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Trends in Research Methods

Optimizing Vocabulary Acquisition Through Time-Pressured Practice: A Cognitive Load Perspective

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Abstract
The current study examines the effects of time pressure on vocabulary learning from a cognitive load perspective. It investigated whether the imposition of time restrictions would facilitate automatization and subsequent vocabulary acquisition by managing cognitive resources. Sixty-two Japanese female junior college students were divided into a time-restricted (TR) group and a time-unrestricted (TU) group. Participants learned 20 new English vocabulary items via a computer-based program and were required to select the correct L1 meaning for each item from three options. The TR group was given a 3000-millisecond time limit per item, whereas the TU group was allowed to proceed at their own pace. Following a 15-minute training session, a computer-based test measured vocabulary meaning recognition speed (RTs), learning gains, and the number of practice attempts. A surprise delayed post-test was administered two weeks later to assess long-term retention. The findings suggest that time pressure did not directly improve immediate meaning recognition RTs or learning scores. However, the TR group showed a significantly higher number of practice attempts and a superior long-term retention score. This paradoxical outcome suggests that time pressure, by increasing extrinsic cognitive load, may have expedited the learning process, thereby enabling more practice attempts. These additional attempts, in turn, may have facilitated the automatization of lexical access, leading to enhanced long-term retention. These results indicate that, while not directly improving RTs, time-pressured practice can be a beneficial pedagogical tool for EFL vocabulary learning by increasing a learner's engagement and practice opportunities.

Keywords
Vocabulary acquisition, response speed, time-restriction, EFL, cognitive load

1 Introduction

Although vocabulary began to attract attention in second-language acquisition (SLA) research and pedagogy in the 1990s (Al-Hoorie et al., 2022), its importance has remained underappreciated in many English as a foreign language (EFL) and English as a second language (ESL) classrooms. Even when

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teachers emphasize vocabulary instruction, they often limit it to the words presented in their teaching materials (Hartshorn et al., 2023).

The primary objective of second language (L2) learning is to facilitate effective communication. For this purpose, learners must be able to not only access a vast store of linguistic knowledge but also process that knowledge at a high speed. While a significant body of research has focused on the acquisition of new vocabulary items, the literature has often overlooked the crucial role of processing speed and its influence on cognitive resources. In real-life communication, whether reading, listening, or speaking, rapid and automatic word recognition is essential for fluent comprehension and production. According to Cognitive Load Theory (CLT), working memory capacity is strictly limited (Sweller, 1988). When a task, such as reading a text, requires learners to simultaneously process new information and integrate it with existing knowledge, the cognitive load can exceed working memory capacity, leading to a breakdown in comprehension (Just & Carpenter, 1980; Daneman & Carpenter, 1980). To reduce this load, the automatization of lower-level processes, such as word recognition, is critical, as it frees up cognitive resources for higher-level tasks like semantic integration and pragmatic interpretation (Grabe, 2009).

This process of automatization is a key concept in skill acquisition theory, which posits that with repeated practice, reaction time and error rates gradually decrease, leading to automatic performance (DeKeyser, 2020). While time pressure is a common factor in real-life communication, its role in facilitating this automatization process in a pedagogical context remains underexplored. This study, therefore, investigates whether the imposition of time pressure during vocabulary learning serves as a mechanism to manage cognitive load and, consequently, promotes the automatization of word recognition and vocabulary acquisition. By doing so, it aims to fill a significant gap in the literature by providing empirical evidence on the effects of time-pressured practice on L2 vocabulary learning from a cognitive-theoretical perspective.

2 Literature Review

2.1 The role of automatization and cognitive load in L2 vocabulary learning

According to Harrington (2018), vocabulary knowledge is a multifaceted construct that encompasses both the breadth of knowledge (size) and efficiency of access and retrieval (speed). While vocabulary size is a fundamental measure of the number of words a learner knows, lexical facilities that integrate knowledge with rapid processing skills offer a more nuanced understanding of proficiency. This conceptualization differs from Godfroid's (2020) framework of lexical processing, which focuses on a broader set of online mechanisms involved in word recognition and comprehension. In contrast, Harrington's work suggests that lexical facilities emphasize synthesizing vocabulary knowledge and accessing that knowledge efficiently. Such synthesis is critical for fluent L2 communication, because inefficient word recognition can place a heavy burden on a learner's limited working memory capacity, potentially leading to a breakdown in comprehension and production (Grabe, 2009; Sweller, 1988).

The development of this processing speed is a process of automatization, a core concept in Skill Acquisition Theory. According to DeKeyser (2020), skill acquisition in L2 learning progresses from an initial cognitive stage, where learners rely on explicit rules and focused attention, to an associative stage, and finally to an automatic stage, where the skill can be performed quickly and effortlessly. This automatization is primarily achieved through repeated practice, which consolidates knowledge and reduces the cognitive resources required for performance (Logan, 1988).

Several studies have explored the processing speed of L2 vocabulary. Till et al. (1988) established a baseline of 350-millisecond for proficient native English speakers' discourse comprehension. For Japanese EFL learners, studies by Chiba et al. (2012) and Iso et al. (2012) have demonstrated a clear correlation between proficiency level and faster lexical access times (RTs), suggesting that as learners become more proficient, they rely less on conscious processing. However, these studies primarily focused on high-frequency words that learners were already familiar with, and thus did not investigate how RTs develop for newly acquired vocabulary, a critical gap that this study aims to address. Additionally, while these studies highlight the importance of speed, they do not explore pedagogical methods for facilitating this automatization process.

To measure processing stability and automaticity, the coefficient of variation (CV), which is an individual's standard deviation of RT divided by their mean RT, has been introduced as a reliable metric (Hui, 2020; Segalowitz & Segalowitz, 1993). A decrease in CV is indicative of increased automaticity. For instance, Elgort (2011) demonstrated that newly learned pseudowords could be processed with a high degree of automaticity by advanced L2 learners. While this study provides clear methodological details, its focus on highly proficient learners limits its direct applicability to lower-level EFL learners, such as those around the Common European Framework of Reference for Languages (CEFR) A2 to B1. This limitation highlights the need for further research on less advanced populations.

Furthermore, recent research has suggested that the CV trajectory is more complex than a simple linear decrease. Hui (2020) investigated the full learning trajectory and found an inverted U-shaped CV development during intentional word learning. This suggests that the CV initially increases before decreasing as knowledge is automatized. Critically, this nonlinear pattern has not been observed in the context of incidental learning. Given that the current study employs an intentional learning intervention, Hui's finding is highly relevant, as it provides a crucial nuanced metric for measuring the full development of automaticity for newly acquired vocabulary.

In summary, while the importance of automatization in vocabulary learning is well-established, the specific pedagogical conditions that can effectively promote this process remain largely unexplored. Our study addresses this lacuna by examining how a time-pressured learning environment, by influencing cognitive load and practice counts, can facilitate the automatization of new vocabulary and enhance long-term retention.

2.2 The effects of time pressure on language learning

The imposition of time pressure in language learning contexts has yielded mixed results, with studies reporting both beneficial and detrimental effects on performance. On the one hand, time pressure has been shown to improve reading comprehension (Hazaea & Almekhlafy, 2022), enhance attention, and expedite task completion (Baron & Mattila, 1989), thereby serving as a form of training that can optimize task performance. On the other hand, research on complex decision-making tasks has shown that high time pressure can deteriorate performance, particularly for individuals with fewer cognitive resources (Lerch et al., 1999). In a language learning context, time pressure can also induce anxiety, which may hinder fluent communication and learning (Hanifa, 2018). For instance, Jónsdóttir et al. (2023) found that while high time pressure resulted in shorter task completion times for L2 English learners, it was also associated with lower accuracy rates. This trade-off between speed and accuracy suggests that when tasks require significant mental resources, time pressure may increase extraneous cognitive load, potentially reducing learning efficiency (Bidabad et al., 2013).

Despite these potential drawbacks, time restrictions are a prevalent pedagogical tool in L2 classrooms, particularly for developing fluency and automatization. Timed reading, for example, has been widely employed to develop reading fluency and has been shown to be highly effective by encouraging learners to increase their reading speed (McLean & Rouault, 2017). Similarly, timed writing has been found to improve writing fluency through the use of more complex vocabulary (Fellner & Apple, 2006). In speaking, the popular 4/3/2 activity and its variants, such as the 3/2/1 model, deliberately introduce increasing time pressure to foster speaking fluency through repeated practice (Nation, 2022; Thai & Boers, 2016). These activities suggest that a structured increase in time pressure can be a highly effective method for fostering fluency.

Furthermore, reaction time (RT) data, which is often collected under time-pressured conditions, offers a more ecologically valid measure of language processing than untimed tasks (Hui & Jia, 2024). In vocabulary research, time pressure has been used to assess the speed of lexical retrieval. Snellings and van Gelderen (2004) developed the Written Productive Translation Task (WPTT) with a 20-second time limit to measure written lexical retrieval speed. However, this measure was limited to testing written production, and did not examine the effects of time pressure on the learning process itself. Akamatsu (2008) also found that timed word recognition training led to a significant improvement in RTs for familiar high and low-frequency words. While this study provided valuable insights, it focused on pre-existing knowledge rather than the acquisition of new vocabulary.

In summary, while the literature presents a mixed view on the effects of time pressure, its application in L2 classrooms for promoting fluency is well-documented. However, a significant gap remains in the research on how time pressure, as a pedagogical intervention, specifically influences the acquisition and long-term retention of new vocabulary items and the development of their associated processing speed. This study aims to address this critical gap by examining the effect of a time-pressured learning environment on new vocabulary acquisition and automatization.

2.3 Study purpose

Based on the theoretical frameworks of Skill Acquisition Theory and Cognitive Load Theory, this study investigates the pedagogical effects of time-pressured learning on the acquisition of new vocabulary items. Specifically, we examine whether a time-restricted environment can facilitate the automatization of word recognition and enhance long-term retention. To address the significant gap in the literature regarding time-pressured learning of new vocabulary in an EFL context, the following research questions were addressed:

RQ1. Which learning conditions, time-restricted or time-unrestricted, yield faster vocabulary recognition RT immediately after the training period?

RQ2. Which learning conditions, time-restricted or time-unrestricted, yield better short-term retention of newly learned vocabulary items?

RQ3. Which learning conditions, time-restricted or time-unrestricted yield better long-term retention of newly learned vocabulary items?

RQ4. Which learning conditions, time-restricted or time-unrestricted, yield better short-term retention of target items during the training period?

RQ5. Is there a difference in practice counts between the time-restricted and time-unrestricted groups?

RQ6. Is there any correlation between the retention of vocabulary items and practice counts in the immediate computer-based (CB) post-test and paper-based (PB) delayed post-test under different conditions?

3 Method

3.1 Participants

A total of 64 female Japanese native speakers, aged 18–19 and enrolled in their first year of a junior college, participated in the study. Their self-reported English proficiency ranged from CEFR A1 to B1 (corresponding to Grades 3 to Grade 2 of the Eiken English Proficiency Test). According to a 2023 annual survey conducted by the Ministry of Education, Culture, Sports, Science, and Technology (MEXT), 50.6% of Japanese students have reached the national target of Grade Pre-2 in the Eiken Test

(CEFR A2) by the time of high school graduation (MEXT, 2024). Therefore, the participants in this study can be considered as having an average proficiency level for Japanese learners. As Japan is an EFL context, their learning challenges with vocabulary in general, and especially academic vocabulary, are expected to be greater than those of speakers of languages of Greek or Latin origin (Coxhead, 2024).

The study employed a quasi-experimental between-participants design, with participants assigned to one of two groups based on their pre-existing class groups: a Time-Restricted (TR, n = 33) and a Time-Unrestricted (TU, n = 31) group. The data from participants who were absent from any of the three sessions—the training session, the immediate computer-based post-test, or the delayed paper-based post-test—were excluded from the final analysis. This resulted in a final sample of 32 participants in the TR group and 30 in the TU group.

To confirm that the two groups were comparable in their pre-existing vocabulary knowledge, the Vocabulary Size Test (VST; Nation & Beglar, 2007) was administered to both groups, covering the 1,000 to 5,000-word levels. The mean scores for the TR group (M = 33.78, SD = 4.45) and the TU group (M = 34.50, SD = 4.44) were not found to be significantly different. A Bayesian independent samples t-test was performed for this analysis, as it allows for a more direct interpretation of the evidence for the null hypothesis (i.e., no difference between groups) compared to traditional null-hypothesis significance testing. The results, with a Bayes Factor (BF_{10}) of 0.31, provided evidence in favor of the null hypothesis, confirming that the groups were well-matched in terms of vocabulary size prior to the intervention (CI = [-0.60, 0.32], Error percentage = 0.011%, d = -0.162).

3.2 Material

3.2.1 Target vocabulary items

The target vocabulary items were selected from the 5,000-word frequency level of the New JACET 8000-word List (JACET, 2016), under the assumption that these words would be unfamiliar to the participants. To ensure consistency and reduce confounding variables, only nouns were selected, as they represent the largest category within this frequency band, allowing for the creation of standardized distractor items. Word length was also controlled, ranging from 4 to 13 characters.

Following the methodology of Iso (2014), two distractors were created for each target item. These distractors met the following stringent criteria, in addition to being of the same part-of-speech and similar frequency level: (1) the initial letter was identical to that of the target item, (2) the number of letters was the same as the target item, and (3) they were not English loanwords in Japanese to prevent incidental recognition. The L1 (Japanese) equivalents of these distractor items served as the actual distractors in the computer-based training session, where participants were required to select the correct Japanese meaning from three options for each English target word.

Initially, 30 items were selected and administered to the participants in a pre-test to confirm their unfamiliarity. Any item that was already known (even partially) to any participant was excluded. This rigorous screening process resulted in a final list of 20 English (L2)–Japanese (L1) noun pairs (see Appendix) that were confirmed to be novel to the study participants. This systematic approach ensures that the learning gains observed were a direct result of the experimental conditions rather than prior knowledge.

3.2.2 Vocabulary learning software

A novel online vocabulary-learning software program was specifically developed for this study in collaboration with a local software programming company. The software was designed with various modes to facilitate the experiment, including Learning, Testing, Practice, and RT Measurement modes.

All modes, with the exception of the RT Measurement Mode, allowed for the selection of a time limit: no time limit, a 3000-millisecond time limit, and a 2000-millisecond time limit. A diminishing bar on the top-left of the screen visually represented the remaining time for the time-restricted conditions. The order of the target items and the positions of the L1 (Japanese) options were randomized for each set of 20 questions in the Learning and Testing modes to mitigate the potential for serial order effects.

In the Learning Mode, participants were presented with an L2 target item at the center of the screen and three L1 options below. Upon selecting an option, immediate feedback was provided, indicating whether the choice was correct or incorrect, and highlighting the correct option. Participants then pressed the space key to advance to the next item. The Testing Mode followed the same format as the Learning Mode but without providing any feedback. The Practice Mode presented 10 questions in a format identical to the Learning Mode. Participants' reaction times (RTs) were recorded for each item in these three modes.

To obtain a precise measure of an individual's intrinsic motor speed, the RT Measurement Mode was employed. In this mode, participants were instructed to press the "H" key as quickly as possible upon the appearance of a large circle at the center of the screen. The circle appeared at random intervals (e.g., 1000 ms, 500 ms, 1200 ms). This task was performed five times, and the average time was recorded as the participant's baseline reaction time. The actual time taken to recognize the vocabulary item was then calculated by subtracting this baseline motor RT from the overall response time recorded in the Testing Mode.

3.2.3 Questionnaires and informal interviews

Immediately following the computer-based post-test, participants completed a questionnaire designed to gather self-reported data on their perceptions of the learning experience. The questionnaire included both quantitative and qualitative items.

For quantitative Items, items 1-3 were rated on a 5-point Likert scale (1 = strongly disagree, 5 = strongly agree) to assess participants' perceptions of the software's usability and the effects of the time constraint on their concentration.

For qualitative Items, items 4-6 were open-ended, allowing for free-response comments. This qualitative data was crucial for gaining deeper insights into participants' experiences, beyond the quantitative measures.

Specifically, the questionnaire included the following items:

1. "This software is easy to use." (Likert scale)
2. "I was able to concentrate on learning because of the time constraints in the Learning Mode." (Likert scale)
3. "I was unable to focus on learning due to the time constraints in the Learning Mode." (Likert scale)
4. "Have you used online learning software before?" (Yes/No)
5. "Please share your thoughts on your experience with this software and any suggestions for improvement." (Free-response)
6. "Please tell us about your general vocabulary study habits, including the tools you use, your study methods, and the frequency of your study sessions." (Free-response)

Additionally, informal, semi-structured interviews were conducted with eight selected participants to corroborate and provide further depth to their questionnaire responses. This mixed-methods approach—combining quantitative data from the post-tests and qualitative data from the questionnaires and interviews—ensures a comprehensive and robust analysis of the study's findings.

3.3 Procedure

The experimental procedure was conducted across four weeks, as summarized in Table 1. Participants from two existing institutional classes were assigned to either the Time-Restricted (TR) or Time-Unrestricted (TU) group.

In Week 1, all participants completed a paper-based (PB) pre-test to screen the target vocabulary items and the Vocabulary Size Test (VST) to assess their pre-existing vocabulary knowledge.

In Week 2, participants gathered in a computer room where they were individually assigned a computer. The instructor verbally explained the purpose of the study. Specifically, participants were informed that the study would use a vocabulary learning program, currently under development. The participants were instructed to use the program to learn vocabulary. They were also told that the purpose was to evaluate the effectiveness of the program and collect feedback and suggestions. The experimental session began with a baseline reaction time (RT) measurement, followed by a practice session. For the practice session, both groups were exposed to 10 sample vocabulary items under their respective time conditions (3000-ms limit for TR and no limit for TU). Subsequently, all participants completed a computer-based (CB) pre-test on the 20 target vocabulary items without a time limit. Following the pre-test, the instructor presented the target words and their L1 equivalents on the monitors for 3 minutes, guiding participants to pronounce each item twice.

The core training session commenced at the instructor's signal. The TR group was provided with a 3000-ms time limit per item, while the TU group was allowed to proceed at their own pace. The training session concluded after 15 minutes, at which point the instructor instructed all participants to stop. After a brief 2-minute break, a CB post-test, identical in format to the CB pre-test, was administered. All key data, including RTs and scores for each item, were automatically recorded by the software. Upon completion, participants filled out the Google Forms questionnaire.

Two weeks later, in Week 4, a surprise delayed paper-based post-test was administered to assess long-term retention. Participants were asked to write down the L1 equivalents of the 20 target items. After the tests were collected, informal interviews were conducted with four participants from each group. Notes were taken during the interviews, but no audio recordings were made as this is not common practice. This approach was chosen to minimize participants' psychological resistance and hesitation to speak, thus allowing them to respond freely in an environment similar to their usual classroom setting. Finally, all participants were fully debriefed about the study's purpose and provided their informed consent.

Table 1
Procedures of the Present Study

Week	Time Restricted group	Time Unrestricted group
Week 1	VST, Paper-based pretest of the 30 items	
Week 2	Orientation, Computer-based Pretest, Training Session (15 minutes)	
Week 2	Computer-based Posttest (Posttest 1) and the Questionnaire	
Week 4	Paper-based Posttest (Posttest 2) and Informal Interviews	

4 Data Collection and Data Analysis

All quantitative data, including RTs, scores from the CB pre- and post-tests, and practice counts, were automatically collected by the custom-designed vocabulary learning software.

To address RQ1, a thorough analysis of RTs was performed. First, only RTs for correct responses were included in the analysis. Second, outlier data points were eliminated using the established criteria:

responses faster than 5 ms of an individual's mean motor RT or slower than three standard deviations from the mean (Snellings & van Gelderen, 2004). Furthermore, as recommended by Hui and Jia (2024), RTs were adjusted for accuracy by dividing the mean RT by the error rate to account for the speed-accuracy trade-off. The coefficient of variation (CV) and RT-CV correlations were also computed to assess processing stability and automaticity.

Given that Shapiro-Wilk tests indicated significant deviations from normality for all RT data sets (CB pre-test TR: $W = 0.90$, $p < .01$; TU: $W = 0.87$, $p < .01$; CB post-test TR: $W = 0.87$, $p < .01$; TU: $W = 0.82$, $p < .01$), non-parametric methods were deemed appropriate. Bayesian Mann-Whitney U tests were utilized to compare RTs between the TR and TU groups, while Bayesian Wilcoxon signed-rank tests were applied to analyze within-group changes. The choice of Bayesian statistics, over traditional frequentist methods, was made to provide a more direct assessment of the evidence for or against the null hypothesis.

To address RQ2 and RQ3, all test responses were coded as correct (1) or incorrect (0). Minor spelling or character errors in the delayed paper-based post-test were tolerated to provide a more lenient assessment of retention. A logistic Generalized Linear Mixed Model (GLMM) with a logit link, estimated using the *lme4* package in R (Bates et al., 2015), was employed to analyze the effects of the intervention on both short-term and long-term retention. The logistic GLMM was chosen because it effectively accounts for the hierarchical structure of the data, where responses are cross-classified by participants and items by modeling both fixed effects (e.g., group and test conditions) and random effects (e.g., individual differences and item difficulty). The best-fit models, as determined by the lowest Akaike's Information Criterion (AIC), were: For short-term retention (RQ2)**:** Correct ~ Group × Test + VST + (1|ID) + (1|Word), and for long-term retention (RQ3): Correct ~ Group + VST + (1|ID) + (1|Word). Post-hoc analyses of interaction effects were conducted using the *lsmeans* package (Lenth, 2018).

To answer RQ4, a Bayesian repeated-measures ANOVA with a 2 (Group) × 3 (Practice Time: first, fourth, and eighth) mixed design was conducted to compare practice counts over time, given that the minimum number of practice sessions was eight. Differences between groups at specific time points were assessed using post-hoc tests.

The comparison of practice counts between the TR and TU groups (RQ5) was performed using a Bayesian independent *t*-test. Finally, Bayesian Pearson's *r* was used to address RQ6 by examining the correlations between practice counts and both short-term and long-term retention scores. Qualitative data from the questionnaires and interviews were analyzed thematically by the author to supplement the quantitative findings.

5 Results

The mean reaction times (RTs) and standard deviations for both groups in the pre-test and post-test are presented in Table 2. To address RQ1, a series of Bayesian non-parametric analyses were conducted on the adjusted mean RTs, given that the data failed to meet the assumption of normality.

A Bayesian Mann-Whitney U test revealed no significant differences in RTs between the Time-Restricted (TR) and Time-Unrestricted (TU) groups at the pre-test ($BF_{10} = 0.32$) or the post-test ($BF_{10}= 0.27$). These Bayes Factor values provide moderate evidence in favor of the null hypothesis, suggesting that the time restriction did not have a direct facilitative effect on the speed of vocabulary recognition.

However, Bayesian Wilcoxon signed-rank tests demonstrated significant within-group improvements in RTs from the pre-test to the post-test for both the TR group ($BF_{10} = 9631.19$) and the TU group ($BF_{10}= 18097.93$). The extremely high Bayes Factors indicate overwhelming evidence that both groups became significantly faster at recognizing the target vocabulary items after the training session.

Finally, to directly compare the learning gains in RT between the two groups, a Bayesian Mann-Whitney U test on the difference scores (post-test minus pre-test RTs) was performed. The result ($BF_{10}=$

0.31) again provided moderate evidence in favor of the null hypothesis, confirming that there was no significant difference in RT improvement between the two groups.

The coefficient of variation (CV), an indicator of processing stability, was also assessed. The CV for both groups decreased from the pre-test to the post-test, suggesting that processing became more stable with practice. A Bayesian Pearson correlation between RT and CV yielded a Bayes Factor of 0.307, with a 95% credible interval ranging from -0.102 to 0.377. This finding provides moderate evidence for the null hypothesis, suggesting that there is no meaningful relationship between a participant's reaction time and the stability of their processing.

Table 2

Mean RT and CV on CB Tests

Group	CB Pretest				CB Posttest			
	RT		CV		RT		CV	
TR (*n* = 32)	3616.05	(1549.57)	0.42	(0.14)	1176.02	(423.82)	0.35	(0.11)
TU (*n* = 30)	3723.73	(1646.65)	0.44	(0.23)	1239.09	(459.95)	0.36	(0.12)

Note. A parenthesis after each mean shows a standard deviation. The unit of measurement for RT is ms.

The mean scores and standard deviations for the short-term and long-term retention tests, as well as practice counts, are presented in Table 3. The internal consistency of the tests was assessed using Cronbach's α: CB pre-test (α = .57), CB post-test (α = .40), and PB delayed post-test (α = .61).

To address RQ2 concerning short-term retention, a logistic GLMM was conducted. The analysis revealed a significant main effect of the test condition (pre- vs. post-test), indicating that both groups' scores significantly increased from the pre-test to the post-test. However, there was no significant interaction effect between Group and Test, nor a significant main effect of Group. These results suggest that while both groups showed significant short-term learning gains, the time restriction did not lead to a superior performance in the immediate post-test.

For RQ3, which examined long-term retention, the logistic GLMM analysis of the PB delayed post-test scores showed a significant main effect of group, indicating that the Time-Restricted (TR) group achieved significantly higher scores than the Time-Unrestricted (TU) group (p = .018). This finding suggests that the time-pressured learning environment facilitated a more robust long-term retention of vocabulary items. Additionally, a significant main effect of Vocabulary Size Test (VST) scores was observed, confirming that participants with a larger pre-existing vocabulary size performed better on the delayed post-test. The mean scores on the delayed posttest were low for both groups.

To address RQ5, a Bayesian independent t-test was performed to compare the practice counts between the two groups. The result, with a Bayes Factor (BF_{10}) of 69.40, provides overwhelming evidence that the TR group had a significantly higher mean practice count than the TU group (see Table 3). This indicates that the time restriction, by expediting the learning process, enabled learners in the TR group to engage in more practice attempts within the same 15-minute training session.

Finally, to address RQ6, a Bayesian Pearson's r was used to explore the correlation between practice counts and retention scores (see Table 3). The results showed weak to no correlations between practice counts and immediate retention for both the TR group (BF_{10} = 0.27) and the TU group (BF_{10} = 0.33). For the delayed post-test, a weak positive correlation was observed for the TR group (r = .21), but the Bayes Factor (BF_{10} = 0.43) indicated that the evidence favored the null hypothesis (no correlation). No correlation was found in the TU group (BF_{10} = 0.24). Note that a BF_{10} of 1 indicates that the data are equally likely under the null and alternative hypotheses, values greater than 1 provide evidence in favor of the alternative hypothesis, and values less than 1 provide evidence in favor of the null hypothesis.

Overall, although there was a numerical trend suggesting a possible link between increased practice counts and long-term retention in the time-restricted condition, the Bayesian evidence did not provide strong support for this relationship.

Table 3

Mean Scores on CB and PB Tests and Practice Count

Group	**CB Pretest**		**CB Posttest**		**PB Delayed Posttest**		**Practice Count**	
TR (*n* = 32)	9.00	(2.38)	19.72	(0.63)	2.22	(1.81)	15.30	(3.11)
TU (*n* = 30)	8.77	(1.98)	19.70	(0.60)	1.37	(1.38)	12.72	(2.64)

Note. A parenthesis after each mean shows a standard deviation.

The mean scores for the training sessions for both the Time-Restricted (TR) and Time-Unrestricted (TU) groups are presented in Table 4. To address RQ4, a Bayesian repeated-measures ANOVA was performed to evaluate the learning effect over the course of the training sessions.

The analysis revealed a substantial learning effect across sessions, as evidenced by a posterior probability of 1.000 (P(effect included | data) = 1.000). This posterior probability reflects the overwhelming evidence that a learning effect is present in the data. In other words, based on the observed data and model, the probability that the session's effect is included is essentially certain. This confirmed a strong learning progression for all participants, with scores significantly improving from the beginning to the end of the training session.

However, the analysis found that the group effect was less pronounced, with a Bayes Factor of 0.180, providing moderate evidence in favor of the null hypothesis. This indicates that the overall learning progress did not differ significantly between the TR and TU groups.

Post-hoc comparisons further clarified these findings. Significant improvements were observed in scores between the First and Fourth sessions, the First and Eighth sessions, and the Fourth and Eighth sessions. The extremely high posterior odds and Bayes Factors for these comparisons provide overwhelming evidence that both groups continuously improved their scores throughout the training session. The effect sizes were large for the improvements from the first session (d = -1.17 for First vs. Fourth, d = -1.48 for First vs. Eighth), while the improvement between the fourth and eighth sessions was of a medium effect size (d = -0.32), suggesting that the most rapid learning occurred in the early stages of the training.

In summary, while both groups demonstrated a significant and continuous learning effect during the training sessions, there was no significant difference in the overall rate of improvement between the TR and TU groups. This finding suggests that while time pressure did not accelerate the learning process itself, it did not hinder it either.

Table 4

Mean Scores in Each Practice Session

Group	First		Fourth		Eighth	
TR (*n* = 32)	14.44	(3.27)	18.63	(1.54)	19.13	(1.24)
TU (*n* = 30)	14.53	(3.60)	18.83	(1.95)	19.43	(1.19)

Note. A parenthesis after each mean shows a standard deviation.

The results from the questionnaire and informal interviews provided valuable qualitative insights to complement the quantitative findings. Table 5 presents the results from the Likert-scale items. A Bayesian independent samples *t*-test on Item 1, which assessed software usability, revealed no significant difference between the TR and TU groups ($BF_{10} = 0.30$). This suggests that the imposition of time pressure did not affect participants' perception of the software's ease of use.

Items 2 and 3, designed to evaluate the effect of time constraint on concentration, showed a high internal consistency ($\alpha = 0.92$) and an average score of over 4 points, indicating that both groups generally perceived the software to be a positive learning tool. The questionnaire also revealed that a majority of participants (82.26%) had prior experience with online English learning.

Table 5

Questionnaire Results for Each Group

Item	**TR（*n* = 32)**	**TU (*n* = 30)**
1. This software is easy to use.	4.31	4.40
2. I was able to concentrate on learning because of the time constraints for the Learning Mode.	4.31	
3. I was not able to focus on learning because there was no time constraints for the Learning Mode. (＊)	4.22	
4. I have used online learning software via smartphone or computer. (%)	84.38	80.00

Note. The item marked with an asterisk (*) was reverse-scored.

Qualitative data from the free-response comments (Table 6) and informal interviews (Table 7) provided a deeper understanding of the participants' experiences. Thematic analysis revealed that some participants in the TR group felt that the time pressure encouraged them to stay focused and prevented them from getting distracted. This is consistent with the finding that the TR group engaged in a higher number of practice attempts. Conversely, some participants in the TU group commented on the flexibility of learning at their own pace, which allowed them to take more time to process difficult words.

These qualitative findings are particularly important for interpreting the seemingly contradictory quantitative results. While time pressure did not directly improve immediate RTs or short-term retention scores, the self-reported data suggests that it influenced learning behaviors (e.g., concentration and practice count), which, in turn, may have contributed to the superior long-term retention observed in the TR group. This mixed-methods approach provides a more comprehensive explanation for the study's outcomes.

Table 6

Free Comments for the Improvement of the Software

Typical Comments	**TR (*n* = 32)**	**TU (*n* = 30)**
I remembered the correct answer because the set of options for each target word were always the same.	15	7
Use a typing method instead of a choice method.	3	1
I wish I could reconsider the option I once chose.	2	2
Other	1	3

Table 7
Study Materials, Methods, and the Frequency of Studies

Material (Method)	Number	Frequency	Number
Vocabulary book	32	Everyday	16
Textbook (Class material)	17	1 to 4 times a week	14
App	11	Before tests	4
Self-made	5	No Comments	28

6 Discussion

This study aimed to investigate the effects of time-pressured learning on the automatization of vocabulary recognition and long-term retention. The findings, while seemingly paradoxical, provide valuable insights into how time constraints can influence the learning process.

The results from RQ1 and RQ4 showed that although both the time-restricted (TR) and time-unrestricted (TU) groups demonstrated significant improvements in RTs and training session scores, there was no significant difference in the rate of improvement between the two groups. This suggests that time pressure did not directly accelerate the development of word recognition speed or short-term learning gains.

One possible explanation for this outcome is that the task itself—a multiple-choice meaning recognition task—was not cognitively demanding enough to elicit a differential effect. As suggested by Bidabad et al. (2013) and Lerch et al. (1999), high time pressure may only impair performance when it adds a significant extraneous cognitive load to an already complex task. In this study, the task's simplicity may have prevented time pressure from becoming a hindrance. Furthermore, the questionnaire results confirmed that participants did not perceive the time restriction as highly anxiety-inducing. This suggests that the time pressure facilitated learning without triggering the kind of anxiety that, as Hanifa (2018) argues, could impede learning. The consistent reduction in the coefficient of variation (CV) for both groups, a measure of processing stability, suggests that practice alone was sufficient to promote a degree of automatization. However, the lack of a strong correlation between RT and CV warrants caution in drawing definitive conclusions about the effects of the short training period (Hui & Jia, 2024).

The observed inverted U-shaped trajectory of the CV, as reported in a previous study (Hui, 2020), suggests that initial increases in processing variability may reflect early stage cognitive instability during learning, followed by stabilization as partial automatization occurs. In the present study, while CV decreased with practice, the trajectory did not decline linearly. This indicates that CV primarily captures short-term processing dynamics rather than directly predicting long-term retention. This pattern supports the view that monitoring CV can provide valuable insight into the learning process, although it is not the sole determinant of durable vocabulary acquisition.

In addition, the internal consistency of the tests, as measured by Cronbach's α, was relatively low (CB pre-test $\alpha = .57$; CB post-test $\alpha = .40$; PB delayed post-test $\alpha = .61$). This can be attributed to test-specific factors. In the CB pre-test, many correct responses were likely because of guessing, limiting true differences among learners; in the CB post-test, most participants scored near-perfectly, producing a ceiling effect; and in the PB delayed post-test, uniformly low scores restricted variance. In all cases, restricted between-participant variance reduced item intercorrelations, which contributed to the lower α values.

The most intriguing finding of this study is the significant difference in long-term retention (RQ3), where the TR group outperformed the TU group on the delayed post-test. This result is particularly noteworthy given the absence of a direct effect of time pressure on immediate RTs and short-term retention. The analysis of practice counts (RQ5) and the qualitative data provide a compelling explanation for this apparent paradox.

The Bayesian analysis showed overwhelming evidence that the TR group completed significantly more practice attempts within the 15-minute training session. This outcome aligns with Baron and Mattila's (1989) finding that time constraints can expedite task completion. From a Cognitive Load Theory perspective, the time restriction may have served as a mechanism to manage participants' cognitive resources, forcing them to focus on the task and discouraging unproductive metacognitive activities (e.g., overthinking or dwelling on a single item). This increased efficiency allowed them to engage in more repetitions.

The enhanced long-term retention in the TR group can therefore be attributed to this increase in practice count. This finding is consistent with Instance Theory of Automatization (Logan, 1988), which posits that with each exposure, a separate memory trace, or "instance," is stored. A higher number of practice attempts, facilitated by the time restriction, leads to the accumulation of more instances, which ultimately strengthens the memory trace and leads to a more robust, automated lexical access in the long term.

To further explore the relationship between practice and retention (RQ6), the correlation between practice counts and test scores was examined. Unlike Webb (2007), who reported a weak positive correlation, the corresponding Bayes Factor in the present study suggested that the evidence favored the absence of a correlation for the TR group's delayed post-test scores. This indicates that, although increased repetition in the time-restricted condition might have contributed to long-term retention, the effect is weak, and other factors are likely to play a more substantial role in explaining retention outcomes.

The low scores on the delayed paper-based post-test can be attributed to differences in the test format. The computer-based (CB) tests primarily measured recognition speed among participants who were presented with an English word along with three Japanese meanings and asked to select the correct one. In contrast, the paper-based (PB) test presented only English words, requiring participants to recall and write the Japanese meaning, which is generally more challenging. This mismatch between the learning and test formats likely contributed to the low scores, reflecting limitations in transfer-appropriate processing (Morris et al., 1977) and the increased retrieval effort required for free recall.

Possible contributing factors include the concept of desirable difficulties (Karpicke & Roediger, 2007) and the spacing effect. While the time restriction may have increased the number of practice attempts, the retrieval effort required by the multiple-choice format may have been too low to create a strong memory trace. This could explain the weak correlation and the low scores on the challenging delayed recall test. The participants' comments in the questionnaires and interviews support this notion, with many suggesting a more challenging format, such as typing the answers, which would require greater retrieval effort.

6.1 Pedagogical implications

A central pedagogical implication of this study is the time efficacy of learning. The findings suggest that time-pressured learning can serve as a highly efficient method for vocabulary acquisition. In contexts where class time and individual study time are limited, the introduction of time constraints may help learners to better focus on tasks and expedite their learning process. This, in turn, allows for a greater number of practice attempts within a given timeframe, which was found to be the key factor in facilitating long-term retention.

This study also highlights the value of technology-based learning. As a growing number of students are accustomed to digital tools, educators can leverage online software to precisely measure learning behaviors, such as practice counts and reaction times. With shifts in communication in the digital age, it is also important to integrate multimodal literacy into English education (Lim, 2025). However, teachers' current levels of digital literacy remain insufficient, highlighting the need for proper training (Mullen, 2025). These data-driven insights can then inform instructional decisions, allowing teachers to maximize learning outcomes by pairing technology-based practice with complementary activities. Such activities may include retrieval practice that incorporates peer-based retrieval (e.g., pair work, which has been shown to promote longer-term retention compared to individual learning; see Iwata et al., 2024), ensuring that learners actively recall information rather than passively recognize it, and repeated exposure through multiple assessments with the same vocabulary items, which further consolidates memory traces.

6.2 Limitations

The primary limitations of this study are related to the controlled experimental conditions. First, participants were exposed to only a single, 15-minute training session. The notably low scores on the delayed post-test suggest that such a brief exposure is insufficient for robust long-term retention. Future research should therefore investigate the effects of time-pressured learning across multiple spaced sessions in order to determine the optimal frequency for enhancing retention and promoting the development of rapid and automated lexical access. Second, the study did not assess reaction times in the delayed post-test. Including this measure in future research would help determine whether the increased long-term retention observed in the time-restricted group is accompanied by a corresponding long-term improvement in word recognition speed. Finally, the study sample was limited to a specific demographic—Japanese female junior college students—which may restrict the generalizability of the findings to other populations or learning contexts.

7 Conclusion

This study aimed to determine the effects of time restrictions on the development of vocabulary meaning recognition speed and acquisition. The results indicate that time pressure did not directly facilitate faster reaction times or superior short-term retention. However, our findings reveal a crucial indirect effect in that time constraints expedited the learning process and allowed participants in the time-restricted group to complete a significantly higher number of practice attempts. This increased repetition, in turn, led to superior long-term retention of newly learned vocabulary items. In conclusion, our study suggests that time-pressured practice, rather than being a source of anxiety, can be a beneficial pedagogical tool that fosters more efficient learning behaviors and ultimately enhances long-term retention. The findings provide a strong argument for the strategic integration of time constraints into vocabulary learning, particularly in contexts where learning efficiency is a key concern.

Declaration of conflicting interest

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Appendix: The Target Items and Their Distractor Items

Target Item		Distractor Item (Only Japanese was used)			
English	Japanese	English	Japanese	English	Japanese
1. bundle	束	ballot	投票	breach	違反
2. deterioration	悪化	deforestation	森林破壊	disappearance	消失
3. discrepancy	食い違い	designation	指定	declaration	宣言

4. disgrace	不名誉	dementia	痴呆症	doctrine	信条
5. drainage	排水	distress	苦悩	drawback	欠点
6. ditch	溝	dough	生地	digit	桁
7. enclosure	囲い	exclusion	排除	excursion	小旅行
8. flaw	欠陥	fist	握り拳	fate	運命
9. haul	運搬	herd	群れ	heap	堆積
10. influx	流入	intake	摂取量	intent	意図
11. intrusion	侵入	intuition	直感	itinerary	旅程
12. myriad	無数	misery	悲惨	memoir	回想
13. novice	初心者	nephew	おい	noodle	麺類
14. plague	伝染病	parcel	小包	pillar	支柱
15. recurrence	再発	relocation	再配置	reflection	反射
16. redundancy	余剰性	renovation	修復	repetition	反復
17. rubble	がれき	ration	割当量	runoff	流出
18. shrub	低木	stain	汚点	serum	血清
19. vicinity	近所	vitality	生命力	validity	妥当性
20. warranty	保証	windmill	風車	workload	作業量

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