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The interplay between bilingualism and sleep quality in modulating executive performance

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Abstract

We investigated the interactive effects of bilingualism and sleep on executive functioning at the behavioral level. We conducted two experiments using two independent samples of bilingual young adults, the Flanker task to assess executive performance, the Pittsburg Sleep Quality Index to measure retrospective sleep quality over a one-month period and the Insomnia Severity Index to assess insomnia-related symptoms. In Experiment 1, we registered bilingualism effects on executive performance in poor, but not in good sleepers. In Experiment 2, the magnitude of bilingual effects increased with increasing severity of insomnia symptoms. We conclude that when poor sleep quality and insomnia negatively affect cognitive resources, bilingualism-related cognitive effects emerge more prominently. This suggests higher degrees of bilingualism may compensate detrimental effects of poor sleep quality and insomnia on executive functioning. We suggest that cognitive research in bilingualism and sleep could benefit from controlling for interindividual variability in sleep quality and vice versa.

Highlights

- We investigated the effects of bilingualism and sleep on executive performance
- Experiment 1 focused on sleep quality, Experiment 2 on insomnia symptoms
- Bilingualism affects performance for poor, but not for good sleep-quality participants
- The magnitude of bilingual effects increased with increased severity of insomnia
- Bilingualism may mitigate the detriments of poor sleep on executive function

1. Introduction

Various lifestyle factors and everyday activities such as nutrition, physical exercise, memory and technology training have been shown to affect cognitive processing (Dresler et al., 2013). Two of such everyday activities – sleep and bilingualism – are known to influence similar cognitive and neural mechanisms (see Gallo et al., 2025, for a review). Nonetheless, the joint effects of sleep and bilingualism on cognition have never been addressed together. This study is the first attempt to fill this gap. Before we introduce the present study in more detail, we will briefly consider each of these two factors' implications for cognitive functioning.

1.1. Bilingualism and cognition

Research on the cognitive consequences of bilingualism is gaining increasing interest due to how widespread this life experience is, with more than half of the world's population currently estimated to be bilingual (Grosjean, 2021). Moreover, recent research indicates that, alongside other sociodemographic variables, bilingualism plays a significant role in promoting higher levels of well-being (Wang & Wei, 2023) across various age groups and bilingual contexts (Müller et al., 2020; Sari et al., 2019). Existing research provides ample evidence suggesting that bilingualism and multilingualism[1] influence neural and cognitive functioning (DeLuca et al., 2019a; Green & Abutalebi, 2013; Valian, 2015). One of the mechanisms underlying these effects is the constant co-activation of all languages in the bilingual brain, as demonstrated by behavioral and neuroimaging research (Abutalebi et al., 2007; Bialystok & Craik, 2022; Bialystok et al., 2012; Kroll et al., 2015). As a result, language processing in bilinguals heavily relies upon a 'language control'

[1]For conciseness, below we will use the words *bilingualism* and *bilingual* to describe both bilingual and multilingual language use.

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mechanism (Abutalebi & Green, 2007), which ensures that only the target language is selected and any intrusions from the non-relevant language(s) are successfully inhibited. Language control requires the engagement of cognitive mechanisms of selection, inhibition and switching, which are continuously required to manage potential interferences between different language codes (Abutalebi & Green, 2007). The language control system is underpinned by a network of cortico-subcortical regions at least partially related to domain-general executive functions (Abutalebi & Green, 2007, 2016; Green & Abutalebi, 2013).

The term *executive functions* (EF) refers to the higher-order, top-down cognitive processes essential for control and coordination of lower-level processes, which enable self-regulation and contribute to successful goal-directed behavior. EF comprise several cognitive abilities, including working memory, inhibitory control, cognitive flexibility, planning, reasoning and problem-solving (Diamond, 2013). It is argued that due to the overlap between the cognitive mechanisms and the brain networks implicated in bilingual language control and general executive control, the constant necessity for language selection has consequences for domain-general executive functioning across a wide range of activities, both at the behavioral and at the neural level (Abutalebi et al., 2011; Bialystok et al., 2009; Bialystok, 2017; Kroll et al., 2015).

Experimental findings have shown that bilingual experience exerts pronounced effects on EF at the behavioral level, with effects emerging in various EF tasks across different age groups, including children, young and older adults (for a review, see Bialystok, 2017; Grundy, 2020). At the neural level, it has been shown that bilingual experience is linked to modifications in grey matter density and white matter integrity in regions of the domain-general executive control network (for a review, see Taylor et al., 2022). Importantly, it has also been suggested that because of these neuroplastic changes, the bilingual brain is more resistant to cognitive decline (Gallo et al., 2022).

However, findings supporting bilingual cognitive effects have not always been replicated and have been contested in some research (for a review, see Paap, 2022). Debate continues regarding the nature and the magnitude of the bilingualism-related effects on EF, with some meta-analyses suggesting that this advantage could either be task- (Ware et al., 2020) or age-specific (Lehtonen et al., 2018; Lowe et al., 2021). Particularly inconsistent are the studies using young adult populations (Valian, 2015). One of the potential explanations is that young adults are at their cognitive efficiency peak (Kroll & Bialystok, 2013): Young adults have faster average reaction times than either children or older adults. The performance of young adults in simple EF tasks could easily reach ceiling levels, which may conceal the cognitive contributions of bilingualism (Bialystok, 2016). Nonetheless, ceiling effects can be overcome in high-demand tasks; when task demands were increased, bilinguals showed a clear advantage in executive control (Kuipers &Westphal, 2020). Moreover, cognition and EF are themselves influenced by various lifestyle factors, and it is possible that (some of) the previous research has failed to properly control for the full range of experiences that might affect EF, thereby diluting the putative positive effects of bilingualism (Valian, 2015). Importantly, however, other meta-analyses and systematic reviews support the general conclusion that bilingualism has an effect on aspects of EF (Grundy, 2020; Van Den Noort et al., 2019). Furthermore, numerous studies have documented neurocognitive consequences of bilingualism (Tao et al., 2021), including delay of the onset of Alzheimer's disease and dementia (Anderson et al., 2020; Brini et al., 2020). So overall, while existing controversies may be partially due to task and age-specific sample differences and/or a publication bias (De Bruin et al., 2014; Leivada, 2023), the exact and dynamic nature of the bilingualism effects on both mind and brain requires further investigation.

1.2. Sleep quality and cognition

Another factor known to have massive effects on cognitive functioning is sleep. Sleep constitutes a large proportion of the human lifetime, with around one-third of our entire life spent sleeping. Sleep has been extensively shown to play an essential role in day-to-day functioning across a range of physiological and cognitive functions (Tai et al., 2022), and sleep quality, duration and consistency have all been linked by numerous studies to well-being (e.g., Jean-Louis et al., 2000). Indeed, insufficient or poor-quality sleep impairs a wide variety of cognitive functions, including attention, language use, reasoning, learning and memory (Barclay & Myachykov, 2016; Barclay et al., 2020; Durmer & Dinges, 2005; Guttesen et al., 2022; Jackson et al., 2013). Importantly, sleep quality, consistency and duration have been simultaneously associated with various aspects of cognitive functioning, on one hand, and with the success of language learning and use, on the other hand (Gallo et al., 2025).

One of the most common disturbances associated with sleep is insomnia. Recent reports estimate that 10–15% of individuals suffer from insomnia disorder, i.e., persistent insomnia that lasts for more than three months (Fortier-Brochu et al., 2012; Nguyen et al., 2019). Individuals with insomnia commonly report various subjective difficulties in different cognitive functions (Harris et al., 2015), including working and episodic memory as well as some aspects of EF (Cellini, 2017). Importantly, these results cannot be explained simply by fatigue or boredom, appearing to be the direct effects of sleep loss. Indeed, several studies reveal detrimental effects of insomnia on the integrity and functionality of prefrontal and frontal lobes – areas underpinning EF, among other cognitive processes (Krause et al., 2017; Lowe et al., 2017). A neurobiological explanation for this negative effect of insomnia can be individuated in reduced electroencephalographic slow-wave activity (0.5–4 Hz) during non-rapid eye-movement sleep, normally associated with cortical reorganization. The loss of slow-wave sleep occurring in insomnia is thought to affect the prefrontal and frontal cortices and may thus underpin the negative relationship between sleep deprivation and EF (Wilckens et al., 2018). Nonetheless, difficulties in capturing EF deficits linked to subjective and objective assessments of sleep have so far prevented researchers from obtaining consistent patterns of results (Zavecz et al., 2020). Some studies report that individuals with insomnia, as compared to controls, have impaired performance in reaction-time tasks assessing inhibitory control (Haimov et al., 2008; Joo et al., 2013; Liu et al., 2014), while others report that insomnia does not substantially affect the inhibitory function (Perrier et al., 2015; Sivertsen et al., 2013). This inconsistency may, potentially, be explained in that sleep loss does not always lead to a global degradation of cognitive performance; rather, it impacts various components of cognitive functioning in different ways (Aidman et al., 2018). Similarly, results from structural neuroanatomical studies demonstrate that poor sleep quality (Koo et al., 2017; Stoffers et al., 2013; Van et al., 2021) and insomnia (Altena et al., 2010; Falgàs et al., 2021; Winkelman et al., 2013) are associated with volume loss in cortical and subcortical areas associated with EF.

1.3. The present study

As summarized above, both '*how well we speak another language*' and *'how well we sleep'* represent two everyday experiences with a

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potentially significant impact on general cognition and the underlying neural substrate. However, research in both fields has produced inconsistent results, which may be due to the failure to control other factors that influence EF, resulting in specific effects potentially being obfuscated or insufficiently manifested. Thus, it can be hypothesized that the points of intersection between sleep and bilingualism may be significant at a theoretical and functional level (Gallo et al., 2025). Specifically, it can be assumed that these two lifetime experiences may modulate each other's impact on cognitive functioning. Based on the evidence from the two research strands reviewed above, our primary hypothesis, therefore, is that bilingualism may overcome the detrimental effects of poor sleep quality upon EF. Conversely, poor sleep quality could potentially exert a mitigating effect on the beneficial consequences of bilingualism. Thus, for theoretical reasons, a simultaneous analysis of the effects of different factors on cognitive functioning may provide further clarity in both fields. As a practical implication, such studies may lay the groundwork for using knowledge of sleep quality to enhance the impact of language use in old age, or simply to improve language learning at any age. The aim of the present study is, for the first time, to test the interlinked consequences of bilingualism and sleep for cognition. To this end, we investigated, in two separate experiments, the effects of bilingualism and sleep on executive performance. We used two distinct samples of late unbalanced bilinguals with varying levels of sleep quality but without any clinical insomnia diagnosis or obvious self-reported sleep dysfunctions at the time of testing.

2. Experiment 1

2.1. Participants

Forty bilinguals (first language, L1: Russian; second language, L2: English; 10 males; mean age = 21.93, SD ± 2.75) were recruited from the population of students at HSE University, Moscow, Russian Federation. All participants acquired English as an L2 formally through instruction at school. Note that our participants resided in a predominantly L1-speaking environment, thus their engagement with L2 was regular but limited in terms of daily percentage. Requirements to participate in the study included absence of psychiatric or neurological conditions and normal or corrected-to-normal vision. All participants were interviewed about their age, educational level, and socioeconomic status (SES) using the MacArthur Scale of Subjective Social Status (MacArthur Foundation, 2007). Monthly household income, used as a proxy of SES, was calculated as the sum of incomes of all household members divided by the number of residents; this ensured incomes were more comparable across families of different sizes. An estimation of participants' general intelligence was based on their performance on an abridged version of the Colored Progressive Matrices (Raven, 1958) consisting of five elements from each of the three subsets, for a total of 15 elements. Descriptive statistics for sociodemographic and linguistic background profiles are reported in Table 1. The study was approved by the local research ethics committee at HSE University, and written informed consent was obtained from each participant.

2.2. Procedure

Participants were tested using behavioral testing facilities at the Institute for Cognitive Neuroscience, HSE University. All participants completed the experiment session in an acoustically insulated cubicle using the same equipment. Participants filled out the Russian version of the Pittsburgh Sleep Quality Index (PSQI; Buysse et al., 1989) questionnaire, Raven's Colored Progressive Matrices, and the Russian version of the Language Experience and Proficiency Questionnaire (LEAP-Q; Marian et al., 2007). As an EF test, we used the Flanker task (Eriksen & Eriksen, 1974; see below) in an experiment designed using the OpenSesame software (v. 3.3.7). Responses were recorded using a 5-button response pad (RB-740, Cedrus Inc.). The Cambridge General English Test for Adult Learners (https://www.cambridgeenglish.org/test-your-english/general-english/) was also administered in the laboratory setting without time limits. All tasks were performed in the same experimental session, which lasted around 60 minutes.

Table 1. Sociodemographic and L2 background profiles of participants

Variable	Mean (SD)	Range (min and max)
Age (years)	21.93 (2.75)	18–29
Education (years)	14.88 (1.96)	11–18
SES (band)	4.1 (1.87)	1–6
Raven's matrices (score)	14.68 (0.53)	13–15
L2 AoA (years)	7.98 (3.03)	4–16
L2 exposure (daily percentage)	23.42 (13.05)	2–60
L2 proficiency (score)	18.3 (4.12)	10–25
PSQI (score)	6.2 (2.23)	2–12

Note: Mean, standard deviation (SD) and range are provided for each measure.

2.3. Sleep quality assessment

The Russian version of the Pittsburgh Sleep Quality Index (PSQI – Buysse et al., 1989) was used to examine individual sleep quality. The PSQI consists of 19 individual items, forming 7 component scores and one 'global' composite score assessing sleep quality retrospectively over the preceding one-month period. In our analyses, we focused on the global composite score, providing a general overview of an individual's recent sleep quality.

2.4. Bilingual experience assessment

The Russian version of the LEAP-Q (Marian et al., 2007) assessed several dimensions of individual bilingual experience, including L2 age of acquisition (AoA) and L2 exposure in various modalities (i.e., writing, reading, speaking, listening). To obtain an objective measure of L2 proficiency, we administered the Cambridge General English Language Test for Adult Learners, containing 25 questions addressing various aspects of English proficiency (https://www.cambridgeenglish.org/test-your-english/general-english/).

2.5. Executive performance assessment

To assess executive performance, we used a version of the Flanker task (Eriksen & Eriksen, 1974). In this task, participants are instructed to identify the direction of a central target arrow by pressing the left or right arrow button on the response box as fast and as correctly as possible (the leftmost key on the response pad was used for responses to left-pointing targets and the rightmost key for right-pointing ones). The task includes three different conditions: congruent, where the target arrow is flanked by arrows pointing to the same direction; incongruent, where the target and

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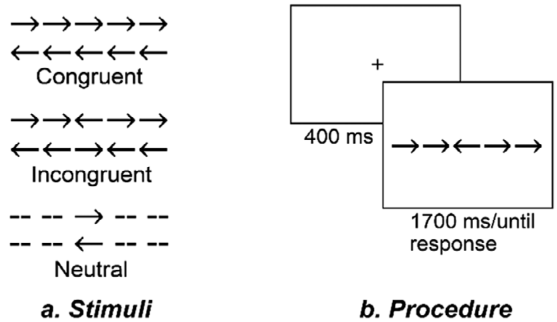

Figure 1. (A) Schematic overview for stimuli in the Flanker task. (B) Schematic diagram showing the procedure of the Flanker task.

flankers point in opposite directions; and neutral, where the target is flanked by dashes rather than arrows (Figure 1A). In each trial, an initial central fixation point (400 ms duration) was followed by an array of five arrows (1700 ms duration) (Figure 1B). Participants had a practice run consisting of 24 pseudo-randomized trials, followed by two experimental runs with 96 items per run (32 items of each condition) presented in a pseudo-randomized order.

2.6. Statistical analyses

All statistical analyses were conducted using Stata 17 (StataCorp, 2021). In order to conduct analysis on the Flanker task's reaction times (RTs), we removed error trials, false-start trials with RTs below 200 ms, and outlier trials, i.e., those falling outside 3 standard deviations from the individual participants' mean RT values. This preprocessing procedure resulted in the discarding of 1.13% of the total data. Neutral trials were also removed. Subsequently, we calculated the Flanker conflict effect for each participant as the difference between the average RTs in incongruent and congruent trials (Eriksen & Eriksen, 1974). The conflict effect is taken as an individual measure of the 'cognitive cost' of processing the conflicting information contained in the incongruent trials, as compared to the congruent ones.

To examine the individual effects of bilingual experience, sleep quality, and their interactive effect on executive inhibitory performance, we first built a full linear regression model with Flanker conflict effect as the dependent variable. The independent variables included main effects of L2 exposure, L2 AoA, L2 proficiency and PSQI score, as well as interactions between each bilingual experience factor and PSQI score. Covariates included age, sex, general intelligence, SES and maximal educational attainment – all factors known to affect executive performance. We applied a backward stepwise search via Stata's *stepwise* command starting from the full model and aiming to identify the most parsimonious model – by sequentially removing variables that did not contribute significantly to the model fit (p value > 0.2).

3. Results

The best fitting model included main effects of L2 AoA, L2 exposure and PSQI score, as well as interactions between L2 AoA and PSQI score, L2 exposure and PSQI score, and L2 proficiency and PSQI score. Covariates for age, SES, sex and education were also retained. Significant interactions emerged between PSQI score and each of the three bilingual experience exponents, L2 AoA ($\beta = 1.307$; $p = 0.005$), L2 proficiency ($\beta = -0.824$; $p = 0.028$) and L2 exposure ($\beta = 0.26$; $p = 0.014$). After model estimation, we estimated the marginal effect of each of the three interactions via Stata's *margins* command. For L2 proficiency and L2 AoA, the effect plot revealed that the beneficial effect of bilingual experience on Flanker performance (i.e., smaller conflict effect) was limited to poor sleepers (see Figure 2, panels a and b). For L2 exposure, the opposite trend emerged, with increasing exposure predicting a smaller conflict effect only for good sleepers (see Figure 2, panel c). Full model estimates are reported in Table 2.

4. Experiment 2

Relying on the PSQI as a questionnaire for subjective sleep quality provides numerous advantages. It is the most widely used tool and has been shown to be reliable and valid. Nevertheless, questions regarding the factor model, large recall period and scoring system are the main controversial issues that cause debate on the value of the global PSQI score when it comes to distinguishing between poor and good sleepers. Besides that, it is important to note that poor sleep quality can be a crucial symptom of many sleep disorders, in particular, insomnia (Fabbri et al., 2021). Considering the findings from Experiment 1, as well as the potential disadvantages of the PSQI, we designed another experiment (Experiment 2) using a more specific and sensitive measure of insomnia – the Insomnia Severity Index (ISI). The ISI measures perceived insomnia severity, focusing on the level of disturbance to the sleep pattern and on the consequences of insomnia (Bastien et al., 2001). The ISI is a widely used instrument for insomnia screening and treatment, as well as for research focusing on insomnia. It has been productively employed in both clinical settings and sleep research across a range of populations (Jun et al., 2022). In order to make results comparable, in Experiment 2, we followed the same procedure as in Experiment 1.

4.1. Participants

A different cohort of 42 Russian-English bilinguals (13 males; mean age = 20.55, SD ± 3.02) was recruited from the HSE University student population. All participants acquired English as an L2 formally through formal instruction at school and use it regularly but to a limited extent, due to residing in a predominantly L1-speaking environment. As for Experiment 1, the requirements to participate included the absence of psychiatric or neurological conditions and normal or corrected-to-normal vision. The same type of sociodemographic and linguistic background data as in Experiment 1 were collected (see Table 3). The study was approved by the local research ethics committee at HSE University, and written informed consent was obtained from each participant.

4.2. Procedure

The procedure for bilingual experience and executive performance assessments, as well as various questionnaires, was the same as in Experiment 1, except that participants filled out the Russian version of the ISI questionnaire instead of the PSQI, as detailed below. All tasks were performed in one experimental session, which lasted around 60 min.

4.3. Insomnia assessment

To obtain a more sensitive and specific measure of insomnia, we used the ISI – a seven-item questionnaire related to subjective qualities of the respondent's sleep, including the severity of symptoms, the respondent's satisfaction with their sleep patterns, the

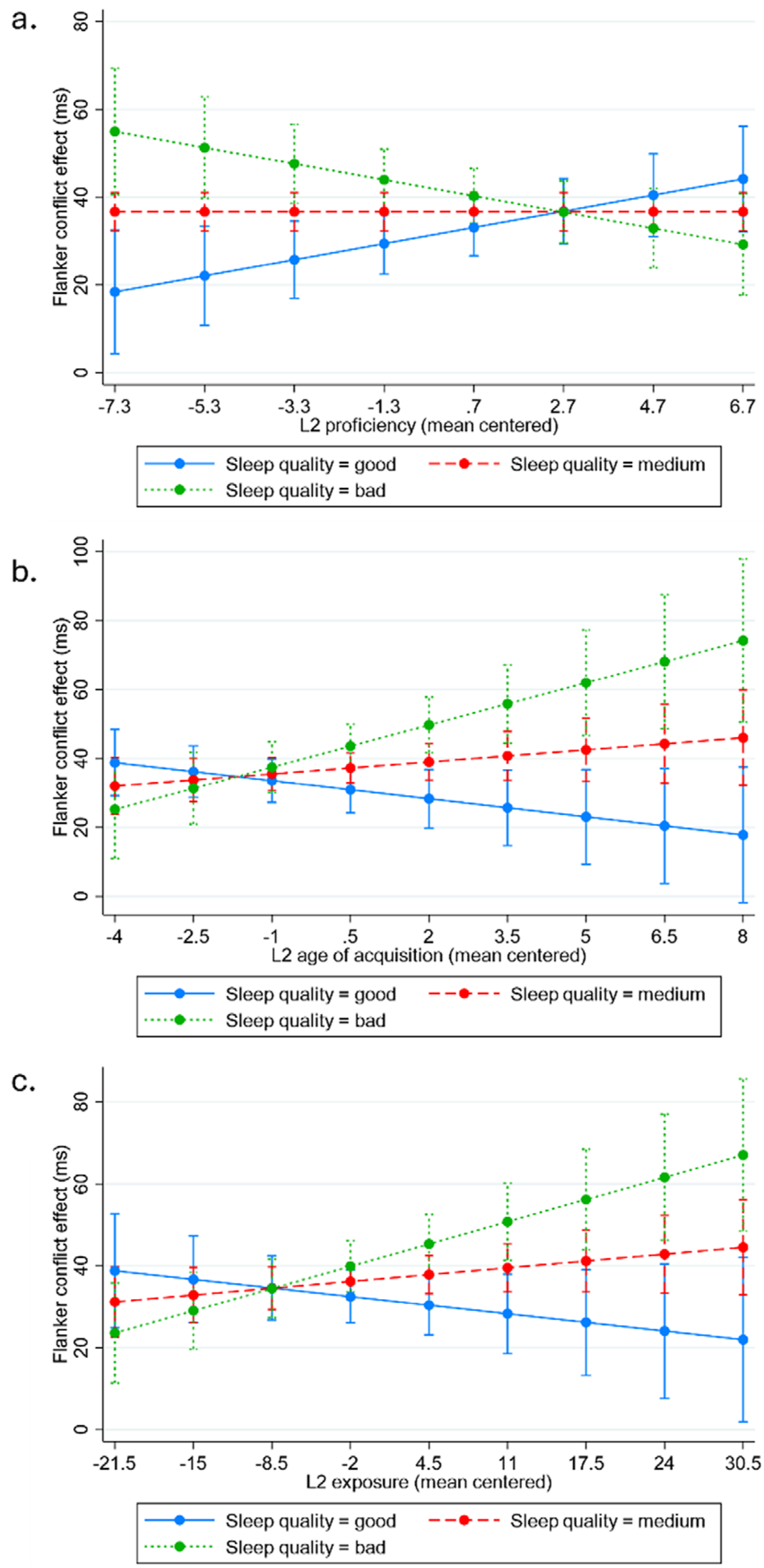

Figure 2. Interaction plot for the two-way interaction between bilingual experience factors*sleep quality predicting Flanker conflict effect (in ms). The conflict effect was calculated as the difference between the average individual RTs in the incongruent and congruent conditions. (A) L2 proficiency, (B) L2 age of acquisition, (C) L2 exposure. For graphical representation purposes, here we selected three representative values of PSQI score, i.e., 1 SD below the mean, mean and 1 SD above the mean, to represent three levels of sleep quality in our sample, i.e., good, medium and bad, respectively. Please note that the PSQI score was inserted as a continuous variable in the statistical model.

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Table 2. Estimates from the best-fitting linear model predicting Flanker conflict effect (in ms) based on the interaction between bilingual experience factors and PSQI score

Conflict effect (ms)	β	Standard error	t	p > |t|	[95% conf. interval]	
L2 exposure × PSQI score	0.259907	0.0993263	2.62	0.014	0.0567618	0.4630521
L2 age of acquisition × PSQI score	1.307253	0.4337738	3.01	0.005	0.4200859	2.19442
L2 proficiency × PSQI score	−0.8237275	0.3556874	−2.32	0.028	−1.55119	−.0962651
Socioeconomic status (level 6 versus level 1)	12.16879	5.558334	2.19	0.037	0.8007157	23.53686
L2 age of acquisition	1.166414	0.8204969	1.42	0.166	−0.5116909	2.844518
L2 exposure	0.2558442	0.1706323	1.50	0.145	−0.0931381	0.6048266
PSQI score	2.180288	1.0293	2.12	0.043	0.0751329	4.285443
Sex (male versus female)	18.11202	5.594481	3.24	0.003	6.670023	29.55402
Age	2.818677	1.370847	2.06	0.049	0.0149808	5.622374
Years of education	−7.667623	2.036794	−3.76	0.001	−11.83333	−3.501911
Intercept	29.73809	2.853069	10.42	0.000	23.90291	35.57327

Note: All variables are mean-centered.

Table 3. Sociodemographic and L2 background profiles of participants

Variable	Mean (SD)	Range (min and max)
Age (years)	20.55 (3.02)	18–34
Education (years)	13.71 (1.94)	11–19
SES (band)	3.79 (2.03)	1–6
Raven's matrices (score)	14.45 (0.71)	12–15
L2 AoA (years)	7.93 (2.66)	3–15
L2 exposure (daily percentage)	19.11 (12.39)	2–51
L2 proficiency (score)	16.57 (4.07)	8–25
ISI (score)	5.93 (3.63)	0–14

Note: Mean, standard deviation (SD) and range are provided for each measure.

degree to which insomnia interferes with daily functioning, how noticeable the respondent perceives their insomnia is to others and the overall level of distress caused by the sleep problem (Morin et al., 2011). Its content overlaps with the diagnostic criteria of insomnia listed in the Diagnostic and Statistical Manual of Mental Disorders (DSM-V). Additionally, the ISI is a powerful measure for research purposes due to its high reliability, validity and sensitivity (Bastien et al., 2001).

4.4. Statistical analyses

The same approach to data filtering as well as statistical analyses as in Experiment 1 was used in Experiment 2. Here, we built a full linear regression model with Flanker conflict effect as the dependent variable and main effects of L2 exposure, L2 AoA, L2 proficiency and ISI score, as well as interactions between each bilingual experience factor and ISI score, as predictors. As in Experiment 1, covariates included age, sex, general intelligence, SES and maximal educational attainment.

5. Results

The best-fitting model in Experiment 2 included SES and the interaction term between L2 AoA and ISI. While following the expected direction and in line with results from Experiment 1 (see Figure 3, panel a), this interaction only showed a trend towards significance, but did not reach the alpha level of 0.05 (β = 0.935; p = 0.092; full model estimates reported in Table 4).

As discussed in the Introduction, the effects of insomnia on cognitive performance are more difficult to observe at the behavioral level than effects related to general sleep quality. As a result, we hypothesize that the effect of interest might not have been sufficiently strong to emerge in our sample of 42 participants. For this reason, we conducted an additional exploratory analysis using a single-trial linear mixed regression focusing on the interaction between L2 AoA and ISI, to increase the statistical power of our model (see Baayen et al., 2008). Indeed, this approach allowed us to increase the number of data points per participant from 1 (one measure of the conflict effect) to 128 (one for each individual trial). However, it prevented us from using the Flanker conflict effect as a dependent variable, since averages had been substituted with single-trial RTs. To overcome this issue, we included an interaction term for trial type (congruent versus incongruent) in our model, to ensure that our effect of interest was observed independently in the congruent and incongruent conditions. Thus, we tested the model with single-trial Flanker RTs as the dependent variable, main effects of trial type, L2 AoA, ISI score and their interaction as independent variables, as well as covariates for age, sex, general intelligence, SES and maximal educational attainment. Random effects included random intercepts for individual participants and random slopes for single trials. Our analysis revealed a significant interaction between L2 AoA, ISI score and Flanker trial type (β = 0.884; $p < 0.001$). After model estimation, we estimated the marginal effect of the interaction via Stata's *margins* command. The interaction plot shows that, for all levels of insomnia severity, earlier L2 AoA predicted improved Flanker performance (i.e., lower RTs), differentially for congruent and incongruent trials. Importantly, the strength of this relationship increased with increasing insomnia severity (see Figure 3, panel b). Full model estimates are reported in Table 5.

6. Discussion

The two experiments presented here aimed at investigating the putative relationship between bilingualism and sleep quality/

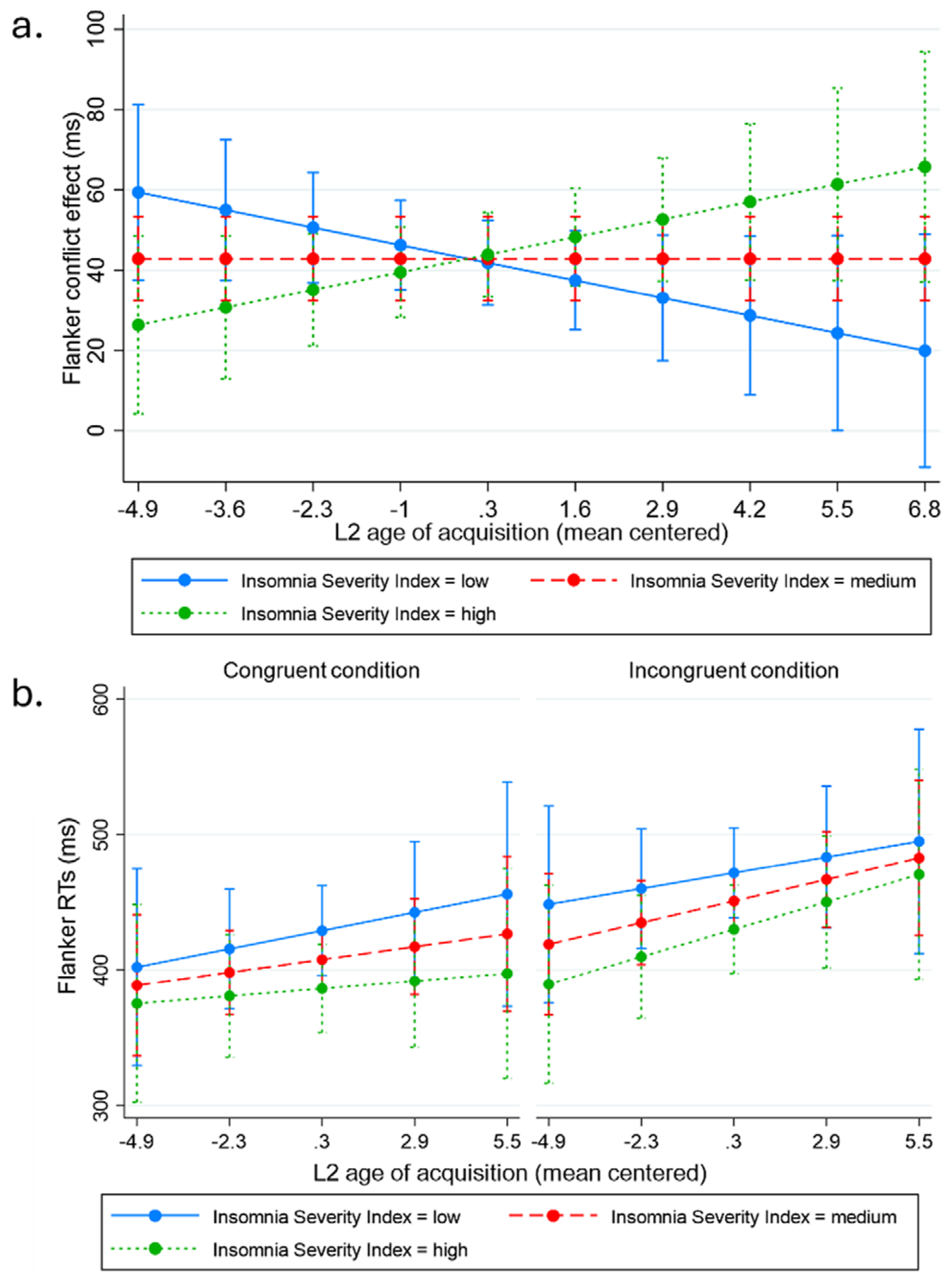

Figure 3. (A) Interaction plot for the two-way interaction between L2 age of acquisition*insomnia-related symptoms predicting Flanker conflict effect (in ms). The conflict effect was calculated as the difference between the average individual RTs in the incongruent and congruent conditions. For graphical representation purposes, the three levels of ISI selected for plotting (low, medium, high) are represented as 1 SD below the mean, mean, and 1 SD above the mean of our sample, respectively. Please note that ISI score was inserted as a continuous variable in the statistical model. (B) Interaction plot for the three-way interaction between L2 age of acquisition*insomnia-related symptoms*task condition predicting Flanker RTs (in ms). For graphical representation purposes, the three levels of ISI selected for plotting (low, medium, high) are represented as 1 SD below the mean, mean, and 1 SD above the mean of our sample, respectively. Please note that ISI score was inserted as a continuous variable in the statistical model.

Table 4. Estimates from the best-fitting linear model predicting Flanker conflict effect (in ms) based on the interaction between bilingual experience factors and ISI score

Conflict effect (ms)	*β*	Standard error	*t*	P > |t|	[95% conf. interval]	
Socioeconomic status (level 4 versus level 1)	27.35267	14.78856	1.85	0.072	−2.560021	57.26536
L2 age of acquisition × ISI score	0.9354986	0.5423166	1.73	0.092	−.1614402	2.032437
Intercept	38.96034	5.589609	6.97	0.000	27.65429	50.2664

Note: All variables are mean-centered.

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Table 5. Estimates from the single-trial linear mixed model predicting Flanker RTs (in ms) based on the interaction between L2 age of acquisition and ISI

Flanker raw RTs	*β*	Standard error	z	*p* > |*z*|	[95% conf. interval]	
Trial type (incongruent versus congruent)	42.435	2.179	19.47	0.000	38.164	46.705
L2 age of acquisition	3.652	4.922	0.74	0.458	−5.995	13.300
Trial type (incongruent versus congruent) × L2 age of acquisition	2.478	0.830	2.99	0.003	0.852	4.104
ISI score	−5.804	3.477	−1.67	0.095	−12.618	1.010
Trial type (incongruent versus congruent) × ISI score	−0.124	0.612	−0.20	0.839	−1.324	1.075
L2 age of acquisition X ISI score	−0.424	1.296	−0.33	0.743	−2.964	2.116
Trial type (incongruent versus congruent) × L2 age of acquisition × ISI score	0.884	0.231	3.83	0.000	0.431	1.337
Sex (male versus female)	−9.994	28.233	−0.35	0.723	−65.329	45.341
Ravens matrices score	11.360	17.686	0.64	0.521	−23.304	46.025
Years of education	4.153	10.321	0.40	0.687	−16.075	24.381
Socioeconomic status (level 3 versus level 1)	−48.493	48.421	−1.00	0.317	−143.396	46.410
Socioeconomic status (level 4 versus level 1)	−57.494	41.412	−1.39	0.165	−138.659	23.671
Socioeconomic status (level 5 versus level 1)	−123.152	44.546	−2.76	0.006	−210.461	−35.844
Socioeconomic status (level 6 versus level 1)	−85.983	49.680	−1.73	0.083	−183.354	11.388
Socioeconomic status (level 7 versus level 1)	−61.369	33.579	−1.83	0.068	−127.182	4.444
Age	−2.874	6.527	−0.44	0.660	−15.667	9.919
Intercept	463.949	24.433	18.99	0.000	416.061	511.837

insomnia-related symptoms in their capacity to affect cognitive performance. For this purpose, we tested the interactive contribution of these two factors on EF performance at the behavioral level. Our results, for the first time, reveal an interplay between bilingualism and sleep quality in their capacity to affect EF performance by showing that the degree of bilingualism (as indexed by L2 proficiency and L2 AoA) may compensate for the detrimental effects of poor sleep quality upon EF. On the other hand, no such L2 effects were present for those reporting good sleep quality. This tendency was further corroborated for insomnia-related symptoms, known to deplete cognitive resources. This novel finding supports the argument by Valian (2015), suggesting that since young adults are at cognitive peak, to observe bilingualism-induced cognitive effects in this population, cognitive resources must be effectively depleted. Our data support this view by showing that, in young bilinguals, bilingualism-induced effects on EF only emerged when poor sleep quality and insomnia symptoms negatively affected cognitive resources. This result suggests that we should be more cautious in interpreting null results with regard to the effects of bilingualism on cognitive performance, especially in young population samples. Among other things, we would like to emphasize that we do not determine these relationships as causal, but rather as mediated relationships that appear as a byproduct of the intersection of bilingualism and sleep, which have an impact on the same cognitive functions. Furthermore, our study sheds light on the fact that previously reported inconsistent findings can be a consequence of the failure to control for the effects of confounding factors, which might affect cognition. Indeed, had we not controlled for the sleep-related effects observed in our samples, we might have reported the absence of any bilingualism-induced cognitive effects in our study, which would clearly constitute a Type 2 error. This suggests that future bilingualism studies should control for individual sleep quality/disturbances profiles, aiming to establish a balance between testing efficiency and testing adequacy. For similar reasons, future studies investigating the cognitive effects of sleep quality/disturbances should also control for the language background of participants.

Another important finding from Experiment 1 is that L2 exposure's effect followed an inverse trend as compared to the L2 proficiency and L2 AoA effects. Indeed, while the beneficial effect of increasing proficiency and AoA on Flanker performance emerged for poor sleepers, that of exposure emerged for good sleepers. This is a somewhat unexpected finding; nevertheless, we think it deserves a putative mechanistic explanation.

Note that our analyses used several partially overlapping yet distinct bilingual experience factors that tap into different aspects of bilingual experience. One interpretation is that the sociolinguistic setting – with participants being primarily dominant in their L1 and living in an environment that reflected this dominance – underscored the multifaceted nature of bilingual experience. First of all, exposure on the one hand, and AoA and proficiency on the other, might index different facets of bilingual experience. While exposure *per se* most clearly indexes *quantity* of engagement with an L2, earlier AoA (i.e., contact with L2 beginning in more 'plastic' stages of neurocognitive development) and achieved higher proficiency go beyond, indexing *qualitative* aspects of opportunities for meaningful engagement with individual bilingual experience. Indeed, in an L1-dominant environment, the relationship between a degree of engagement and resulting level of L2 fluency may vary as a function of individual factors such as the meaningfulness (i.e., quality and timing) of engagement and the individual propensity to (language) learning. As such, one could expect exposure and proficiency/AoA to produce different cognitive consequences in a sociolinguistic context like the one sampled in the current investigation.

A different pattern, instead, could be expected in L2-immersive contexts, where individuals experience more consistent engagement with L2. In such a context, the cognitive adaptations associated with bilingualism may go beyond what can be accounted for by L2 proficiency alone (see DeLuca et al., 2019b; Pereira Soares et al., 2022). To evaluate this possibility, further research is necessary that directly compares bilingual experiences across diverse sociolinguistic settings. Indeed, existing research supports the notion of partially *differential* contributions of proficiency and exposure to bilinguals' cognitive functioning (Bonfieni et al., 2019; DeLuca et al., 2019b; Pereira Soares et al., 2022). Similarly, our own research, both published and under review, reports a similar dissociation between different exponents of bilingual experience emerging in the same type of sociolinguistic context (Gallo et al., 2021, 2025, under review). Most importantly, our results confirm that bilingual experience can still affect cognition, though the average exposure in our participants across various modalities in both experiments was relatively low – ranging roughly between 2% and 60% of daily time, since they resided in a predominantly L1-speaking environment. Further research is needed to clarify the specific contribution of different aspects of bilingual experience in various bilingual populations, as well as their detailed relationship with sleep quality.

It is also important to note that our results have several practical implications. First, they may inform our understanding of how bilingualism mitigates the effects of cognitive aging. Of note, high degrees of bilingualism have been shown to be associated with cognitive reserve accrual and, as such, to act as a neuroprotective factor (Gallo et al., 2022). Previous studies emphasized that the build-up of this cognitive reserve begins in youth (e.g., Gallo et al., 2024). Thus, we can hypothesize that under the right conditions, bilingualism can compensate for cognitive detriments stemming from poor sleep quality. In addition, our findings draw attention to sleep as an important factor to consider when investigating language learning and general memory functioning: Although research is available on the topic of sleep and language learning (see e.g., Rasch, 2017), future studies will need to examine in more detail how sleep quality/deprivation is associated with learning additional languages (Dumay & Gaskell, 2007). The results presented here highlight the potential of a broader empirical study at the intersection of bilingual language learning and usage, sleep and cognitive science to identify behavioral consequences and to uncover the underlying neurocognitive architecture of the interactions between sleep and bilingualism.

Finally, it is important to highlight methodological issues that may limit the generalizability of our findings. While subjective sleep quality assessment instruments like PSQI and ISI are useful due to their affordability and ease of use, they do not offer a full and objective picture of participants' profiles. The dissociation between subjective and objective sleep quality has been shown to lead to inconsistent results (Zavecz et al., 2020). Consequently, our findings need to be considered with a degree of caution. Future studies should include objective sleep quality assessments, such as electrophysiological measures.

Data availability statement. The data that support the findings of this study are available on request.

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Competing interests. The authors declare that they have no competing interests.

References

Abutalebi, J., Annoni, J. M., Zimine, I., Pegna, A. J., Seghier, M. L., Lee-Jahnke, H., Lazeyras, F., Cappa, S. F., & **Khateb, A.** (2007). Language control and lexical competition in bilinguals: An event-related FMRI study. *Cerebral Cortex*, **18**(7), 1496–1505. https://doi.org/10.1093/cercor/bhm182

Abutalebi, J., Della Rosa, P. A., Green, D. W., Hernández, M., Scifo, P., Keim, R., Cappa, S. F., & **Costa, A.** (2011). Bilingualism tunes the anterior cingulate cortex for conflict monitoring. *Cerebral Cortex*, **22**(9), 2076–2086. https://doi.org/10.1093/cercor/bhr287

Abutalebi, J., & **Green, D. W.** (2007). Bilingual language production: The neurocognition of language representation and control. *Journal of Neurolinguistics*, **20**(3), 242–275. https://doi.org/10.1016/j.jneuroling.2006.10.003

Abutalebi, J., & **Green, D. W.** (2016). Neuroimaging of language control in bilinguals: Neural adaptation and reserve. *Bilingualism: Language and Cognition*, **19**(4), 689–698. https://doi.org/10.1017/s1366728916000225

Aidman, E., Jackson, S., & **Kleitman, S.** (2018). Effects of sleep deprivation on executive functioning, cognitive abilities, metacognitive confidence, and decision making. *Applied Cognitive Psychology*, **33**(2), 188–200. https://doi.org/10.1002/acp.3463

Altena, E., Vrenken, H., Van Der Werf, Y. D., Van Den Heuvel, O. A., & **Van Someren, E. J.** (2010). Reduced orbitofrontal and parietal gray matter in chronic insomnia: A voxel-based morphometric study. *Biological Psychiatry*, **67**(2), 182–185. https://doi.org/10.1016/j.biopsych.2009.08.003

Anderson, J. A. E., Hawrylewicz, K., & **Grundy, J. G.** (2020). Does bilingualism protect against dementia? A meta-analysis. *Psychonomic Bulletin & Review*, **27**(5), 952–965. https://doi.org/10.3758/s13423-020-01736-5

Baayen, R. H., Davidson, D. J., & **Bates, D. M.** (2008). Mixed-effects modeling with crossed random effects for subjects and items. *Journal of Memory and Language*, **59**(4), 390–412.

Barclay, N. L., & **Myachykov, A.** (2016). Sustained wakefulness and visual attention: Moderation by chronotype. *Experimental Brain Research*, **235**(1), 57–68. https://doi.org/10.1007/s00221-016-4772-8

Barclay, N. L., Rowley, S., Robson, A., Akram, U., & **Myachykov, A.** (2020). Sleep duration, sleep variability, and impairments of visual attention. *Quarterly Journal of Experimental Psychology*, **73**(6), 868–880. https://doi.org/10.1177/1747021819895771

Bastien, C., Vallières, A., & **Morin, C. M.** (2001). Validation of the Insomnia Severity Index as an outcome measure for insomnia research. *Sleep Medicine*, **2**(4), 297–307. https://doi.org/10.1016/s1389-9457(00)00065-4

Bialystok, E. (2016). Bilingual education for young children: Review of the effects and consequences. *International Journal of Bilingual Education and Bilingualism*, **21**(6), 666–679. https://doi.org/10.1080/13670050.2016.1203859

Bialystok, E. (2017). The bilingual adaptation: How minds accommodate experience. *Psychological Bulletin*, **143**(3), 233–262. https://doi.org/10.1037/bul0000099

Bialystok, E., & **Craik, F. I. M.** (2022). How does bilingualism modify cognitive function? Attention to the mechanism. *Psychonomic Bulletin & Review*, **29**(4), 1246–1269. https://doi.org/10.3758/s13423-022-02057-5

Bialystok, E., Craik, F. I. M., Green, D. W., & **Gollan, T. H.** (2009). Bilingual minds. *Psychological Science in the Public Interest*, **10**(3), 89–129. https://doi.org/10.1177/1529100610387084

Bialystok, E., Craik, F. I. M., & **Luk, G.** (2012). Bilingualism: Consequences for mind and brain. *Trends in Cognitive Sciences*, **16**(4), 240–250. https://doi.org/10.1016/j.tics.2012.03.001

Bonfieni, M., Branigan, H. P., Pickering, M. J., & **Sorace, A.** (2019). Language experience modulates bilingual language control: The effect of proficiency, age of acquisition, and exposure on language switching. *Acta Psychologica*, **193**, 160–170. https://doi.org/10.1016/j.actpsy.2018.11.004

Brini, S., Sohrabi, H. R., Hebert, J. J., Forrest, M. R. L., Laine, M., Hämäläinen, H., Karrasch, M., Peiffer, J. J., Martins, R. N., & **Fairchild, T. J.** (2020). Bilingualism is associated with a delayed onset of dementia but not with a lower risk of developing it: A systematic review with meta-analyses. *Neuropsychology Review*, **30**(1), 1–24. https://doi.org/10.1007/s11065-020-09426-8

Buysse, D. J., Reynolds, C. F., Monk, T. H., Berman, S. R., & **Kupfer, D. J.** (1989). The Pittsburgh sleep quality index: A new instrument for psychiatric practice and research. *Psychiatry Research*, **28**(2), 193–213. https://doi.org/10.1016/0165-1781(89)90047-4

Cellini, N. (2017). Memory consolidation in sleep disorders. *Sleep Medicine Reviews*, **35**, 101–112. https://doi.org/10.1016/j.smrv.2016.09.003

Diamond, A. (2013). Executive functions. *Annual Review of Psychology*, **64**(1), 135–168. https://doi.org/10.1146/annurev-psych-113011-143750

De Bruin, A., **Treccani, B.**, & **Della Sala, S.** (2014). Cognitive advantage in bilingualism. *Psychological Science*, **26**(1), 99–107. https://doi.org/10.1177/0956797614557866

DeLuca, V., **Rothman, J.**, **Bialystok, E.**, & **Pliatsikas, C.** (2019a). Redefining bilingualism as a spectrum of experiences that differentially affects brain structure and function. *Proceedings of the National Academy of Sciences of the United States of America*, **116**(15), 7565–7574. https://doi.org/10.1073/pnas.181151311

DeLuca, V., **Rothman, J.**, & **Pliatsikas, C.** (2019b). Linguistic immersion and structural effects on the bilingual brain: A longitudinal study. *Bilingualism: Language and Cognition*, **22**(5), 1160–1175. https://doi.org/10.1017/S1366728918000883

Dresler, M., **Sandberg, A.**, **Ohla, K.**, **Bublitz, C.**, **Trenado, C.**, **Mroczko-Wąsowicz, A.**, **Kühn, S.**, & **Repantis, D.** (2013). Non-pharmacological cognitive enhancement. *Neuropharmacology*, **64**, 529–543. https://doi.org/10.1016/j.neuropharm.2012.07.002

Dumay, N., & **Gaskell, M. G.** (2007). Sleep-associated changes in the mental representation of spoken words. *Psychological Science*, **18**(1), 35–39. https://doi.org/10.1111/j.1467-9280.2007.01845.x

Durmer, J. S., & **Dinges, D. F.** (2005). Neurocognitive consequences of sleep deprivation. *Seminars in Neurology*, **25**(01), 117–129. https://doi.org/10.1055/s-2005-867080

Eriksen, B. A., & **Eriksen, C. W.** (1974). Effects of noise letters upon the identification of a target letter in a nonsearch task. *Perception & Psychophysics*, **16**(1), 143–149. https://doi.org/10.3758/bf03203267

Fabbri, M., **Beracci, A.**, **Martoni, M.**, **Meneo, D.**, **Tonetti, L.**, & **Natale, V.** (2021). Measuring subjective sleep quality: A review. *International Journal of Environmental Research and Public Health/International Journal of Environmental Research and Public Health*, **18**(3), 1082. https://doi.org/10.3390/ijerph18031082

Falgàs, N., **Illán-Gala, I.**, **Allen, I. E.**, **Mumford, P.**, **Essanaa, Y. M.**, **Le, M. M.**, **You, M.**, **Grinberg, L. T.**, **Rosen, H. J.**, **Neylan, T. C.**, **Kramer, J. H.**, & **Walsh, C. M.** (2021). Specific cortical and subcortical grey matter regions are associated with insomnia severity. *PLOS ONE*, **16**(5), e0252076. https://doi.org/10.1371/journal.pone.0252076

Fortier-Brochu, É., **Beaulieu-Bonneau, S.**, **Ivers, H.**, & **Morin, C. M.** (2012). Insomnia and daytime cognitive performance: A meta-analysis. *Sleep Medicine Reviews*, **16**(1), 83–94. https://doi.org/10.1016/j.smrv.2011.03.008

Gallo, F., **DeLuca, V.**, **Prystauka, Y.**, **Voits, T.**, **Rothman, J.**, & **Abutalebi, J.** (2022). Bilingualism and aging: Implications for (delaying) neurocognitive decline. *Frontiers in Human Neuroscience*, **16**, 819105. https://doi.org/10.3389/fnhum.2022.819105

Gallo, F., **Myachykov, A.**, **Abutalebi, J.**, **DeLuca, V.**, **Ellis, J.**, **Rothman, J.**, & **Wheeldon, L. R.** (2025). Bilingualism, sleep, and cognition: An integrative view and open research questions. *Brain and Language*, **260**, 105507. https://doi.org/10.1016/j.bandl.2024.105507

Gallo, F., **Novitskiy, N.**, **Myachykov, A.**, & **Shtyrov, Y.** (2021). Individual differences in bilingual experience modulate executive control network and performance: Behavioral and structural neuroimaging evidence. *Bilingualism: Language and Cognition*, **24**(2), 293–304.

Gallo, F., **Terekhina, L.**, **Abutalebi, J.**, **Shtyrov, Y.**, & **Myachykov, A.** (2025). Cognitive efficiency and expertise-dependent automaticity in the working memory performance of bilinguals. *Brain and Cognition*, **187**, 106308.

Gallo, F., **DeLuca, V.**, **Rothman, J.**, **Abutalebi, J.**, **Shtyrov, Y.**, & **Myachykov, A.** (under review). Automaticity-related neurocognitive modulations of the cerebellum in bilinguals: Evidence from structural MRI. *Cognition*.

Gallo, F., **Terekhina, L.**, **Shtyrov, Y.**, & **Myachykov, A.** (2024). Neuroplasticity and cognitive reserve effects in the Caudate Nucleus of young bilingual adults. *Bilingualism: Language and Cognition*, **27**(1), 107–116. https://doi.org/10.1017/s1366728923000457

Green, D. W., & **Abutalebi, J.** (2013). Language control in bilinguals: The adaptive control hypothesis. *Journal of Cognitive Psychology*, **25**(5), 515–530. https://doi.org/10.1080/20445911.2013.796377

Grosjean, F. (2021). *The extent of bilingualism. In Life as a Bilingual: Knowing and Using Two or More Languages* (pp. 27–39). Cambridge University Press. https://doi.org/10.1017/9781108975490.003

Grundy, J. G. (2020). The effects of bilingualism on executive functions: An updated quantitative analysis. *Journal of Cultural Cognitive Science*, **4**(2), 177–199. https://doi.org/10.1007/s41809-020-00062-5

Guttesen, A. Á. V., **Gaskell, M. G.**, **Madden, E. V.**, **Appleby, G.**, **Cross, Z. R.**, & **Cairney, S. A.** (2022). Sleep loss disrupts the neural signature of successful learning. *Cerebral Cortex*, **33**(5), 1610–1625. https://doi.org/10.1093/cercor/bhac159

Haimov, I., **Hanuka, E.**, & **Horowitz, Y.** (2008). Chronic insomnia and cognitive functioning among older adults. *Behavioral Sleep Medicine*, **6**(1), 32–54. https://doi.org/10.1080/15402000701796080

Harris, K., **Spiegelhalder, K.**, **Espie, C. A.**, **Macmahon, K.**, **Woods, H.**, & **Kyle, S. D.** (2015). Sleep-related attentional bias in insomnia: A state-of-the-science review. *Clinical Psychology Review*, **42**, 16–27. https://doi.org/10.1016/j.cpr.2015.08.001

Jackson, M. L., **Gunzelmann, G.**, **Whitney, P.**, **Hinson, J. M.**, **Belenky, G.**, **Rabat, A.**, & **Van Dongen, H. P. A.** (2013). Deconstructing and reconstructing cognitive performance in sleep deprivation. *Sleep Medicine Reviews*, **17**(3), 215–225. https://doi.org/10.1016/j.smrv.2012.06.007

Jean-Louis, G., **Kripke, D. F.**, & **Ancoli-Israel, S.** (2000). Sleep and quality of well-being. *SLEEP-NEW YORK-*, **23**(8), 1115–1121.

Joo, E. Y., **Noh, H.**, **Kim, J.**, **Koo, D. L.**, **Kim, D.**, **Hwang, K. J.**, **Kim, J. Y.**, **Kim, S. T.**, **Kim, M. R.**, & **Hong, S. B.** (2013). Brain gray matter deficits in patients with chronic primary insomnia. *Sleep*, **36**(7), 999–1007. https://doi.org/10.5665/sleep.2796

Jun, J., **Park, C. G.**, & **Kapella, M. C.** (2022). Psychometric properties of the Insomnia Severity Index for people with chronic obstructive pulmonary disease. *Sleep Medicine*, **95**, 120–125. https://doi.org/10.1016/j.sleep.2022.04.017

Koo, D. L., **Shin, J. H.**, **Lim, J. S.**, **Seong, J. K.**, & **Joo, E. Y.** (2017). Changes in subcortical shape and cognitive function in patients with chronic insomnia. *Sleep Medicine*, **35**, 23–26. https://doi.org/10.1016/j.sleep.2017.04.002

Krause, A., **Simon, E. B.**, **Mander, B. A.**, **Greer, S.**, **Saletin, J. M.**, **Goldstein-Piekarski, A. N.**, & **Walker, M. P.** (2017). The sleep-deprived human brain. *Nature Reviews Neuroscience*, **18**(7), 404–418. https://doi.org/10.1038/nrn.2017.55

Kroll, J. F., & **Bialystok, E.** (2013). Understanding the consequences of bilingualism for language processing and cognition. *Journal of Cognitive Psychology*, **25**(5), 497–514. https://doi.org/10.1080/20445911.2013.799170

Kroll, J. F., **Dussias, P. E.**, **Bice, K.**, & **Perrotti, L.** (2015). Bilingualism, mind, and brain. *Annual Review of Linguistics*, **1**(1), 377–394. https://doi.org/10.1146/annurev-linguist-030514-124937

Kuipers, J. R., & **Westphal, K. H.** (2020). Auditory processing and high task demands facilitate the bilingual executive control advantage in young adults. *Journal of Neurolinguistics*, **57**, 100954. https://doi.org/10.1016/j.jneuroling.2020.100954

Lehtonen, M., **Soveri, A.**, **Laine, A.**, **Järvenpää, J.**, **De Bruin, A.**, & **Antfolk, J.** (2018). Is bilingualism associated with enhanced executive functioning in adults? A meta-analytic review. *Psychological Bulletin*, **144**(4), 394–425. https://doi.org/10.1037/bul0000142

Leivada, E. (2023). A classification bias and an exclusion bias jointly overinflated the estimation of publication biases in bilingualism research. *Behavioral Sciences*, **13**(10), 812. https://doi.org/10.3390/bs13100812

Liu, H., **Wang, D.**, **Li, Y.**, **Li, Z.**, **Zhang, Y.**, **Lei, F.**, **Du, L.**, & **Tang, X.** (2014). Examination of daytime sleepiness and cognitive performance testing in patients with primary insomnia. *PLOS ONE*, **9**(6), e100965. https://doi.org/10.1371/journal.pone.0100965

Lowe, C. J., **Safati, A. B.**, & **Hall, P. A.** (2017). The neurocognitive consequences of sleep restriction: A meta-analytic review. *Neuroscience & Biobehavioral Reviews*, **80**, 586–604. https://doi.org/10.1016/j.neubiorev.2017.07.010

Lowe, C. J., **Cho, I.**, **Goldsmith, S. F.**, & **Morton, J. B.** (2021). The bilingual advantage in children's executive functioning is not related to language status: A meta-analytic review. *Psychological Science*, **32**(7), 1115–1146. https://doi.org/10.1177/0956797621993108

MacArthur foundation (2007) *The MacArthur research network on socioeconomic status and health*. https://macses.ucsf.edu/research/psychosocial/subjective.php#measurement

Marian, V., **Blumenfeld, H. K.**, & **Kaushanskaya, M.** (2007). The Language Experience and Proficiency Questionnaire (LEAP-Q): Assessing language profiles in bilinguals and multilinguals. *Journal of Speech Language and Hearing Research*, **50**(4), 940–967. https://doi.org/10.1044/1092-4388(2007/067

Morin, C. M., **Belleville, G.**, **Bélanger, L.**, & **Ivers, H.** (2011). The Insomnia Severity Index: Psychometric indicators to detect insomnia cases and evaluate treatment response. *SLEEP*, **34**(5), 601–608. https://doi.org/10.1093/sleep/34.5.601

Müller, L., **Howard, K.**, **Wilson, E.**, **Gibson, J.**, & **Katsos, N.** (2020). Bilingualism in the family and child well-being: A scoping review. *International Journal of Bilingualism*, **24**(5–6), 1049–1070. https://doi.org/10.1177/1367006920920939

Nguyen, V., **George, T.**, & **Brewster, G.** (2019). Insomnia in older adults. *Current Geriatrics Reports*, **8**(4), 271–290. https://doi.org/10.1007/s13670-019-00300-x

Paap, K. (2022). *The bilingual advantage in executive functioning hypothesis: How the debate provides insight into psychology's replication crisis*. Routledge.

Pereira Soares, S. M., **Prystauka, Y.**, **DeLuca, V.**, & **Rothman, J.** (2022). Type of bilingualism conditions individual differences in the oscillatory dynamics of inhibitory control. *Frontiers in Human Neuroscience*, **16**, 910910.

Perrier, J., **Chavoix, C.**, & **Bocca, M.** (2015). Functioning of the three attentional networks and vigilance in primary insomnia. *Sleep Medicine*, **16**(12), 1569–1575. https://doi.org/10.1016/j.sleep.2015.06.025

Rasch, B. (2017). Sleep and language learning. *Brain and language*, **167**, 1–2.

Raven, J. C. (1958). *Guide to using the coloured progressive matrices*. H. K. Lewis & Co.

Sari, B. T., **Chasiotis, A.**, **Van De Vijver, F. J.**, & **Bender, M.** (2019). We feel better when we speak common language; Affective well-being in bilingual adolescents from three ethnic groups in Indonesia. *International Journal of Intercultural Relations*, **71**, 84–95. https://doi.org/10.1016/j.ijintrel.2019.05.002

Sivertsen, B., **Hysing, M.**, **Wehling, E.**, **Pallesen, S.**, **Nordhus, I. H.**, **Espeseth, T.**, & **Lundervold, A. J.** (2013). Neuropsychological performance in older insomniacs. *Aging Neuropsychology and Cognition*, **20**(1), 34–48. https://doi.org/10.1080/13825585.2012.672947

StataCorp. (2021). *Stata statistical software: Release 17*. College Station, TX: StataCorp LLC.

Stoffers, D., **Altena, E.**, **Van Der Werf, Y. D.**, **Sanz-Arigita, E.**, **Voorn, T.**, **Astill, R. G.**, **Strijers, R.**, **Waterman, D.**, & **Van Someren, E. J.** (2013). The caudate: A key node in the neuronal network imbalance of insomnia? *Brain*, **137**(2), 610–620. https://doi.org/10.1093/brain/awt329

Tai, X. Y., **Chen, C.**, **Manohar, S.**, & **Husain, M.** (2022). Impact of sleep duration on executive function and brain structure. *Communications Biology*, **5**(1). https://doi.org/10.1038/s42003-022-03123-3

Tao, L., **Wang, G.**, **Zhu, M.**, & **Cai, Q.** (2021). Bilingualism and domain-general cognitive functions from a neural perspective: A systematic review. *Neuroscience & Biobehavioral Reviews*, **125**, 264–295. https://doi.org/10.1016/j.neubiorev.2021.02.029

Taylor, C., **Hall, S.**, **Manivannan, S.**, **Mundil, N.**, & **Border, S.** (2022). The neuroanatomical consequences and pathological implications of bilingualism. *Journal of Anatomy*, **240**(2), 410–427. https://doi.org/10.1111/joa.13542

Valian, V. (2015). Bilingualism and cognition. *Bilingualism: Language and Cognition*, **18**(1), 3–24. https://doi.org/10.1017/s1366728914000522

Van, N. H. D. B., **Pozzobon, A.**, **Fang, Z.**, **Al-Kuwatli, J.**, **Toor, B.**, **Ray, L. B.**, & **Fogel, S.** (2021). Sleep enhances consolidation of memory traces for complex Problem-Solving skills. *Cerebral Cortex*, **32**(4), 653–667. https://doi.org/10.1093/cercor/bhab216

Van Den Noort, M., **Struys, E.**, **Bosch, P.**, **Jaswetz, L.**, **Perriard, B.**, **Yeo, S.**, **Barisch, P.**, **Vermeire, K.**, **Lee, S.**, & **Lim, S.** (2019). Does the bilingual advantage in cognitive control exist and if so, what are its modulating factors? A systematic review. *Behavioral Sciences*, **9**(3), 27. https://doi.org/10.3390/bs9030027

Wang, J., & **Wei, R.** (2023). Is bilingualism linked to well-being? Evidence from a big-data survey. *Bilingualism Language and Cognition*, **27**(4), 546–556. https://doi.org/10.1017/s1366728923000603

Ware, A. T., **Kirkovski, M.**, & **Lum, J. a. G.** (2020). Meta-Analysis reveals a bilingual advantage that is dependent on task and age. *Frontiers in Psychology*, **11**, 1458. https://doi.org/10.3389/fpsyg.2020.01458

Wilckens, K. A., **Ferrarelli, F.**, **Walker, M. P.**, & **Buysse, D. J.** (2018). Slow-wave activity enhancement to improve cognition. *Trends in Neurosciences*, **41**(7), 470–482. https://doi.org/10.1016/j.tins.2018.03.003

Winkelman, J. W., **Plante, D. T.**, **Schoerning, L.**, **Benson, K. L.**, **Buxton, O. M.**, **O'Connor, S.**, **Jensen, J. E.**, **Renshaw, P. F.**, & **Gönenç, A.** (2013). Increased rostral anterior cingulate cortex volume in chronic primary insomnia. *SLEEP*, **36**(7), 991–998. https://doi.org/10.5665/sleep.2794

Zavecz, Z., **Nagy, T.**, **Galkó, A.**, **Németh, D.**, & **Janacsek, K.** (2020). The relationship between subjective sleep quality and cognitive performance in healthy young adults: Evidence from three empirical studies. *Scientific Reports*, **10**(1). https://doi.org/10.1038/s41598-020-61627-6