Research Article

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Cognitive fatigue induced by spaced and massed practice: effects on idiom accuracy across L2 proficiency levels

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Abstract: This study investigated the effects of spaced and massed practice on cognitive fatigue across L2 proficiency levels. 92 L2 learners completed idiom comprehension tasks under spaced and massed practice conditions and then the five dimensions of their cognitive fatigue (cognitive, emotional, physical, behavioral, and motivational) were measured in two ways: perceived cognitive fatigue through a self-report scale and performance-based cognitive fatigue via a free recall idiom accuracy test. Results revealed that spaced practice significantly reduced overall cognitive fatigue, with the effect being most pronounced among low-proficiency learners. Results also indicated significant interactions between practice type and proficiency level across all fatigue dimensions. Multiple regression further demonstrated that while cognitive engagement positively predicted idiom comprehension accuracy, physical fatigue emerged as the strongest negative predictor. These results have important implications for L2 pedagogy, highlighting the need for differentiated instruction that considers practice distribution and learners' susceptibility to various dimensions of cognitive fatigue.

Keywords: cognitive fatigue; spaced/massed practice; idiom accuracy; L2 proficiency

1 Introduction

L2 learning is a complex cognitive process that involves mastering not only vocabulary and grammar but also the intricacies of idiomatic expressions. Idioms, which often defy literal translation, pose particular challenges for L2 learners due to their non-literal meanings and cultural nuances (Schmitt 2004). Understanding idioms is

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crucial for achieving fluency in an L2, as they are common in everyday communication, both in written and spoken forms (Tizón-Couto and Lorenz 2024; Zwier and Boers 2023). However, the acquisition of idiomatic expressions requires substantial cognitive effort, particularly when learners are required to retrieve and apply them in different contexts.

One factor that may influence L2 learners' ability to comprehend idioms is cognitive fatigue, a state of mental exhaustion that results from prolonged cognitive effort. Cognitive fatigue has been widely studied in other contexts (e.g., in educational psychology and cognitive science) but remains underexplored in L2 learning, especially concerning the acquisition of complex structures such as idioms. Cognitive fatigue is thought to impair performance by decreasing attention, processing speed, and the ability to recall information, making it a potential barrier to successful L2 learning.

Another important factor in L2 learning is the type of practice employed (Rogers 2022). Spaced practice, which involves spreading learning sessions over time, is typically associated with better long-term retention compared to massed practice, which involves cramming or concentrating practice into a short period (Macis et al. 2025; Nakata and Suzuki 2019). However, recent research suggests that massed practice may induce greater cognitive fatigue, potentially impacting learning outcomes in the short term (Chen et al. 2018). In contrast, spaced practice might help alleviate cognitive load by providing learners with rest intervals that allow for recovery (Li and Lei 2024). While these two types of practice have been shown to affect cognitive load in general learning contexts, their impact on cognitive fatigue and idiom comprehension in L2 learners has not been systematically explored.

This study aims to fill this gap by investigating the cognitive fatigue induced by spaced and massed practice on idiom comprehension across different L2 proficiency levels. The study also examines whether proficiency level moderates the relationship between practice type and cognitive fatigue, providing insights into how practice schedules can be optimized for L2 learners at various stages of proficiency.

2 Theoretical framework

2.1 Idioms

Idioms are expressions whose meanings cannot be inferred from the meanings of the individual words, making them a particularly challenging aspect of L2 learning. Examples like *kick the bucket* or *break the ice* require learners to understand not only the individual words but also cultural nuances and metaphorical meanings (Liontas 2017). The ability to comprehend and use idiomatic expressions is often considered a marker of advanced L2 proficiency (Liontas 2017). However, learners must overcome significant cognitive challenges to comprehend idioms effectively, as idiom comprehension involves complex cognitive processes. L2 learners often struggle with these non-literal meanings, which might interfere with their fluency and overall communication in the target language. Previous studies have highlighted that idiom comprehension is particularly taxing for learners due to the need for both conceptual and linguistic processing (Cacciari et al. 2018). Cognitive load theory, similarly, suggests that complex tasks like idiom comprehension require learners to manage cognitive resources effectively, but the demands of such tasks can lead to cognitive fatigue (Sweller et al. 2011a, 2011b). Cacciari et al. (2018) emphasized the relationship between cognitive functions and idiom comprehension, suggesting that successful idiom processing may require advanced cognitive skills that develop later in language acquisition (Sprenger et al. 2019). This connection implies that idiom comprehension is not merely a function of exposure but also reflects underlying cognitive capacities that vary among learners. Such individual differences can affect the stability and reliability of idiom knowledge, particularly among younger learners who may not have developed a robust idiomatic vocabulary (Sprenger et al. 2019).

In general, the acquisition of idiomatic expressions in L2 is intricately tied to cognitive processes similar to those governing other linguistic behaviors and learning paradigms. Fundamental principles of long-term memory formation, such as noticing, encoding, storage, and retrieval, play a crucial role in learning multi-word figurative expressions, paralleling the learning of individual word meanings (Vasiljevic 2015). Research has indicated that idiom comprehension and acquisition depend significantly on individual differences, including cognitive abilities and personality traits, which can influence both the learning process and the eventual mastery of idioms (Sprenger et al. 2019).

2.2 Cognitive fatigue and its dimensions

Cognitive fatigue is a multifaceted construct that affects various domains, from workplace productivity to learning (Karim et al. 2024). Researchers have identified five core dimensions of cognitive fatigue: cognitive, emotional, physical, behavioral, and motivational fatigue. These dimensions capture the complex and interconnected nature of fatigue and its impact across different domains of functioning. Cognitive fatigue is characterized by a decline in mental efficiency, attention, and decision-making abilities after prolonged mental exertion. Neurocognitive models suggest that cognitive fatigue arises from resource depletion in the prefrontal cortex, which governs higher-order cognitive functions such as working memory and executive control (Baumeister and Vohs 2016). Empirical studies have also shown that sustained cognitive tasks, such as problem-solving or learning, lead to decreased accuracy and slower response times (Ackerman 2011). This dimension is particularly relevant in academic and professional contexts where mental stamina is critical. In language learning, cognitive fatigue can impair processing, retention, and recall, particularly in demanding tasks like idiom learning or complex grammar exercises.

Emotional fatigue refers to feelings of emotional depletion and reduced emotional resilience due to prolonged exposure to stress or emotionally taxing situations. Symptoms include irritability, apathy, and a reduced capacity to empathize with others (Maslach and Leiter 2016). Emotional fatigue is linked to burnout in high-stress environments, such as teaching, caregiving, or jobs requiring extensive interpersonal interactions. In SLA, emotional fatigue may affect learners' attitudes and motivation, particularly when they face repeated setbacks or challenges in acquiring a new language.

Physical fatigue involves a decline in physical energy and endurance due to sustained physical effort or inadequate recovery. While primarily related to bodily exertion, physical fatigue often interacts with cognitive and emotional fatigue, as seen in holistic tasks like teaching or sports (Kroemer and Grandjean 1997). Physiological markers include increased heart rate, muscular soreness, and reduced physical stamina. It can indirectly impair cognitive tasks by diminishing overall energy levels (Marcora et al. 2009). In SLA, physical fatigue may arise in immersive language programs where learners participate in extended classroom activities and extracurricular engagement.

Behavioral fatigue manifests as reduced initiative, decreased task engagement, and an increased likelihood of errors in performance. Behavioral fatigue often presents as procrastination, withdrawal from demanding tasks, or avoidance behaviors (Ackerman and Kanfer 2009). Behavioral changes may exacerbate fatigue, creating a cycle of reduced effort and poor outcomes. In SLA, this dimension is evident when learners disengage from practice, fail to complete assignments, or avoid communicative opportunities due to perceived effort.

Motivational fatigue is a decline in the drive or willingness to engage in tasks, often stemming from repeated failures, monotonous routines, or perceived lack of progress. Generally, motivational traits significantly influence L2 proficiency and, consequently, idiom acquisition. Many studies, such as Dunn and Iwaniec (2022) and Papi and Khajavy (2021), have highlighted the noticeable relationships between various motivational constructs and L2 learning across L2 proficiency levels. Accordingly, learners experiencing motivational fatigue often report feelings of boredom, frustration, or defeat. Motivational fatigue can lead to dropout or reduced practice, particularly when learners do not perceive clear progress or relevance in their studies (Schunk and Zimmerman 2007).

Of note, the five dimensions of cognitive fatigue are not isolated entities but rather deeply interconnected and overlapping. These dimensions form a dynamic system where the effects in one domain can cascade into others, amplifying the overall experience of fatigue. For instance, cognitive fatigue from prolonged mental effort can heighten emotional fatigue, leading to frustration or irritability. Similarly, physical fatigue can diminish cognitive efficiency and motivation, creating a cycle where learners struggle to focus, lose emotional resilience, and withdraw from tasks (behavioral fatigue). This interplay is particularly evident in high-demand settings like language acquisition, where sustained effort is required across all these domains. Recognizing this interconnectedness is crucial for designing effective interventions. Holistic approaches that address multiple dimensions – such as combining physical rest, cognitive breaks, emotional support, and motivational incentives – are more likely to mitigate fatigue and promote sustained performance and well-being.

In summary, cognitive fatigue should not be viewed as a singular issue but as a complex, multi-dimensional phenomenon where the boundaries between its components blur, influencing each other in meaningful ways.

2.3 Spaced versus massed practice and cognitive fatigue

Spaced practice, also known as distributed practice, involves spreading learning sessions over time, allowing for periods of rest between learning episodes. The spacing effect, first identified by Ebbinghaus (1885), indicates that learners retain information better when study sessions are spaced out rather than crammed into a short period. Studies in the domain of SLA have found that spaced practice improves retention and recall, particularly for vocabulary and grammar (Bahrick et al. 1993). In contrast, massed practice, or cramming, involves concentrated practice over a short period, often without sufficient breaks or rest. While massed practice may lead to short-term improvements in performance (e.g., recall during a single session), it can induce cognitive fatigue over time. Research by Chen and Kalyuga (2020) found that massed practice leads to higher levels of cognitive fatigue, as learners must sustain attention and effort over extended periods. The fatigue induced by massed practice is thought to decrease cognitive resources, making it harder for learners to process new information effectively (Chen and Kalyuga 2020). Despite its drawbacks, massed practice has been shown to provide temporary benefits for tasks that require quick, focused performance. However, these benefits often dissipate over time, and learners may experience a performance decline (Dunlosky et al. 2013).

The concepts of cognitive fatigue, particularly in the context of spaced versus massed practice, are essential to understanding idiom learning. Spaced practice (i.e., distributing learning over time) has been shown to facilitate deeper processing and better long-term retention of language material, including idioms, compared to massed practice, which tends to lead to cognitive fatigue (Vasiljevic 2015). More clearly, by spacing out learning sessions, learners are given time to consolidate information, making it easier to retrieve and apply in future contexts (Cepeda et al. 2006). This approach also alleviates cognitive fatigue by preventing prolonged periods of intensive cognitive effort, which can lead to exhaustion and performance declines.

Overall, the effects of spaced and massed practice on L2 learning have been well-documented. For example, Bahrick et al. (1993) demonstrated that spaced review of vocabulary words led to better retention in the long term compared to massed review. Similarly, studies on grammar learning have found that spaced practice enhances both short-term and long-term performance (Miles 2014). In exploring the effects of task repetition on fluency in L2 learning, Lambert et al. (2017) conducted a detailed analysis of Japanese EFL learners engaged in repeated speaking tasks. Their study found that fluency improvements were significant up to the fourth or fifth performance, highlighting the potential benefits of structured practice on idiom usage and production (Suzuki and Hanzawa 2022). These findings align with the understanding that repeated exposure and practice can alleviate cognitive fatigue and enhance fluency in language learners. However, less attention has been paid to how these practices influence cognitive fatigue during tasks that require substantial cognitive effort, such as idiom comprehension.

2.4 Cognitive fatigue and L2 learning

Research on cognitive fatigue in education suggests that learners often experience a decline in task performance, attention, and motivation when fatigued. Studies by de Lange et al. (2004) and Kok (2022) showed that cognitive fatigue impairs performance in tasks requiring sustained attention and working memory. In the context of L2 learning, cognitive fatigue may hinder learners' ability to recall and apply idiomatic expressions, as the retrieval of non-literal meanings requires substantial cognitive effort (Schmitt 2010).

L2 proficiency, as an important component of SLA, plays a crucial role in how learners manage cognitive fatigue during language tasks. Research suggests that learners at different L2 proficiency levels experience cognitive load differently, with higher proficiency learners often better equipped to handle complex tasks (Sweller et al. 2011a, 2011b). For example, high proficiency learners may have more efficient mental representations of vocabulary and grammar, which reduces the cognitive effort required for tasks like idiom comprehension (Fitzpatrick and Barfield 2009). Low proficiency learners, on the other hand, are likely to experience greater cognitive fatigue because they lack the mental frameworks and processing strategies needed to handle the complexity of idioms. As a result, they may struggle to recall and apply idiomatic expressions effectively, especially under conditions of high cognitive load (Macis et al. 2021). In contrast, more advanced learners may have developed strategies to manage cognitive fatigue, such as chunking or relying on context to interpret idiomatic meanings. Studies have also shown that proficiency level affects both task performance and the ability to manage cognitive fatigue. For example, research by Ellis (2008) suggests that higher proficiency learners can handle more complex language tasks, such as idiom comprehension, with less cognitive strain. This implies that lower proficiency learners may experience more fatigue, leading to declines in accuracy and recall when engaging in tasks like idiom comprehension.

2.5 Measuring cognitive fatigue in SLA

Two main types of methods to measure cognitive fatigue, especially in educational contexts, are self-report and performance-based methods. Self-report measures are widely used to assess cognitive fatigue because they provide direct insights into learners' subjective experiences. Among these, the VAS is commonly employed in educational studies (Nguyen and Fabrigar 2018). It allows learners to rate their perceived fatigue on a continuous scale, providing a simple yet reliable tool to capture fluctuations in mental effort during learning tasks. Previous studies in SLA have used VAS to track cognitive fatigue before and after learning tasks, with findings indicating that learners report increased fatigue after intense study sessions (Lee and Park 2023).

Performance-based measures, such as accuracy tracking, can also provide an objective way to assess cognitive fatigue. Studies have shown that cognitive fatigue often manifests in declining performance, such as slower reaction times or decreased accuracy (Eysenck et al. 2007). In the context of idiom comprehension, accuracy tracking through tasks like free recall can offer valuable insights into how cognitive fatigue impacts learners' ability to recall and apply idiomatic expressions. Research by Kok (2022) showed that cognitive fatigue is associated with lower accuracy and longer response times in cognitive tasks, making it an effective indicator of mental exhaustion.

3 Objectives of study

This study aimed to bridge these gaps by investigating the cognitive fatigue induced by spaced and massed practice on idiom comprehension across low, mid, and high L2 proficiency learners. The following research questions were addressed:

1. How does spaced practice versus massed practice affect overall cognitive fatigue in L2 learners across L2 proficiency levels (low, mid, high)?
2. How L2 proficiency levels differ in terms of the dimensions of cognitive fatigue under spaced and massed practice?
3. What is the relationship between cognitive fatigue and idiom comprehension accuracy in L2 learners?

Cognitive fatigue, particularly as it relates to spaced and massed practice, has significant implications for the accuracy of idiom acquisition across varying L2 proficiency levels. Idioms, which are expressions that convey meanings not deducible from their individual words, present unique challenges in L2 learning due to their complexity and cultural nuances. Understanding the impact of cognitive fatigue on language processing is essential, as it directly influences learners' ability to comprehend and retain idiomatic expressions, which are critical for fluency and effective communication. Research indicates that cognitive fatigue can hinder the learning process, particularly in environments that favor massed practice, which often lead to overload and diminished retention. In contrast, spaced practice, characterized by distributed learning sessions over time, has been shown to enhance memory retention and deeper processing of idioms, thus improving overall idiomatic accuracy among learners. These distinctions highlight the importance of effective instructional strategies that accommodate cognitive limitations and enhance learning outcomes across different proficiency levels. Ultimately, investigating this topic is pivotal in understanding how cognitive fatigue interacts with idiomatic expression learning, providing insights that can refine language teaching methodologies.

4 Methods

4.1 Research design

Quasi-experimental between-participant research design was used for the study as it offers several merits for this study. By assigning participants to different proficiency levels and practice schedule conditions (spaced vs. massed), this design helps isolate the effects of each independent variables (i.e., practice conditions and L2 proficiency level) on dependent variables (i.e., cognitive fatigue and idiom accuracy) without the risk of carryover effects that might occur in a within-subjects design. It allows for a clearer comparison of how different proficiency levels interact with varying practice schedules, providing distinct group-level insights. This design also reflects real-world scenarios where learners typically engage in either spaced or massed practice, rather than both, ensuring ecological validity.

4.2 Participants

The participants were 92 young adult English as a Foreign Language (EFL) learners with mean age of 21 years old belonging to six intact classes from three different L2 proficiency levels (two classes per L2 proficiency): low (n = 33), mid (n = 31), and high (n = 28). They were all Iranian, with Persian/Farsi as their first language. Their exposure to the target language, English, was primarily limited to academic settings, as English is not commonly used in daily situations in the country. The participants' L2 proficiency level was specified by the placement test of the language school. More specifically, based on the CEFR standard, the low L2 proficiency learners were at A1, mid L2 proficiency learners were at B1 level, and the high L2 proficiency learners were at C1 level. The Updated Vocabulary Levels Test (UVLT) results also indicated that the low, mid, and high L2 proficiency groups had lexical knowledge of the first 2,000 words, 3,000 words, and 4,000 words, respectively.

All participants were informed about the study's purpose, procedures, and their rights before participation. Informed consent was obtained in writing from all participants. As an incentive, participants received graded readers upon completion of the study.

4.3 Materials

Considering the class time constraints, 20 opaque idioms were selected for the study from which 12 idioms were the main target idioms, and eight ones were control items. The idioms all shared some features. First, they were restricted to three to four words to uphold consistency in complexity and guarantee that they remained cognitively manageable for learners across all proficiency levels. Second, they did not include any pronouns to prevent learners from needing to significantly alter the idiomatic expressions during the learning process (e.g., pull my leg, pull his leg, etc.). Third, the individual constituents of them were within the most frequent 3,000 word families (based on COCA), so that the participants knew the meanings of the individual words but not the meaning of the whole idiom. The identical sets of English idioms were employed across all three proficiency groups of participants, enabling a direct comparison of the impact of learner proficiency on idiom acquisition. Control items were chosen based on the same criteria applied to the target idioms. This alignment between the control and target items facilitated the researcher's ability to isolate the effects of independent variables while reducing the influence of potential confounding variables.

To prepare the idioms, first, an idiom pool consisting of 40 idioms was compiled. Then, a norming task was administered online with 10 native speakers of English to check the transparency of the idioms. The native speakers were required to rate the transparency of the idioms (i.e., the degree to which the meaning of an idiom can be understood from the meaning of its individual components) on a rating scale from 1 to 7 (1 and 2 indicated high transparency while 6 and 7 indicated low transparency). In the next stage, only the idioms with mean transparency of four and above were kept (26 idioms). This threshold was chosen because it signifies the midpoint of the scale, differentiating between idioms that possess minimal to no compositional meaning and those that provide a certain level of transparency. Moreover, in the course of initial data gathering and analysis of responses from native speakers, it was observed that idioms rated above 4 were uniformly assessed as lacking a significant connection between their elements and their figurative interpretation.

Following this, the list was reviewed by the participants' classroom teachers, who were asked to provide feedback on the idioms' familiarity and potential recognition by learners at different proficiency levels. Based on their professional judgment, the teachers identified three idioms that might have been recognizable or guessable due to a similar idiom in their first language. These idioms were removed to ensure that all selected idioms were genuinely unknown to the participants across all proficiency levels.

The remaining idioms were then given to 15 advanced-level (IELTS level) L2 learners in another online norming task to ensure the meaning of the idioms was unknown to them. The main reason for selecting advanced-level L2 learners for the norming task was that if they did not know the idioms, it was highly likely that intermediate and low-level learners did not know them either. This stage also resulted in omission of three other idioms.

4.4 Procedure

4.4.1 Pretest

All participants first completed a pre-test, 16 days before the outset of the study, to make sure the idioms were unknown to the participants. The pre-test consisted of 12 idioms. The test was given to the participants under time pressure (to minimize the chance of committing them to memory) and required the participants to indicate whether they knew the idiom (Yes or No) and if yes, explain the idiom meaning in any way (i.e., writing synonyms, describing the meaning, writing sentence examples, etc.). The pretest results showed that all the idioms were unknown to the participants.

4.4.2 Cognitive fatigue measurement

Two types of measures were used to assess cognitive fatigue. First, to assess participants' subjective experience of cognitive fatigue, a self-report cognitive fatigue scale was employed. It consisted of 20 items distributed across five dimensions of cognitive fatigue: cognitive fatigue, emotional fatigue, physical fatigue, behavioral fatigue, and motivational fatigue. Each dimension was represented by four items, designed to capture the nuanced effects of fatigue experienced during intensive idiom learning tasks. Participants rated each item on a 5-point Likert scale, ranging from 1 (Strongly Disagree) to 5 (Strongly Agree), allowing them to indicate the extent to which they experienced fatigue-related symptoms at the moment of completing the questionnaire. Participants were instructed to read each statement carefully and respond based on how they feel at the moment after completing the learning session, with the goal of providing an honest self-assessment of their cognitive fatigue.

The development of this scale was informed by several widely used fatigue inventories, including the Multidimensional Fatigue Inventory (MFI-20) (Smets et al. 1995), the Profile of Mood States (POMS) fatigue subscale (McNair et al. 1971), and the Subjective Fatigue Scale employed in experimental learning studies (Ackerman and Kanfer 2009). These instruments have demonstrated strong psychometric properties and have been adapted in previous pertinent research studies to investigate fatigue in different tasks. The scale demonstrated strong internal consistency, as evidenced by Cronbach's Alpha values for each dimension (89.90, 88.69, 87.83, 91.13, and 88.69 for cognitive fatigue, emotional fatigue, physical fatigue, behavioral fatigue, and motivational fatigue, respectively) and the full scale (i.e., 86.18). In addition, content validity was ensured through expert review. Two researchers specializing in second language acquisition and psycholinguistics independently reviewed the items for relevance, clarity, and appropriateness for the L2 learning context. Any ambiguities or redundancies were addressed prior to data collection.

The second one was a performance-based measure that measured idiom accuracy. This free recall form task was similar to the pretest task except the order of items that were randomized. For this measure, after completing the spaced or massed practice sessions, participants were asked to recall and write down the idioms they had learned. To be more specific, the task consisted of 12 prompts, each providing a brief context or definition related to the idioms and the participants were required to recall and write the idiom that best fit each prompt. This task did not provide any cues or prompts, so the participants needed to rely on their memory of the idioms from the practice sessions. The number of correctly recalled idioms was recorded as an indicator of their idiom comprehension accuracy. This task directly assessed participants' ability to recall idioms' form, which served as a measure of their comprehension. Successful recall indicates that the participant has internalized the form of the idioms. It also provides insight into the cognitive load and memory retention associated with the different practice schedules (spaced vs. massed) and proficiency levels (low, mid, high). It helped to gauge how well participants had processed and retained the idioms.

4.4.3 The learning treatment

Prior to the start of the study, participants were recruited from intact classes. Interested learners were provided with an information sheet outlining the study's purpose, time commitment, and data confidentiality. Written informed consent was collected from each participant before they were assigned to either the spaced or massed practice condition. Those in the spaced practice condition completed their practice sessions three sessions with one day in between, while those in the massed practice condition completed all the practice in one continuous session. For each spaced and massed practice conditions, the same amount of time (i.e., 20 min) was dedicated and involved exposure to idioms' form (i.e., presenting the idiom form), meaning (showing the meaning of the idiom), and use (presenting a sentence example). To control the number of repetitions, they were presented as flashcards in the form of PowerPoint slides. The slides were both audio and visual as the teachers read them loud to the learners and learners could see them on the screen.

4.4.4 Scoring approach

To score the self-report cognitive fatigue scale responses, given that it consisted of five main dimensions, with each dimension containing 4 items, for each participant, the score for each dimension was calculated by summing the responses to the items in that dimension. Each subscale score represented the participant's level of fatigue in that specific dimension (i.e., the higher the score, the higher the reported cognitive fatigue in that dimension). In addition, the overall cognitive fatigue score of the participants was also calculated by summing the scores from all 20 items across all dimensions. This score provided an overall measure of cognitive fatigue, where a higher score reflected a higher level of fatigue.

To score the free recall task, a lenient binary approach was used. For each item, the responses was assigned either 0 (meaning wrong answer) or 1 (meaning correct answer). Only minor misspellings (such as repetition of a single letter or insertion of an extra letter) were ignored. Then the total number of correct responses for each participant was computed. 25 % of the responses were also scored by a second rater and interrater reliability was calculated using Cohen's Kappa which was 94.85 %. The discrepancies in scoring was resolved via discussing them.

4.5 Data analysis

For the first research question, asking how spacing schedule affects overall cognitive fatigue across L2 proficiency levels, two-way ANOVA was conducted in which spacing schedule and L2 proficiency were taken as independent variables and overall cognitive fatigue as the dependent variable. This statistical approach could help to determine if there were significant differences in cognitive fatigue across L2 proficiency groups and practice conditions. One important point to highlight is that given that Cohen's d is particularly useful for comparing two groups and Partial η^2 is more appropriate for factors with multiple levels, in case of obtaining significant results, both indexes were calculated to be able to make more fine-tuned interpretations. For the second research question, asking about how L2 proficiency levels differ in terms of cognitive fatigue dimensions under spacing schedules, to compare cognitive fatigue levels (cognitive fatigue scale scores) across the practice schedule (spaced vs. massed) and proficiency groups (low, mid, high), MANOVA was used in which the five dimensions of cognitive fatigue were taken as dependent variables and L2 proficiency and spacing schedules as independent variables. This statistical technique could determine if there were statistically significant differences in cognitive fatigue across the L2 proficiency groups and practice types while controlling for type I error rates. Finally, to examine the third research question examining the relationship between cognitive fatigue and idiom comprehension across L2 proficiency levels, multiple regression analysis was employed as it could assess how well cognitive fatigue predicts idiom comprehension accuracy while controlling for L2 proficiency levels.

5 Results

5.1 Spacing schedule and overall cognitive fatigue across L2 proficiency levels

Findings pertinent to the first research question underscored a clear gradient in the differential effects of practice type on cognitive fatigue, with the impact of massed practice intensifying as proficiency levels increase (Figure 1). To be more detailed, in the low L2 proficiency, massed practice resulted in slightly higher cognitive fatigue compared to spaced practice, indicating a marginal difference in fatigue levels between the two conditions. In contrast, mid L2 proficiency learners exhibited a notable disparity, with fatigue levels significantly higher under massed practice than under spaced practice. The trend was even more pronounced in high L2 proficiency learners, where massed practice caused markedly elevated cognitive fatigue compared to spaced practice.

The two-way ANOVA results (Table 1) indicate significant main effects of both L2 proficiency ($F(2,86) = 74.408$, $p < 0.001$) and spacing condition ($F(1,86) = 832.744$, $p < 0.001$), as well as a significant interaction between them ($F(2,86) = 183.051$, $p < 0.001$).

Statistical analyses further revealed substantial effect sizes across all factors examined (Table 2). The spacing condition emerged as the most influential factor,

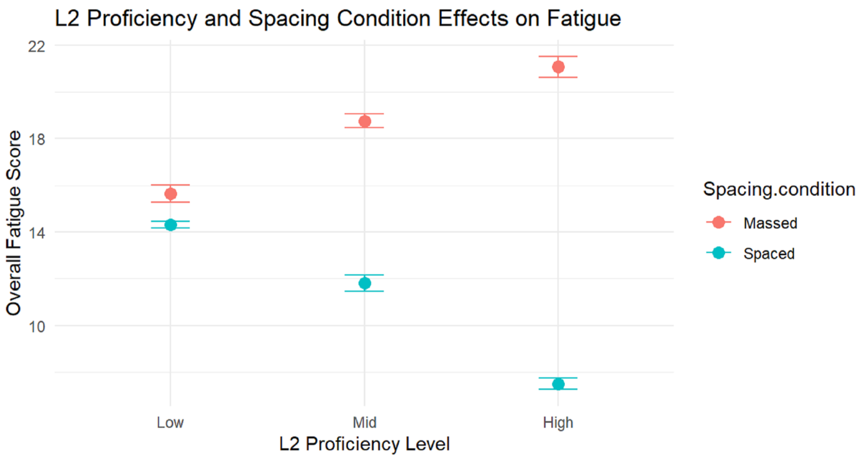

Figure 1: Mean overall fatigue across practice conditions and L2 proficiency levels.

Table 1: ANOVA table (Type III) results.

	Sum Sq	*df*	*F* value	Pr (>*F*)
(Intercept)	6,216.1	1	4,014.934	<0.001
L2 proficiency	230.4	2	74.408	<0.001
Spacing condition	1,289.3	1	832.744	<0.001
L2 proficiency: Spacing.condition	566.8	2	183.051	<0.001
Residuals	133.1	86		

Table 2: Effect size results for main effects and interaction effects.

Factor	Effect size (partial η^2)	*F* value	*df*	*p*-value
Spacing condition	0.906	832.744	1.86	<0.001
L2 proficiency	0.604	832.744	2.86	<0.001
Interaction effect	0.810	183.51	2.86	<0.001
Spacing condition (Cohen's *d*)	2.468			

demonstrating an exceptionally large effect size (partial $\eta^2 = 0.906$, Cohen's $d = 2.468$), accounting for 90.6 % of the variance in fatigue scores when controlling for other variables. This effect is particularly evident in the mean differences between massed ($M = 18.32$, SD = 2.65) and spaced practice conditions ($M = 11.36$, SD = 2.99).

L2 proficiency level also demonstrated a considerable effect (partial $\eta^2 = 0.634$), explaining 63.4 % of the variance in fatigue scores. Moreover, a robust interaction effect between spacing condition and L2 proficiency was observed (partial $\eta^2 = 0.810$), indicating that 81 % of the variance could be attributed to the combined influence of these factors. Following Cohen's (1988) guidelines for effect size interpretation, where η^2 values of 0.01, 0.06, and 0.14 represent small, medium, and large effects respectively, all observed effects in this study can be classified as very large.

The magnitude of these effects, particularly the spacing condition's impact ($d = 2.468$), substantially exceeds Cohen's conventional threshold for a large effect ($d = 0.80$). This finding underscores the practical significance of implementing spaced practice in L2 learning contexts. The robust interaction effect further suggests that the impact of spacing conditions varies meaningfully across proficiency levels, highlighting the importance of considering both factors in pedagogical design. These findings provide strong support for the implementation of spaced practice in L2 learning environments.

5.2 L2 proficiency differences and cognitive fatigue dimensions under spacing schedules

A MANOVA was conducted to examine the effects of L2 Proficiency, Spacing Condition, and their interaction on the combined dimensions of cognitive fatigue (Table 3). Several results were observed. First, A significant multivariate effect was observed for L2 proficiency (Pillai's Trace = 1.513, $F(10,166) = 51.533$, $p < 0.001$) indicating that L2 proficiency levels significantly influenced the combined dimensions of cognitive fatigue. Second, A significant multivariate effect was also found for spacing condition

Table 3: MANOVA results for cognitive fatigue dimensions.

Effect	Pillai's trace	*F* value	Numerator *df*	Denominator *df*	*p*-value
L2 proficiency	1.513	51.533	10	166	<0.001
Spacing condition	0.919	185.288	5	82	<0.001
L2 proficiency × spacing condition	1.349	34.425	10	166	<0.001

(Pillai's Trace = 0.919, $F(5,82) = 185.288$, $p < 0.001$) suggesting that the practice condition (spaced vs. massed) had a substantial impact on cognitive fatigue dimensions. Third, the interaction between L2 Proficiency and spacing condition was significant (Pillai's Trace = 1.349, $F(10,166) = 34.425$, $p < 0.001$) indicating that the effect of spacing condition on cognitive fatigue dimensions varies across L2 proficiency levels.

To further understand the magnitude of these effects, partial eta squared values were calculated for each dimension of cognitive fatigue (Table 4). The motivational dimension showed the strongest effect of spacing condition ($\eta^2 = 0.838$, $\eta^2 = 0.838$), while the emotional dimension exhibited the largest effect of L2 Proficiency ($\eta^2 = 0.748$, $\eta^2 = 0.748$). The physical dimension demonstrated the most substantial interaction effect ($\eta^2 = 0.669$, $\eta^2 = 0.669$), highlighting the interplay between L2 proficiency and spacing condition in influencing this dimension. These findings collectively suggest that both L2 proficiency and spacing condition, as well as their interaction, significantly influence various dimensions of cognitive fatigue, with varying magnitudes across dimensions.

To be more specific, Figure 2 clearly underscores the nuanced interplay between L2 proficiency and spacing conditions, with distinct patterns emerging across different dimensions of cognitive fatigue. In the cognitive dimension, spaced learning consistently results in lower fatigue scores compared to massed learning, with the largest differences observed in mid-proficiency learners. The emotional dimension shows a similar trend, though the gap between spacing conditions

Table 4: Partial eta squared values for cognitive fatigue dimensions.

Dimension	L2 proficiency	Spacing condition	Interaction
Cognitive	0.378	0.342	0.429
Emotional	0.748	0.411	0.643
Physical	0.686	0.627	0.669
Behavioral	0.445	0.518	0.585
Motivational	0.043	0.838	0.106

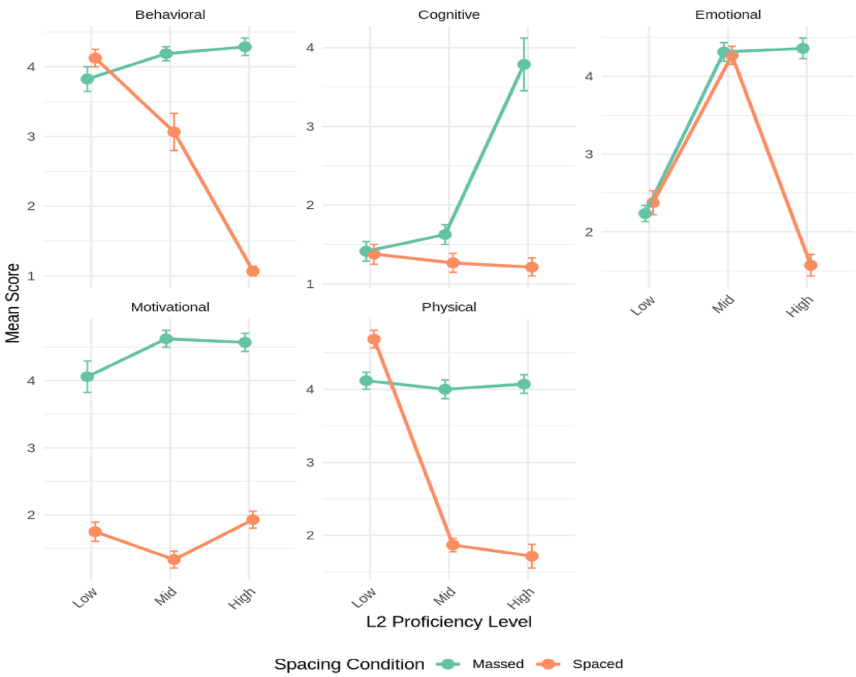

Figure 2: Cognitive fatigue dimensions across L2 proficiency levels and practice conditions.

narrows for high-proficiency learners. The physical dimension reveals substantial variability, with mid-proficiency learners showing the most pronounced differences between spacing conditions. The behavioral dimension demonstrates relatively stable patterns, with spaced learning generally leading to lower fatigue scores across all proficiency levels. Finally, the motivational dimension exhibits a unique trend where the impact of spacing conditions diminishes as proficiency increases, with high-proficiency learners showing minimal differences between massed and spaced conditions.

5.3 Relationship between cognitive fatigue and idiom comprehension across L2 proficiency

Lastly, data associated with the third research question (i.e., the interrelationship of overall cognitive fatigue and idiom comprehension) revealed a consistent negative relationship between cognitive fatigue and idiom task performance across all L2 proficiency levels, indicating that higher fatigue is generally associated with lower task accuracy. For high L2 proficiency learners, spaced practice yielded higher idiom task accuracy (M = 9.86) compared to massed practice (M = 7.93), suggesting the benefits of distributed learning for this group. Similarly, mid L2 proficiency learners demonstrated improved accuracy under spaced practice (M = 8.67) relative to massed practice (M = 6.00), reinforcing the efficacy of spaced intervals for enhancing learning outcomes. Interestingly, for low L2 proficiency learners, the trend was reversed, with slightly better idiom scores observed under massed practice (M = 6.88) compared to spaced practice (M = 5.38).

More specifically, the multiple regression analysis (Table 5) examining the relationship between cognitive fatigue dimensions and idiom comprehension accuracy yielded a statistically significant model ($F(5, 86) = 32.82$, $p < 0.001$), with an adjusted R^2 of 0.636, indicating that approximately 63.6 % of the variance in idiom comprehension accuracy is explained by the five dimensions of cognitive fatigue. Three dimensions emerged as significant predictors: Cognitive fatigue showed a positive relationship ($\beta = 0.634$, $p < 0.001$), emotional fatigue showed a negative relationship ($\beta = -0.240$, $p < 0.05$), and physical fatigue showed a strong negative relationship ($\beta = -1.048$, $p < 0.001$). Behavioral and Motivational dimensions did not significantly predict idiom comprehension accuracy ($p > 0.05$).

The Variance Inflation Factors (VIF) range from 1.37 to 2.54, indicating acceptable levels of multicollinearity (all values < 3). The correlation matrix reveals particularly strong negative correlations between idiom task scores and physical fatigue ($r = -0.718$) and behavioral fatigue ($r = -0.575$). These findings suggest that while increased cognitive engagement may facilitate idiom comprehension, physical and emotional fatigue may impair performance. The strong negative correlation with physical fatigue particularly highlights the importance of managing physical fatigue in L2 learning contexts.

Table 5: Regression coefficients for cognitive fatigue dimensions and idiom accuracy.

Variable	Idiom score	Cognitive	Emotional	Physical	Behavioral	Motivational
Idiom score	1	0.084	−0.1	−0.718	−0.575	−0.268
Cognitive	0.084	1	0.382	0.287	0.289	0.415
Emotional	−0.1	0.382	1	0.04	0.433	0.295
Physical	−0.718	0.287	0.04	1	0.661	0.467
Behavioral	−0.575	0.289	0.433	0.661	1	0.386
Motivational	−0.268	0.415	0.295	0.467	0.386	1

6 Discussion

The first research question asked about how spaced and massed practice affect overall cognitive fatigue in L2 learners across L2 proficiency levels. The ANOVA results revealed significant differences in overall cognitive fatigue between spaced and massed practice conditions. Spaced practice consistently resulted in lower levels of cognitive fatigue across all proficiency levels. However, the magnitude of this effect varied by proficiency level, with low L2 proficiency learners experiencing the greatest reduction in fatigue under spaced practice. From a theoretical perspective, this finding aligns with cognitive load theory, as lower L2 learners typically experience higher intrinsic cognitive load due to their limited schema development. The reduced cognitive fatigue under spaced practice conditions may indicate more efficient processing and consolidation of new linguistic information. In addition, it support the cognitive load reduction of spaced practice, while simultaneously highlighting the importance of considering individual differences, particularly L2 proficiency, in language learning capability. The differential effects observed across proficiency levels indicate that the cognitive benefits of spacing may be moderated by existing language competency, presenting important implications for adaptive learning design. These results extend previous research on the spacing effect by explicitly considering cognitive fatigue as a mediating factor in language learning outcomes. While prior studies have predominantly focused on retention and performance metrics, this investigation illuminates the role of practice distribution in managing cognitive resources. The systematic variation in fatigue reduction across proficiency levels also suggests a potential interaction between learner expertise and the cognitive benefits of spaced practice.

From an empirical perspective, the finding that spaced practice resulted in lower cognitive fatigue across all proficiency levels corresponds with studies in SLA suggesting that spacing provides learners with more time to consolidate information, mitigating the strain on working memory resources (Suzuki et al. 2019). This temporal spacing likely allows learners to engage in deeper processing during each session, reducing the cognitive effort required to revisit the material. In contrast, massed practice has been linked to increased cognitive fatigue due to its demands on sustained attention and working memory over extended periods. Studies such as Draheim et al. (2022) highlight that continuous, repetitive practice can lead to attentional depletion and reduced engagement, particularly in tasks requiring high cognitive involvement, such as idiom learning. This aligns with the observed higher levels of fatigue under massed conditions across all proficiency levels in the current study. The finding that low-proficiency learners experienced the greatest reduction in fatigue under spaced practice warrants special attention. Low-proficiency learners often exhibit limited linguistic resources and working memory capacity, making massed practice particularly taxing for them. Suzuki and DeKeyser (2017) argue that spaced intervals can provide learners with more opportunities for reflection and retrieval, reducing the cognitive effort required to process and store new information. This may explain why the fatigue-reducing effects of spacing are more pronounced for lower-proficiency learners, who benefit most from the additional time to consolidate learning.

The second research question was about how L2 proficiency levels differ in terms of the dimensions of cognitive fatigue under spaced and massed practice. The MANOVA analysis demonstrated significant interactions between practice type and L2 proficiency level across the five dimensions of cognitive fatigue. Low L2 proficiency learners exhibited higher levels of emotional and physical fatigue under massed practice compared to their mid and high L2 proficiency counterparts. Conversely, high L2 proficiency learners showed greater resilience to fatigue, particularly in the cognitive and motivational dimensions. The differential impact on low L2 proficiency learners is particularly noteworthy. Their heightened susceptibility to emotional and physical fatigue under massed practice conditions suggests that concentrated learning sessions may pose significant challenges for beginners. This vulnerability likely stems from the increased cognitive resources required to process new linguistic information without well-established language schemas. In a similar vein, Suzuki and DeKeyser (2017) contended that low-proficiency learners often struggle with limited linguistic and cognitive resources, making the intensive demands of massed practice particularly taxing. Further, emotional fatigue may arise from frustration and reduced self-efficacy when learners repeatedly encounter difficulties without sufficient breaks to process material. It also suggests that their limited working memory capacity (Baddeley 2003) and less automated language skills exacerbate the cognitive demands of massed practice, making it a suboptimal learning condition for this group.

The demonstrated resilience of high L2 proficiency learners, especially in cognitive and motivational dimensions, suggests the development of more efficient processing mechanisms and stronger metacognitive strategies. This resilience may result from their more extensive linguistic knowledge base, which allows for more automated processing and reduced cognitive load during learning tasks. In other words, the greater resilience of high L2 proficiency learners to fatigue, particularly in the cognitive and motivational dimensions, even under massed practice corroborates with the cognitive resource allocation theory suggesting that more advanced learners are better equipped to manage the cognitive demands of massed practice due to their more automated language skills and greater experience with complex linguistic tasks (Kuldas et al. 2014). Motivational resilience may also stem from the ability of high l2 proficiency learners to focus on long-term goals and derive intrinsic satisfaction from mastering challenging material. Studies on self-regulated learning in SLA (e.g., Dörnyei 2009; Kuldas et al. 2014) support this perspective, highlighting the role of motivation as a buffer against fatigue in demanding learning environments.

Finally, the third research question addressed the relationship between cognitive fatigue and idiom comprehension accuracy in L2 learners. The multiple regression analysis revealed that cognitive fatigue dimensions significantly predict idiom comprehension accuracy. Cognitive fatigue positively influenced accuracy, suggesting that moderate cognitive engagement may enhance performance. In contrast, emotional and physical fatigue negatively impacted accuracy, with physical fatigue showing the strongest detrimental effect. The positive association between cognitive fatigue dimension and comprehension accuracy suggests that moderate cognitive engagement, rather than being detrimental, may actually enhance performance in idiom comprehension tasks. This aligns with the desirable difficulty hypothesis (Bjork and Bjork 1992), which posits that tasks requiring moderate cognitive effort can lead to deeper processing and better retention of information. In the context of idiom learning, cognitive fatigue might reflect sustained mental engagement, promoting deeper semantic and syntactic processing necessary for understanding idiomatic expressions. Suzuki et al. (2019) also demonstrated that tasks involving moderate cognitive demand, such as spaced retrieval, foster better learning outcomes by requiring learners to actively reconstruct linguistic knowledge. Similarly, Fleming et al. (2023) found that tasks requiring sustained cognitive effort can improve lexical and phraseological accuracy, provided that the effort does not exceed learners' cognitive capacities.

However, the negative impact of emotional and physical fatigue on comprehension accuracy presents a contrasting pattern that requires attention. Emotional fatigue, often characterized by frustration or a lack of motivation, can impair learners' ability to focus and process new information effectively (Dörnyei 2009). This aligns with research by Manchón et al. (2023), who found that high emotional strain negatively affects learners' willingness to engage in challenging language tasks, reducing comprehension and performance. Physical fatigue, the strongest predictor of reduced accuracy, is particularly concerning in prolonged learning sessions or under massed practice conditions. Studies in cognitive psychology, such as those by Ackerman (2011), highlight the detrimental effects of physical exhaustion on attention, working memory, and overall cognitive performance. For idiom comprehension, which requires the integration of lexical, syntactic, and contextual knowledge, physical fatigue likely disrupts these processes, leading to reduced accuracy.

One notable and somewhat counterintuitive finding was that low-proficiency learners demonstrated slightly better idiom recall under massed practice compared to spaced practice. While this contrasts with the general benefits of spacing observed across other proficiency levels and fatigue dimensions, it can be understood in light of several cognitive and motivational factors. First, low-proficiency learners often exhibit limited schema development and weaker long-term memory representations for idiomatic expressions. In massed practice, the temporal proximity between learning and testing may have preserved information in short-term memory, facilitating better immediate recall. This aligns with findings from Nakata and Suzuki (2019), who noted that novices benefit from concentrated exposure when retrieving newly learned material shortly after learning. Second, the novelty and intensity of the massed practice condition may have temporarily elevated attention and task engagement, particularly among learners encountering idioms for the first time. Dörnyei (2009) highlights that early-stage learners often respond positively to high-intensity, focused tasks that create a sense of immediacy and challenge, potentially enhancing encoding efficiency. Finally, the delays inherent in spaced practice may have introduced forgetting or interference, particularly for learners lacking robust linguistic frameworks. Without sufficient reinforcement or contextual scaffolding, the fragile memory traces formed during spaced sessions may have weakened before retrieval. Additionally, spaced learning demands greater metacognitive regulation, which may exceed the self-regulatory capacities of low-proficiency learners at this stage of development.

These findings suggest that while spaced practice is generally advantageous for reducing cognitive fatigue and supporting long-term retention, massed practice may offer short-term benefits for absolute beginners, especially in highly controlled, teacher-guided environments. However, these benefits appear to diminish over time, underscoring the importance of gradually transitioning to spaced formats as learners develop stronger lexical and cognitive foundations.

7 Conclusions

This study investigated the impact of practice conditions (spaced vs. massed) and L2 proficiency levels (low, mid, high) on overall cognitive fatigue across L2 proficiency learners. The findings provide valuable insights into the nuanced effects of cognitive fatigue dimensions and their implications for L2 learning. The study collectively revealed that both L2 proficiency and practice condition significantly influence cognitive fatigue. Spaced practice consistently reduces fatigue across all L2 proficiency levels, but with different magnitudes of effects. Higher L2 proficiency learners also exhibit lower cognitive fatigue across all dimensions under spaced practice compared with lower L2 proficiency learners. Ultimately, there is a negative correlation between overall cognitive fatigue and idiom comprehension accuracy, implying that higher fatigue may impair comprehension abilities.

The findings of this study offer several practical implications for L2 instruction, particularly in relation to idiom learning and the management of cognitive fatigue across proficiency levels. First, the results suggest that spaced practice should be prioritized over massed practice when teaching idiomatic expressions, especially for low-proficiency learners who are more susceptible to cognitive fatigue. Spacing out learning sessions allows learners time to consolidate information and recover from mental effort, which appears to enhance both cognitive efficiency and idiom comprehension accuracy. Therefore, instructors are encouraged to distribute idiom learning tasks across multiple sessions rather than condensing them into a single session, even when short-term performance may seem comparable under massed practice. Second, given that physical fatigue emerged as the strongest negative predictor of idiom comprehension accuracy, teachers should be mindful of how long and how intensively learners engage in cognitively demanding tasks. For example, incorporating brief pauses between learning segments or alternating between high-effort and low-effort tasks may help reduce physical fatigue without interrupting the learning process.

Third, the interaction between proficiency level and fatigue dimensions highlights the need for differentiated instruction. While high-proficiency learners demonstrated greater resilience to fatigue, particularly in cognitive and motivational dimensions, even under massed conditions, low-proficiency learners experienced significantly higher emotional and physical fatigue, which hindered their performance. This suggests that beginners may benefit from additional scaffolding, such as visual aids, simplified contexts, or collaborative practice, to reduce cognitive load and support comprehension. Finally, since cognitive fatigue was found to have a positive relationship with comprehension accuracy, indicating that moderate mental engagement can support deeper processing, teachers should aim to strike a balance between mental challenge and cognitive overload. Tasks that require active retrieval and spaced review, rather than passive exposure, appear to align well with this principle.

While this study contributes valuable insights into the effects of spaced and massed practice on cognitive fatigue and idiom comprehension across L2 proficiency levels, it is not without limitations. First, the participants in this study were all adult Persian-speaking learners of English studying in Iran. While this allowed for greater control over linguistic background variables, it also limits the generalizability of the findings to other L2 populations, such as ESL learners or those with different first languages. Second, cognitive fatigue was assessed using both self-report scales and performance-based measures. However, self-reported fatigue data are inherently subjective and may be influenced by individual differences in perception, interpretation, and response bias. Although expert validation and reliability checks were conducted, incorporating physiological indicators (e.g., heart rate variability, eye-tracking, or EEG) could enhance the objectivity of fatigue measurement in future studies. Third, this study focused on immediate post-practice cognitive fatigue and idiom comprehension but did not assess long-term retention or transfer of idiom knowledge. As such, the findings reflect short-term effects rather than sustained learning outcomes.

The findings of this study also open up several promising avenues for future research that build directly on the observed effects of cognitive fatigue across practice conditions and L2 proficiency levels. First, longitudinal studies are needed to examine how cognitive fatigue evolves over extended periods of language learning and whether the benefits of spaced practice persist beyond short-term outcomes. Second, future studies could explore the role of individual differences, such as working memory capacity, motivation, and self-regulation, in moderating the relationship between cognitive fatigue and idiom comprehension. For example, high-proficiency learners in this study showed greater resilience to fatigue under massed practice, which may be attributed to stronger metacognitive skills or higher intrinsic motivation. Investigating these factors in detail could help identify which learners benefit most from specific practice schedules.

Third, researchers could investigate how technology-enhanced learning environments influence cognitive fatigue during spaced and massed practice. Adaptive learning systems, mobile apps, or AI-driven platforms could be used to personalize practice intervals and adjust task difficulty based on real-time fatigue indicators (e.g., response time, error patterns, or self-reports). Such tools could provide insights into optimizing learning while minimizing fatigue, especially for low-proficiency learners who are more vulnerable to emotional and physical fatigue. Fourth, future research could extend this work by examining other complex linguistic structures, such as phrasal verbs, collocations, or figurative language, to determine whether the fatigue-reducing effects of spaced practice generalize beyond idioms. This would help establish whether the observed patterns are specific to idiomatic expressions or reflect broader trends in L2 processing under cognitive load.

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