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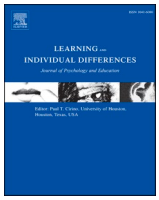

Executive functions and multiple-text comprehension

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A R T I C L E I N F O

Keywords:
Executive functions
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A B S T R A C T

Background: The present study aims at investigating the direct and indirect relationships between executive functions on multiple-text comprehension performance and processes.
Methods: The research questions were investigated through a path analysis approach. The participants in this study were 286 university students. The tasks were subdivided into three sessions to regulate cognitive fatigue during testing: demographic (age and gender) and control variables (perceived prior knowledge, prior knowledge, and need for cognition), executive functions (verbal and visuospatial working memory, inhibition, and shifting), and 3) multiple-text comprehension task (reading four texts and writing and argumentative essay: reading time, writing time, essay length, depth of comprehension, argumentative quality, text relevance ratings, and strategic processing).
Results: The estimated path model had an excellent fit. Visuospatial working memory and inhibition were associated with depth of comprehension.
Conclusion: The results of the study allow to delineate a cognitive control theory of multiple-text comprehension.
Educational relevance statement:

1. What is already known about this topic

- When people turn to the Internet to find an answer to relevant questions, they must face an overwhelming quantity of knowledge.
- Readers' competences are suboptimal for dealing with the increased complexity of reading for critical thinking, knowledge acquisition and decision making.
- Executive functions play a main role in supporting reading comprehension processes.

2. What this paper adds

- This paper compares the effect of multiple measures of executive functions on multiple-text comprehension outcomes and processes.
- We tested the direct and indirect effect of executive functions on depth of reading comprehension and source-based argumentation.
- This paper contributes to defining a cognitive control theory of multiple-text comprehension.

3. Implications for theory, policy, or practice

- The study contributes to the literature on multiple-texts comprehension by emphasizing the role of executive functions.
- The interactivity between source elements may determine the extent to which specific levels of working memory are required to complete the task.
- Working memory and inhibition contribute to multiple-text comprehension by supporting the ability to suppress irrelevant information and in managing cognitive resources.

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1. Introduction

Reading multiple texts is a crucial competence. The advent of the Internet has democratized access and production of knowledge. However, this achievement came with a few side effects. When people turn to the Internet to find an answer to relevant questions, they have to face an overwhelming quantity of knowledge, spread across different sources, which vary on several aspects, such as trustworthiness, perspective, relevance to the topic. Several studies (Bråten et al., 2011; Tarchi & Villalón, 2021) have emphasized how readers' competences are suboptimal for dealing with the increased complexity of reading for critical thinking, knowledge acquisition and decision making. Readers oftentimes overestimate their knowledge about a topic, are not motivated to engage in a complex task or lack of the cognitive tools to integrate information across texts (List & Alexander, 2019).

Multiple-text comprehension has received considerable attention in recent years in the scientific literature. Past research has identified several cognitive and motivational processes (Anmarkrud et al., 2022) that influence individuals' performance in multiple-text comprehension tasks. However, the role of cognitive control processes, such as Executive Functions (EF), has been partially neglected (Follmer & Sperling, 2020; Tarchi et al., 2021). This is surprising, given the importance of these processes to regulate mental functioning in complex learning situations (Diamond, 2013). Drawing from the literature on the relationship between EF and reading comprehension, we aim at identifying how EF are engaged with multiple-text comprehension outcomes by comparing the effect of different EF (i.e., working memory, inhibition and shifting) on different processes (i.e., strategic processes, relevance ratings and engagement) and products of multiple-text comprehension (i.e., depth of comprehension and argumentative quality).

1.1. Multiple-text comprehension

Several theories have been proposed to describe the processes involved when reading multiple texts (see for instance the Special Issue "Multiple Document Comprehension" published in Cognition and Instruction in 2013, or the Special Issue "Models of Multiple Text Comprehension" published in Educational Psychologist in 2017, or the Special Issue "Toward A Model of Multi-Source, Multi-Modal Processing" published in Learning and Instruction in 2018). The Documents model framework (Perfetti et al., 1999) is considered as the foundational theoretical model for multiple-text comprehension. It suggests that, ultimately, readers need to create a global representation of how the issue is represented in each informational source. This document model depends on two levels of representation: the integrated mental model and the intertext model. The integrated mental model is a representation of how the issue is depicted in each text and it should include both, complementary and conflictual information across texts. The intertext model includes a representation that focuses on source information, in specific source-content links (e.g., who says what) and source-source links (e.g., agreement or disagreement between sources). If these two levels of representation are not simultaneously present, then readers construct either mush models (i.e., an integrated representation of content across texts not linked to source information) or separate representations model (i.e., information is accurately mapped on sources, with limited intertextual integrated) (List & Alexander, 2019).

Given the complexity of the task and the overwhelming quantity of available informational resources, it is essential for readers to assess the extent to which sources are relevant for their purposes (Bråten et al., 2018). Thus, readers should engage in relevance evaluation, to determine the perceived instrumental value of content for their goals or purposes (McCrudden et al., 2010). Several times, the multiple-text reading task is performed to identify a perspective on a specific issue. After reading, individuals need to be able to hold a stance on the issue and support it with arguments. In this process, readers can adopt several strategies to identify positions and evaluate the strength of their argumentation. Readers may report one position only and support it, refute the opposite perspective, weigh the arguments supporting each perspective or synthesize opposing perspectives (Barzilai et al., 2020; Mateos et al., 2018; Tarchi & Villalón, 2021). Supporting or refutation are low-integration strategies while weighting or synthesizing are high-integration strategies (Mateos et al., 2018; Tarchi & Villalón, 2021). Students can also simply list disconnected ideas (Barzilai et al., 2020; Martínez et al., 2015), although this behaviour cannot be considered an effective strategy.

When processing information within and across texts, in order to achieve a coherent representation of the issue as discussed by the sources, readers need to engage in deep comprehension processes. According to the Construction-Integration Model (Kintsch, 1988, 1998), when readers limit themselves to a semantic representation of the text, they are only able to construct a surface-level representation of the text. When readers engage in inferential reasoning aiming at connecting the text with their prior knowledge, they are able to construct a deeper level of representation. Thus, deep reading requires inferential reasoning. When engaged with multiple-text comprehension, readers have to draw inferences across texts (intertextual inferences) besides drawing inferences within each text (intratextual inferences) (Demir et al., 2024).

Readers' level of representation when elaborating multiple texts depends on several variables that define their approach to multiple-text comprehension. The implementation of high-integration strategies when creating an integrated representation of the issue may depend on the use of deep comprehension strategies while reading (Bråten & Strømsø, 2011). Past studies have also emphasized the importance of cognitive styles (i.e., thinking dispositions), such as need for cognition (Cacioppo & Petty, 1982) in influencing readers' engagement with the multiple-text reading task, for instance by inducing a higher strategic processing (Bråten et al., 2014). Individuals with a higher need for cognition tend to employ more strategic processing strategies, leading to better comprehension outcomes, especially in multiple-text comprehension tasks (Tarchi & Villalón, 2021). Prior (topic) knowledge and perceived prior knowledge play a relevant contribution too (Le Bigot & Rouet, 2007). Readers with higher levels of prior knowledge are better equipped to integrate new information, while perceived confidence in one's knowledge can positively impact engagement and comprehension processes. While a few studies have considered these two constructs as 'two faces of the same coin' (Andiliou et al., 2012; Bråten et al., 2016), they may be associated with different components of multiple-text comprehension.

1.2. Executive functions

Executive Functions (EF) is an "umbrella" term that refers to a set of higher-order processes that allow an individual's mental processes and behaviours to be controlled and regulated, especially in novel and complex circumstances where automated processes or instinctive behaviours are not adequate to environmental demands (Diamond, 2013). EF subtend highly connected brain circuits that have protracted maturation over a lifetime, which is associated with a high malleability of EF to the environment and a developmental curve that grows into young adulthood (i.e., fourth decade of life). Moreover, in recent decades there has been an increase in the mutability of environmental demands and hyperstimulation (e.g., globalization and the web have drastically reduced spatio-temporal boundaries and altered the criteria that the individual could use to define the salience and relevance of a stimulus or demand): these aspects require greater processes of self-regulation and control. Thus, having good EF turns out to be an essential factor in learning and adapting to the current environment as they allow us to respond appropriately to novel, complex and/or adverse circumstances (Moffitt et al., 2011).

In addition, it should be noted that in the 1990s EF were conceptualized by unitary cognitive models, which described control processes as a kind of single supervisory system (e.g., conductor of an orchestra) that

fatigued to be operationalized into its basic processes (i.e., a black box). In contrast, since the 2000s, "fractional models" have been developed that allow identification of the different processes that make up the construct, making these processes more easily studied in cognitive, clinical, and educational psychology. Two fractional models have found the most scientific evidence and applicability, Arika Miyake's model (Miyake et al., 2000) and Adele Diamond's model (Diamond, 2013). Both models distinguish between basic, early-onset and more complex components. Both Miyake's and Diamond's models postulate that the basic components are fundamental for learning and for developing more complex EF processes such as planning and problem solving.

Three main basic components can be identified: *Inhibition*, a process that allows the suppression of an instinctive, automatic response or overbearing information; *working memory*, the ability to temporary manage information and manipulate it for cognitive tasks; and *shifting*, an essential operation for good cognitive flexibility as it allows "online" change of processing and/or response rules. Although the goal of fractional models is to separate the most essential operations of executive control, both Miyake's and Diamond's models entail the existence of links between the different components and interactions with the stimulus processing mode. For example, the ability to effectively change a rule (e.g., "if it is at the top choose the colour (rule 1), if it is at the bottom, choose the shape (rule 2)") depends on the ability to update information held temporarily in memory (top: rule 1, bottom: rule 2) and to inhibit perseverative responses (keeping on the first rule adopted).

1.3. Executive functions and reading comprehension

The role that EF play when comprehending written texts has received consistent attention, leading to the development of several theoretical models. Relevant to this study is Cartwright et al.'s work (Cartwright et al., 2020). According to the authors, theoretical perspectives on reading comprehension such as the simple view of reading (Gough & Tunmer, 2016) risk oversimplifying a complex process such as reading comprehension. Indeed, the active and goal-directed nature of reading comprehension is not captured by the simple view of the reading model (Cartwright et al., 2020). Thus, the authors investigated a complex model that captures the contribution of EF on reading comprehension in university students. However, the evidence regarding the structure of EF when it comes to their contributions on reading comprehension is controversial (Cartwright et al., 2020). Some studies suggest that working memory, inhibition and shifting have independent contributions (Potocki et al., 2017), some others suggest that inhibition and shifting operate together (Friedman & Miyake, 2017). In their study, Cartwright et al. (Cartwright et al., 2020) tested the goodness of fit of a path model, and found that a working memory, inhibition and shifting loaded on a domain-general EF factor which, in turn, was indirectly associated with reading comprehension (of notice is that the direct association was just above the threshold of $p = .05$).

In a meta-analysis conducted on the association between EF and reading comprehension, Follmer (2018) found that EF support readers' planning while reading, allows them to integrate information with prior knowledge and previously read text, allows them to inhibit irrelevant information and process different components of the text, and fosters strategic reading. Specifically, the author found a significant relation between reading comprehension and the following EF measures: working memory ($r = 0.38$, z = 15.23, $p < .001$), 95 % CI [0.34, 0.43], shifting ($r = 0.39$, z = 3.86, p < .001), 95 % CI [0.20, 0.56], inhibition ($r = 0.21$, z = 4.69, p < .001, 95 % CI [0.13, 0.30], planning ($r = 0.36$, z = 4.23, p < .001), 95 % CI [0.20, 0.50], and sustained attention and monitoring ($r = 0.25$, z = 3.15, $p < .01$), 95 % CI [0.10, 0.39]. Additionally, in a study conducted on young adults, Georgiou and Das (2018) tested the goodness of fit of a path model and found that only shifting (and not inhibition or working memory) directly predicted reading comprehension.

EFs may be differently associated with comprehension at different levels of depth. Certainly, EFs are involved at the deep level of comprehension, as they influence inferential reasoning. Updating (García-Madruga et al., 2014; Potocki et al., 2017), inhibition (Kieffer, Vukovic, et al., 2013) have been found to be associated with inference-making skills when reading a text. Updating or inhibition seem not to be involved at surface-level comprehension (e.g., Potocki et al., 2017), whereas shifting supports lower-level reading processes aiming at constructing a surface-level representation of the text (Altemeier et al., 2008). Of notice, evidence on the relationship between EFs and depth of comprehension is largely based on school-age children and adolescents, whereas not much is known about the same relationship in young adults. Moreover, research on EF and multiple-text comprehension is still emerging. For these reasons, in the present study the independent contribution of each EF was explored. Moreover, the results from the Cartwright et al.'s study (2020) suggest investigating indirect contributions of EF on reading comprehension, besides the direct ones.

1.4. Expected associations between executive functions and multiple-text comprehension

A recent literature review identified only seven studies on the association between EF and multiple-text comprehension (Tarchi & Villalón, 2021). Not only the number of studies is scarce, but they vary in outcomes EF measures or target population. With regard to older students (high school or university students), most of the attention was dedicated to verbal working memory. Andresen et al. (2019) found that working memory was associated with intertextual integration after reading three web pages in high school students (with a medium effect size). Braasch et al. (2014) asked high school and college students to read six documents and perform a series of tasks (low effect size). They found that working memory was associated with students' abilities to discriminate between more and less relevant documents and their ability to draw inferences across documents. More recently, Follmer and Tise (2022) investigated the association between a composite measure of inhibition and lexical access (measured through a modified version of the verbal fluency task) and comprehension-integration of texts through a structural equation model approach. They found that inhibition/lexical access predicted comprehension–integration of conflicting informational texts both directly and indirectly, via the mediation of strategic processing (i.e., cross-text elaboration).

In a theoretical chapter describing the hypothetical involvement of EF in multiple-text comprehension, Follmer and Sperling (2020) suggested that working memory should be involved in relevance evaluation, inference-making and intertextual integration; inhibition should mainly have a role in relevance evaluation; shifting should be involved in intertextual integration and inference-making.

1.5. The present study

The present study aimed at investigating how executive functions, specifically working memory, inhibition, and shifting, directly and indirectly influence processes and outcomes of multiple-text comprehension in university students (RQ). To the best of our knowledge, this is the first study that compares the effect of multiple measures of EF on multiple-text comprehension outcomes and processes. Past studies (Andresen et al., 2019; Braasch et al., 2014; Follmer & Tise, 2022) have suggested that working memory and inhibition may have direct and indirect effects on multiple-text comprehension outcomes. Theoretical contributions have suggested that shifting may be involved too when reading multiple texts (Follmer & Sperling, 2020).

We expected a direct and indirect effect of EF on the depth of comprehension (Butterfuss & Kendeou, 2018; Cartwright et al., 2020). In turn, depth of comprehension was expected to mediate the effect of EF on argumentative quality. Moreover, the contribution of EF to multiple-text comprehension outcomes was expected to be mediated by strategic

processing or engagement (i.e., time spent reading the texts or essay length, see Eisenberger et al., 1982; Latini et al., 2019; Tarchi & Villalón, 2021). Perceived prior knowledge, prior knowledge and need for cognition were included as control variables as they capture relevant individual differences in multiple-text comprehension. Moreover, time spent writing and essay length were included as control variables for depth of comprehension and argumentative quality. Strategic processing was hypothesized to be associated with need for cognition (Bråten et al., 2014). Relevance ratings were hypothesized to be associated with prior knowledge (Kaakinen et al., 2002, 2003). See Fig. 1 for a graphic representation of the expected association.

2. Method

2.1. Participants

The participants in this study were 286 university students (Age = 23.90 ± 4.56; 266 females, 18 males, 2 preferred not to declare their gender). They were characterized by a middle-high socio-economic status and spoke Italian as a primary language.

2.2. Procedure

The recruitment was done in a public university in Central Italy. The participants were recruited among students attending a degree in either psychology, educational sciences, or primary teacher education. The participation was voluntary. The study was conducted on Gorilla, a cloud-based research platform to create and deploy behavioural (reaction-time) experiments online. A link to the online study on Gorilla was sent to all the students who expressed their interest to participate (n = 336): 38 did not access the experimental environment at all, 12 were excluded because they did not complete the assigned tasks within the time limit (one week). Preliminary data analyses were conducted on the 286 subjects who completed all the tasks within the time limit assigned. After careful analysis of the dataset, we removed 13 subjects as they had very low reading times (< 1 min per text)- The final sample included 273 subjects. The sample size was adequate for testing the expected path model, as estimated with a rule-of-thumb approach, given the exploratory nature of the present study. Kline (2005) suggests a sample of >200 (considered large) for complex models such as the one tested in this study.

The tasks were subdivided into three sessions to regulate cognitive fatigue during testing: 1) demographic (age and gender) and control variables (perceived prior knowledge, prior knowledge, and need for cognition), 2) executive functions (verbal and visuospatial working memory, inhibition, and shifting), and 3) multiple-text comprehension task (reading four texts and writing and argumentative essay: reading time, writing time, essay length, depth of comprehension, argumentative quality, text relevance ratings, and strategic processing). The tasks included in the three sessions had to be completed on different days, in which students had to wait at least 24 h between the first and the second session, and another 24 h between the second and the third session.

This study was approved by the Ethics Committee of the University of Florence (Approval Number: [0028872]). All procedures involving human participants were conducted in accordance with the ethical standards of the institution, as well as with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. Informed consent was obtained from all individual participants included in the study.

2.3. Materials and measures

2.3.1. Texts

Students were assigned four texts to read with the following instructions: "We ask you to read the following texts with the purpose of writing an argumentative text on the topic of the increase of diagnosis of learning disabilities that occurred in the last years." The texts were equivalent for length, difficulty, and trustworthiness, whereas they differed by relevance. A description of the texts is reported in Table 1. Two texts were very relevant for the task and were conflictual. Two other texts were not very relevant for the task, since they did not include useful information for the assigned task. The texts were constructed based on authentic sources.

2.3.2. Multiple-text comprehension outcomes and processes

After having read the texts, the students were asked to write an

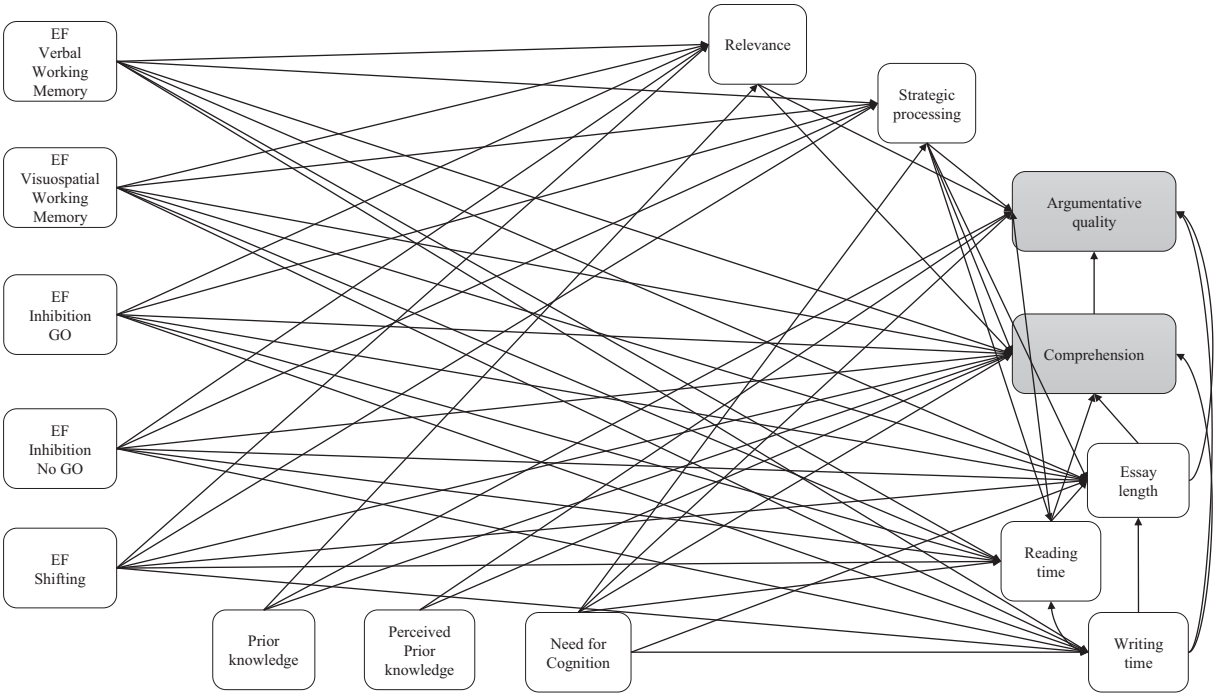

Fig. 1. Expected model for the association between executive functions, control variables and multiple-text comprehension outcomes.

argumentative essay, without access to the texts. Their answers were coded with two measures: depth of comprehension and argumentative quality. The first measure—amount of very relevant and not very relevant information reported—assesses comprehension by evaluating the ability to discern and retain essential information, as supported by prior studies (e.g., Demir et al., 2024; Perret, 2021). The second measure—argumentative quality of the essay—reflects elaboration and integration of perspectives and is consistent with previous research on argumentative skills (e.g., Mateos et al., 2018; Tarchi & Casado Ledesma, 2024). See appendix A for examples of high-, medium- and low-score essays.

2.3.2.1. Depth of comprehension. Two independent raters coded all the participants' essays on several categories. As participants were provided with very relevant and not very relevant texts, we analysed the extent to which each text was elaborated by identifying information literally recalled from each text, valid inferences drawn from each text and valid inferences drawn across texts. Overall the following categories were identified: literal or paraphrased statements from very relevant texts (PAR_rel, $k = 0.97$); literal or paraphrased statements from not very relevant texts (PAR_Nrel, $k = 0.96$); intratextual inferences drawn from each very relevant text (intraINF_rel, $k = 0.90$); intratextual inferences drawn from each not very relevant text (intraINF_Nrel, $k = 0.91$); intertextual inferences drawn across texts (interINF, $k = 0.88$).

As texts differed by relevance and categories differed by complexity, to calculate a comprehensive score for depth of comprehension we created a formula to attribute specific weights. Indeed, recalling information from texts is a positive outcome, but to achieve a deep understanding of a topic readers have to make relevance judgments and focus on those elements in the text necessary to construct a mental representation of the topic (McCrudden et al., 2011).

$$\text{Comprehension} = [(\text{PAR\_rel} + \text{intraINF\_rel} + \text{interINF})*2] + (\text{PAR\_Nrel} + \text{intraINF\_Nrel})$$

Table 1
Description of texts.

Texts	Source	Length	Topic	Relevance
A more sensitive school	A report published by the Italian Association of Dyslexia, Prof. Azzurri, University of Perugia	722 words	It links the increases in diagnosis to a higher awareness about learning disabilities and the availability of more effective instruments.	Very relevant to the assigned task
The diagnosis boom	A report published by the Italian Association of ADHD, Prof. Noferi, University of Siena	715 words	It underlines the pitfalls of an excessive amount of diagnosis in terms of discrimination, disengagement from the certified students, and overload on the school system.	Very relevant to the assigned task
Typologies of learning disabilities	Report published by the Educational Research and Policy Association, Prof. Rigoli, University of Verona	716 words	It defines the criteria to define, diagnose and intervene on learning disabilities.	Not very relevant to the assigned task
Professional development on learning disabilities	Report published by the Italian Association for Research in Learning Disabilities, Prof. Felini, University of Genova	702 words	It supports the importance of implementing professional development on learning disabilities for teachers.	Not very relevant to the assigned task

2.3.2.2. Argumentative quality. Two independent raters coded all the participants' essays on several categories to capture the quality of participants' argumentation. First, we identified what strategies were used to process each text's argumentation. One-sided strategies included simply listing arguments (LIST, $k = 0.91$) or supporting one position only (SUPP, $k = 0.92$). Supporting one position and refuting the other one is considered as a low-integration strategy. (REF $k = 0.89$). Weighing the arguments supporting each position is considered a high-integration strategy (WEIGHT $k = 0.87$). Finally, identifying a solution that synthesizes the argumentations offered by each position is considered as a more sophisticated high-integration strategy (SYNTH $k = 0.84$). We also analysed whether participants wrote a conclusion in their essay, and if yes, whether the conclusion was: one-sided (1S_concl $k = 0.93$), two-sided (2s_concl $k = 0.87$), or discussed a resolution between positions (RES_concl $k = 0.85$). Each category was coded in a categorical way (0 absent, 1 present). As strategies differed by complexity and categories by contribution to argumentative quality, to calculate a comprehensive score for argumentative quality we created a formula to attribute specific weights. A higher weight was given to two-sided reasoning strategies (Nussbaum, 2021), with synthesis being characterized by an even higher level of sophistication, as it requires identifying a third perspective that reconciles the two opposing perspectives presented in the texts (Mateos et al., 2018; Tarchi & Casado Ledesma, 2024). At the same time, we coded conclusions for the level of intertextual integration, as people can attempt to integrate positions in the body of their essay, but still provide a one-sided conclusion.

$$\text{Argumentative quality} = (\text{LIST} + \text{SUPP} + \text{REF} + 1\text{S\_concl}) + [(\text{WEIGHT} + 2\text{S\_concl})*2] + [(\text{RES\_concl} + \text{SYNTH})*3]$$

2.3.2.3. Process variables. The following process variables were measured during the reading and writing tasks: reading time, writing time and essay length.

2.3.3. Relevance rating

After having read the texts and written the essay, the participants were asked to rate the relevance of each text for the assigned task. The following instructions were given: "You are asked to rate the 4 texts you read for relevance to the task "*write an argumentative essay on the topic of increasing diagnosis of learning disabilities*" Each text should be rated on a 1-5 scale: 1= not at all relevant; 2; 3; 4; 5= absolutely relevant". Following, participants had to rate each text (presented in random order) on the 5-point Likert scale. The total score was calculated by summing the scores assigned to very relevant texts and subtracting the scores assigned to not very relevant texts. Thus, scores could range from −8 to +8. The reliability of the instrument was acceptable ($\alpha = 0.61$).

2.3.4. Strategic processing

This variable was assessed through the cross-text elaboration scale of the Multiple-Text Strategy Inventory (Bråten & Strømsø, 2011). The participants had to rate their agreement with 10 statements on a 10-point Liker scale (1 = not at all, 10 = to a very large extent). An example of an item was: "I tried to note disagreements among the texts". The reliability of the instrument was acceptable ($\alpha = 0.83$).

2.3.5. Executive functions

The following EF tasks were used. Reliability coefficients are not

available as we collected composite scores through the Gorilla platform. The measure here described are very common in traditional assessment of executive functions and their validity has been demonstrated in several studies: Go-NoGo task (e.g., Gomez et al., 2007), Digit and visuospatial n-back task (e.g., Groeger et al., 1999) and alternate switching task (e.g., Wasylyshyn et al., 2011).

2.3.5.1. Go-NoGo task. The Go-NoGo task measures the inhibition control through the identification of target stimuli (EF inhibition GO) among non-target stimuli (EF inhibition No GO). Students were asked to press the spacebar as soon as possible each time the letters (2 × 2 cm) *a*, *d*, *w*, or *x* appeared in the centre of the screen but not when the stimulus was the letter *y*. The task consisted of 70 target stimuli and 20 non-target stimuli. Stimuli were presented sequentially in a randomized order with a presentation time of 700 ms and an interstimulus interval (ISI) of 300 ms. The subject had 1000 ms to respond. As soon as the space bar was pressed, the stimuli disappeared.

The number of correct responses to Go stimuli (from 0 to 70), the number of correct responses (from 0 to 20) to NoGo stimuli were measured.

2.3.5.2. Digit span backward task. This task measures verbal working memory. Subjects were asked to read a sequence of digits presented in succession in the centre of the screen and rewrite them in reverse order in a dedicated space that appeared at the end of the sequence. The task consisted of 15 sequences of digits, from 3 to 7, presented in the same order for all subjects. Each number was presented for 200 ms; the interval between one trial and subsequent depended on the time the subject needed to provide the response. The number of sequences correctly reproduced was measured (from 0 to 15).

2.3.5.3. Visuospatial N-Back task. This task measures visuospatial working memory. Stimuli were 9 grey rectangles (5 × 4 cm) presented in a fixed scattered position on the computer screen. In each trial a given number of stimuli (from 5 to 9) turned blue according to a random order and subjects were asked to press the spacebar, as soon as possible, when a stimulus turned blue twice subsequently (1-back) or one (2-back) or two (3-back) stimuli before. The task was composed by 16 trials, one example and 3 trials for each blue stimuli length (from 5 to 9). Stimuli lasted blue for 500 ms; the interstimulus interval (ISI) between one blue stimulus and the next one was 500 ms; response time was1000 ms. The number of correct responses (from 0 to 15) was measured.

2.3.5.4. Alternate switching task. This task measures shifting. Subjects saw a sequence of 120 coloured shapes (6 × 6 cm OR 6 × 4 cm) on the screen and were instructed to follow alternatively two rules. When the stimulus appeared at the top of the screen, subjects had to answer according to the colour, pressing F if it was blue and J if it was green. When the stimulus appeared at the bottom of the screen, subjects had to press F if it was square and J if the shape was rectangular. 120 stimuli were presented one at a time in a randomized order and lasted until the subject answered. Feedback for 200 ms was included in the task (a green thumb up was presented when the subject's response was correct and a grey thumb when it was incorrect). A 350 ISI was used. The number (from 0 to 120) of correct responses was measured.

2.3.6. Control variables

Perceived prior knowledge, prior knowledge and need for cognition were assessed. By measuring these three variables, the unique contribution of executive functions to multiple-text comprehension was better isolated while controlling for other potentially confounding factors (Bråten et al., 2014; Le Bigot & Rouet, 2007; Tarchi & Villalón, 2021).

2.3.6.1. Perceived prior knowledge. Participants were asked to rate their level of prior knowledge on the topic of learning disabilities on a slider (minimum = 1, maximum = 100).

2.3.6.2. Prior (topic) knowledge. Participants were asked 15 multiple choice questions on learning disabilities. The questions were created by expert researchers in learning disabilities. An example of a multiple-choice question is: "*A diagnosis of Specific Learning Disorder can be made: A. as early as birth; B. as early as kindergarten; C. not earlier than the second primary school; D. only in secondary school.*". The reliability coefficient was relatively low (α = 0.58), but still acceptable for research purposes (Hair et al., 2006). A principal component analysis was conducted to confirm the uni-dimensionality of this scale (KMO = 0.60; Bartlett's sphericity test, $\chi^2 = 275.09$, $p < .001$).

2.3.6.3. Need for cognition. This variable was assessed with an Italian translation of the original 18-item inventory developed by Cacioppo and Petty (1982). Participants had to rate their agreement with the items on a 5-point Likert scale (1 = absolutely false; 5 = absolutely true). An example of an item is: "*I like tasks where you have to find new solutions to problems*". The reliability was acceptable (α = 0.89).

2.4. Data analysis

We investigated direct and indirect effects of executive functions, specifically working memory, inhibition, and shifting, on multiple-text comprehension in university students through a path analysis approach. Data were analysed through Mplus with a robust estimator method (maximum likelihood parameter). The fit of the model was estimated by several indices: the chi-square ($p > .05$), the root mean square error of approximation (RMSEA <0.05) and the comparative fit index (CFI > 0.95) (Hu & Bentler, 1999).

3. Results

3.1. Descriptive and correlation analysis

Descriptive results are presented in Table 2. See appendix B for correlations.

3.2. Path model for the association between executive functions, control variables and multiple-text comprehension

The estimated path model had an excellent fit ($\chi^2 = 24.94$, df = 19, $p = .18$; RMSEA = 0.03; CFI = 0.99) (see Fig. 2). See appendix C for the standardized coefficients and p-values for direct estimated paths, see appendix D for standardized coefficients and *p*-values for indirect estimated paths. The model was able to explain a significant portion of variance in both outcome variables, comprehension ($R^2 = 0.66$, $p < .01$) and argumentative quality ($R^2 = 0.18$, $p < .01$). Moreover, it explained a significant portion of variance of strategic processing ($R^2 = 0.10$, $p < .05$), reading time ($R^2 = 0.08$, $p < .05$), writing time ($R^2 = 0.07$, $p < .05$), and essay length ($R^2 = 0.27$, $p < .01$), but not relevance ($R^2 = 0.02$, $p > .05$).

Multiple-text comprehension was significantly associated with EF inhibition No GO (β = 0.09, $p < .05$), and EF visuospatial working memory (β = 0.08, $p < .05$). Moreover, it was associated with essay length (β = 0.72, $p < .001$), reading time (β = 0.13, $p < .01$), strategic processing (β = 0.08, $p = .05$),

Argumentative quality was not significantly associated with any EFs. Conversely, it was significantly associated with essay length (β = 0.72, $p < .001$), perceived prior knowledge (β = 0.12, $p < .05$), and relevance (β = 0.18, $p < .01$).

Strategic processing was significantly associated with spatial working memory (β = 12, $p = .05$) and need for cognition (β = 0.24, $p < .001$). Relevance was significantly associated with prior knowledge (β = 0.13, $p < .05$).

Table 2
Descriptive statistics of all measures ($n = 273$).

	N	Min	Max	M	Swn	Kurt
Perceived prior knowledge	273	0	100	48.48 ± 20.96	−0.385 ± 0.15	−0.463 ± 0.29
Prior knowledge	273	2	14	8.42 ± 2.17	−0.072 ± 0.15	−0.048 ± 0.29
Need for cognition	273	43.00	87.00	67.18 ± 8.58	−0.457 ± 0.15	0.069 ± 0.29
EF Verbal working memory	273	0	13	3.66 ± 3.19	0.717 ± 0.15	−0.184 ± 0.29
EF Spatial working memory	269	1	15	11.33 ± 2.57	−1.414 ± 0.15	2.464 ± 0.30
EF Inhibition Go	250	60	70	68.14 ± 1.94	−1.406 ± 0.15	2.273 ± 0.30
EF Inhibition NoGo	271	0	20	13.80 ± 4.45	−1.543 ± 0.15	2.372 ± 0.30
EF Shifting	272	57	120	106.31 ± 15.25	−1.412 ± 0.15	0.957 ± 0.29
Relevance	273	−7	8	0.45 ± 2.13	0.471 ± 0.15	1.557 ± 0.29
Strategic processing	273	17	100	72.11 ± 13.08	−0.383 ± 0.15	0.643 ± 0.29
Reading time	271	1.28	64.11	18.62 ± 11.45	1.143 ± 0.15	1.853 ± 0.30
Writing time	271	0.26	112.42	27.16 ± 19.87	1.354 ± 0.15	2.056 ± 0.30
Essay length	265	22	931	295.76 ± 153.54	0.926 ± 0.15	1.114 ± 0.30
Comprehension	266	0.00	42.00	14.05 ± 7.99	0.596 ± 0.15	0.222 ± 0.30
Argumentative quality	268	0.00	6.00	1.66 ± 1.29	1.439 ± 0.15	1.902 ± 0.30

Note. EF = Executive Function.

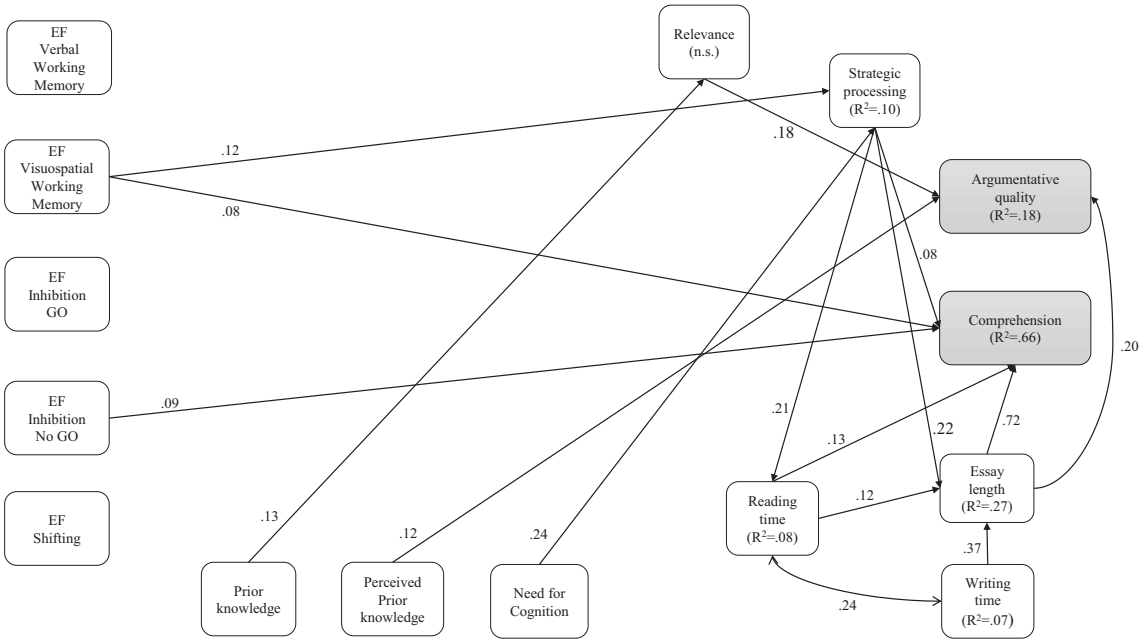

Fig. 2. Path model for the association between executive functions, control variables and multiple-text comprehension outcomes [standardized coefficients]. Continuous lines represent paths significant for $p < .05$.

The essay length was associated with writing time (β = 0.37, p < .001), reading time (β = 0.12, p = .05), and strategic processing (β = 0.22, p < .05). Reading time was significantly associated with strategic processing (β = 0.21, p < .001). Writing time was not significantly associated with any variables (besides an association with inhibition GO approaching significance, β = −0.12, $p = .06$). Writing and reading time significantly correlated with each other (β = 0.24, p < .001).

Indirect effects were also tested, and the following ones were statistically significant. Need for cognition had a totally mediated effect on argumentative quality (β = 0.05, p = .05), although no specific indirect path reached the threshold for significance. Need for cognition had also a totally mediated effect on comprehension (β = 0.12, p < .05). In specific, need for cognition indirectly influenced comprehension through the mediation of strategic processing and reading time (β = 0.01, p = .05), and strategic processing and essay length (β = 0.04, p < .05).

4. Discussion

The present study investigated the direct and indirect effects of executive functions on multiple-text comprehension outcomes in university students. Reading multiple texts about controversial topics is a complex but fundamental process today. Given the amount and variability of information that can be easily accessed when reading on the Internet, an involvement of executive functions is expected. In specific, in this study, we focused on working memory, inhibition and shifting.

The results of the path analysis only partially confirmed the research hypothesis. In synthesis, (visuospatial) working memory was associated with an outcome variable (comprehension) and a process-level variable (strategic processing). Inhibition was associated with comprehension. Shifting was not associated with any of the outcome variables. Overall, EF were associated with comprehension of multiple texts but not with the argumentative quality of participants' essays.

The significant association between (visuospatial) working memory and multiple-text comprehension is in line with past research, more surprising is the lack of an effect of verbal working memory. Carretti et al.'s meta-analysis (2009) found that poor comprehenders had lower scores than good comprehenders in verbal complex span tasks but not in visuospatial working memory complex span or verbal simple span tasks. However, the scenario may differ with less traditional texts. For

instance, Pazzaglia et al. (2008) asked secondary school students to process texts on an hypermedium and found that both verbal and visuospatial working memory sub-components were associated with reading comprehension performance. In specific, verbal working memory seemed associated with semantic knowledge, whereas visuospatial working memory seemed involved with the ability to construct a representation of the document structure. In the domain of research on multiple-text comprehension, past studies with high school or university students have found significant associations between verbal working memory and intertextual integration (Andresen et al., 2019), relevance ratings and intertextual inferences (Braasch et al., 2014). The inconsistency in results between past studies and our study may be attributed to a difference in task complexity. Andresen et al. (2019) presented web pages to read to the participants each including a text, a video, and an image. Although the material was designed in accordance with principles for multimedia learning (Mayer, 2014), it was certainly characterized by a higher level of interactivity than the textual material used in the present study. As a consequence, Andresen et al.'s material may have been more taxing for students' working memory than the material presented in this study. The same explanation may be applied when comparing our results with Braasch et al.'s study (2014). Here, six documents were given to the participants, varying by source. The higher number of sources (six instead of four) and higher variability in source information (which were held constant across texts in our study) determined a higher complexity in Braasch et al.'s study (2014) than our material. Indirect evidence to this hypothesis comes from Scharinger et al.'s study (2015). The authors investigated the additional load imposed on executive functions by link-selection processes during computer-based reading. Reading processes were measured through methodology of combined EEG and eye-tracking data recording and analysis. Load on executive functions was measured through two physiological load-measures, namely pupil dilation and EEG alpha frequency band power. According to the results, the two physiological measures were associated with increased load on EF during hyperlink-like selection processes.

The recent study by Hildenbrand and Wiley (2023) partially contrasts with the results of previous studies, aligning with what the present study found. In detail, the authors, investigating the association between working memory and comprehension in a multiple text assessment, found that only performance on inference questions exhibited a unique correlation with working memory, contrasting with the absence of a significant relationship observed for textbase and across-text questions. The authors suggested that working memory continues to influence comprehension even when texts are readily available, with its impact notably pronounced in tasks requiring integration of information.

Another hypothesis to explain the inconsistency on the role played by verbal working memory refers to its measure. Andresen et al. (2019) and Braasch et al. (2014) have measured verbal working memory with tasks derived from the reading span test, whereas we measured verbal working memory with a digit span task. While both indices have been largely used to measure the impact of verbal working memory on reading comprehension (e.g. Andresen et al., 2019; Georgiou & Das, 2018; Nouwens et al., 2021), tasks as the reading span test load more on verbal processing than those using digits, thus interacting more with the verbal comprehension domain. Indeed, some evidence (e.g. St Clair-Thompson, 2010) suggests that the working memory load associated with a digit span task is low, especially in adults. It is therefore advisable for future studies to use more sensitive measures to detect this complex process.

At the same time, multiple-text comprehension measures used by Andresen et al. (2019) and Braasch et al. (2014) were differently coded in comparison to the measures implemented in this study, which may support the inconsistencies found across results. Specifically, Andresen et al. (2019) scored the oral responses in terms of the degree of integration of: i) the two main perspectives presented in the materials and ii) information from three different web pages and their representations. Conversely, Braasch et al. (2014) used a rank-order justifications task to evaluate for the existence of various types of content-based justifications and a verification task to assess students' ability to make inferences by combining information from provided documents.

Overall, the relationship between working memory and multiple-text comprehension seems more complex than straightforward. Future studies using multiple measures of verbal working memory (with low vs. high verbal processing load) and multiple measures of comprehension (with text vs. multimedia materials) may be helpful in resolving this issue. This is an important issue as it emphasizes that the relationship with working memory still needs to be investigated further despite the attention working memory received in past studies.

Our results on inhibition confirmed the results from Follmer and Tise (2022). In both studies, inhibition was associated with multiple-text comprehension. Inhibition allows eliminating the irrelevant details in complex patterns of stimuli such as texts. This process allows the reader to deeply comprehend the texts through inferences. One added contribution of the present study is that we derived two measures from the inhibition task: identification of relevant stimuli (Go score) and inhibition of irrelevant stimuli (NoGo score). Most of the studies on inhibition, consider a total score by combining scores in the Go trials and in the NoGo trials. However, only the NoGo score is a pure measure of inhibition, that indeed was associated with comprehension scores. Conversely, the Go score is rather a superficial measure of the ability to identify relevant elements. This ability may be helpful in identifying keywords in a text (e.g., LD in a text on learning disabilities), but this alone leads to skimming the text, rather than reading it (thus, the negative association between the Go score and comprehension). Overall, further research on the association between inhibition and multiple-text comprehension is needed, in light of inconsistent findings in existing research in the context of single-text comprehension (Follmer, 2018).

Shifting was not associated with any process-level or outcome variable. Not much research is available on the link between shifting and multiple-text comprehension, besides what is hypothesized in theoretical contributions (Follmer & Sperling, 2020). Of notice, the correlational analyses suggest the existence of associations between shifting and strategic processing, writing time, essay length and association (with r-scores ranging between 0.13 and 0.16, thus of small effect size). On a speculative level, we may suggest that, while inhibition has an intrinsic automatic component (it is possible to inhibit without being aware), shifting may require an aware control of cognitive flexibility, as suggested by the correlation with strategic processing. This interpretation is consistent with past studies that found shifting implicated with readers' abilities to switch mental sets and form new concepts while reading (e.g., Kieffer, Biancarosa, et al., 2013; Latzman et al., 2010). Of course, these speculations need to be investigated by future research.

The two outcome variables of this study, comprehension and argumentative quality, were dissociated. If on the one hand this result may sound surprising, on the other hand it is consistent with past research (Diakidoy et al., 2015, 2017; Tarchi & Villalón, 2021). Thus, students' ability in evaluating arguments occurs without information being deeply elaborated. This lack of association may explain why students struggle in argumentative quality. Of notice, the dissociation occurs also at the level of associations with the exogenous variables: comprehension was associated with executive functions, strategic processing, and (indirectly) need for cognition, whereas argumentative quality was associated with relevance judgment ability and perceived prior knowledge.

4.1. Limitations and directions for future research

The results of this study are affected by a few limitations. Firstly, the results are limited to the characteristics of the material presented to the participants. Texts with different levels of complexity (e.g., with a higher level of interactivity between elements or with more technical jargon) may require different levels of executive functioning. This reflection extends to the number of texts read, the length, or the degree

of relevance.

Secondly, given that the research was conducted remotely, it was not possible to control the behaviour of the students during the performance of the task, for example any environmental distractions and influencing contextual factors. We conducted the study through Gorilla, a reliable platform for research in the field of experimental psychology, which allows to control for confounding variables such as time spent on the task, device used, Internet speed, to exclude subjects who performed the experiment in suboptimal conditions.

A third limitation of this study is the lack of control for participants' reading and writing skills. The study was conducted on university students with no reported learning disorders, who are admitted to the course degree after having passed a test assessing reading comprehension. Nevertheless, individual differences in reading comprehension and writing skills still exist even in young adults. By controlling for these variables, future research can provide a more accurate and nuanced understanding of the interplay between executive functions and reading comprehension, leading to more reliable and valid conclusions.

Fourthly, the present results are limited by the choice of outcome variables and the formula designed to capture students' performances. Multiple-text comprehension is assessed with a variety of tasks and outcome measures (Primor & Katzir, 2018), spanning from recognition (such as sentence-verification tasks) to production tasks (such as essay writing). Correlations between performances in these tasks are not always significant, for instance comprehension of text content does not seem to correlate with evaluation of arguments (see Tarchi & Villalón, 2021). In this study we introduced two measures, one tapping on comprehension and the other one tapping on argumentative quality. In both cases, we designed formulas to synthesize different sources data with specific weights attributed, in order to provide theoretically-driven comprehensive scores. Such formulas should be validated in future research in order to draw definitive conclusions on data collected through them.

Fifthly, the associations found among variables were small in effect size. Moreover, the research design was correlational. For these discussed limitations, data need to be interpreted with caution and it is not possible to draw definitive conclusions on the direction of the association between executive functions and multiple-text comprehension. Future studies should focus on the specific associations found in this study and validate the results with an experimental research design.

Finally, the present study was conducted on a sample of non-clinical adult subjects, but the results may have relevant implications for different populations that have difficulty understanding multiple texts, such as children, or even young adults, with Specific Learning Disorders. Understanding how domain-general cognitive control processes, such as executive functions, can support different stages of comprehension of multiple digital texts may indeed enrich preventive intervention measures.

5. Conclusions

Despite these limitations, the present study contributes to the literature on multiple-texts comprehension by emphasizing the role of executive functions. The results of the study allow to delineate a cognitive control model of multiple-text comprehension. Three main effects were identified:

1) The role played by working memory when reading multiple texts needs further investigation, given the presence of contradictory results. Visuospatial working memory (but not verbal working memory) was involved with multiple-text comprehension. We contend that the contribution of working memory may depend on the characteristics of the task. The number of texts or the interactivity between source elements may determine the extent to which specific levels of working memory are required to complete the task. This effect is supported by the cognitive load theory (Mutlu-Bayraktar et al., 2019). It is important to untangle this aspect, as an implication of this effect would be the importance of clearly defining the characteristics that can facilitate the process of reading multiple texts for individuals with low working memory skills.

2) Inhibition may influence multiple-text comprehension mostly through its suppression component, rather than through its identification component. Identifying key elements appears to be a shallow strategy, if not coupled with engagement.

3) Shifting was not associated with any variable in this study. This EF needs further analysis in the context of multiple-text comprehension as it received less attention than the former two EF components (see Tarchi et al., 2021).

Ethical approval

The authors declare that ethical approval for this study was obtained.

CRediT authorship contribution statement

Christian Tarchi: Writing – original draft, Supervision, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Costanza Ruffini:** Writing – original draft, Data curation. **Chiara Pecini:** Writing – original draft, Methodology, Conceptualization.

Conflict of interest

The authors have no conflict of interest to declare.

Data availability

Data are available upon request to the authors.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.lindif.2024.102566.

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