Supporting Mobile Reading While Walking with Automatic and Customized Font Size Adaptations

Junhan Kong[*]
University of Washington
Seattle, Washington, USA
junhank@uw.edu

Jacob O. Wobbrock
University of Washington
Seattle, Washington, USA
wobbrock@uw.edu

Tianyuan Cai
Adobe Research
San Francisco, California, USA
tcai@adobe.com

Zoya Bylinskii
Adobe Research
Cambridge, Massachusetts, USA
bylinski@adobe.com

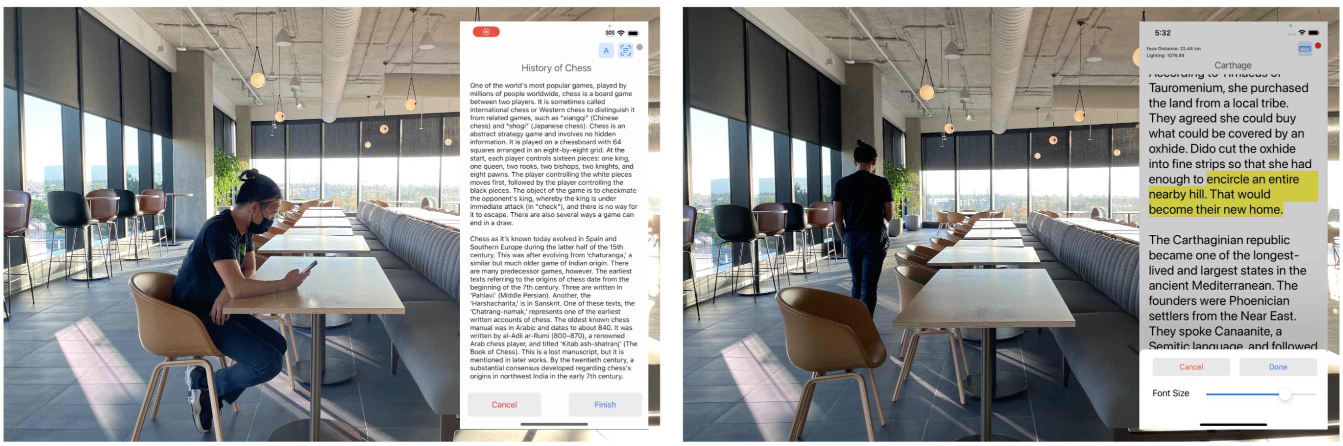

Figure 1: We collected reading behaviors and sensor data under situational impairments caused by walking while reading. During our experiment sessions, participants switched between sitting and walking as they read on a mobile device. We evaluated how custom and automated adjustments to text format may improve reading performance while users read and walk.

Abstract

The pervasive use of mobile devices for information consumption makes reading on-the-go an unavoidable daily occurrence, whereby walking creates a natural situational impairment for reading. In this work, we quantify the impact of walking on reading performance and compare automatic system adaptations with user customizations for mitigating these impacts. We collected user interactions and mobile sensor data of reading while walking in a controlled lab study with 45 participants. We found that automatic font size adjustment by viewing distance mitigated the performance degradation from walking, yielding faster reading speed and increased comfort. Furthermore, exposure to the automatic adaptation functionality influences user customization behavior and preferences for reading while walking. We discuss implications and provide design suggestions for personalizing interfaces when reading on-the-go, including blending system recommendation with user customization, offering multiple points of customization through appropriately-timed prompts, and refining recommendations based on observed preferences.

CCS Concepts

• **Human-centered computing → Empirical studies in ubiquitous and mobile computing**.

Keywords

Situational impairments, mobile readability, personalization, adaptivity, adaptability, customization

[*]Also with Adobe Research, as an intern.

This work is licensed under a Creative Commons Attribution 4.0 International License.
CHI '25, Yokohama, Japan
© 2025 Copyright held by the owner/author(s).

ACM ISBN 979-8-4007-1394-1/25/04
https://doi.org/10.1145/3706598.3713367

ACM Reference Format:
Junhan Kong, Jacob O. Wobbrock, Tianyuan Cai, and Zoya Bylinskii. 2025. Supporting Mobile Reading While Walking with Automatic and Customized Font Size Adaptations. In *CHI Conference on Human Factors in Computing Systems (CHI '25), April 26–May 01, 2025, Yokohama, Japan.* ACM, New York, NY, USA, 13 pages. https://doi.org/10.1145/3706598.3713367

1 Introduction

From checking the calendar while catching buses to online shopping in the subway, we read on our mobile phones in diverse and complex circumstances. Among all these situations that can affect our abilities to read, namely "situational impairments" [35, 60, 75], walking is an especially common one. Walking can significantly affect our abilities to use mobile devices [35]—specifically, it can compromise our visual ability to view the text [30, 42], fine motor ability to navigate documents through touch-based gestures [25, 45], and cognitive ability to comprehend the content [59].

With the increasing dependence on mobile devices for information consumption and communication in daily life, mobility becomes a common and often unavoidable context for reading. Prior research suggests that users will continue to read under various conditions [46, 58, 70], highlighting a persistent need to make reading more efficient and accessible in motion. In the past, a variety of systems have been created to mitigate the effect of walking and other situational impairments, and to facilitate technology use under these impairments [25, 35, 36, 45, 60]. However, the majority of past interventions focus on creating system-initiated, automatic adaptations to detected walking, providing the same adaptation for every user. In the meantime, a handful of prior research suggest the need for diverse, personalized adaptations of text settings, since users often have diverging needs and preferences [11–13, 71]. However, user-initiated customization can be especially challenging when reading on-the-go, since one's physical and cognitive abilities can be compromised. With such a conflict of needs for reading on-the-go, little work has been done to specifically compare system automation with user customization within the context of situational impairments.

In this work, we conducted a controlled lab study to quantify the effect of walking on mobile reading. We also compared *system automatic* and *user customized* adaptations for reading while walking, through the lens of adapting a single text setting—the font size. Specifically, this work aims to answer two research questions:

- **RQ1:** How does walking affect one's mobile reading performance and experience?
- **RQ2:** Is system automatic or user customized adaptation better for improving mobile reading experiences on-the-go?

To answer these questions, we first developed a mobile reading application that detects walking using smartphone built-in sensors and provides different forms of adaptations upon detected walking. The app automatically calculates a system recommendation of font size based on a user's viewing distance from the screen, or prompts the user to customize font size through a slider in a pop-up drawer window when walking is detected. The reading app also integrates with a few visual cues drawing from prior work [37, 42, 49], to help a user easily resume reading after the font size changes.

We collected a dataset of mobile reading behaviors while walking, through in-person lab study sessions with 45 participants. While participants read, our app recorded sensor and interaction data, such as the current posture (walking/sitting), text setting changes, and reading performance measures such as speed and comprehension.

In our analyses, we used four metrics to quantitatively measure the reading experience: speed, comprehension, task load, and preference. We found that walking significantly slowed down reading, but increasing font sizes mitigated its impact. Despite the difference in reading speed, we found no differences in reading comprehension with or without the adaptations. Additionally, we found that both automatic and customized adaptations to font size reduced task load. Even though automatic adaptations led to improved reading performance while customized adaptations were more challenging to specify while walking, users nevertheless preferred customization for the agency and predictability afforded. On top of the general trend, we still found large variations in individual preferences—for example, some users preferred automatic adaptations as they were simple and easy to use, while others preferred customization due to the preservation of agency and context of reading. Furthermore, we found that exposure to the automatic adaptation influenced user customization behavior and preferences for font sizes.

Based on these findings, we discuss design implications for adaptations to improve mobile readability on-the-go—blending automatic suggestions with user customization to help users identify effective interventions; providing options for customization throughout the process when user preferences diverge; choosing appropriate timings to prompt for user customization; and observing such customization behavior to improve future recommendations.

The major contributions of this work are:

- A mobile reading app that detects walking and provides automatic and customized adaptations;
- A data set of mobile reading behaviors while walking collected in a lab study with 45 participants ;
- A quantitative characterization of the effects of walking on the mobile reading experience;
- A comparison of automatic and customized reading adaptations on-the-go, and design implications for future mobile reading adaptations to walking.

2 Related Work

2.1 Walking and Situational Impairments

As discussed by Wobbrock et al. in Ability-Based Design (ABD) [76, 77], *abilities* are not simply properties of users in isolation, but should be considered as *situated* within users' contexts, activities, or environments. Prior work has assessed and addressed various forms of "situational impairments" [35, 60, 75], such as distraction [42], water drops on screens [69], temperature effects [48, 55], intoxication [43], stress [56, 64]. Walking is one of the most common forms of situational impairments, and prior work investigated the effects of walking on technology use and proposed adaptations to mitigate such impairments. For example, Sears et al. [60] identified walking as a factor that could negatively affect text entry performance; Kane et al. [35] proposed adaptive mobile user interfaces for using mobile devices while walking; WalkType by Goel et al. [25] adapts user touch locations on soft keyboards based on sensor data when walking is detected; Cluster Touch by Mott et al. [45] addresses walking-related touch inaccuracies by modeling user touches; Khan et al. [36] developed eye-reduced document skimming to facilitate non-visual document reading under situational impairments.

2.2 Mobile Readability

Prior research has found that font, particularly font size, can significantly affect readability [3–8, 10, 51–53, 74], yet there is no one-size-fits-all font [12, 13, 71]. Due to the outstanding effect of font sizes on readability, we chose this setting as a lens to investigate adaptations of reading interfaces. While there is a need for personalization of text settings, prior work has also found recommending text settings challenging, particularly due to the need of balancing multiple objectives and meeting diverse user preferences [11, 12]. On top of general findings on readability, mobile reading is unique in its limited screen size to display text, while prior work found that larger text size did not yield better performance on mobile reading due to "the increased demand for scrolling" [59].

Under situational impairments, one's ability to read on mobile devices can be largely compromised. Specifically, walking can compromise one's visual ability to view the text content [30, 46], fine motor ability to navigate documents through touch-based gestures [25], and cognitive ability to comprehend the content while navigating the physical environment [50, 59]. Together, the compromised visual, motor, and cognitive abilities can significantly impact the reading experience. Particularly, users can experience greater impairment while using smaller devices like mobile phones compared to desktop devices [57, 78]. Conradi [18] investigated reading single words while walking and found that display time, walking speed, and number of letters all affected reading; Mustonen et al. [46] examined mobile text legibility while walking and found that visual performance degrades with increasing walking speed; Vadas et al. [70] compared audio with hand-held displays for reading on-the-go, highlighting the improved reading speed and comprehension through non-visual UI; to a similar end, Schartmuller et al. [58] investigated text comprehension with heads-up versus auditory displays in automated vehicles, and found significant reduction in task load with reduced visual interactions. On top of prior work, this work extends the understanding of how walking influences the mobile reading experience, and further investigates the effects of different runtime UI adaptations on mitigating such influences.

2.3 Adaptive, Adaptable, and Mixed-Initiative User Interfaces

Among all different forms of interface adaptations, there has been a longstanding discussion around system-initiated adaptivity and user-initiated adaptability. In the early discussions, there was a strong "tension" between interface agents and direct manipulation [1, 39, 41, 62, 63]. Horvitz [32] later proposed the concept of "mixed-initiative user interfaces", suggesting that collaboration of human direct manipulation with intelligent agents should be favored, instead of treating them as non-compatible. A handful of prior work also theoretically discussed "adaptive" versus "adaptable" interfaces [65, 66] and investigated difference between them—system-initiated adaptations are shown to be efficient in many prior work [21, 23, 25, 26], yet its unpredictability of actions [23], possibility for errors [32] and potential misalignment with user intention [68] can be undesirable; on the other hand, while user-initiated adaptability is generally preferred due to the sense of control and higher perceived performance [19], there might be "awareness" issues [19–22, 67] as users may not know how to tailor the full set of features to their needs. Despite general comparison of the two forms of adaptations in literature, no prior work has compared them within the context of situational impairments, a unique setting in which a user's physical and cognitive abilities are already compromised. While a handful of inventions designed to address situational impairments have taken the system adaptive approach [25, 35, 42, 45], little has been done to investigate how user customization can address such impairments.

This work is inspired by Findlater and McGrenere's [19] comparison of static, adaptive, and adaptable split menus. Similarly, this work quantifies the impact of walking on mobile reading, and compares the effectiveness of automatic ("*adaptive*") and customized ("*adaptable*") adaptations to walking. While this work considers the two approaches in separation, our findings point to design implications for mixed-initiative interventions to improve the mobile reading experience while walking.

3 Reading Interface Design

We developed a mobile reading application in iOS to run the experiments and collect user reading data. The reading app leverages standard mobile native libraries for walking detection and incorporates UI intervention design suggestions for reading while walking from a preliminary study [37].

Walking Detection. The app wraps the Apple Core Motion [34] library to detect walking, and applies a three-second smoothing filter to avoid undesirable interface changes due to frequent switching between stationary and walking modes.

Reading Ruler for Reading Resumption. Preliminary study results on mobile reading adaptations while walking [37] suggest that users can easily lose track of reading after interface adaptations. To help users quickly resume reading, we designed a visual intervention similar to Digital Reading Rulers [49] to let users calibrate an area on the screen they usually read (Figure 2a) through tapping input. We leverage a similar visual cue as SwitchBack [42] to highlight the text a user was reading before any adaptations, and help bring the text back into focus after the adaptation (Figure 2b).

Calculating Font Size for Automatic System Adaptation. Our calculation of the system-recommended font size for automatic adaptations is based on prior research into average user reading behavior patterns and recommendations for comfortable reading font sizes [2, 61]. We define S as the system-recommended font size in iOS point size, H_x as the average reading font size of users reported in prior work (in inches), $R_{xHeight}$ as x-height ratio of the system font size, R_{va} as the visual acuity ratio of reading font size for comfortable reading, based on recommendations of Sheedy and Shaw-McMinn [61], PPI as the device pixel per inch (PPI) specification, R_{ios} as the ratio of standard point size measurement by iOS point size, D_{user} as the user's detected reading distance while walking obtained using the Apple ARKit [33] through the front camera stream, D_{avg} as the average user reading distance reported in prior work [2]:

$$S = \frac{H_x \times R_{va}}{R_{xHeight}} \times \frac{PPI}{R_{ios}} \times \frac{D_{user}}{D_{avg}} \tag{1}$$

The calculated system-recommended font size is approximately 28.8 pt in iOS on a recent iPhone Pro series model when a user is reading at the 32.2 cm average reading distance.

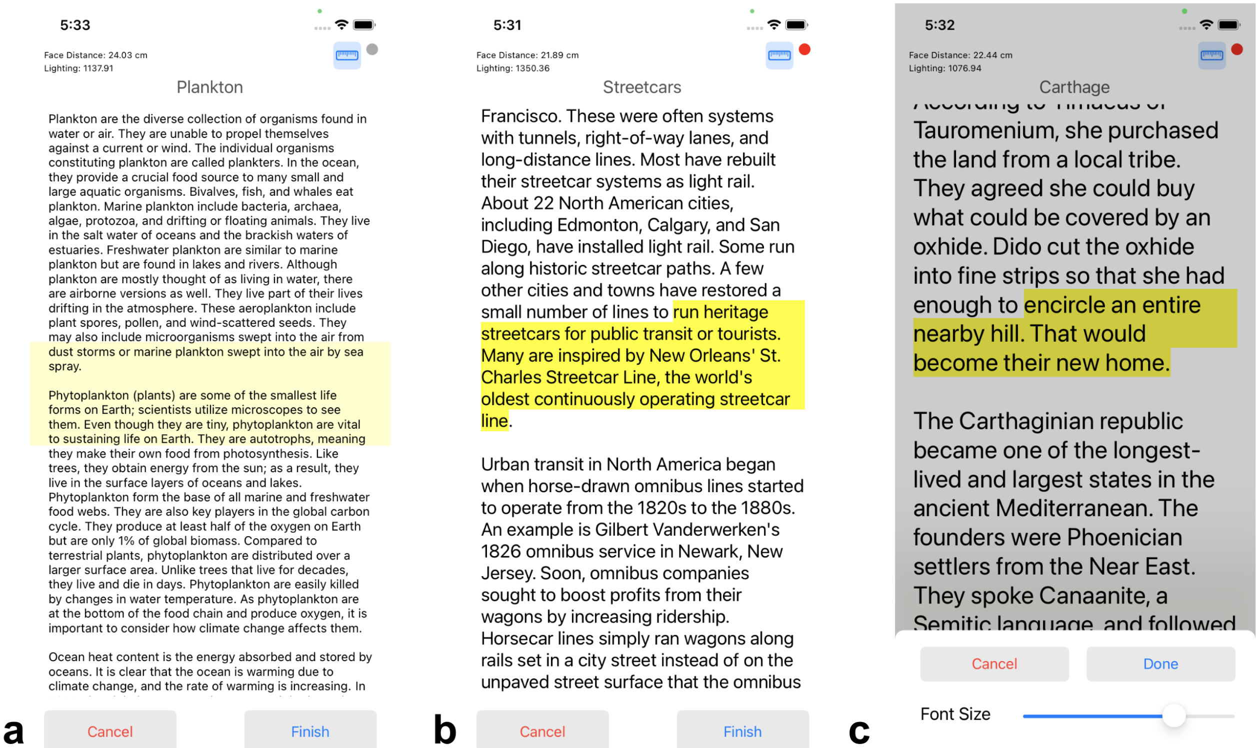

Figure 2: Example screens of the reading app. The top-left corner shows the real-time reading distance and lighting intensity captured. The top-right corner indicates the current posture of the user, gray meaning stationary, red meaning walking. (a) A reading ruler in the middle of the screen highlighting a user's regular reading area, which can be dismissed with a double-tap; (b) Automatic adaptations applied when walking is detected, with the original text in the reading ruler area highlighted and preserved at the same location on the screen; (c) User can also customize font sizes using a slider in the bottom drawer. The reading ruler helps retain the original reading area while the drawer is toggled.

Interface Design for User Customization. Preliminary study results on mobile reading on-the-go [37] also suggest that UI interventions should reduce occlusion of text and favor gestural control over target acquisition like button taps. Based on this finding, we use a pop-up drawer window containing a slider at the bottom of the screen to reduce text occlusion (Figure 2c), and a user can tap anywhere on the screen to dismiss the window.

In both interventions, font size adaptations are only triggered when a user starts or stops walking. The font size then remains unchanged until the next posture transition is detected. Throughout each reading session, our app records:

- **Sensor data on the user activity**, including whether the user is detected to be walking or stationary, raw motion events detected before smoothing, raw accelerometer and gyroscope data, as well as viewing distance and lighting intensity based on the ARKit face tracking and lighting estimate data [33] (not all of which was used for this work);
- **User behavior**, including scrolling events while reading and the font sizes selected;
- **Questionnaire responses** for comprehension questions and subjective ratings.

4 Study Methods

4.1 Terminology

We first clarify the terms used in the rest of this paper. Specifically, we focus on comparing three types of mobile reading interfaces while walking:

- **Automatic**: The interface adapts to walking through *system-determined* font size changes (known as "adaptive" interfaces).
- **Customized**: The interface adapts to walking through *user-specified* font size changes (known as "adaptable" interfaces).
- **Static**: The interface does not change during use.

4.2 Interface Conditions

We compared four different mobile interfaces for reading while walking: *Automatic*, *Customized*, *Static-Small*, *Static-Big*. The two static conditions serve as our baselines for this comparison.

Automatic. This interface applies the iOS default body text font size (14 pt) at the beginning. When a user starts walking, it automatically calculates and changes the font size to a system-recommended font size (Eq. 1). When a user stops walking, it automatically changes the font size back to default.

Figure 3: Participant walking path during a study session. Participants start seated at the corner seat, then walk around the space along a rectangular path. No obstacle is present on the walking path, yet participants need to pay attention to nearby furniture while turning. To ensure enough walking data is collected, participants are instructed to walk for additional laps if they reach the starting position before finishing reading half of the passage. They always return to the same seat and finish reading seated.[1]

Customized. This interface applies the iOS default body text font size (14 pt) at the beginning. When a user starts walking, it displays a slider at the bottom of the screen for the user to specify desired font size for walking (Figure 2c). When a user stops walking, it displays the slider again for the user to update the font size.

Static-Small. This interface applies the iOS default body text font size (14 pt) and provides no adaptations.

Static-Big. This interface applies a system-recommended font size (same as in the *automatic* condition, Eq. 1) throughout the reading and provides no adaptations.

We include two baseline conditions in our comparison: *static-small* represents the "default" reading interface with system-default font sizes, while *static-big* uses the same system-recommended walking font size regardless of the user's posture.

4.3 Participants

We recruited 45 participants from Adobe through internal Slack posting. Participants were on average 30.7 years old (*SD*=6.6), self-reported identifying as 22 women and 23 men. We include the participant demographics in our supplementary materials.

4.4 Apparatus

The mobile reading app we developed for the experiments is an iOS app running on an iPhone 11 Pro Max with iOS version 16.4. The reading passages are from a pool of 14 different carefully leveled Grade 8 passages from the Readability Consortium resources library.[2] Each passage contains 4 paragraphs and 600 words. We also used accompanying comprehension questions from the same library, consisting of one main idea question and four detail questions for each paragraph. All questions are multiple-choice with one correct answer and three confounding options.

4.5 Procedure

We define a *reading session* as the complete process of a user reading one complete 600-word passage. Participants all started their reading session while seated. After they read a few sentences, they could stand up and start walking around the experiment space at their normal walking pace while using mobile devices, while reading the passage, and then sit down to finish the rest of the passage. We asked participants to only start walking after they begin to scroll over the passage, to obtain an accurate measurement of their reading speed. After each article, they were directed to answer a set of subjective rating questions and comprehension questions in the app. After completing four reading sessions corresponding to the four study conditions, they were asked to rank their preferences over the four interfaces and to share the rationale behind their preferences, desired adaptations for reading on-the-go, features they would like beyond existing interventions, and additional comments on the experience if they had any. *Before* and *after* the reading sessions, participants were also asked to specify their preferred font sizes for reading while sitting and while walking (except P01 to P09, P11, and P19, for whom only preferred font sizes *during* the sessions were recorded).

Participants were presented with all four interfaces (except P01 to P07, who only experienced the first three interface conditions). We randomized the order of *automatic* and *customized* conditions, while we kept the *static-small* condition always the first as the baseline, and the *static-big* condition always the last as the it relies on the system-recommended font size calculated during the automatic condition. During each reading session, the passage was randomly

[1] As study sessions ran in three parallel locations, the experiment spaces share similar layouts yet specific positions and numbers of tables and chairs vary.
[2] https://thereadabilityconsortium.org/resources.

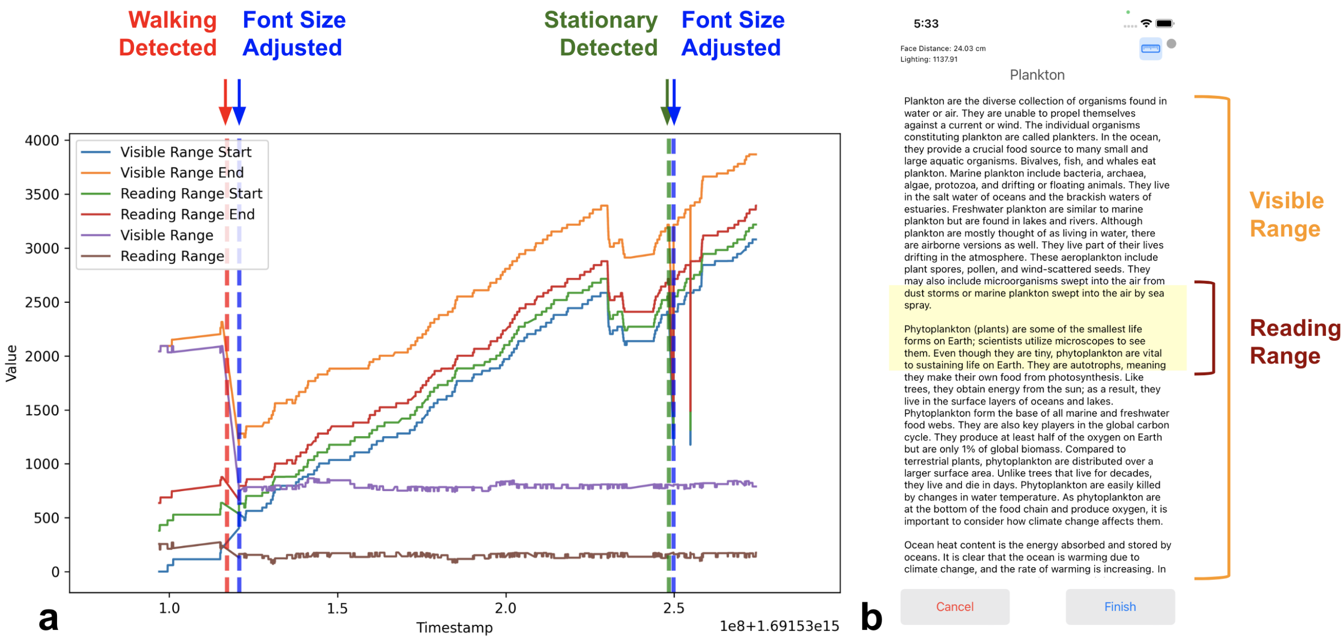

Figure 4: (a) Example plot of scrolling data collected in a single reading session. The x and y axes are the timestamp and indices of reading characters in the text content. The plotted lines indicate the start and end of the visible range of characters displayed on the screen, as well as the range of characters currently inside the reading ruler area. Sudden spikes of the ranges could be due to system auto-scroll to reposition text after adjustments or random user scrolling behavior, and were cleaned up in further calculation through outlier removal. (b) Demonstration of the visible range and reading range on an example screen.

drawn from the pool of passages, and different participants read different passages for each condition.

4.6 Dataset

We collected a dataset containing 173 reading sessions from the 45 participants. We include a summary of anonymized user demographic information and questionnaire responses regarding their usage of mobile phones for reading under different situational impairments in our data set. We also include time of day, location of study, and qualitative descriptions of environment lighting and sources of distraction like environment noise as observed by the experimenter for each session. The dataset is publicly available.[3]

4.7 Design and Analysis

4.7.1 Measurement. We measure the mobile reading experience using four metrics [6, 11, 12, 17, 38, 44, 53, 71]: (1) speed, (2) comprehension, (3) task load, and (4) preference. The first two characterize the performance of reading, while the last two characterize user subjective perception of the experience.

We measure the reading **speed** based on scrolling behavior and record the results in words per minute (WPM) (Figure 4). Specifically, we measure the number of characters a user read while stationary and walking, divided by the total reading time a user spent while sitting (stationary) and walking, respectively. For each reading session, we segment the time intervals for sitting and walking (specifically, we ignore the transition time between the detection of activities to the font size changes being applied), and accumulate the number of characters a user reads during that interval, after applying an outlier removal of scrolling events. We then convert this calculated speed from characters per second (CPS) to words per minute (WPM).[4] In our analyses, we removed outlier data with reading speeds below 50 WPM or above 650 WPM, similar to prior work [15, 16, 49, 71–73]. After outlier removal, there are 300 valid segments (86.7%) from the reading sessions in the data.

We measure the reading **comprehension** using the comprehension questions associated with the passages as discussed in Section 4.4, and measure the correctness of the main idea question and four specific questions.

We measure the reading **task load** using rating questions based on the NASA-TLX [27, 28] questionnaire—physical demand, mental demand, temporal demand, performance, effort, and frustration, each on a Likert scale from 1 to 7. Lower rating values indicate lower physical/mental/temporal demand, better perceived performance, lower effort, and less frustration.

We measure user **preferences** using two metrics: preference of the type of adaptation (the four experiment conditions), and the preferred reading font sizes. We measure user preference over the four conditions through user preference rankings, encoded as six binary values (whether a user prefers condition A over B). We encode preference as binary values, as the rank is not necessarily linearly correlated with user preference. We exclude user data without preferred font sizes *before* or *after* the sessions being recorded while comparing different *phases*. We take the user-customized font sizes while reading and walking as their preferred font sizes.

[3] https://github.com/judykong97/ReadingOnTheGo.

[4] The conversion is done by multiplying the reading speed in CPS by 60 seconds/minute, and then dividing it by an estimate of 5 characters/word.

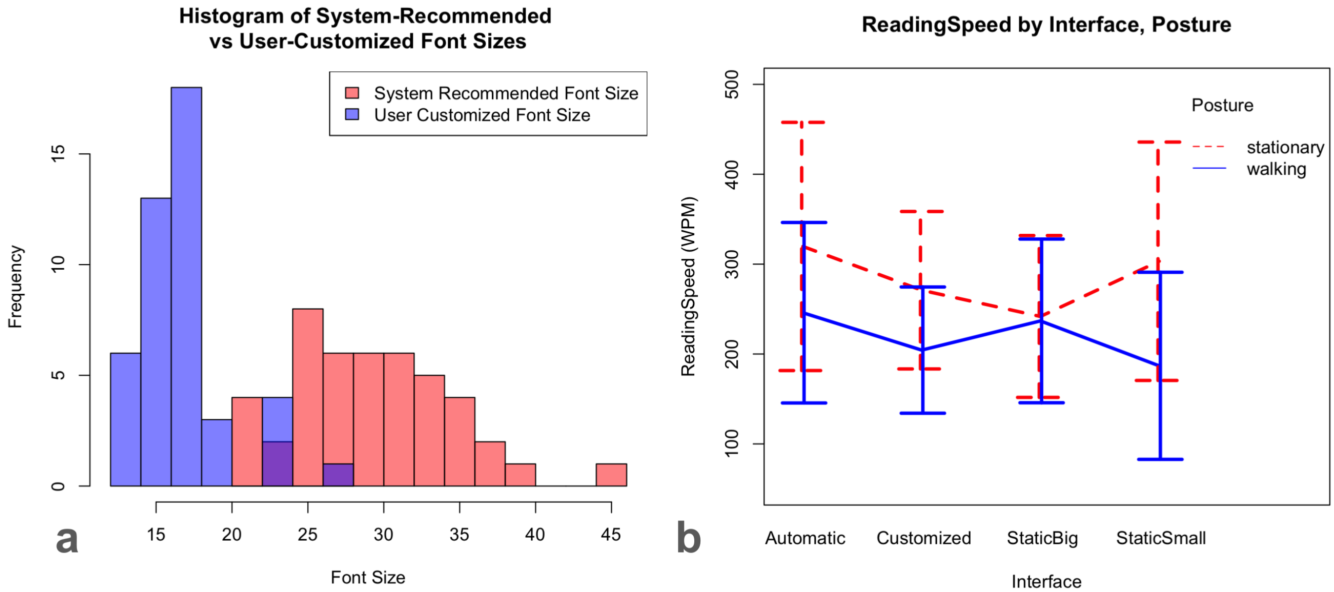

Figure 5: (a) Histogram of system-recommended vs. user-customized font sizes applied during walking in the automatic and customized conditions. Participants tended to choose font sizes closer to the small default size, while the system recommended larger font sizes; (b) Interaction plot showing mean and standard deviation of reading speed while user was stationary and walking for each of the four interface conditions. The *automatic*, *customized*, and *static-small* interfaces all showed reading speed degradation while walking compared to stationary, but such degradation didn't appear for the *static-big* interface.

4.7.2 Analysis Method. We ran a linear mixed model (LMM) [24, 40] to compare the reading speed while sitting and walking under the four interface conditions. We modeled the interaction between interface and posture (sitting or walking) as fixed effects, and subject and article as random effects. We checked for normality through examination of residuals and found the data normally distributed. *Post hoc* pairwise comparisons were corrected with Holm's sequential Bonferroni procedure [31] following a significant omnibus test.

We ran a generalized linear mixed model (GLMM) [9] to compare the binomial correctness of the main idea question and each of the four specific comprehension questions, respectively. We used interface as the fixed effect, and subject and article as random effects. We then ran mixed ordinal logistic regression models [29] to compare the perceived task load ratings. We modeled interface as the fixed effect, and subject and article as random effects. We also used mixed ordinal logistic regression to analyze the preference rankings of interfaces, modeling interface as the fixed effect and subject as a random effect. *Post hoc* pairwise comparisons were corrected with Holm's sequential Bonferroni procedure [31] following significant omnibus tests.

Finally, we ran an LMM [24, 40] to compare user preferred font sizes at different times of the adaptations, using phase (*before*, *during*, and *after*) as the fixed effect and subject as a random effect. We checked for normality through examination of residuals and found the data normally distributed. *Post hoc* pairwise comparisons were corrected with Holm's sequential Bonferroni procedure [31] following a significant omnibus test.

The LMMs and GLMMs were implemented in R's `lme4` package and the ordinal logistic regression models were implemented in R's `ordinal` package. All *post hoc* pairwise comparisons were implemented in R's `emmeans` package.

5 Results

5.1 Summary of Data

Reading sessions lasted 208.0 seconds (SD=62.6) on average. Users spent an average of 71.4 seconds (SD=21.9) reading while walking, and 130.9 seconds (SD=58.5) reading while stationary. The overall average reading speeds while walking and stationary were 218.8 WPM (SD=94.8) and 286.1 WPM (SD=118.4), respectively. During the sessions, the average font size *recommended by the system* across users while walking was 29.7 pt (SD=5.4), and the average font size *customized by users* while walking was 17.4 pt (SD=3.1).

5.2 Speed

We report means and standard deviations of walking and stationary reading speeds under the four conditions in Figure 5 and Table 1. Overall, we found significant main effects of interface condition ($F_{3,221} = 5.71, p < .01$) and posture ($F_{1,238} = 47.63, p < .01$), and a significant interaction effect between interface condition and posture ($F_{3,238} = 5.46, p < .01$).

Table 1: Means and standard deviations of walking and stationary reading speeds under the four conditions.

	Reading Speed Walking (WPM)		Reading Speed Stationary (WPM)	
	M	SD	M	SD
Automatic	245.9	100.4	319.7	138.1
Customized	204.4	70.2	271.0	87.6
Static-Small	186.9	104.1	303.2	132.6
Static-Big	236.8	91.1	241.8	90.0

Table 2: Mean and standard deviation values of the task load ratings for the four conditions.

	Physical Demand		Mental Demand		Temporal Demand		Performance		Effort		Frustration	
	M	**SD**	**M**	**SD**	**M**	**SD**	**M**	**SD**	**M**	**SD**	**M**	**SD**
Automatic	3.1	1.2	3.1	1.2	3.3	1.3	3.8	1.5	3.5	1.5	3.4	1.4
Customized	3.2	1.1	3.8	1.3	3.4	1.3	3.8	1.3	4.0	1.5	3.2	1.4
Static-Small	3.5	1.5	4.3	1.3	4.1	1.3	4.2	1.3	4.6	1.3	3.7	1.4
Static-Big	2.6	1.2	3.0	1.4	2.9	1.3	3.2	1.2	2.9	1.4	2.6	1.4

Table 3: z-statistics for all significant differences between the conditions for the task load ratings. Significance indicators: $^{*}p < .05$, $^{**}p < .01$, $^{***}p < .001$.

	Physical Demand	Mental Demand	Temporal Demand	Performance	Effort	Frustration
Automatic-Customized	–	–	–	–	-2.03 *	–
Automatic-StaticBig	2.71 *	2.69 *	–	–	2.34 *	2.90 *
Automatic-StaticSmall	–	-2.73 *	-4.56 ***	–	-4.44 ***	–
Customized-StaticBig	3.16 **	3.40 **	–	–	4.10 ***	2.53 *
Customized-StaticSmall	–	–	-4.07 ***	–	-2.74 *	–
StaticBig-StaticSmall	-3.84 ***	-4.96 ***	-5.47 ***	-4.06 ***	-6.00 ***	-4.02 ***

Walking leads to slower reading speed, but not for larger fonts. We found that there is significant reading speed degradation while walking compared to stationary for the *static-small* ($t_{238} = 6.12, p < .01$), *automatic* ($t_{238} = 4.13, p < .01$), and *customized* ($t_{238} = 3.55, p = .01$) interfaces. In contrast, the *static-big* interface did not show such reading speed degradation ($t_{238} = 0.25, p = .81$).

Bigger font sizes improve reading speed while walking. Comparing the reading speed while walking across the four interface conditions, we found that bigger font sizes automatically calculated from user viewing distance either significantly (in the *automatic* interface, $t_{251} = 3.35, p < .01$) or marginally (in the *static-big* interface, $t_{250} = 2.54, p = 0.06$) improved reading speed on the walk compared to smaller font sizes (in the *static-small* interface).

Increasing font sizes yield larger gains in reading speed for walking compared to stationary. Comparing the reading speed under larger font sizes (in the *static-big* interface) versus smaller font sizes (in the *static-small* interface), we found that increasing the font size while walking resulted in a 21.1% average reading speed improvement ($t_{250} = 2.54, p = .01$); in contrast, increasing the font size while stationary even made reading a little slower, resulting in a 20.3% average degradation ($t_{250} = -3.02, p < .01$).

5.3 Comprehension

Comprehension is unaffected by walking adaptations. Overall, the average correctness rates of the main idea comprehension question were 60.0% ($SD = 49.5$), 57.8% ($SD = 49.9$), 53.3% ($SD = 50.5$), 60.5% ($SD = 49.5$), respectively for the *automatic*, *customized*, *static-small*, and *static-big* conditions. We found no significant main effect of *interface* on the main idea correctness ($\chi^2_3 = 0.58, p = .90$). We also found no significant main effect of *interface* on the correctness of the four detailed comprehension questions corresponding to the first ($\chi^2_3 = 1.09, p = .78$), second ($\chi^2_3 = 2.83, p = .42$), third ($\chi^2_3 = 3.76, p = .29$), and fourth ($\chi^2_3 = 3.67, p = .30$) paragraph.

5.4 Task Load

Font size adaptations during walking reduce perceived reading task load. We report the means and standard deviations of all six task load ratings for each of the four interface conditions in Table 2. We found a significant main effect of *interface* on all six task load ratings—physical demand ($\chi^2_3 = 16.70, p < .01$), mental demand ($\chi^2_3 = 27.03, p < .01$), temporal demand ($\chi^2_3 = 37.91, p < .01$), performance ($\chi^2_3 = 17.20, p < .01$), effort ($\chi^2_3 = 43.88, p < .01$), frustration ($\chi^2_3 = 18.57, p < .01$).

All significant and marginal *post hoc* pair-wise comparison results were reported in Table 3. The *static-big* interface was rated to have lower physical and mental demand, require lower effort, and cause less frustration compared to all other interfaces. Both the *automatic* and *customized* interfaces were rated to have lower temporal demand and require lower effort compared to the *static-small* interface. Additionally, the *automatic* interface was rated to require lower effort than the *customized* interface, and have lower mental demand compared to the *static-small* interface.

5.5 Preference

Customized and static-big interfaces are overall more preferred than automatic and static-small interfaces. We found that participants preferred the *customized* and *static-big* interfaces over the *automatic* and *static-small* interfaces. Specifically, participants preferred the *customized* interface over the *automatic* ($z = 3.36, p < .01$) and *static-small* ($z = -4.85, p < .01$) interfaces, and preferred the *static-big* interface over the *automatic* ($z = 3.10, p < .01$) and *static-small* ($z = -4.49, p < .01$) interfaces.

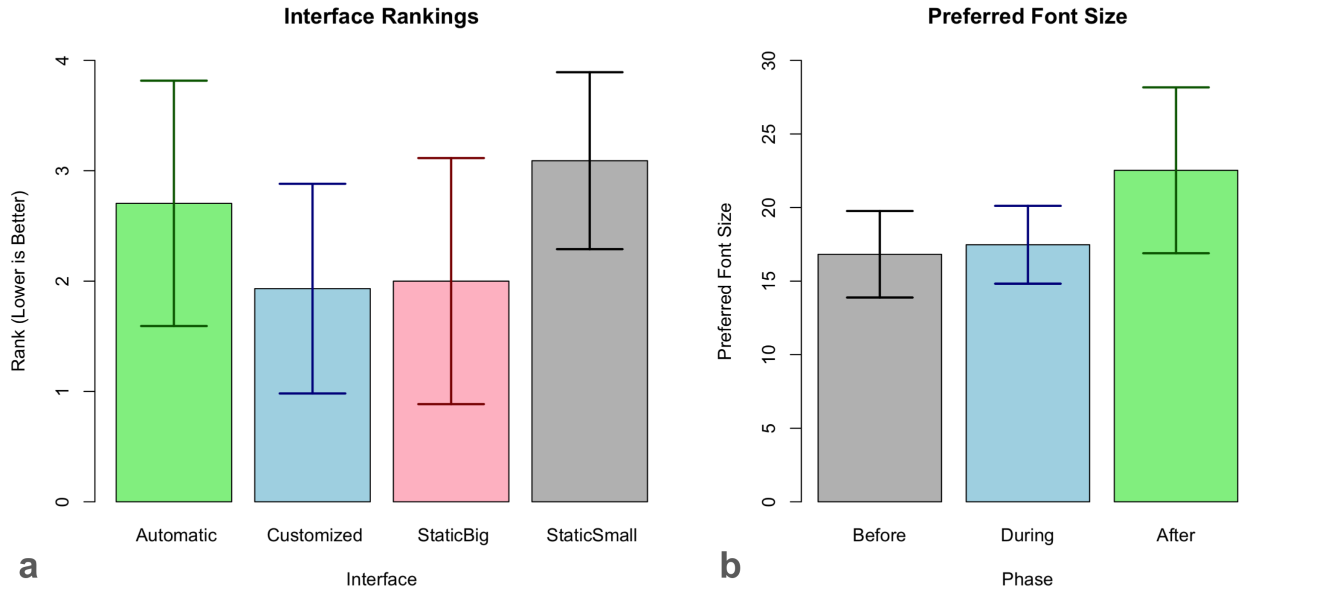

Figure 6: Preferences for reading font sizes while walking, specified by participants *before*, *during*, and *after* reading sessions. Participants were asked to specify their preferred font size for walking at the beginning of the session, i.e., before they were presented with the system-recommended font sizes; participants were then prompted by the app to specify their preferred font sizes *in-the-moment*, i.e., during the *customized* condition when they started walking; finally, at the end of each session, participants were again asked to specify their preferred font size for walking *after* they were done with all the reading sessions and had been presented with both system-recommended font size adaptations and their customized font sizes.

There is no difference in preferences between *automatic* and *static-small* ($z = -1.52, p = .26$), or between *customized* and *static-big* ($z = -0.04, p = .97$).

Divergence of preferences over adaptations and font sizes still exist despite the overall trend. While there is a general trend favoring customized over automatic adaptations, individual preferences vary and there is no one design for all. The average user-specified font size during customization while walking was 17.4 pt (SD=3.1); compare this to the default (static-small) font size of 14 pt. Seven participants ranked the *automatic* condition most preferred among all four options, as it was "helpful" (P18) and "convenient" (P20); 18 participants ranked the *customized* condition most preferred, often as they could "have the option to choose" (P30) and thus "be in control" (P45). In regard to preferences over font sizes, one participant mentioned that they particularly preferred smaller font sizes as they "provide more context" (P13) and there was fewer scrolling "back and forth" (P13). Three participants particularly preferred larger font sizes as they were "easier to read" (P20) or because they had visual conditions resulting in difficulty when reading small text.

Users preferred font sizes increase after they are presented with larger font sizes during reading. Comparing font size preferences across different *phases*, preferred font size for walking specified by participants was on average 16.8 pt (SD=2.9) *before* the reading session, 17.5 pt (SD=2.6) *during* the reading session, and 22.5 pt (SD=5.6) *after* the reading session. There is a significant main effect of *phase* on the preferred font size ($F_{2,66} = 40.65, p < .01$).

Post hoc pairwise comparisons suggest that user preferred font sizes *after* the reading increased compared to what they set *before* ($t_{66} = 8.23, p < .01$) and *during* ($t_{66} = 7.30, p < .01$) the reading, respectively by 33.9% and 29.0%. Six participants explicitly mentioned that their preferred font size "got bigger" (P18) or that they found "bigger font sizes actually worked better" (P27) after they were presented with the system recommendations, even mentioning that they "should have read at this font before" (P20) as it was "so comfortable" (P20).

5.6 Additional Customization Options Participants Requested

Aside from having varying attitudes towards the interventions, participants also shared additional customization options they desired (Table 4). These options cover how the app responds to change of posture, whether the app directly applies or recommends font sizes, text and interface settings, and format of control.

6 Discussion

6.1 Findings

In this section, we summarize a few main takeaways from our analysis results around mobile reading while walking.

Automatic font size adjustment by viewing distance can mitigate reading performance degradation while walking. When reading using the same default small font size, there was a significant reading speed degradation when a user was walking, while this effect was mitigated with the larger font size calculated by the *automatic* interface. Our results provide new insight into the effectiveness of font size increments on reading speed—previously, Schildbach and Rukzio [59] found that larger text sizes did not yield

Table 4: Additional customization options requested by participants.

Category	Customization Option (Count)
How the app responds to change of posture	No prompts at all (2), persistent customization prompts (3), option to enable or disable prompts (1), automatic disappearance of prompts after timeout (1)
Whether the app directly applies or recommends font sizes	Automatically apply a font size then allow the user to further adjust (6), recommend a font size and let the user confirm (4)
Text settings	Text and background color (9) such as dark mode, line and character spacing (4), font family (1), text formatting (1) such as bold and italic
Interface settings	Reading ruler appearance and position (6), adaptive screen brightness (4), display of sensor stats (1), success message after reading (1)
Format of control	Font size manipulations (9) such as tapping, zooming in/out, buttons, arrows, reading ruler manipulations (5) such as tapping and dragging, reading navigation (3) such as page flipping

faster mobile reading speeds because of the additional scrolling required on phone screens; notably, we arrived at a different conclusion, possibly due to the additional burden of reading with small fonts under a situational impairment, i.e., while walking.

Better reading speed and comfort are not necessarily associated with preference over adaptations. In our analyses, we found that reading with the *automatic* adaptations were rated to require less effort than the *customized* one. Additionally, the *automatic* adaptations also yielded higher reading speed while walking. However, participants overall still preferred the *customized* adaptations which required more time and effort to read, suggesting that their preference may be heavily influenced by other factors, such as the sense of agency. The degree of interruption they felt could also influence their preference—despite our attempted mitigations to assist with reading resumption (implemented using a reading ruler experience), the *static-big* condition using the same font size for walking was overall more preferred by participants. This points to future work in designing more seamless transitions.

User customization choices of font sizes is influenced by awareness and exposure to recommendations. When we compared users' preferred font sizes for walking *before*, *during*, and *after* the reading sessions, we found that users' preferred font sizes (1) became larger after the reading sessions, and (2) changed after they were presented with the often larger system-recommended sizes. We hypothesize users were either unaware of the benefits of larger fonts, or simply felt unmotivated to switch to unfamiliar reading settings. This is corroborated by participants' reflections that they "became more conscious" (P32) of the effects of font sizes on reading and found that larger fonts actually worked better, admitting they "underestimate[d] the size [they] wanted" (P12), sometimes even reflecting on the fact that they "hated big font sizes" (P42) at the beginning of the study. Additionally, customizing text settings *ad hoc* during situational impairments can be challenging, and participants sometimes felt overwhelmed with making such adjustments when reading while walking, as there were already "so many things going on" (P43), further suggesting the need for recommendations beyond purely manual and user-initiated adaptations.

In prior research, end user customization and controllability are often demanded and preferred, yet customization options often remain unused in practice [14, 19, 54]. The lack of "awareness" prevails in adaptable systems [19–22, 67]—users are often unaware of what they can customize and the tangible benefits such adaptations can have. Our finding aligns with prior work and further suggests the need for reading adaptation recommendations, which can help address this "awareness" gap with customization.

6.2 Design Implications

Nowadays, few human-computer interfaces are purely automatic or customized, as most are mixed-initiative. In this work, we strictly separate the conditions to understand the effect of each, yet our findings point to better design of mixed-initiative interfaces combining system automatic and user customized adaptations to situational impairments such as walking.

Blending system recommendation with user customization. Although participants more frequently preferred the customized approach, perhaps due to the preserved sense of agency, automatic font size adjustments yielded better reading speed and comfort, and can further influence user customization behavior and awareness of adaptable settings. Future reading adaptations should blend these two approaches, yet aim for smoother transitions during the interface adaptations for minimum interruption.

Multiple points of customization during the adaptation process to situational impairments. Based on the additional customization options participants requested (Section 5.6), we identify five areas of customization to consider for reading adaptations while walking:

- Customizing whether or not to **respond to** walking or **initiate** any adaptation;
- Customizing whether or not to **recommend** a font size at the beginning of user customization;
- Customizing whether or not to **directly apply** system-recommended font size for walking;

- Customizing the **text settings** and **interface settings** for reading while walking;
- Customizing the **format of control** to manipulate text and interface settings (e.g. sliders, buttons, pinch and zoom, other gestural control).

While we discuss these five areas of customization within our specific context of reading while walking, they can potentially be generalized to other situational impairments in the future.

Choosing when to prompt for customization, presenting users with recommendations, and learning user preferences over time to refine recommendations. In our study, even the same user action of adjusting font sizes with a slider can vary over time. This reflects the dynamic nature of user preferences, e.g., when exposed to alternative font sizes, which might help users move towards settings that work best for them. Thus, we recommend carefully choosing when to prompt for customization, presenting users with recommendations before offering options for customization, and observing user customization behavior over time to adapt to changing preferences, thus iteratively improving recommendations to be more personalized over time.

6.3 Concerns and Ethics of Reading while Walking

Admittedly, reading while walking can be dangerous [47]. For better safety, everyone should simply stop looking at the phone and attend to the surrounding environment while walking. However, in reality, people will always read on-the-go, whether they *must* or *decide to*, for example, check notes while running to a meeting, or refer to the agenda while navigating an event venue. Similar to prior work that investigated reading while walking [46, 70] or in vehicles [58], our goal is to make this experience safer and more comfortable. Meanwhile, future applications should consider detecting and handling cases where reading becomes highly risky, for example, when users are at a busy crossroad.

In this work, we use walking as an instantiation of a "situational impairment" [35, 60, 75]—one that allows us to easily control experiment conditions. Our findings can potentially be meaningful for other situational impairments that cause similar degradation in abilities but are harder to investigate, for example, reading while on a bus or sitting in the passenger seat—in which case, reading would be much safer.

6.4 Limitations and Future Work

In our study, we only investigated adaptations of one single text setting, the font size, and assumed walking dynamics to be similar between participants. Future work can investigate other text setting adaptations and incorporate different walking patterns and behaviors. This work also focuses on analyzing reading behavior associated with detected walking, yet we did not make use of the full set of sensor data captured such as lighting conditions, nor did we measure specific walking metrics such as walking speed or gait patterns. The effect of these parameters is ripe for future work.

Our calculation of reading speeds may be biased towards smaller differences between stationary and walking due to the short delay in walking detection. Our calculation also assumed that the user was reading within the the reading ruler area, which might introduce random errors even with our outlier removal. Additionally, scrolling behavior approximates but does not precisely measure the reading speed. Future work may integrate gaze tracking as a more accurate measurement of reading attention.

During the study sessions, we intentionally chose an indoor experiment environment with minimal distraction to analyze the effect of walking in isolation, yet in reality, there are usually more complex forms of situational impairments interacting with each other [42, 59], resulting in potentially different desired interventions from this study. For example, a user might walk across a crowded street, trying to navigate and read under high noise levels. Future work might leverage the interactions of these different situational impairments. Due to the limitations of recruiting, our participant age group was not very diverse and was heavily biased towards young working professionals. While we aimed to keep reading difficulty consistent using passages of the same grade level, participants still found some passages easier to read than others, for example, due to prior knowledge or interest in particular topics. Additionally, we evaluated reading on a small set of carefully-leveled ready passages to measure comprehension, yet these passages might not reflect the common materials read on-the-go in daily life, such as text messages, emails or social media. In the future, we might also deploy the app and collect more naturalistic reading data through field studies to understand reading while walking in the real world.

7 Conclusion

Walking can significantly influence our abilities to read on mobile devices. In this work, we conducted a controlled lab study with 45 participants to quantitatively measure the effect of walking on mobile reading, and compared automatic versus customized adaptations for reading while walking. We developed a mobile reading app that detects walking, calculates and applies a system-recommended font size based on viewing distance detected during walking, and alternatively prompts users to customize font sizes through a drawer window that pops up when walking is detected. We collected a data set including 173 reading sessions of participants reading passages while both sitting and walking. We also recorded user interaction behavior and sensor data about their situated abilities during the reading sessions. In our analyses, we used four metrics to evaluate the reading experience—speed, comprehension, task load, and preference. We found that walking slows down one's reading speed, but automatic font size adjustments by viewing distance can mitigate reading performance degradation associated with walking. We also found such automatic adaptations lowered the required effort during reading, even though this improvement in speed and task load did not correlate with user preference—instead participants overall preferred the customized adaptations over automatic ones. Furthermore, we found that exposure to the automatic adaptation influences user customization behavior and preferences over font sizes for walking. Our findings suggest that future interventions for mobile reading while walking should blend system recommendation with user customization, leave options open for multiple points of customization throughout the process, choose appropriate timings to prompt for user customization, and observe and learn user preferences over time to refine recommendations.

References

[1] Christopher Ahlberg and Ben Shneiderman. 1994. Visual Information Seeking: Tight Coupling of Dynamic Query Filters with Starfield Displays. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*. ACM, Boston Massachusetts USA, 313–317. doi:10.1145/191666.191775

[2] Yuliya Bababekova, Mark Rosenfield, Jennifer E. Hue, and Rae R. Huang. 2011. Font Size and Viewing Distance of Handheld Smart Phones. *Optometry and Vision Science* 88, 7 (July 2011), 795. doi:10.1097/OPX.0b013e3182198792

[3] Jayeeta Banerjee, Deepti Majumdar, Madhu Sudan Pal, and Dhurjati Majumdar. 2011. Readability, Subjective Preference and Mental Workload Studies on Young Indian Adults for Selection of Optimum Font Type and Size during Onscreen Reading. *Al Ameen Journal of Medical Sciences* 4, 2 (2011), 131–143.

[4] Sofie Beier. 2009. *Typeface Legibility: Towards Defining Familiarity.* Royal College of Art (United Kingdom).

[5] Sofie Beier and Kevin Larson. 2013. How Does Typeface Familiarity Affect Reading Performance and Reader Preference? *Information Design Journal* 20, 1 (2013), 16–31.

[6] Michael Bernard, Bonnie Lida, Shannon Riley, Telia Hackler, and Karen Janzen. 2002. A Comparison of Popular Online Fonts: Which Size and Type Is Best. *Usability news* 4, 1 (2002), 2002.

[7] David Beymer, Peter Z. Orton, and Daniel M. Russell. 2007. An Eye Tracking Study of How Pictures Influence Online Reading. In *Human-Computer Interaction – INTERACT 2007*, Cécilia Baranauskas, Philippe Palanque, Julio Abascal, and Simone Diniz Junqueira Barbosa (Eds.). Springer, Berlin, Heidelberg, 456–460. doi:10.1007/978-3-540-74800-7_41

[8] Sanjiv K Bhatia, Ashok Samal, Nithin Rajan, and Marc T Kiviniemi. 2011. Effect of Font Size, Italics, and Colour Count on Web Usability. *International journal of computational vision and robotics* 2, 2 (2011), 156–179.

[9] Benjamin M. Bolker, Mollie E. Brooks, Connie J. Clark, Shane W. Geange, John R. Poulsen, M. Henry H. Stevens, and Jada-Simone S. White. 2009. Generalized Linear Mixed Models: A Practical Guide for Ecology and Evolution. *Trends in Ecology & Evolution* 24, 3 (March 2009), 127–135. doi:10.1016/j.tree.2008.10.008

[10] Dan Boyarski, Christine Neuwirth, Jodi Forlizzi, and Susan Harkness Regli. 1998. A Study of Fonts Designed for Screen Display. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems - CHI '98*. ACM Press, Los Angeles, California, United States, 87–94. doi:10.1145/274644.274658

[11] Tianyuan Cai, Aleena Gertrudes Niklaus, Bernard Kerr, Michael Kraley, and Zoya Bylinskii. 2024. COR Themes for Readability from Iterative Feedback. In *Proceedings of the 2024 CHI Conference on Human Factors in Computing Systems (CHI '24)*. Association for Computing Machinery, New York, NY, USA, 1–23. doi:10.1145/3613904.3642108

[12] Tianyuan Cai, Shaun Wallace, Tina Rezvanian, Jonathan Dobres, Bernard Kerr, Samuel Berlow, Jeff Huang, Ben D. Sawyer, and Zoya Bylinskii. 2022. Personalized Font Recommendations: Combining ML and Typographic Guidelines to Optimize Readability. In *Proceedings of the 2022 ACM Designing Interactive Systems Conference (DIS '22)*. Association for Computing Machinery, New York, NY, USA, 1–25. doi:10.1145/3532106.3533457

[13] Aurélie Calabrese, Allen MY Cheong, Sing-Hang Cheung, Yingchen He, MiYoung Kwon, J Stephen Mansfield, Ahalya Subramanian, Deyue Yu, and Gordon E Legge. 2016. Baseline MNREAD Measures for Normally Sighted Subjects from Childhood to Old Age. *Investigative ophthalmology & visual science* 57, 8 (2016), 3836–3843.

[14] Ana Caraban, Evangelos Karapanos, Daniel Gonçalves, and Pedro Campos. 2019. 23 Ways to Nudge: A Review of Technology-Mediated Nudging in Human-Computer Interaction. In *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems (CHI '19)*. Association for Computing Machinery, New York, NY, USA, 1–15. doi:10.1145/3290605.3300733

[15] Ronald P Carver. 1990. *Reading Rate: A Review of Research and Theory.* Academic Press.

[16] Ronald P. Carver. 1992. Reading Rate: Theory, Research, and Practical Implications. *Journal of Reading* 36, 2 (1992), 84–95. jstor:40016440 https://www.jstor.org/stable/40016440

[17] Maneerut Chatrangsan and Helen Petrie. 2019. The Effect of Typeface and Font Size on Reading Text on a Tablet Computer for Older and Younger People. In *Proceedings of the 16th International Web for All Conference (W4A '19)*. Association for Computing Machinery, New York, NY, USA, 1–10. doi:10.1145/3315002.3317568

[18] Jessica Conradi. 2017. Influence of Letter Size on Word Reading Performance during Walking. In *Proceedings of the 19th International Conference on Human-Computer Interaction with Mobile Devices and Services (MobileHCI '17)*. Association for Computing Machinery, New York, NY, USA, 1–9. doi:10.1145/3098279.3098554

[19] Leah Findlater and Joanna McGrenere. 2004. A Comparison of Static, Adaptive, and Adaptable Menus. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*. 89–96.

[20] Leah Findlater and Joanna McGrenere. 2007. Evaluating Reduced-Functionality Interfaces According to Feature Findability and Awareness. In *Human-Computer Interaction – INTERACT 2007*, Cécilia Baranauskas, Philippe Palanque, Julio Abascal, and Simone Diniz Junqueira Barbosa (Eds.). Springer, Berlin, Heidelberg, 592–605. doi:10.1007/978-3-540-74796-3_59

[21] Leah Findlater and Joanna McGrenere. 2008. Impact of Screen Size on Performance, Awareness, and User Satisfaction with Adaptive Graphical User Interfaces. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '08)*. Association for Computing Machinery, New York, NY, USA, 1247–1256. doi:10.1145/1357054.1357249

[22] Leah Findlater and Joanna McGrenere. 2010. Beyond Performance: Feature Awareness in Personalized Interfaces. *International Journal of Human-Computer Studies* 68, 3 (March 2010), 121–137. doi:10.1016/j.ijhcs.2009.10.002

[23] Leah Findlater, Karyn Moffatt, Joanna McGrenere, and Jessica Dawson. 2009. Ephemeral Adaptation: The Use of Gradual Onset to Improve Menu Selection Performance. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '09)*. Association for Computing Machinery, New York, NY, USA, 1655–1664. doi:10.1145/1518701.1518956

[24] Brigitte N Frederick. 1999. Fixed-, Random-, and Mixed-Effects ANOVA Models: A User-Friendly Guide for Increasing the Generalizability of ANOVA Results. (1999).

[25] Mayank Goel, Leah Findlater, and Jacob Wobbrock. 2012. WalkType: Using Accelerometer Data to Accomodate Situational Impairments in Mobile Touch Screen Text Entry. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '12)*. Association for Computing Machinery, New York, NY, USA, 2687–2696. doi:10.1145/2207676.2208662

[26] Mayank Goel, Alex Jansen, Travis Mandel, Shwetak N. Patel, and Jacob O. Wobbrock. 2013. ContextType: Using Hand Posture Information to Improve Mobile Touch Screen Text Entry. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '13)*. Association for Computing Machinery, New York, NY, USA, 2795–2798. doi:10.1145/2470654.2481386

[27] Sandra G. Hart. 2006. Nasa-Task Load Index (NASA-TLX); 20 Years Later. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting* 50, 9 (Oct. 2006), 904–908. doi:10.1177/154193120605000909

[28] Sandra G. Hart and Lowell E. Staveland. 1988. Development of NASA-TLX (Task Load Index): Results of Empirical and Theoretical Research. In *Advances in Psychology*, Peter A. Hancock and Najmedin Meshkati (Eds.). Human Mental Workload, Vol. 52. North-Holland, 139–183. doi:10.1016/S0166-4115(08)62386-9

[29] Donald Hedeker and Robert D. Gibbons. 1994. A Random-Effects Ordinal Regression Model for Multilevel Analysis. *Biometrics* 50, 4 (1994), 933–944. doi:10.2307/2533433 jstor:2533433

[30] Juan David Hincapié-Ramos and Pourang Irani. 2013. CrashAlert: Enhancing Peripheral Alertness for Eyes-Busy Mobile Interaction While Walking. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '13)*. Association for Computing Machinery, New York, NY, USA, 3385–3388. doi:10.1145/2470654.2466463

[31] Sture Holm. 1979. A Simple Sequentially Rejective Multiple Test Procedure. *Scandinavian Journal of Statistics* 6, 2 (1979), 65–70. jstor:4615733 https://www.jstor.org/stable/4615733

[32] Eric Horvitz. 1999. Principles of Mixed-Initiative User Interfaces. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '99)*. Association for Computing Machinery, New York, NY, USA, 159–166. doi:10.1145/302979.303030

[33] Apple Inc. 2023. ARKit. https://developer.apple.com/documentation/arkit

[34] Apple Inc. 2023. Core Motion. https://developer.apple.com/documentation/coremotion

[35] Shaun K. Kane, Jacob O. Wobbrock, and Ian E. Smith. 2008. Getting off the Treadmill: Evaluating Walking User Interfaces for Mobile Devices in Public Spaces. In *Proceedings of the 10th International Conference on Human Computer Interaction with Mobile Devices and Services (MobileHCI '08)*. Association for Computing Machinery, New York, NY, USA, 109–118. doi:10.1145/1409240.1409253

[36] Taslim Arefin Khan, Dongwook Yoon, and Joanna McGrenere. 2020. Designing an Eyes-Reduced Document Skimming App for Situational Impairments. In *Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems (CHI '20)*. Association for Computing Machinery, New York, NY, USA, 1–14. doi:10.1145/3313831.3376641

[37] Junhan Kong, Tianyuan Cai, and Zoya Bylinskii. 2023. Improving Mobile Reading Experiences While Walking Through Automatic Adaptations and Prompted Customization. In *Adjunct Proceedings of the 36th Annual ACM Symposium on User Interface Software and Technology (UIST '23 Adjunct)*. Association for Computing Machinery, New York, NY, USA, 1–3. doi:10.1145/3586182.3616666

[38] Tugba Kulahcioglu and Gerard de Melo. 2021. Semantics-Aware Typographical Choices via Affective Associations. *Language Resources and Evaluation* 55, 1 (March 2021), 105–126. doi:10.1007/s10579-020-09499-0

[39] Henry Lieberman et al. 1995. Letizia: An Agent That Assists Web Browsing. *IJCAI (1)* 1995 (1995), 924–929.

[40] R. C. Littell, P. R. Henry, and C. B. Ammerman. 1998. Statistical Analysis of Repeated Measures Data Using SAS Procedures. *Journal of Animal Science* 76, 4 (April 1998), 1216–1231. doi:10.2527/1998.7641216x

[41] Pattie Maes. 1995. *Agents That* Reduce Work and Information Overload. In *Readings in Human–Computer Interaction*, RONALD M. Baecker, JONATHAN Grudin, WILLIAM A. S. Buxton, and SAUL Greenberg (Eds.). Morgan Kaufmann, 811–821. doi:10.1016/B978-0-08-051574-8.50084-4

[42] Alexander Mariakakis, Mayank Goel, Md Tanvir Islam Aumi, Shwetak N. Patel, and Jacob O. Wobbrock. 2015. SwitchBack: Using Focus and Saccade Tracking to Guide Users' Attention for Mobile Task Resumption. In *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems (CHI '15)*. Association for Computing Machinery, New York, NY, USA, 2953–2962. doi:10.1145/2702123.2702539

[43] Alex Mariakakis, Sayna Parsi, Shwetak N. Patel, and Jacob O. Wobbrock. 2018. Drunk User Interfaces: Determining Blood Alcohol Level through Everyday Smartphone Tasks. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems (CHI '18)*. Association for Computing Machinery, New York, NY, USA, 1–13. doi:10.1145/3173574.3173808

[44] Gail McKoon and Roger Ratcliff. 2016. Adults with Poor Reading Skills: How Lexical Knowledge Interacts with Scores on Standardized Reading Comprehension Tests. *Cognition* 146 (Jan. 2016), 453–469. doi:10.1016/j.cognition.2015.10.009

[45] Martez E. Mott and Jacob O. Wobbrock. 2019. Cluster Touch: Improving Touch Accuracy on Smartphones for People with Motor and Situational Impairments. In *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems (CHI '19)*. Association for Computing Machinery, New York, NY, USA, 1–14. doi:10.1145/3290605.3300257

[46] Terhi Mustonen, Maria Olkkonen, and Jukka Hakkinen. 2004. Examining Mobile Phone Text Legibility While Walking. In *CHI '04 Extended Abstracts on Human Factors in Computing Systems (CHI EA '04)*. Association for Computing Machinery, New York, NY, USA, 1243–1246. doi:10.1145/985921.986034

[47] Judith Mwakalonge, Saidi Siuhi, and Jamario White. 2015. Distracted Walking: Examining the Extent to Pedestrian Safety Problems. *Journal of Traffic and Transportation Engineering (English Edition)* 2, 5 (Oct. 2015), 327–337. doi:10.1016/j.jtte.2015.08.004

[48] Maia Naftali and Leah Findlater. 2014. Accessibility in Context: Understanding the Truly Mobile Experience of Smartphone Users with Motor Impairments. In *Proceedings of the 16th International ACM SIGACCESS Conference on Computers & Accessibility (ASSETS '14)*. Association for Computing Machinery, New York, NY, USA, 209–216. doi:10.1145/2661334.2661372

[49] Aleena Gertrudes Niklaus, Tianyuan Cai, Zoya Bylinskii, and Shaun Wallace. 2023. Digital Reading Rulers: Evaluating Inclusively Designed Rulers for Readers With Dyslexia and Without. In *Proceedings of the 2023 CHI Conference on Human Factors in Computing Systems (CHI '23)*. Association for Computing Machinery, New York, NY, USA, 1–17. doi:10.1145/3544548.3581367

[50] Antti Oulasvirta, Sakari Tamminen, Virpi Roto, and Jaana Kuorelahti. 2005. Interaction in 4-Second Bursts: The Fragmented Nature of Attentional Resources in Mobile HCI. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '05)*. Association for Computing Machinery, New York, NY, USA, 919–928. doi:10.1145/1054972.1055101

[51] Eustace Christopher Poulton. 1965. Letter Differentiation and Rate of Comprehension in Reading. *Journal of Applied Psychology* 49, 5 (1965), 358.

[52] Luz Rello and Ricardo Baeza-Yates. 2013. Good Fonts for Dyslexia. In *Proceedings of the 15th International ACM SIGACCESS Conference on Computers and Accessibility*. 1–8.

[53] Luz Rello, Martin Pielot, and Mari-Carmen Marcos. 2016. Make It Big! The Effect of Font Size and Line Spacing on Online Readability. In *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems (CHI '16)*. Association for Computing Machinery, New York, NY, USA, 3637–3648. doi:10.1145/2858036.2858204

[54] Quentin Roy, Futian Zhang, and Daniel Vogel. 2019. Automation Accuracy Is Good, but High Controllability May Be Better. In *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems (CHI '19)*. Association for Computing Machinery, New York, NY, USA, 1–8. doi:10.1145/3290605.3300750

[55] Zhanna Sarsenbayeva, Jorge Goncalves, Juan García, Simon Klakegg, Sirkka Rissanen, Hannu Rintamäki, Jari Hannu, and Vassilis Kostakos. 2016. Situational Impairments to Mobile Interaction in Cold Environments. In *Proceedings of the 2016 ACM International Joint Conference on Pervasive and Ubiquitous Computing (UbiComp '16)*. Association for Computing Machinery, New York, NY, USA, 85–96. doi:10.1145/2971648.2971734

[56] Zhanna Sarsenbayeva, Niels van Berkel, Danula Hettiachchi, Weiwei Jiang, Tilman Dingler, Eduardo Velloso, Vassilis Kostakos, and Jorge Goncalves. 2019. Measuring the Effects of Stress on Mobile Interaction. *Proc. ACM Interact. Mob. Wearable Ubiquitous Technol.* 3, 1 (March 2019), 24:1–24:18. doi:10.1145/3314411

[57] Zhanna Sarsenbayeva, Niels van Berkel, Chu Luo, Vassilis Kostakos, and Jorge Goncalves. 2017. Challenges of Situational Impairments during Interaction with Mobile Devices. In *Proceedings of the 29th Australian Conference on Computer-Human Interaction (OzCHI '17)*. Association for Computing Machinery, New York, NY, USA, 477–481. doi:10.1145/3152771.3156161

[58] Clemens Schartmüller, Klemens Weigl, Philipp Wintersberger, Andreas Riener, and Marco Steinhauser. 2019. Text Comprehension: Heads-Up vs. Auditory Displays: Implications for a Productive Work Environment in SAE Level 3 Automated Vehicles. In *Proceedings of the 11th International Conference on Automotive User Interfaces and Interactive Vehicular Applications (AutomotiveUI '19)*. Association for Computing Machinery, New York, NY, USA, 342–354. doi:10.1145/3342197.3344547

[59] Bastian Schildbach and Enrico Rukzio. 2010. Investigating Selection and Reading Performance on a Mobile Phone While Walking. In *Proceedings of the 12th International Conference on Human Computer Interaction with Mobile Devices and Services (MobileHCI '10)*. Association for Computing Machinery, New York, NY, USA, 93–102. doi:10.1145/1851600.1851619

[60] Andrew Sears, Mark Young, and Jinjuan Feng. 2009. Physical disabilities and computing technologies: an analysis of impairments. In *Human-Computer Interaction*. CRC Press, 87–110.

[61] James E Sheedy, Peter G Shaw-McMinn, et al. 2002. *Diagnosing and Treating Computer-Related Vision Problems.* Elsevier Health Sciences.

[62] Ben Shneiderman. 1992. *Designing the User Interface: Strategies for Effective Human-Computer Interaction.* Addison-Wesley.

[63] Ben Shneiderman and Pattie Maes. 1997. Direct Manipulation vs. Interface Agents. *interactions* 4, 6 (Nov. 1997), 42–61. doi:10.1145/267505.267514

[64] Zinovia Stefanidi, George Margetis, Stavroula Ntoa, and George Papagiannakis. 2022. Real-Time Adaptation of Context-Aware Intelligent User Interfaces, for Enhanced Situational Awareness. *IEEE Access* 10 (2022), 23367–23393. doi:10.1109/ACCESS.2022.3152743

[65] Constantine Stephanidis. 2001. Adaptive Techniques for Universal Access. *User Modeling and User-Adapted Interaction* 11, 1 (March 2001), 159–179. doi:10.1023/A:1011144232235

[66] Constantine Stephanidis, Demosthenes Akoumianakis, and Anthony Savidis. 1995. Design Representations and Development Support for User Interface Adaptation. *Institute of Computer Science Foundation for Research and Technology* (1995).

[67] Wolfgang Stuerzlinger, Olivier Chapuis, Dusty Phillips, and Nicolas Roussel. 2006. User Interface Façades: Towards Fully Adaptable User Interfaces. In *Proceedings of the 19th Annual ACM Symposium on User Interface Software and Technology (UIST '06)*. Association for Computing Machinery, New York, NY, USA, 309–318. doi:10.1145/1166253.1166301

[68] Daisuke Tajima, Jun Nishida, Pedro Lopes, and Shunichi Kasahara. 2022. Whose Touch Is This?: Understanding the Agency Trade-Off Between User-Driven Touch vs. Computer-Driven Touch. *ACM Trans. Comput.-Hum. Interact.* 29, 3 (Jan. 2022), 24:1–24:27. doi:10.1145/3489608

[69] Ying-Chao Tung, Mayank Goel, Isaac Zinda, and Jacob O. Wobbrock. 2018. RainCheck: Overcoming Capacitive Interference Caused by Rainwater on Smartphones. In *Proceedings of the 20th ACM International Conference on Multimodal Interaction (ICMI '18)*. Association for Computing Machinery, New York, NY, USA, 464–471. doi:10.1145/3242969.3243028

[70] Kristin Vadas, Nirmal Patel, Kent Lyons, Thad Starner, and Julie Jacko. 2006. Reading On-the-Go: A Comparison of Audio and Hand-Held Displays. In *Proceedings of the 8th Conference on Human-computer Interaction with Mobile Devices and Services (MobileHCI '06)*. Association for Computing Machinery, New York, NY, USA, 219–226. doi:10.1145/1152215.1152262

[71] Shaun Wallace, Zoya Bylinskii, Jonathan Dobres, Bernard Kerr, Sam Berlow, Rick Treitman, Nirmal Kumawat, Kathleen Arpin, Dave B. Miller, Jeff Huang, and Ben D. Sawyer. 2022. Towards Individuated Reading Experiences: Different Fonts Increase Reading Speed for Different Individuals. *ACM Trans. Comput.-Hum. Interact.* 29, 4 (March 2022), 38:1–38:56. doi:10.1145/3502222

[72] Shaun Wallace, Rick Treitman, Jeff Huang, Ben D. Sawyer, and Zoya Bylinskii. 2020. Accelerating Adult Readers with Typeface: A Study of Individual Preferences and Effectiveness. In *Extended Abstracts of the 2020 CHI Conference on Human Factors in Computing Systems (CHI EA '20)*. Association for Computing Machinery, New York, NY, USA, 1–9. doi:10.1145/3334480.3382985

[73] Shaun Wallace, Rick Treitman, Nirmal Kumawat, Kathleen Arpin, Jeff Huang, Ben Sawyer, and Zoya Bylinskii. 2020. Individual Differences in Font Preference & Effectiveness as Applied to Interlude Reading in the Digital Age. *Journal of Vision* 20, 11 (Oct. 2020), 412. doi:10.1167/jov.20.11.412

[74] Arnold Wilkins, Roanna Cleave, Nicola Grayson, and Louise Wilson. 2009. Typography for Children May Be Inappropriately Designed. *Journal of Research in Reading* 32, 4 (2009), 402–412.

[75] Jacob O. Wobbrock. 2019. Situationally-Induced Impairments and Disabilities. In *Web Accessibility: A Foundation for Research*, Yeliz Yesilada and Simon Harper (Eds.). Springer, London, 59–92. doi:10.1007/978-1-4471-7440-0_5

[76] Jacob O. Wobbrock, Krzysztof Z. Gajos, Shaun K. Kane, and Gregg C. Vanderheiden. 2018. Ability-Based Design. *Commun. ACM* 61, 6 (May 2018), 62–71. doi:10.1145/3148051

[77] Jacob O. Wobbrock, Shaun K. Kane, Krzysztof Z. Gajos, Susumu Harada, and Jon Froehlich. 2011. Ability-Based Design: Concept, Principles and Examples. *ACM Trans. Access. Comput.* 3, 3 (April 2011), 9:1–9:27. doi:10.1145/1952383.1952384

[78] Yeliz Yesilada, Simon Harper, Tianyi Chen, and Shari Trewin. 2010. Small-Device Users Situationally Impaired by Input. *Computers in Human Behavior* 26, 3 (May 2010), 427–435. doi:10.1016/j.chb.2009.12.001