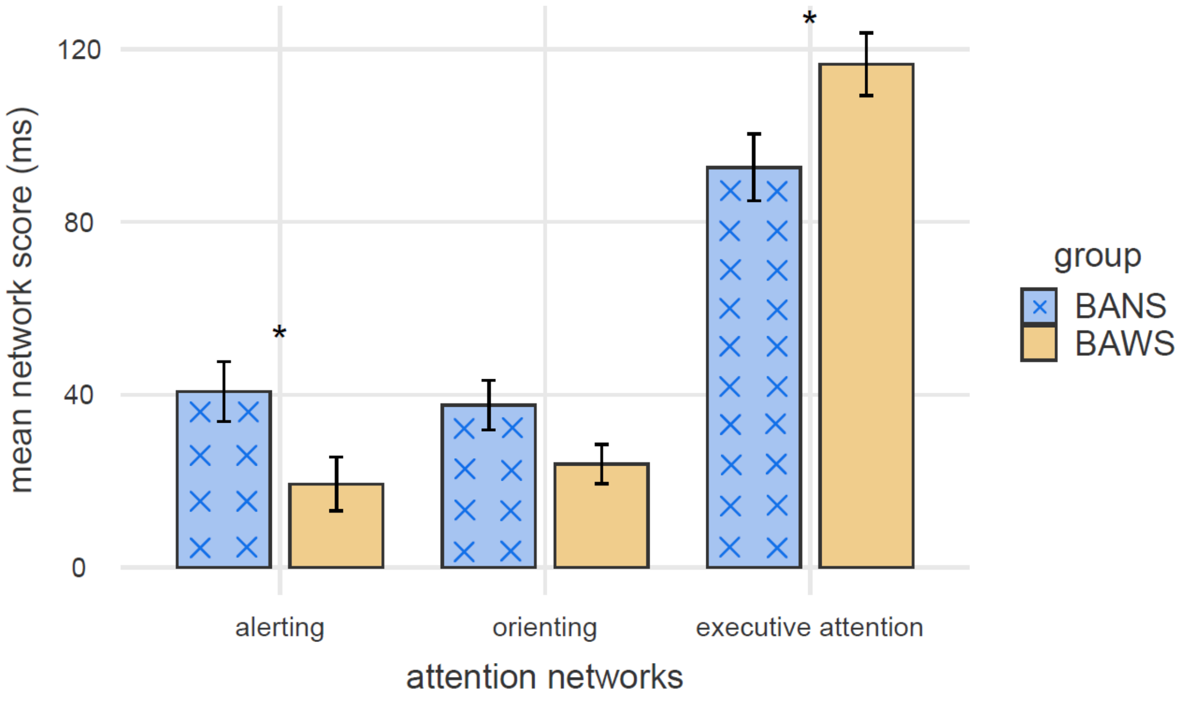


Figure 4

Attention network scores for reaction time in BAWS (n = 13) and BANS (n = 13).



Note. Error bars 95% *CI*; * *p* < .05; efficient = higher alerting and orienting scores and lower executive attention scores.

Tables

Table 1.

Participant demographics presented for bilingual adults who stutter (n = 13) and do not stutter (n = 13).

	BAWS	**BANS**	**Difference**	**t(24)**	***p***
Age (years)	26.9 (7.71)	26.5 (7.52)[a]	-0.4 [-6.6 – 5.8][b]	-0.129	0.899
Handedness[c]	8.6 (3.33)	6.5 (7.06)	-2.1 [-6.6 – 2.5]	-9.60	0.350
Education level[d]	4.0 (0.82)	4.3 (.95)	7.9 [-0.4 – 1.0]	0.887	0.384
Standardized L2 proficiency[e]	71.0 (11.80)	80.5 (10.70)	9.5 [0.405 – 18.6]	2.160	0.041*
Self-reported L2 proficiency[f]	6.8 (1.74)	6.8 (1.07)	0.08 [-1.09 – 1.25]	0.136	0.893
Years of L2 classes	6.1 (1.66)	6.15 (1.86)	0.08 [-1.35 – 1.50]	0.111	0.912

Note. BAWS: bilingual adults who stutter; **BANS**: bilingual adults who do not stutter; **L2:** second language; [a] Mean (standard deviation); [b] 95% *CI*; [c] Dutch Handedness Inventory; [d] Scored on a six-point scale (International Standard Classification of Education; 2011): 1, primary education; 2 lower secondary education; 3, upper secondary education; 4, bachelor; 5, master, 6, doctor; [e] Based upon LexTALE scores; [f] Based upon an 11-point Likert scale (0 = no proficiency, 10 = high proficiency); * $p < .05$.

Table 2.

Standardized and self-reported L2 proficiency scores for each matched pair of BAWS (n = 13) and BANS (n = 13).

Matched participants	BAWS		BANS	
	Standardized L2 proficiency[a] (%)	Self-reported L2 proficiency[b] (/ 10)	Standardized L2 proficiency[a] (%)	Self-reported L2 proficiency[b] (/ 10)
1	63.8	3	68.8	8
2	87.5	7	80.0	6
3	75.0	7	66.3	6
4	92.5	9	80.0	6
5	57.5	6	67.9	7
6	77.5	9	76.3	7
7	67.5	7	73.8	5
8	83.8	7	85.0	7
9	57.5	6	92.5	7
10	63.8	8	98.8	8
11	74.1	7	93.8	9
12	58.8	4	73.8	6
13	65.0	8	90.0	7

Note. BAWS: bilingual adults who stutter; **BANS**: bilingual adults who do not stutter; **L2**: second language; [a] Based upon LexTALE scores; [b] Based upon an 11-point Likert scale (0 = no proficiency, 10 = high proficiency).

Table 3.

Age of stuttering onset and the SSI-4 characteristics of stuttered speech in bilingual adults who stutter (n = 13).

	Age of stuttering onset (years)	Frequency		Duration (sec)	Physical concomitants[1] (/20)	Percentile rank	Severity
		Reading (%SS)	Speaking (%SS)				
BAWS 1	2	1.64	2.11	0.5 – 0.9	1	1 - 4	Very mild
BAWS 2	2	2.18	1.40	≤ 0.5	8	5 - 11	Very mild
BAWS 3	3	1.09	2.24	2.0 – 2.9	4	5 - 11	Very mild
BAWS 4	4	0.55	2.44	≤ 0.5	5	1 - 4	Very mild
BAWS 5	2	1.09	2.00	0.5 - 0.9	1	1 - 4	Very mild
BAWS 6	3	1.64	2.41	2.0 – 2.9	5	12 - 23	Mild
BAWS 7	3	3.79	5.19	0.5 - 0.9	9	24 - 40	Mild
BAWS 8	5	4.37	2.82	2.0 – 2.9	5	24 - 40	Mild
BAWS 9	3	7.65	3.23	1.0 – 1.9	2	12 - 23	Mild
BAWS 10	5	2.73	3.08	1.0 – 1.9	5	12 - 23	Mild
BAWS 11	4	8.20	7.60	2.0 – 2.9	8	61 - 77	Moderate
BAWS 12	3	7.10	8.21	3.0 – 3.9	9	78 – 88	Severe
BAWS 13	3	3.23	9.69	3.0 – 3.9	10	78 - 88	Severe

Note. [1] Scale scores SSI-4 (Riley, 2009); **%SS:** percentage stuttered speech; **sec:** seconds.

Table 4.

Number of included trials for bilingual adults who stutter (n = 13) and do not stutter (n = 13) for each stimulus type of the auditory phoneme discrimination and categorization tasks (MMN, P300).

	BAWS		BANS	
	Standard	**Deviant**	**Standard**	**Deviant**
MMN	596 (6.3)[1]	149 (1.3)	590 (12.4)	148 (2.5)
	99% (1.1%)	99% (0.9%)	98% (2.1%)	99% (1.7%)
P300	158 (3.3)	39 (1.5)	154 (10.0)	38 (3.1)
	99% (2.1%)	98% (3.8%)	96% (6.3%)	95% (7.8%)

Note. [1] Mean (standard deviation); **BAWS:** bilingual adults who stutter; **BANS:** bilingual adults who do not stutter.

Table 5.

Overview of the dependent variables, their measured constructs, specific measures, and general interpretation for each research question.

RQ 1: Do BAWS and BANS differ in sublexical speech perception and does this difference depend on the listening mode?			
Sublexical speech perception			
Construct	**Dependent variable**	**Measured from**	**Interpretation**
– Inattentive phoneme discrimination	MMN mean amplitude (μV)	Difference waves[a] across F3-Fz-F4-C3-Cz-C4	Amount of neural resources allocated
	MMN onset latency (ms)	Difference waves across F3-Fz-F4-C3-Cz-C4	Processing speed
– Attentive early auditory sensory processing	P1-N1-P2 amplitude (μV)	Standard & deviant waves across F3-Fz-F4-C3-Cz-C4	Amount of neural resources allocated
	N1-P2 onset latency (ms)	Standard & deviant waves across C3-Cz-C4 (N1) F3-Fz-F4 (P2)	Processing speed
– Attentive phoneme categorization, attention allocation	P300 mean amplitude (μV)	Difference waves across P3-Pz-P4	Amount of neural resources allocated
	P300 onset latency (ms)	Difference waves across P3-Pz-P4	Processing speed
RQ 2: Do BAWS and BANS differ in terms of nonlinguistic, nonauditory attention networks?			
Nonlinguistic, nonauditory attention networks			
Construct	**Dependent variable**	**Measured from**	**Interpretation**
– Alerting[b]	Alerting reaction time (ms)	No – double cue	Achieving and maintaining readiness to respond to environmental stimuli
– Orienting[b]	Orienting reaction time (ms)	Central – spatial cue	Selecting information from auditory input
– Executive attention[c]	Executive attention reaction time (ms)	Incongruent – congruent flanker	Focusing on relevant input while inhibiting irrelevant and competing stimuli
RQ 3: Does second language proficiency influence sublexical speech perception and nonlinguistic attention networks in BANS and BAWS?			
Second language proficiency			
Construct	**Dependent variable**	**Measured from**	**Meaning**
– Standardized L2 proficiency	Standardized L2 proficiency(%)	Lexical decision for words and pseudowords	Vocabulary knowledge
– Subjective L2 proficiency	Subjective L2 proficiency (/10)	Self-rating on speaking, writing, listening, and reading	Self-estimation of L2 abilities
Sublexical speech perception (RQ 1)			
Nonlinguistic, nonauditory attention networks (RQ 2)			

Note. [a] For the MMN and P300, amplitude and latency are typically examined using a difference wave. This wave is created by subtracting the ERP response of the standard stimulus wave from the deviant stimulus wave, thereby isolating neural activity specifically related to the experimental manipulation; [b] higher RT is more efficient; [c] lower RT is more efficient.

Table 6.

Summary of statistical analysis results on the effects of the participant group and the electrode positions on the amplitude and onset latency of the MMN effect.

Factor	df	F	p	η²p
Amplitude (μV)				
Participant group	1, 25	0.15	.700	0.008
Standardized L2 proficiency	1, 25	0.46	.505	0.022
Self-reported L2 proficiency	1, 25	0.16	.691	0.008
Participant group x Standardized L2 proficiency	1, 25	0.001	.979	0.000
Participant group x Self-reported L2 proficiency	1, 25	0.09	.767	0.004
Onset latency (ms)				
Participant group	1, 25	0.002	.962	0.000
Standardized L2 proficiency	1, 25	0.35	.561	0.017
Self-reported L2 proficiency	1, 25	0.21	.655	0.010
Participant group x Standardized L2 proficiency	1, 25	0.60	.446	0.029
Participant group x Self-reported L2 proficiency	1, 25	0.76	.395	0.036

Note. Participant group: stuttering versus nonstuttering adults; **L2**: second language; **×**: interaction between two factors; ***** $p < .05$; ****** $p < .001$.

Table 7.

Summary of statistical analysis results on the effects of the participant group and stimulus type on the amplitude and onset latency of the P1-N1-P2 complex.

	Factor	df	F	p
Amplitude (μV)				
P1	Participant group	1, 20	0.53	.474
	Stimulus type	1, 24	0.54	.470
	Standardized L2 proficiency	1, 20	0.65	.430
	Self-reported L2 proficiency	1, 20	0.01	.904
	Stimulus type × Participant group	1, 24	0.03	.875
	Participant group × Standardized L2 proficiency	1, 20	0.04	.844
	Participant group × Self-reported L2 proficiency	1, 20	1.49	.237
N1	Participant group	1, 20	0.006	.935
	Stimulus type	1, 24	1.14	.296
	Standardized L2 proficiency	1, 20	0.03	.934
	Self-reported L2 proficiency	1, 20	0.35	.559
	Stimulus type × Participant group	1, 24	0.45	.509
	Participant group × Standardized L2 proficiency	1, 20	0.09	.772
	Participant group × Self-reported L2 proficiency	1, 20	1.06	.315
P2	Participant group	1, 20	1.07	.314
	Stimulus type	1, 24	18.94	**<.001****
	Standardized L2 proficiency	1, 20	1.48	.239
	Self-reported L2 proficiency	1, 20	3.79	.066
	Stimulus type × Participant group	1, 24	4.80	**.038***
	Participant group × Standardized L2 proficiency	1, 20	1.21	.285
	Participant group × Self-reported L2 proficiency	1, 20	0.13	.722
Onset latency (ms)				
N1	Participant group	1, 20	0.02	.903
	Stimulus type	1, 24	9.79	.296
	Standardized L2 proficiency	1, 20	0.32	.579
	Self-reported L2 proficiency	1, 20	0.03	.862
	Stimulus type × Participant group	1, 24	0.12	.727
	Participant group × Standardized L2 proficiency	1, 20	2.67	.118
	Participant group × Self-reported L2 proficiency	1, 20	2.41	.136
P2	Participant group	1, 20	0.95	.343
	Stimulus type	1, 24	0.23	.636
	Standardized L2 proficiency	1, 20	4.99	.057
	Self-reported L2 proficiency	1, 20	1.77	.199
	Stimulus type × Participant group	1, 24	1.62	.216
	Participant group × Standardized L2 proficiency	1, 20	0.33	.572
	Participant group × Self-reported L2 proficiency	1, 20	0.63	.437

Note. Participant group: stuttering versus nonstuttering adults; **Stimulus type**: standard versus deviant stimuli; **×**: interaction between two factors; **L2**: second language; * $p < .05$; ** $p < .001$.

Table 8.

Summary of statistical analysis results on the effects of the participant group and electrode positions on the amplitude and onset latency of the P300 effect.

Factor	df	F	p	η^2p
Amplitude (μV)				
Participant group	1, 25	1.25	.277	0.059
Standardized L2 proficiency	1, 25	0.16	.692	0.008
Self-reported L2 proficiency	1, 25	0.70	.413	0.034
Participant group x Standardized L2 proficiency	1, 25	0.11	.739	0.006
Participant group x Self-reported L2 proficiency	1, 25	0.01	.938	0.000
Onset latency (ms)				
Participant group	1, 25	.09	.764	0.005
Standardized L2 proficiency	1, 25	1.09	.308	0.052
Self-reported L2 proficiency	1, 25	0.002	.969	0.000
Participant group x Standardized L2 proficiency	1, 25	1.44	.244	0.067
Participant group x Self-reported L2 proficiency	1, 25	0.03	.877	0.001

Note. Participant group: stuttering versus nonstuttering adults; **L2**: second language; **×**: interaction between two factors; ***** $p < .05$; ****** $p < .001$.

Table 9.

Summary of statistical analysis results on the effects of the participant group and second language proficiency on the attention networks (alerting, orienting, and executive attention).

Factor	df	F	p	η²p
Alerting				
Participant group	1, 25	3.67	**.047***	0.156
Standardized L2 proficiency	1, 25	0.06	.809	0.003
Self-reported L2 proficiency	1, 25	1.22	.282	0.058
Participant group × Standardized L2 proficiency	1, 25	1.31	.266	0.062
Participant group × Self-reported L2 proficiency	1, 25	1.83	.191	0.084
Orienting				
Participant group	1, 25	2.03	.170	0.092
Standardized L2 proficiency	1, 25	0.40	.533	0.020
Self-reported L2 proficiency	1, 25	2.39	.138	0.107
Participant group × Standardized L2 proficiency	1, 25	0.33	0.572	0.016
Participant group × Self-reported L2 proficiency	1, 25	1.55	0.227	0.072
Executive attention				
Participant group	1, 25	9.11	**.007***	0.313
Standardized L2 proficiency	1, 25	1.62	**.037***	0.075
Self-reported L2 proficiency	1, 25	4.19	.053	0.173
Participant group × Standardized L2 proficiency	1, 25	0.61	.443	0.030
Participant group × Self-reported L2 proficiency	1, 25	0.33	.571	0.016

Note. Participant group: stuttering versus nonstuttering adults; **L2**: second language; **×**: interaction between factors; * $p < .05$; ** $p < .001$.

Table 10.

Efficiency of the attention networks for bilingual adults who stutter (n = 13) and who do not stutter (n = 13).

	BAWS		BANS	
	Mean (ms)	SD	Mean (ms)	SD
Total reaction time	507.3	44.50	495.0	31.40
Alerting	19.3	22.52	40.8	25.55
Orienting	24.0	16.40	37.6	20.80
Executive attention	117.0	26.31	92.6	31.4

Note. SD = standard deviation; **BAWS**: bilingual adults who stutter; **BANS**: bilingual adults who do not stutter.

Appendix

RQ 1: Group differences in inattentive and attentive sublexical speech perception

Inattentive sublexical speech perception (MMN effect)

Amplitude & onset latency

- **LM: MMN amplitude (difference wave collapsed over F3-Fz-F4-C3-Cz-C4)**

  lm (MMN amplitude ~ 1 + group + stimulus type + standardized L2 + subjective L2 + standardized L2*group + subjective L2*group)

- **LM: MMN onset latency (difference wave collapsed over F3-Fz-F4-C3-Cz-C4)**

  lm (MMN latency ~ 1 + group + stimulus type + standardized L2 + subjective L2 + standardized L2*group + subjective L2*group)

Attentive sublexical speech perception (P1-N1-P2 complex and P300 effect)

Amplitude & onset latency

- **LMM: P1 amplitude (standard & deviant waves collapsed over F3-Fz-F4-C3-Cz-C4)**

  lmer (P1 amplitude ~ 1 + group + stimulus type + standardized L2 + subjective L2 + stimulus type*group + standardized L2*group + subjective L2*group + (1 | participant))

- **LMM: N1 amplitude (standard and deviant waves collapsed over F3-Fz-F4-C3-Cz-C4)**

  lmer (N1 amplitude ~ 1 + group + stimulus type + standardized L2 + subjective L2 + stimulus type*group + standardized L2*group + subjective L2*group + (1 | participant))

- **LMM: N1 onset latency (standard and deviant waves collapsed over C3-Cz-C4)**

  lmer (N1 latency ~ 1 + group + stimulus type + standardized L2 + subjective L2 + stimulus type*group + standardized L2*group + subjective L2*group + (1 | participant))

- **LMM: P2 amplitude (standard & deviants waves collapsed over F3-Fz-F4-C3-Cz-C4)**

  lmer (P2 amplitude ~ 1 + group + stimulus type + standardized L2 + subjective L2 + stimulus type*group + standardized L2*group + subjective L2*group + (1 | participant))

- **LMM: P2 onset latency (standard and deviant waves collapsed over F3-Fz-F4)**

  lmer (P2 latency ~ 1 + group + stimulus type + standardized L2 + subjective L2 + stimulus type*group + standardized L2*group + subjective L2*group + (1 | participant))

- **LM: P300 amplitude (difference waves collapsed over P3-Pz-P4)**

  lm (P300 amplitude ~ 1 + group + stimulus type + standardized L2 + subjective L2 + standardized L2*group + subjective L2*group)

- **LM: P300 onset latency (difference waves collapsed over P3-Pz-P4)**

  lm (P300 latency ~ 1 + group + stimulus type + standardized L2 + subjective L2 + standardized L2*group + subjective L2*group)

RQ 2: Group differences in the nonlinguistic, nonauditory attention networks

Attention networks

- **LM: alerting (ms)**

  lm (alerting ~ 1 + group + stimulus type + standardized L2 + subjective L2 + standardized L2*group + subjective L2*group)
- **LM: orienting (ms)**

  lm (orienting ~ 1 + group + stimulus type + standardized L2 + subjective L2 + standardized L2*group + subjective L2*group)
- **LM: executive attention (ms)**

  lm (executive attention ~ 1 + group + stimulus type + standardized L2 + subjective L2 + standardized L2*group + subjective L2*group)

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