Mitigating Interruptions in Digital Reading: Strategic Pauses and Note-Taking for Enhanced Cognitive Performance

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Abstract. This study investigates how structured interventions—specifically pausing at natural breakpoints and guided note-taking—affect cognitive performance, memory retention, and task continuity in digital reading. We introduce *SmartPause*, a context-aware bookmarking system that nudges users to pause at meaningful points and externalise insights through lightweight notes. In a controlled experiment (N = 51), participants were assigned to one of three conditions: (1) interruption at an arbitrary point, (2) guided pause at a natural breakpoint, or (3) guided pause with note-taking. Results reveal that guided pauses, particularly when combined with note-taking, significantly enhance long-term memory retention while having no measurable impact on perceived cognitive load or selective attention. These findings highlight the potential of digital tools to support cognitive load management and task continuity by structuring interruptions in alignment with natural cognitive rhythms. The high usability rating of SmartPause underscores its practical applicability across e-reading platforms. This study contributes to human-computer interaction (HCI) by integrating principles from cognitive science into design solutions that enhance comprehension and information retention. Future research should explore personalised interventions, extended retention intervals, and real-world deployment to further optimise cognitive load in digital reading contexts.

Keywords: Human-Computer Interaction · Digital Reading · Cognitive Load Management · Memory Retention · Interruption Design · Strategic Pausing · Note-taking

1 Introduction

Interruptions during task execution significantly impact cognitive performance, with their disruptive effects varying depending on when they occur. Prior research demonstrates that interruptions at natural breakpoints—moments when fewer cognitive

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resources are engaged—are less disruptive than interruptions during active task execution, which is characterised by high memory load and intense cognitive demand [1, 2]. This insight highlights the potential of strategically timed interruptions to minimise cognitive disruption and improve task transitions. However, while studies have explored this concept in contexts such as web searching and media consumption, its application to reading tasks—where unique cognitive processes like language comprehension and memory consolidation come into play—remains underexplored.

Reading tasks involve unique cognitive processes, such as mental workload management and long-term memory retention, making them an important but understudied context for examining interruption management strategies [3–6]. This study addresses this gap by investigating the impact of guided pauses at natural breakpoints and note-taking within a digital reading task. Unlike prior research, which focused on short-term memory or immediate task performance, our study examines long-term memory retention, task continuity, and user experience in the context of reading.

Our study contributes to the field by being the first to explore interruption management strategies in reading tasks using natural breakpoints and note-taking. A controlled experiment with 51 participants tested three conditions: (1) interrupted reading with artificial breakpoints, (2) guided pausing at natural breakpoints, and (3) guided pausing combined with note-taking. The results showed that guided pausing and note-taking enhanced memory retention but had no significant impact on selective attention or mental workload. These findings highlight the potential of strategic design interventions to optimise cognitive performance in reading tasks, particularly by aligning task transitions with natural cognitive rhythms.

By bridging prior research on interruption management with the unique cognitive demands of reading tasks, this study provides actionable insights for designing digital applications that promote cognitive health, efficient task transitions, and user satisfaction, as demonstrated through an e-book reading application incorporating guided pausing and note-taking interventions. This work advances HCI knowledge by empirically studying the impact of interruptions on cognitive performance in reading tasks and offering a novel approach to managing interruptions in digital environments.

2 Background and Related Work

2.1 Interruptions and Task Continuity

Interruptions disrupt task execution by imposing cognitive and memory demands, interfering with neural mechanisms needed to sustain focus and resume tasks efficiently [7]. Natural breakpoints, such as subtask completion, are identified as optimal moments for interruptions, as they minimise disruption to the user's mental model [2]. Additionally, well-timed interruptions reduce stress and enhance task performance across domains [1]. However, their impact on reading tasks, particularly comprehension and memory retention, remains understudied.

2.2 Memory Retention and the Zeigarnik Effect

The Zeigarnik Effect, first described in 1927, highlights the psychological tension associated with incomplete tasks, which linger in memory more than completed ones [8, 9].

While this tension can aid task resumption, it also increases cognitive load and impedes focus. Strategies such as note-taking externalise this tension, improving mental clarity and enabling more efficient task resumption, particularly in digital contexts where they also enhance memory retention [10, 11]. Building on these insights, our study combines natural breakpoints with note-taking to manage cognitive load and enhance long-term memory retention during reading. This dual approach addresses the disruptive impact of interruptions while fostering task continuity.

2.3 Strategic Pausing and Guided Interventions

Strategic pausing at natural breakpoints offers a promising approach for managing interruptions in cognitively demanding tasks. Such pauses align with cognitive rhythms, facilitating smoother transitions and reducing mental strain [2, 6]. While this concept has been applied in various experiments for diverse task contexts, their impact on reading tasks has not been sufficiently studied. Combining strategic pausing with interventions such as note-taking can further support memory retention by externalising information, thus reducing cognitive effort [11–13]. This approach holds potential to enhance memory retention but also to maintain task continuity in reading tasks that require complex linguistic integration over time.

2.4 Self-interruption and Attention Management

Interruptions are not always external; internal factors, such as curiosity or habitual task-switching, often lead to self-interruptions. González and Mark [2004] found that individuals self-interrupt to seek information or alleviate boredom, disrupting focus and prolonging task completion [14]. These behaviours were categorised as discretionary task-switching, which impedes attention and diminishes productivity, and it was further demonstrated that external interruptions often trigger self-interruptions, creating a feedback loop of fragmented attention [15, 16]. In reading, structured interventions, such as guided pauses at logical stopping points, may help manage both external and internal interruptions, fostering sustained focus and cognitive continuity. Given the significance of attention in reading, this approach could improve the user's ability to stay focused and retain information.

2.5 Managing Cognitive Resources During Reading

Reading is a cognitively intensive activity that demands sustained attention, linguistic processing, and memory integration. Interruptions during reading disrupt these processes, requiring additional cognitive resources to reorient the mental model of the text [3]. Strategically timed pauses at natural breakpoints, such as at the end of a section or chapter, combined with note-taking, can reduce memory demands and improve task resumption efficiency.

Previous systems have explored ways to support users during interruptions. For example, Pan et al. [17] developed a bookmarking tool that uses galvanic skin response (GSR) to detect orienting responses and place markers during unplanned disruptions.

While effective, such systems are reactive and depend on biometric sensing. In contrast, SmartPause proactively guides users to pause at meaningful points based on content structure and includes lightweight note-taking prompts to externalise memory. This user-driven design presents a lightweight alternative to sensor-based approaches focused primarily on task resumption.

These interventions have yet to be tested in digital reading contexts, especially as end-user features in digital applications. Therefore, investigating their impact on cognitive resources in this domain presents an important research opportunity, particularly for digital reading applications aimed at mitigating cognitive disruption.

2.6 Research Aims and Questions

While previous research has advanced our understanding of interruption management and cognitive load in general task contexts, there remains a significant gap in applying these strategies and collecting evidence on actual human performance effects in digital reading tasks. This study aims to address this gap by investigating how strategic pausing at natural breakpoints, combined with note-taking, can improve cognitive performance, memory retention, and task continuity during digital reading. By exploring this, we contribute to the broader discourse on HCI design and interruption management, offering insights into how these strategies can be optimised for digital reading environments.

3 SmartPause: A Cognitive Bookmarking System

3.1 Design Overview

SmartPause is a high-fidelity design concept aimed at optimising digital reading experiences by guiding users to pause at strategic moments and externalise their thoughts. Grounded in cognitive psychology and HCI principles, the design reduces cognitive load, enhances memory retention (both long-term and for subsequent tasks), improves selective attention, and supports smoother transitions between reading and subsequent tasks. Leveraging research on task continuity, memory externalisation, and behavioural nudges, SmartPause addresses cognitive challenges faced by readers, improving engagement with reading material and cognitive performance [1, 9]. The prototype simulates the interaction logic through conceptual interfaces and structured prompts but is not a fully interactive system. Rather, it provides a high-fidelity representation of core features for evaluating user perception and cognitive outcomes.

3.2 Key Features and Interaction Flow

The SmartPause prototype was developed as a high-fidelity conceptual system designed to support cognitive continuity in digital reading. Rather than implementing a fully functional application, the prototype simulates a lightweight system architecture that models the user's disengagement intent and delivers structured interventions. Specifically, the interaction flow is organised into five cognitively aligned stages: (1) detecting user disengagement or task exit, (2) prompting continuation to a nearby natural breakpoint, (3)

inviting note-taking upon reaching the breakpoint, (4) saving the note and line-level reading position, and (5) restoring both contextual cues when the user returns. While no real-time sensors or adaptive tracking mechanisms were used, the system assumes intent through user-initiated pause or exit actions. The prototype was evaluated through structured interaction scenarios and a narrated video walkthrough that demonstrated the core features to participants during the study. The prototype's interaction flow is illustrated in Figs. 1 and 2, which visualise the sequential user experience—from initial bookmarking and pause detection to note-taking and context restoration.

Precise Bookmarking with Line-Level Precision. Our design improves traditional eBook bookmarks by allowing users to bookmark specific lines within a page. A slidable widget helps users mark the exact line where they stopped reading, ensuring precise resumption of the task. This feature reduces cognitive load, aiding users in re-engaging with the text without needing to recall where they stopped, thereby improving attention and task continuity. This interaction also reduces task resumption latency by providing exact visual and semantic continuity.

Encouragement to Pause at Natural Breakpoints. A nudge system encourages users pausing at natural breakpoints, like section or chapter endings. If users pause mid-section, a prompt raises awareness of the cognitive benefits of completing the section first [18]. This system aims to reduce cognitive fragmentation and enhance task transitions [2]. Its rationale is grounded in event segmentation theory, which suggests that interruptions occurring at natural boundaries facilitate smoother reorientation and better memory encoding, as they align with shifts in mental models and perceived event structure [19].

Externalising Memories with Note-Taking Integration. Upon placing the bookmark pointer at a natural breakpoint, SmartPause prompts users to summarise their reading before exiting the task. They can type or dictate their thoughts using speech-to-text functionality. This externalises cognitive load and prepares users to resume reading with greater clarity. Mueller and Oppenheimer's work [20] provides empirical support for this design rationale, showing that generative note-taking—particularly when summarising or paraphrasing—leads to deeper processing and better conceptual retention than verbatim transcription. This feature is informed by memory externalisation literature, suggesting that lightweight elaboration improves encoding and later retrieval. It also helps close the memory loop created by unfinished cognitive tasks, consistent with the Zeigarnik Effect.

Visual Continuity for Resumption. When users return, the exact line bookmarked along with the user's notes is displayed. This ensures visual continuity, reducing the cognitive effort needed to recall the context of the previous session. The seamless transition facilitates smoother reading sessions and reduces cognitive interruptions.

This continuity mechanism reinforces the reader's mental model and improves task resumption by bridging the gap between sessions with both location and content cues, consistent with theories of goal resumption which emphasize the importance of contextual retrieval cues for suspended tasks [3].

These features were selected based on an extensive review of literature in cognitive psychology, interruption design, and task scaffolding, ensuring theoretical alignment

rather than arbitrary inclusion. The design was conveyed to participants through a narrated video walkthrough, allowing them to experience the intended interaction flow during the usability assessment.

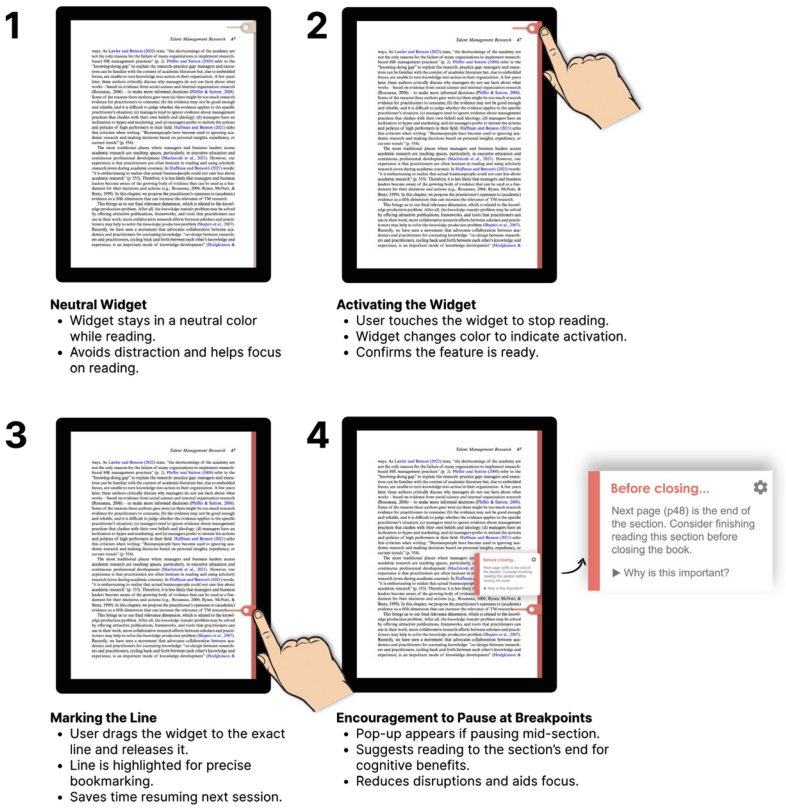

Fig. 1. SmartPause: Prototype interaction flow (1/2). This diagram illustrates the early phase of SmartPause, featuring a bookmarking interface with line-level precision and system-driven detection of disengagement. A visual nudge encourages continued reading toward a nearby natural breakpoint, supporting cognitively aligned transitions and minimizing disruption.

3.3 Hypotheses and Experimental Evaluation

To evaluate the effectiveness of the proposed design, we conducted a controlled experiment using a high-fidelity conceptual prototype of SmartPause. Although the system was not fully interactive, the prototype conveyed a realistic simulation of its core features—including strategically timed pauses, note-taking prompts, and visual continuity—which enabled empirical assessment of its cognitive and usability impacts.

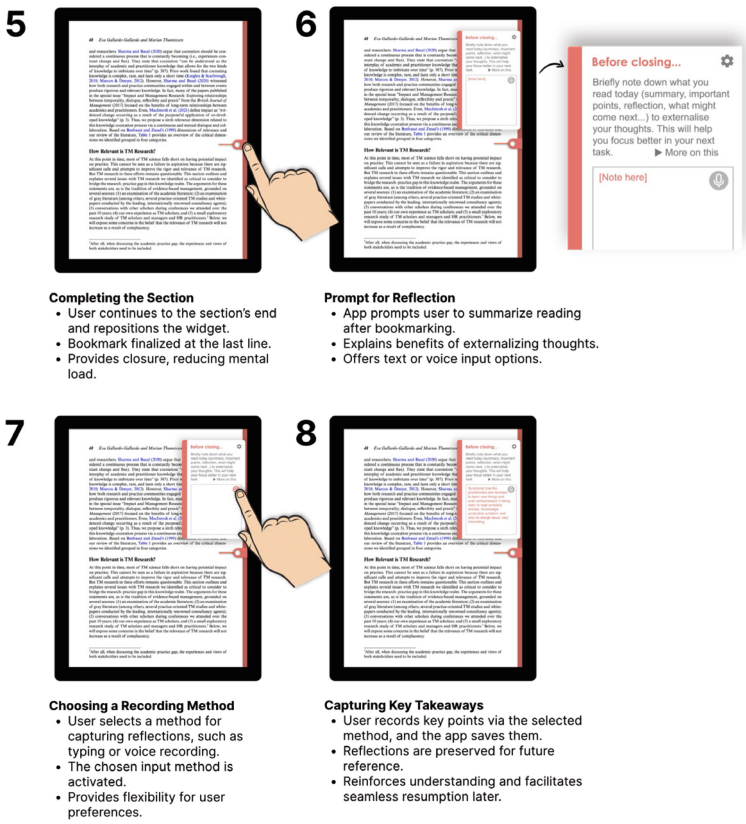

Fig. 2. SmartPause: Prototype interaction flow (2/2). This phase shows post-breakpoint features: an optional note-taking prompt and a return interface restoring the bookmarked line and notes. These support task resumption, lower cognitive load, and aid memory retention.

- H1: Selective attention and processing speed performance will be significantly better when users pause their reading at a natural breakpoint, in at least one of the natural breakpoint conditions (with or without note-taking).
- H2: Cognitive workload will be significantly lower—both in terms of perceived mental load and task engagement duration—when users pause their reading at a natural breakpoint, in at least one of the natural breakpoint conditions (with or without note-taking).
- H3: Long-term memory retention will be significantly improved when users pause their reading at a natural breakpoint, in at least one of the natural breakpoint conditions (with or without note-taking).
- H4: Participants will report high usability and positive engagement with the SmartPause prototype, as measured by the System Usability Scale (SUS) and qualitative feedback.

These hypotheses aim to test whether SmartPause can optimise cognitive resources, enhance user experience, and demonstrate high usability during digital reading by aligning task interruptions with natural cognitive rhythms.

4 Method

4.1 Participants

A total of 51 participants (aged 18–36, M = 25, 25 females, 26 males) were recruited for the study. Among them, 32 were native English speakers. Participants represented a diverse range of ethnic backgrounds, including EU citizens, as well as participants from Asia, Africa, and the Americas. All participants were at least high school graduates and were currently enrolled in or had completed undergraduate education. Inclusion criteria required participants to have normal or corrected-to-normal vision, no history of attention or memory-related disorders, and fluency in English (native or advanced proficiency). The study received ethical approval from the university's Research Ethics Committee.

4.2 Experimental Design and Procedure

This study employed a between-subjects design, with participants randomly assigned conditions: Control Group (Control, n = 17), Intervention Group 1 (IG1, n = 16) and Intervention Group 2 (IG2, n = 16). The experiment aimed to investigate the effects of pausing at natural breakpoints and note-taking on cognitive performance and memory retention during a digital reading task.

1. Control Group: Participants read a 3-page passage, with the latter portion of the text blurred, stopping at a predefined point before the section's conclusion.
2. Intervention Group 1 (IG1): Participants read the same 3-page passage, but they were instructed to pause at the natural breakpoint (i.e., the end of a section), without any additional tasks.
3. Intervention Group 2 (IG2): Participants followed the same procedure as IG1, but with the additional task of note-taking. After reaching the natural breakpoint, they were prompted to take notes on their reading by typing on the laptop.

Participants were first provided with a Participant Information Sheet and an Informed Consent Form. Following consent, participants completed a pre-reading Stroop task to measure baseline selective attention and processing speed. They were then asked to read the assigned passage (and take notes) under their group's condition. After the reading task, participants completed a post-reading Stroop task, the NASA-TLX questionnaire to assess perceived mental workload, and the Big Five Personality Test to assess individual differences in personality traits [21]. A Demographics Survey was also completed at this stage, followed by a Recall Test to measure memory retention based on the text they had read. Finally, participants watched a short video about the SmartPause design and completed a usability questionnaire to provide their feedback.

After completing the recall test, participants were presented with a narrated video demonstration of the SmartPause prototype. This demonstration provided a structured

walkthrough of the system's intended features, including pausing at natural breakpoints, note-taking prompts, and context restoration. The video served as the basis for the subsequent usability evaluation using the System Usability Scale (SUS) (see Fig. 3 for the visual workflow of the experiment).

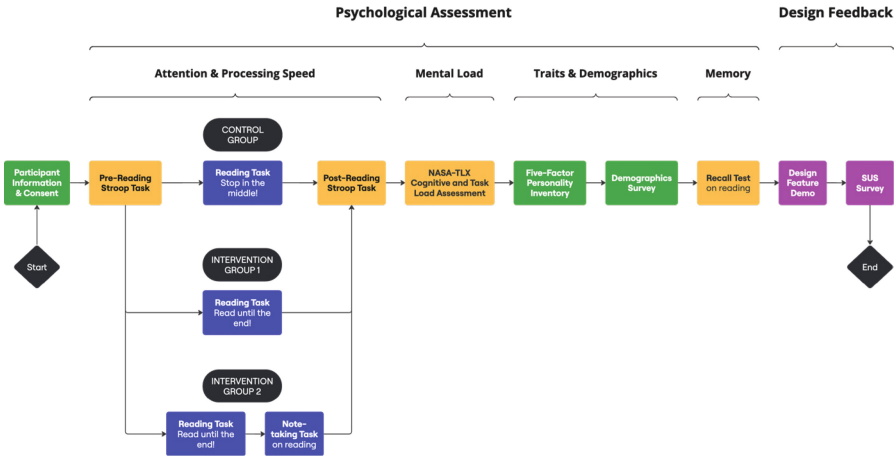

Fig. 3. Experimental workflow diagram. This figure outlines the full experimental sequence: baseline and post-task cognitive assessments, the reading task under one of three conditions, and memory and workload evaluations. The SmartPause demo video followed the recall test and served as the basis for the SUS usability evaluation.

All forms and questionnaires were developed using the Qualtrics platform, hosted on an institution-managed account at the university. A consistent setup was used for all tasks, with participants working on a MacBook Air laptop (M2, 2022, 16 GB RAM) in full-screen mode to minimise distractions. The study was conducted in a controlled, quiet environment with only the participant and the two researchers.

4.3 Materials

The reading material for the study was a 3-page with a Flesch-Kincaid reading score of 60, indicating moderate difficulty suitable for the participants' reading level [22, 23]. The text met the following criteria: it was a standalone section that could be understood independently, the content was non-controversial and free of sensitive material, and the topic was accessible and of a similar level for all participants. To ensure that participants paused before completing the section, 0.5 pages before the section's end were blurred for all groups.

To assess selective attention and processing speed, a Computerised Colour-Word Stroop task was administered using Inquisit Lab 6 software [24, 25]. This task, which involved keyboard input, was conducted both before and after the reading task, allowing for a comparison of attention and processing speed before and after reading [26]. After completing the reading task, participants filled out the NASA-TLX to gauge the cognitive load they experienced during the reading task [27]. The Big Five Personality Test

(BFI-2) was used to assess participants' personality traits, specifically neuroticism. This assessment was included determine how individual personality traits might influence their task performance.

A Recall Test, consisting of 12 multiple-choice, true/false, fill-in-the-blank, matching, and short-answer questions, was designed based on the first 2.5 pages of the text read by all participants. This test assessed their ability to recall specific details from the passage, serving as a measure of long-term memory retention.

Following the recall test, participants were shown a narrated demonstration video of the SmartPause prototype, which visually presented the system's intended features and interaction flow, including strategic pausing, note-taking, and resumption mechanisms. This video served as the basis for the subsequent usability evaluation, conducted using the System Usability Scale (SUS), a validated instrument for assessing user satisfaction and system usability [28].

4.4 Data Analysis Approach

We conducted paired t-tests and ANOVA to compare the effects of reading conditions on the dependent variables. We also examined the main and interaction effects of neuroticism as a personality trait and self-reported English proficiency (native vs. non-native). The dependent variables analysed were Stroop Effect (selective attention and processing speed), NASA-TLX results and time-on-task during reading (both as indicators of mental load), recall test scores (long-term memory), and usability scores. For the Stroop Effect, we calculated three values for both reaction time and accuracy: pre-reading Stroop Effect, post-reading Stroop Effect, and the difference between them. Mental workload was measured using unweighted NASA-TLX scores and time-on-task as a behavioral proxy for cognitive effort. Recall test scores assessed long-term memory, with half credit awarded for inferred short answer responses. Usability scores were analysed based on feedback from the design concept video illustrating features (Sect. 3.2) in the e-book application.

Post hoc t-tests were conducted only when the omnibus ANOVA reached statistical significance, with p-values adjusted using the Benjamini-Hochberg (BH) procedure to control for multiple comparisons [29]. Effect sizes were calculated using Cohen's d for t-tests and partial η^2 for ANOVA. They were interpreted based on Cohen's [30] benchmarks: 0.2 = small, 0.5 = medium, and 0.8 = large, providing a measure of practical significance alongside statistical outcomes.

Table 1. Statistics for Stroop Task Performance, Mental Load, and Recall Metrics

	Control Group		IG1		IG2		Overall	
	M	SD	M	SD	M	SD	M	SD
Pre Stroop Effect RT	189.58	191.72	311.4	328.56	311.74	235.59	269.25	258.41
Post Stroop Effect RT	197.15	146.05	199.33	187.82	200.19	230.84	198.86	186.51

(*continued*)

Table 1. (*continued*)

	Control Group		IG1		IG2		Overall	
	M	SD	M	SD	M	SD	M	SD
Stroop RT Difference	7.57	168.44	−112.06	205.44	−111.55	322.36	−70.39	241.69
Pre Stroop Effect Accuracy	0.04	0.06	0.06	0.17	0.04	0.07	0.05	0.11
Post Stroop Effect Accuracy	0.01	0.05	0.03	0.12	0.02	0.04	0.02	0.07
Stroop Accuracy Difference	−0.03	0.1	−0.03	0.09	−0.01	0.08	−0.02	0.09
NASA-TLX Score	46.57	15.50	41.30	13.96	40.10	11.48	42.74	13.80
Reading Time-on-Task	551.35	170.00	670.13	363.68	841.38	253.14	684.84	292.47
Recall Score	38.15	15.59	49.83	13.04	51.91	18.80	46.46	16.82

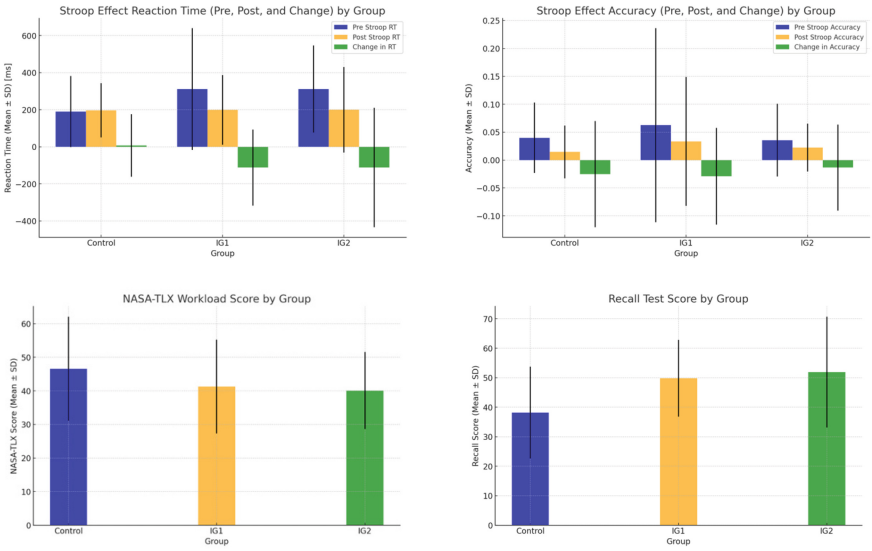

Fig. 4. Stroop Effect Reaction Time, Accuracy NASA-TLX and Recall statistics across groups/

5 Results

The analysis aimed to investigate the effects of the interventions on Selective Attention, Processing Speed, Mental Load and Long-term Memory. Two of the original 51 participants were excluded from the data analysis: one for not reporting ADHD prior to the study, and another due to missing post-reading Stroop task data from a software issue. Table 1 presents the descriptive statistics for each group and overall Stroop Task performance, mental load, and recall metrics while Fig. 4 provides a comparative visualisation of means with standard deviations across groups.

Table 2. Paired Samples t-Test Results for Pre- and Post-Stroop Task Changes

							95% Confidence Interval	
		t(df)	p	Mean diff	SE diff	Cohen's d	Lower	Upper
Reaction Time	Control	0.19 (16)	0.855	7.58	40.90	0.045	−79.04	94.18
	IG1	−2.18 (15)	**0.045***	−112.06	51.36	−0.545	−221.53	−2.59
	IG2	−1.38 (15)	0.187	−111.55	80.59	−0.346	−283.32	60.22
Accuracy	Control	−1.09 (16)	0.291	−0.03	0.02	−0.265	−0.07	0.02
	IG1	−1.34 (15)	0.201	−0.03	0.02	−0.335	−0.08	0.02
	IG2	−0.70 (15)	0.497	−0.01	0.02	−0.174	−0.05	0.03

Table 3. ANOVA Results for Between-Group Analysis of Pre-Post Stroop Effect Reaction Time, Accuracy Difference, Mental Load, and Recall Test Scores

	Sum of Squares	df	Mean Square	F	p	η^2
Stroop Effect RT Difference	158211	2	79105	1.38	0.263	0.056
Stroop Accuracy Difference	0.00213	2	0.00107	0.141	0.868	0.006
NASA-TLX Score	393	2	197	1.03	0.363	0.043
Reading Time-on-Task	698435	2	349218	4.71	**0.014***	0.170
Recall Test Score	1830	2	915	3.58	**0.036***	0.135

Table 4. Main and Interaction Effects of Language Level and Neuroticism on Cognitive Metrics

	Language Level (Main Effect)	*Language Level (Interaction Effect)*	*Neuroticism (Main Effect)*	*Neuroticism (Interaction Effect)*
Stroop RT Difference	F = 1.80 p = 0.186	F = 1.05 p = 0.360	F = 0.03 p = 0.867	F = 0.22 p = 0.801
Stroop Accuracy Difference	F = 0.723 p = 0.400	F = 1.84 p = 0.171	F = 0.50 p = 0.484	F = 0.05 p = 0.949
NASA-TLX Score	F = 7.64 **p = 0.008***	F = 0.84 p = 0.437	F = 0.56 p = 0.458	F = 0.61 p = 0.547
Recall Test Score	F = 6.24 **p = 0.016***	F = 0.36 p = 0.701	F = 0.86 p = 0.358	F = 0.85 p = 0.436

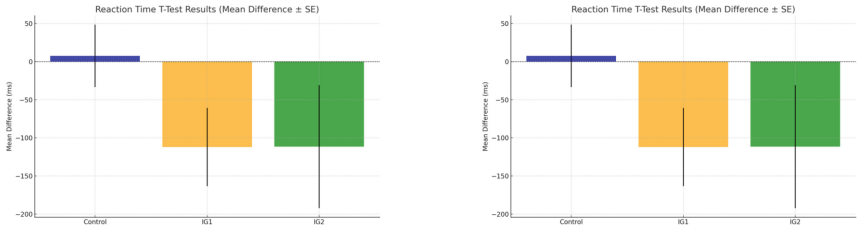

Fig. 5. T-Test Results for Pre- and Post-Stroop Effect Changes

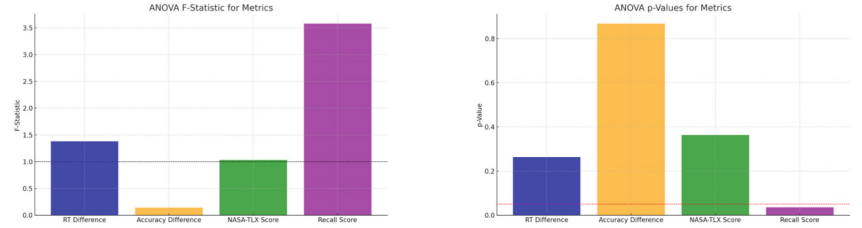

Fig. 6. ANOVA Results for Between-Group Comparison of Reaction Time, Accuracy, and Recall Score

5.1 Selective Attention and Processing Speed Performance

For reaction time, Intervention Group 1 (IG1) showed a significant reduction ($M = -112.06$, $SD = 205.44$; $t(15) = -2.18$, $p = .045$, Cohen's $d = -0.545$), suggesting that pausing at natural breakpoints enhances Selective Attention and Processing Speed. This finding supports Hypothesis 1 (H1), which predicted that pausing would improve reaction time. However, the between-group analysis using ANOVA revealed no significant

differences in reaction time or accuracy across the three groups ($F(2, 46) = 1.38$, $p = .263$, $\eta^2 = .056$), indicating that while IG1 demonstrated a significant reduction, the differences between groups were not statistically meaningful as shown in Table 3 and Fig. 6. This suggests that while pausing at a natural breakpoint may improve cognitive processing speed, it does not significantly impact accuracy, nor does it create substantial differences between the groups.

Table 2 further details the paired t-test results for pre- and post-Stroop Effect changes, confirming the significant reaction time improvement within IG1. Figure 5 visualises these changes, illustrating how the pre- and post-reading Stroop Effect differed across conditions.

In terms of accuracy, IG1 showed a slight improvement, but the change was not statistically significant ($t(15) = -1.34$, $p = .201$, Cohen's $d = -0.335$). Similarly, the Control Group and IG2 showed no significant change either ($p > 0.05$). An ANOVA across the groups (Table 3) revealed no significant difference ($F(2, 46) = 0.14$, $p = .868$, $\eta^2 = .006$), suggesting that the interventions did not have a significant effect on accuracy. These results reinforce the idea that pausing at a natural breakpoint may facilitate faster processing but does not necessarily affect the accuracy of task performance.

Language proficiency and neuroticism were also examined for their effect on both reaction times and accuracy but neither showed a significant main effect or interaction ($p > 0.05$), as detailed in Table 4.

5.2 Mental Load

The intervention groups, particularly IG2, showed reduced mental load compared to the control group. IG2's mean NASA-TLX score was 40.10 (SD = 11.48), while the control group's mean was 46.57 (SD = 15.5). An ANOVA revealed no significant difference ($F(2, 46) = 1.03$, $p = .363$, $\eta^2 = .043$), as shown in Table 3, indicating that the interventions had no significant effect on perceived mental load.

To complement these subjective results, we also examined time-on-task during reading as a behavioural proxy for cognitive effort. A one-way ANOVA revealed a significant difference in time-on-task across groups, $F(2, 46) = 4.71$, $p = .014$, $\eta^2 = .170$. Post hoc comparisons using the Benjamini-Hochberg correction showed that IG2 spent significantly more time on-task than the control group ($t(31) = -3.89$, $p < .001$, BH-adjusted $p = .002$, Cohen's $d = -1.35$), while differences between control and IG1 ($p = .234$) and between IG1 and IG2 ($p = .133$) were not statistically significant. These results suggest that the note-taking intervention led to deeper cognitive engagement, even though participants did not report increased mental effort.

We also examined the relationship between subjective and behavioural indicators using Pearson correlation. The correlation between time-on-task and NASA-TLX scores was weak and non-significant, $r(47) = 0.216$, $p = .136$, suggesting that longer task duration did not correspond to higher perceived cognitive load. However, the visual trend differs across groups: IG1 displays a positive relationship between self-reported mental load and reading duration, while the control group shows little to no association as visualised in Fig. 8. Taken together, these findings provide only partial support for H2: while perceived mental load did not differ significantly across groups, behavioural indicators point to increased engagement in the note-taking condition.

5.3 Long-Term Memory

The ANOVA results revealed a significant effect of the interventions on memory retention ($F(2, 46) = 3.58$, $p = .036$, $\eta^2 = .135$), supporting H3 and indicating that the interventions meaningfully enhanced recall performance**.** Specifically, participants in the condition with guided pausing and note-taking had the highest mean recall score 51.91 (SD = 18.8), followed by those who received guided pausing alone 49.83 (SD = 13.04). In contrast, the control condition showed a lower mean score 38.15 (SD = 15.59), suggesting that the interventions contributed to improved memory retention. Interruptions during reading have been shown to disrupt cognitive flow; however, these results indicate that strategically timed pauses and note-taking may serve as effective countermeasures, reinforcing memory retention processes (Table 5).

Table 5. Pairwise t-test results for Reading Time-on-Task values with Benjamini-Hochberg correction and Cohen's *d* effect sizes

Comparison	t	df	p (raw)	P (BH-adjusted)	Cohen's d
Control vs IG1	–1.21	31	0.234	0.234	–0.423
Control vs IG2	–3.89	31	<.001	**0.002***	–1.35
IG1 vs IG2	–1.55	30	0.133	0.177	–0.547

Table 6. Pairwise t-test results for recall scores with Benjamini-Hochberg correction and Cohen's *d* effect sizes

Comparison	t	df	p (raw)	P (BH-adjusted)	Cohen's d
Control vs IG1	–2.33	31	0.027	**0.0435***	–0.81
Control vs IG2	–2.29	31	0.029	**0.0435***	–0.80
IG1 vs IG2	–0.36	30	0.718	0.718	–0.13

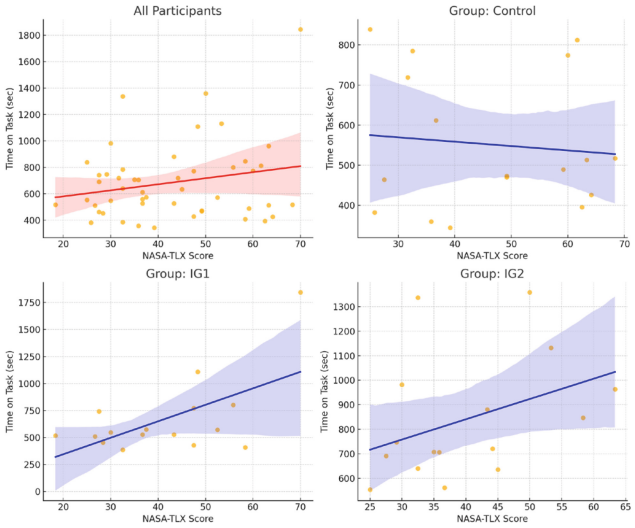

Fig. 7. Correlation between NASA-TLX Scores and Reading Time-on-Task. Scatterplots with regression lines and 95% confidence intervals are shown for all participants and separately by group. IG1 shows the strongest positive trend, IG2 a moderate one, and the Control group displays no apparent relationship.

To examine specific group differences, post hoc independent samples t-tests were conducted and adjusted using the Benjamini-Hochberg procedure. The comparisons between the control group and both intervention groups remained statistically significant after correction (Control vs IG1: $p = .027$, BH-adjusted $p = .0435$; Control vs IG2: $p = .029$, BH-adjusted $p = .0435$), while no significant difference was found between IG1 and IG2 ($p = .718$, BH-adjusted $p = .718$), as detailed in Table 6.

Additionally, language proficiency significantly influenced recall performance, with native speakers outperforming non-native speakers. This finding highlights the impact of language proficiency on memory retention, suggesting that individuals with higher language proficiency may have an advantage in recalling details from the reading task (Fig. 7).

5.4 Usability

Participants evaluated the usability of the system using the SUS questionnaire. The mean SUS score was 85.46 (SD = 12.18), which is considered excellent usability [31]. This score highlights the system's strong user satisfaction, though some participants suggested enhancing note-taking customisation for greater flexibility.

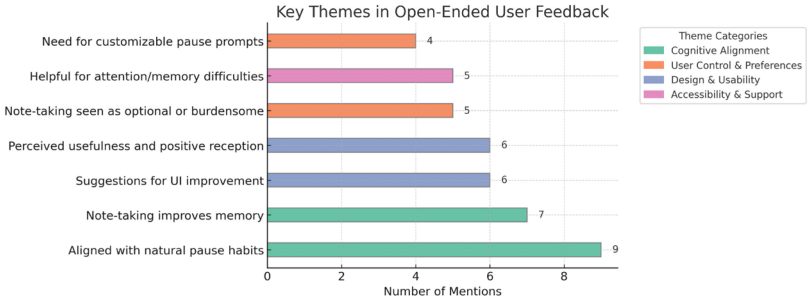

Fig. 8. Key themes identified in open-ended usability feedback from participants. Responses were categorised into four groups: Cognitive Alignment, User Control & Preferences, Design & Usability, and Accessibility & Support. Each bar indicates the frequency of mentions per theme across all participants highlighting perceptions of SmartPause's value and usability features.

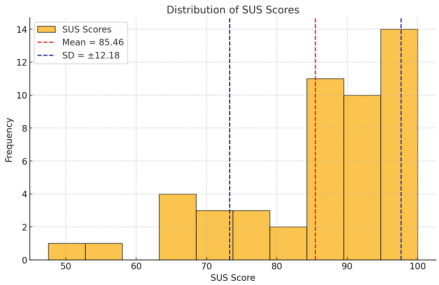

Fig. 9. Distribution of SUS Scores Across Participants

To complement the SUS scores, we analysed open-ended responses to gain deeper insight into users' subjective experiences. Participants generally found the system intuitive and easy to use, particularly valuing how the guided pause mechanism aligned with their natural reading rhythms. Thematic analysis of this feedback revealed several key perceptions (see Fig. 8). The most frequently noted benefit was the alignment with existing pause habits. Many users also reported that note-taking supported memory retention, while a smaller group expressed a preference for disabling this feature in certain contexts, such as casual reading.

Additional themes included appreciation for the bookmark's line-level precision, general satisfaction with the feature's usefulness, and perceived benefits for users with attention or memory challenges. Some participants suggested improvements such as greater flexibility in prompting frequency or the ability to disable summarisation prompts. These responses highlight the need to accommodate varying user preferences through more customisable features.

The usability feedback aligns with the results observed in memory retention, suggesting that guided pauses and note-taking not only improve cognitive performance but

also enhance user experience in digital reading environments. Figure 9 illustrates the distribution of SUS scores across participants, providing insights into individual variations in perceived usability.

6 Discussion

6.1 Cognitive Performance Findings and Interpretation

This study explored the impact of strategic pausing and note-taking interventions on Selective Attention, Processing Speed, Mental Load, and Long-term Memory Retention in digital reading tasks. By testing a system that incorporated these interventions, we demonstrated that pausing at natural breakpoints improved reaction time and processing speed for IG1, while the combination of pausing and note-taking significantly enhanced memory retention. Well-placed pauses are known to reduce the cognitive effort required to resume tasks, aligning with these findings [32].

However, the between-group analysis revealed no significant differences in reaction time or accuracy across the three groups, suggesting it did not create meaningful differences between the groups. This partial support for H1 indicates that pausing may facilitate faster cognitive processing, but its impact on accuracy and between-group performance remains inconclusive.

The mental load results offered mixed evidence for H2. While NASA-TLX scores did not differ significantly across groups, suggesting that perceived mental effort remained stable, time-on-task—a behavioural proxy for cognitive workload—revealed a significant group effect. Participants in the note-taking condition (IG2) spent significantly more time on the reading task than those in the control group, a result interpreted as increased engagement rather than cognitive overload. A weak and non-significant correlation between time-on-task and NASA-TLX scores further supports the notion that behavioural and subjective measures capture distinct aspects of cognitive effort. Thus, H2 was only partially supported: the interventions did not reduce perceived mental load, but they did meaningfully alter behavioural engagement.

In contrast, the memory retention results were robust. Participants in the guided pausing and note-taking condition demonstrated significantly higher recall scores compared to the control group. Post hoc analyses, adjusted using the Benjamini-Hochberg procedure, confirmed that both intervention groups outperformed the control group in memory performance. Moreover, the effect sizes for these differences (Cohen's $d \approx 0.8$) indicate large and practically meaningful impacts. However, the difference between IG1 and IG2 was not statistically significant, suggesting that note-taking may not have provided additional measurable benefit to recall performance. Similar findings have been observed in various digital and non-digital contexts like lecture-based learning, where structured pauses and note-taking enhance memory retention, suggesting the potential for broader application of these techniques [20, 33, 34].

Language proficiency was also found to significantly influence memory retention, with native speakers outperforming non-native speakers. This highlights the importance of considering individual differences, such as language proficiency, when evaluating the effectiveness of cognitive interventions in diverse populations.

6.2 Implications for Design and Research

This study provides insights for designing digital reading platforms and other cognitive task environments. One promising direction is identifying natural breakpoints—moments of lower mental load—and recommending optimal pausing points, aligning with activity theory's emphasis on tools that support user goals and cognitive workflows [35]. SmartPause was intentionally designed not to interrupt arbitrarily, but to respond when users are already attempting to disengage—such as pausing or preparing to leave the task. By encouraging users to continue to a nearby breakpoint, the system aligns with users' cognitive rhythms and intentions, thereby reducing the risk of disruption.

For example, SmartPause could guide users to pause at these breakpoints, while AI tools could detect these moments in real-time, improving focus, memory retention, and overall performance. The SUS results underscore the high usability of the SmartPause system, showcasing its potential to strengthen user engagement and streamline task transitions through an intuitive interface and guided features [36]. Qualitative feedback revealed opportunities to refine note-taking functionality, such as adding tagging and reorganising notes, to provide a more tailored experience and address diverse preferences. The overall feedback reflects key design components such as efficiency and user satisfaction [37]. By managing mental load, systems can help users stay engaged without cognitive overload, enhancing cognitive performance and long-term retention as well-designed interventions reduce cognitive disruptions and improve performance**.**

In addition to usability considerations, the open-ended feedback contributes to the ecological validity of the findings. Several participants described SmartPause as a natural extension of their reading routines, noting that the system's prompts aligned well with how they typically take breaks. While the study was conducted in a controlled environment, these reflections suggest that the core interaction model may be transferable to real-world digital reading scenarios.

Subsequent research should investigate how interventions like SmartPause function in naturalistic contexts such as e-learning, digital scholarship, or workplace reading, where patterns of distraction and engagement are more variable. These investigations would offer a more nuanced understanding of how guided pausing and note-taking function in authentic, everyday reading contexts.

While real-world deployments hold promise, they also raise new challenges. Emerging adaptive systems may introduce friction if they misjudge user intent or overstep the boundaries of user control. Automatically suggesting or enforcing pauses could feel intrusive if not properly personalised or explainable. Designing such features will require careful attention to transparency, timing, and user agency to avoid undermining trust or increasing cognitive burden.

The findings highlight the need for updated design guidelines that prioritise cognitive well-being. Incorporating features like strategic pausing and note-taking can improve memory retention and processing speed. Applications in which the user interfaces provide such interventions to prioritise the users' cognitive well-being is very rare today. Design knowledge available today in the field of HCI could more explicitly make this aspect actionable as principles and guidelines so that interaction designers will more readily consider incorporating such features in their designs. Expanding Nielsen's Usability Heuristics to include methods for managing mental load could enhance user

experience in a variety of applications [38]. Later work should explore how interventions like SmartPause can be personalised based on cognitive profiles and task complexity, with a focus on integrating them into real-world environments to optimise usability and cognitive wellbeing.

7 Limitations and Future Work

Although the study offers valuable insights, several limitations must be addressed. The learning effects from the Stroop task may have influenced reaction times, and individual differences in working memory, attention span, and cognitive resilience were not fully explored [39]. While the cognitive demands of the task were appropriate, the short reading duration limited the ability to assess the full impact of the interventions [40].

The study employed a between-subjects design to avoid learning transfer and reduce participant fatigue, especially given the number of cognitive measures involved. However, this design introduces individual variability, which may reduce sensitivity to condition-level effects. Future studies may benefit from within-subjects designs to better control for such variability and isolate the influence of each intervention.

Moreover, the short retention interval between the reading and recall tests restricts our understanding of the long-term effects. Although the immediate testing allowed for internal consistency, future research should incorporate delayed recall—such as after 24 h or one week—to better assess how guided pausing and note-taking influence long-term memory consolidation. These limitations suggest the need for future work to control for learning effects, account for individual differences through within-group studies, extend reading durations, increase retention intervals, and involve larger, more diverse samples to improve the generalisability of the findings.

While the current study relied on subjective and behavioral measures of mental workload, future research should incorporate physiological indicators such as eye-tracking to better understand attention shifts and cognitive effort in real-time. These methods can provide fine-grained, continuous insights into how users interact with reading interventions, particularly during transition points and pause decisions. Incorporating such objective data would strengthen the triangulation of cognitive engagement and inform the development of adaptive features in SmartPause.

A promising direction for SmartPause is the personalisation of pause timing based on users' engagement patterns. While the current prototype uses static logic, recent advances in explainable AI offer opportunities for adaptive support. For example, Zoppis et al. [41] demonstrate how neural recommendation models can personalise content delivery by weighting user-resource relationships. Although their systems do not address interaction timing, they highlight techniques for tailoring educational technologies to individual needs. SmartPause could extend this line of work by adapting its intervention strategy using lightweight, engagement-sensitive cues.

Building on this, SmartPause could incorporate real-time behavioural and attentional data to dynamically determine whether a pause should be suggested, and if so, how far ahead to nudge the user—e.g., suggesting a section rather than a chapter break if the user typically stops reading within shorter spans. Over time, such a system could learn from individual pause histories, attentional lapses, or task duration to adjust the granularity and frequency of interventions, thereby balancing continuity and cognitive load.

Finally, the use of AI-driven user modelling, particularly in educational and assistive reading platforms, opens pathways for scaling SmartPause to diverse populations, including readers with cognitive or attentional impairments [42]. Future work should explore how human-AI collaboration in cognitive load adaptation can be applied to enhance usability and engagement in real-world digital reading environments. While these mechanisms remain beyond the current scope, acknowledging them helps position this study within the broader research landscape of adaptive learning systems.

8 Conclusion

This study demonstrates that cognitive interventions, such as pausing at natural breakpoints and note-taking, can optimise available cognitive resources and improve long-term memory retention in digital reading tasks. By aligning task activities with users' cognitive rhythms, these strategies present a promising approach for enhancing engagement and recall outcomes.

Building on these findings, subsequent research should explore how such interventions can be adapted to accommodate varying levels of language proficiency, attentional profiles, and cognitive differences, including those experienced by readers with learning difficulties. Expanding task durations, increasing retention intervals, and conducting ecologically valid studies will further elucidate their long-term efficacy. Given the platform-agnostic nature of SmartPause, its applicability across desktop, tablet, and mobile environments positions it as a scalable solution for cognitively supportive digital reading. Together, these directions underscore the importance of inclusive and adaptive design in shaping next-generation digital reading systems.

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