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A Comparison of Perceived Fatigue, Workload, Usability, and Comprehension in Reading on Paper, Mobile Phones, and Laptops

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ABSTRACT

Background: Reading and studying on digital devices—such as personal computers, laptops, and mobile phones—has become integral to daily life. The shift from paper to electronic formats has raised concerns about the impact of digital devices on human performance and health. The current study aimed to compare the effects of paper and electronic devices on perceived fatigue, workload, usability, and comprehension.

Methods: Thirty-six participants (58.3% female) read general passages on three devices in 2021: a laptop, a mobile phone, and paper. After each trial, participants answered ten comprehension questions to assess their understanding. Additionally, fatigue, mental workload, and usability were evaluated using a visual analog scale, NASA-TLX, and the System Usability Scale (SUS).

Results: The results showed that 69.4% of participants preferred reading on paper over screens. The average scores for fatigue (22.64) and workload (40.47) were lower for paper. The usability score for paper was higher (88.44) than for the mobile phone (68.17) and laptop (68.44). While comprehension scores were higher for paper (4.36) than for laptop (4.19) and mobile phone (4.22), the difference was not statistically significant.

Conclusion: Despite the widespread use of electronic devices for reading, paper was rated significantly higher in terms of usability and cognitive workload, although it showed no statistically significant advantage in comprehension.

KEYWORDS: *Mobile learning, Evaluation methodologies, Mental workload, Fatigue, Digital devices*

INTRODUCTION

Within the past few decades, the global proliferation of electronic devices—such as smartphones, tablets, and computers—has positioned digital reading as a prominent phenomenon. Despite the widespread acceptance of this innovation, driven by the convenience of information access and the flexibility of content use, concerns have emerged regarding increased eye fatigue, altered reading behaviors that may impair comprehension, and elevated cognitive load. For instance, Delgado et al. (2018) found that reading on electronic screens can lead to greater fatigue and reduced focus [1]. Additionally, cognitive load theory (Sweller, 1994) suggests that the physical and cognitive

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demands of screen-based reading can impose an extra burden on the information processing system [2]. Rayner's research further underscores the significance of visual factors in reading and information processing [3].

On the other hand, the comprehension and effectiveness of reading on digital media compared to paper remain subjects of ongoing debate. Studies have shown that, although users often prefer reading on paper due to ergonomic factors and established habits, there is no significant difference in comprehension between the two formats [3]. Given the dramatic rise in digital device usage across diverse populations—and the importance of accurately evaluating fatigue, cognitive load, usability, and comprehension—the need for direct comparisons among paper, mobile phones, and laptops becomes evident. Such comparisons can offer more scientifically grounded and practical insights.

Over the past few decades, the use of electronic devices—such as smartphones, computers, and tablets—has increased significantly [4]. Today, electronic versions of books, articles, and other publications are widely accessible and appreciated by users for their convenience and flexibility, allowing access anytime and anywhere. In fact, many individuals prefer e-books over printed ones [5]. Smartphones and tablets, being lightweight and portable, are commonly used before sleep and even in bed [6, 7]. One study found that 90–95% of people aged 13 to 64 reported using an electronic device at least once a week before going to bed [6].

However, despite the benefits and popularity of electronic devices, excessive use can lead to adverse effects. Previous studies have shown that eye symptoms such as fatigue and dryness are significantly more common when reading on screens compared to printed materials [8, 9]. In general, fatigue and dry eyes are prevalent among individuals who spend extended periods staring at screens [7, 10]. Portello et al. reported that 40% of office workers who spend most of their working hours in front of screens experienced eye fatigue, while 30% reported dry eyes [11]. The primary cause of dry eyes is a reduction in blink rate, which is significantly lower during screen use (visual display terminal, VDT) [12]. To examine the effect of VDT use on blink rate, Schlote et al. (2004) [13] compared blinking patterns in patients with dry eye. Their study showed that the blink rate decreased from 17 times per minute during face-to-face conversation to just 6 times per minute when reading text on a screen.

This phenomenon suggests an increase in mental workload when reading on a screen [14]. Brishtel et al. (2018) [15] found that increased pupil diameter, prolonged eye fixation, and elevated electrodermal activity on the skin surface are indicators of heightened fatigue and mental workload during screen-based reading. Psychologists and neuroscientists also emphasize that the shift from paper to screen can influence reading comprehension [16]. Notably, comparative studies suggest that reading printed texts is more effective. Reading on paper has been shown to enhance understanding and is particularly suitable for complex educational and scientific materials [17]. Supporting this, a study conducted at the Reading Center at Stavanger University in Norway found that comprehension and story understanding were significantly higher when reading on paper. Participants who read the story on a screen demonstrated less grasp of its essence and struggled to recall the sequence of events [18].

Investigating reading methods and comprehension as a social phenomenon has long intrigued researchers. Changes in study habits are primarily shaped by cultural, social, economic, and demographic factors [16]. These influences affect individuals' preferences for electronic devices and their inclination toward digital reading, which can vary across societies. Accordingly, experts categorize reading into two main approaches: traditional and digital [11]. The digital method involves using smartphones, laptops, tablets, and other electronic devices, while the traditional method relies on printed books and paper.

Although previous studies have compared reading on paper and screens [19, 20], many human factors and ergonomic indicators remain underexplored. Given the rapid growth of digital reading in contemporary society and the limited comparative research on its impact relative to traditional methods, this study examined reading on paper, mobile phones, and laptops in terms of comprehension, mental workload, fatigue, and usability.

Specifically, the study aimed to address the following research questions and objectives:
1) What are people's preferences for choosing reading tools? Paper, mobile phone or laptop.
2) Which of the methods of studying and reading provides less fatigue and mental workload for people?

3) Comparison of reading and studying on paper, mobile phone and laptop in terms of usability.
4) Examining people's reading comprehension after reading on paper, mobile phone and laptop.
Achieving these objectives and questions will be important for researchers and specialists as well as for the general public, who use these devices daily.

MATERIALS AND METHODS

Participants

All participants were completely healthy. They were evaluated for visual health by an optometrist and were asked to have enough sleep the night before the tests. Also, all participants signed an informed consent form before the study, and they were free to leave at any time.

Selection Criteria

Participants were selected based on the following criteria:
· **Age:** 18 years or older
· **Reading Habits:** Regular daily reading habits, with a minimum of 10 minutes per day
· **Device Familiarity:** Regular use of paper, mobile phones, and laptops for reading
· **Demographic Diversity:** A variety of educational backgrounds and occupations to ensure a diverse sample
The minimum sample size was calculated based on a confidence level of 95% and a margin of error of 5%, resulting in a required sample size of 36 participants for sufficient statistical power.

Sampling Method

The participants were selected using convenience sampling from a pool of individuals who met the study's criteria. Before consenting, participants were informed about the study objectives, methods, and the expected time commitment.

Tools or instrumentation

Texts

Three texts in Persian were selected from reliable Persian-language websites about general information related to public health, with word counts of 1,440, 1,468, and 1,505. The texts were chosen with the help of an expert in Persian literature and linguistics. They were at the same level in terms of content and eloquence. The texts were written in B Nazanin 14 font as PDF files and printed on A4 paper. The line spacing was 1.15, and the page layout was consistent across all three texts.

Platforms

An A4 paper with one-inch margins on both sides, an iPhone 8 Plus with a 5.5-inch (diagonal) widescreen LCD Multi-Touch display featuring IPS technology and a 1920-by-1080-pixel resolution at 401 ppi with Adobe Acrobat Reader (iOS version) installed, and a Vivobook 15 K513 15.6" laptop computer with a Full HD 1920×1080 display, also with Adobe Acrobat Reader (Windows Microsoft version), were used as three different reading platforms.

Dependents Variables

Dependent variables included fatigue, mental workload, usability, and reading comprehension scores. More detail is provided in the next sections. These variables depended on the use of different platforms (paper, mobile phone, and laptop) while studying.

Fatigue

A visual analog scale (VAS) was used to measure self-reported fatigue. Participants were asked to rate their fatigue while reading on paper, mobile phones, and laptops using a Likert scale from 0 (very little fatigue) to 100 (too much fatigue).

Mental workload

In this investigation, the Persian version of the NASA-TLX questionnaire was utilized to assess the degree of the students' cognitive load after using different platforms. It is one of the most popular methods for measuring mental workload and has been found to be valid among the Iranian population, such as in the study by Mohammadi et al. (α = 0.897) [21]. The NASA-TLX questionnaire was used to evaluate the mental workload of the participants after studying on different platforms.

The NASA-TLX method is one of the well-known subjective tools for measuring mental workload in order to evaluate performance. It has been used in various fields such as aviation, health care, and other complex social and technical domains (Noyes & Bruneau, 2007) [22]. NASA-TLX is composed of two aspects: the first involves the measurement of six different dimensions—"mental demand," "physical demand," "time pressure," "effort," "performance," and "frustration"; the second involves the measurement of these dimensions in pairs based on their relative importance. In this investigation, only the first measurement component was used due to the more complicated nature of the pairwise rating feature, which increases the response burden and potentially leads to less accurate results. In addition,

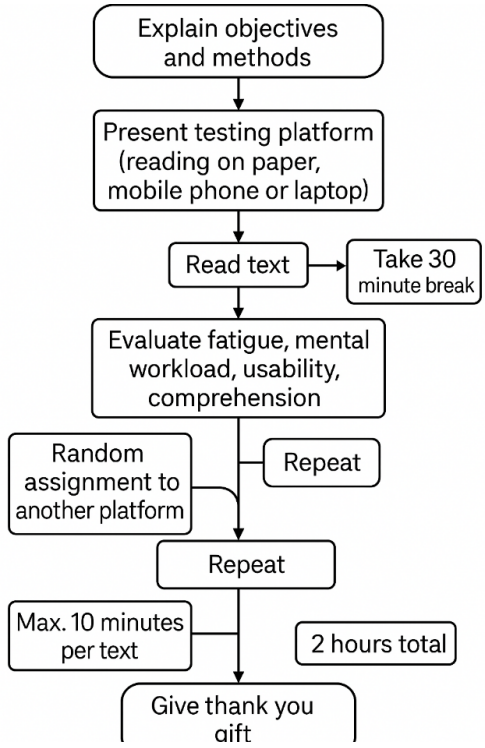

Figure 1. Flowchart of Experiment Procedure in the Study on Testing Platforms

the key focus of this study was to determine the overall student perception related to their cognitive load, not the specific importance of each factor.

Usability

The System Usability Scale (SUS) was used to evaluate the usability of paper, mobile phone, and laptop platforms. Usability specifies how easy and convenient a product is to use. The usability of a product or system is one of the indicators of human-system interaction that leads to better human-centered design (Stanton et al., 2017) [7]. The International Standard Organization has defined usability as the extent to which specified users can use a product to achieve specified goals with effectiveness, efficiency, and satisfaction in a specified context (Bevan et al., 2016) [4]. The usability scores were calculated for the investigated platforms based on the completed questionnaires. A higher score indicates better usability. The Persian version of the questionnaire was validated by Dianat et al. [23].

Comprehension

Ten reading comprehension questions based on each text were designed by three authors and an expert in Persian literature and linguistics using brainstorming. The overall scores for the questions ranged from 0 to 10.

Procedure

At first, the objectives and methods of the study were explained to the participants. Then, each person was presented with one of the testing platforms (reading on paper, mobile phone, or laptop). After reading the text from each platform, fatigue, mental workload, usability, and comprehension were evaluated. To minimize the learning effect, the order of presentation of the platforms was completely randomized. All tests took approximately 2 hours per person. The maximum time given to read each text was 10 minutes, with a 30-minute break after reading each text. All tests were conducted between 8:00 AM and 12:30 PM in a room with standard conditions (temperature: 21 °C and relative humidity: 45%). At the end, participants were given a thank-you gift to show appreciation.

RESULTS

Descriptive Statistics

Thirty-six participants (mean age = 34.17 ± 11 years) were included in this study, of whom 58.3% were female and 41.7% were male. The participants had different occupations and educational levels. Their demographic characteristics, amount of daily reading (in minutes), and preferred tool for reading are shown in Table 1. Accordingly, despite the popularity of smartphones and laptops, paper remains the preferred choice for reading among most individuals.

Table 1. Socio-Demographic Characteristics of Participants

Variables		No (%)	Mean (SD)
Age		-	34.17 (11±3)
BMI		-	23.49 (7.2)
Gender	F	21(58.3)	-
	M	15	-
Daily Reading (minutes)	Paper	-	92.08 (142.8)
	Mobile phone	-	83.89 (62)
	Laptop	-	20.67 (61.9)
Education	High School	13 (36.1)	-
	Bachelor	17 (47.2)	-
	Master	6 (16.7)	-
Reading Preference	Paper	25 (69.4)	-
	Mobile phone	4 (11.1)	-
	Laptop	7 (19.4)	-

Table 2. The mean scores for fatigue, mental workload, usability and comprehension

	Paper	Mobile phone	Laptop
	Mean (SD)	Mean (SD)	Mean (SD)
Fatigue	22.64 (16.6)	47.5 (20.3)	35.14 (21.63)
Mental workload	40.47 (12)	45.83 (12.1)	45.38 (12.7)
Usability	88.44 (9.58)	68.17 (17.28)	68.44 (16.17)
Comprehension	4.36 (0.54)	4.22 (0.83)	4.19 (0.82)

Table 3. Mean and Standard deviation (Mean (SD)) of workload subscales among different platforms of reading

NASA-TLX	Platforms		
	Paper	Mobile phone	Laptop
Mental Demand	54.72 (24.5)	59.17 (19.4)	57.64 (19.4)
Physical Demand	11.67 (10.8)	25.14 (20.6)	20.83 (15.6)
Temporal demand	37.08 (21.1)	42.92 (24.6)	40.5 (25.2)
Performance	75.14 (22)	70.14 (21.8)	76.67 (19.3)
Effort	54.03 (22.9)	60.65 (17.9)	55 (20.4)
Frustration	16.94 (15.3)	24.72 (21.7)	26.94 (23.4)

The mean scores of fatigue, mental workload, usability, and comprehension related to reading on paper, mobile phone, and laptop were also calculated. The information can be seen in Table 2. The average scores for paper in terms of fatigue and workload were lower, at 22.64 and 40.47, respectively. Additionally, the score for paper in terms of usability was higher (88.44) than that for mobile phone (68.17) and laptop (68.44).

Subscales of mental workload were also measured separately, and the mean and standard deviation of the scores for each subscale across all three platforms were calculated and recorded in Table 3. As shown, paper is the better choice for reading across all six subscales.

Analytical Statistics

According to the repeated measures ANOVA test, there were significant differences among the reading methods with respect to fatigue, mental workload, and usability, but no significant differences were observed among the different reading methods with respect to comprehension ($p \leq 0.05$). Accordingly, reading on a mobile phone led to more fatigue than the other two methods, and mental workload was nearly the same when reading on a mobile phone or laptop, but higher than when reading on paper. Also, regarding usability, there was no difference between reading on a mobile phone or a laptop; however, paper appeared to be more usable. Interestingly, our results showed that, in terms of comprehension, there was no difference between reading on paper, mobile phone, or laptop ($p > 0.05$) . The results of the Bonferroni test, used for pairwise comparisons of different reading methods, are presented in Table 4.

The Mixed ANOVA results are as follows:

· **Gender**: The effect of gender on comprehension scores was not statistically significant ($F(1, 28) = 0.595$, $p = 0.447$).

Table 4. Pair wise comparisons of different reading methods

Pair wise comparisons	Variables			
	Fatigue (p-value)	Mental workload (p-value)	Usability (p-value)	Comprehension (p-value)
Paper vs Mobile phone	0.000*	0.005*	0.000*	1.000
Paper vs Laptop	0.003*	0.031*	0.000*	0.734
Laptop vs Mobile phone	0.033*	1.000	1.000	1.000

(*) Indicates significant differences p-value≤0.05

Table 5. Results of ANOVA Testing for the Effects of Gender, Platform

	Source	SS	DF1	DF2	MS	F	p-unc	p-GG-corr	np2	eps	sphericity	W-spher	p-spher
0	Gender	5119.309573	1	28	5119.309573	0.594820	0.447021	NaN	0.020802	NaN	NaN	NaN	NaN
1	Platform	111827.624074	2	56	55913.812037	5.690502	0.005626	0.01377	0.168905	0.657437	FALSE	0.478943	0.000033
2	Interaction	5201.921065	2	56	2600.960532	0.264707	0.768386	NaN	0.009365	NaN	NaN	NaN	NaN

 SS – Sum of Squares **DF1** – Degrees of Freedom (numerator) **DF2** – Degrees of Freedom (denominator) **MS** – Mean Square **F** – F-statistic **p-unc** – Uncorrected p-value **p-GG-corr** – Greenhouse-Geisser corrected p-value **np²** – Partial Eta Squared (η^2_p), effect size **eps** – Epsilon (Greenhouse-Geisser estimate of sphericity) **sphericity** – Indicates whether the assumption of sphericity is met **W-spher** – Mauchly's W statistic for sphericity **p-spher** – p-value for Mauchly's Test of Sphericity

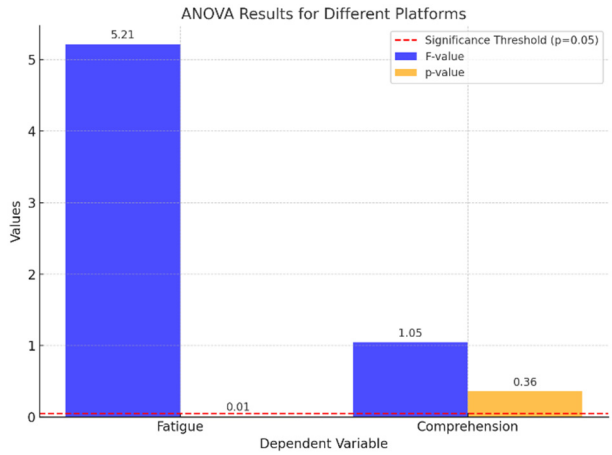

Figure 2. ANOVA Results for Fatigue and Comprehension Across Different Platforms

· **Platform**: There was a statistically significant overall effect of the platform on comprehension scores ($F(2, 56) = 5.691$, $p = 0.006$; Greenhouse-Geisser corrected $p = 0.014$). However, post-hoc pairwise comparisons (Table 4) revealed no significant differences between specific platforms. Thus, while there is an overall effect, no individual platform significantly outperforms the others in comprehension.

· **Interaction (Gender x Platform)**: The interaction effect between gender and platform was not statistically significant ($F(2, 56) = 0.265$, $p = 0.768$). This indicates that the effect of the platform on comprehension does not differ significantly between genders.

These results indicate that while the platform used for reading does have a significant impact on comprehension, this effect is consistent across genders. The chart presents the analysis of variance (ANOVA) conducted to compare the effects of reading platforms (paper, mobile phone, and laptop) on two dependent variables: Fatigue and comprehension. The blue bars represent the F-values,

Male (Gender = 1):

· **Platform**:

· **p-value**: 0.008

· **Partial Eta Squared ((\eta^2_p))**: 0.148

The partial eta squared value of 0.148 indicates a medium effect size, suggesting that the platform has a moderate impact on comprehension scores for males.

Female (Gender = 2):

· **Platform**:

· **p-value**: 0.361

· **Partial Eta Squared ((\eta^2_p))**: 0.047
The partial eta squared value of 0.047 indicates a small effect size, suggesting that the platform has a minimal impact on comprehension scores for females.

DISCUSSION

This study compared reading on different platforms regarding fatigue, mental workload, usability, and comprehension. According to the results, reading on paper was more preferable. Consistent with these findings, Podolsky and Soiferman reported that most students prefer printed texts for academic purposes because taking notes is easier and reading on paper is more comfortable for the eyes, leading to less eye strain and fewer headaches [24]. A 2024 article by Anne Kauranen titled *"Books in, screens out: some Finnish pupils go back to paper after tech push"* reports that in Riihimäki, Finland, pupils have returned to using books and paper after nearly a decade of integrating laptops and other digital devices into their education system [25]. In fact, according to various studies, eye fatigue, the inability to leave marks or make notes in online documents, technostress, and low reading speed are major reasons for users' reluctance to read on a computer screen [17, 26]. Additionally, we found that reading on paper leads to significantly less fatigue and mental workload compared to reading on a mobile phone or a laptop. Brishtel et al. obtained similar results, showing that physiological indicators revealed increased mental workload when reading on a screen [15]. Reading on paper is a relatively primal method that presents almost no complexity for readers. In contrast, mobile phones and laptops, as relatively new electronic tools, can increase users' mental workload and induce fatigue. Admittedly, visual tasks may become more difficult and require more effort and concentration to perform. If the eye muscles become overly fatigued, their function may be less than optimal. This suggests that the reason behind early fatigue when reading on a screen is that eye muscles are overly strained, consequently causing a necessary increase in effort and concentration to maintain performance. An increase in effort and concentration means that more cognitive resources must be allocated to the task. Hence, early fatigue may result from the increased mental workload of individuals reading on a screen [27].

On the other hand, paper is easy to use and has no complications. The long history of paper as a main tool for reading makes it more satisfactory, as demonstrated by higher usability scores. Another main result of our study is that, despite previous studies stating that reading on paper leads to better comprehension of a text, we found no significant differences between reading on paper or a screen in terms of comprehension [17]. Clinton [28] reported that the advantage of on-paper over onscreen reading was more significant for expository texts than for narrative texts. Also, Delgado et al. reported that when reading time was constrained rather than self-paced, reading on paper led to better understanding of the text (Delgado et al., [17, 19]b).

Considering the increased use of electronic devices in the 21st century, people's dependence on these tools has also grown, making it nearly impossible to question their use. The new generation of the 21st century, which grew up with technology, cannot imagine life without computers or smartphones. We have reached the point of shifting media from printed paper to computer screens.

This transition modifies how we read and understand text [29]. Hence, despite the results of this study and the preference of people to read on paper rather than on a screen, this preference may stem from a desire to do things in the simplest way possible, rather than being related to comprehension or understanding of the text. The present study was a subjective investigation based on data obtained from four self-reported questionnaires.

In questionnaire-based studies, there is always a risk of inaccurate information due to underestimation or overestimation. We suggest using a larger sample size or objective methods such as Electromyography (EMG) and Electroencephalography (EEG) in future research to obtain more precise and reliable results.

CONCLUSION

Despite the advancement of technology and the increasing use of computers and smartphones, printed documents still have more supporters and remain the first choice for most people when it comes to reading. Reading on paper as a primary method causes less fatigue, and the mental workload is more acceptable in terms of usability. However, there is no difference in reading comprehension between reading on paper and on a screen. These results underscore the importance of considering user preferences and ergonomics when designing reading materials and digital platforms.

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

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