Challenges of Situational Impairments during Interaction with Mobile Devices

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ABSTRACT

User interaction with mobile devices can be negatively affected by contextual factors, known as situationally-induced impairments. In this paper, we provide a systematic overview of established situational impairments and their impact on interaction with mobile devices, as well as existing methods for their detection and design guidelines to overcome them. We also propose a research roadmap for this topic where we argue that more experiments are required regarding the less investigated situational impairments. Furthermore, we argue that successful detection of the presence of a specific situational impairment is paramount before solutions can be proposed to adapt mobile interfaces to accommodate potential situational impairments.

CCS CONCEPTS

• **Human-centered computing** → Ubiquitous and mobile computing; • **Human-centered computing** → Smartphones

KEYWORDS

Situational impairments, mobile interaction, smartphones, contextual factors.

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1 INTRODUCTION

User interaction with mobile devices can be negatively affected by a vast number of contextual factors, known as situationally-induced impairments. The term situationally-induced impairments (also known as situational impairments) was first introduced by Sears [26], to establish the relationship between the user, the nature of tasks that the user is engaged in, the surrounding environment where the task is performed, and the design of technology used to complete the task. Contextual factors such as ambient temperature [23], mobile state of the user [8], encumbrance [21], ambient light [8], ambient noise [28], and stress [2] are examples of potential situational impairments. Furthermore, the ubiquitous nature of mobile devices requires them to be able to accommodate to the aforementioned situational impairments, in order to reduce the difficulties that people experience during mobile interaction while temporarily impaired.

The literature highlights various examples of the effect of situational impairments on mobile interaction [2,8,19,28]. For instance, previous work has argued that environmental and contextual changes might affect mobile device users in a similar way in which cognitive and physical impairments affect users with disabilities [2]. This connection was showcased in the study by Yesilada *et al.* [29] which showed that a situationally impaired user without physical impairments performed a similar number of errors on a mobile device to a user with physical impairments. As a result, solutions for one user group (*e.g.*, permanently impaired users) could benefit unexpected wider target groups (*e.g.*, situationally impaired users). As such, technology designed for motor-impaired users may be used in reducing the effect of situational impairments on interaction with mobile devices [8].

Similarly, improvements to mobile interaction to address situational impairments might improve the user experience of people with disabilities when interacting with interactive devices. For example, users situationally impaired while walking might interact with the device in a similar way to users with hand tremors [28]. Situational impairments can exacerbate usability issues of people with permanent impairments when interacting with mobile devices [19]. For example, a visually impaired person navigating an unfamiliar route while interacting with their mobile device would need to divide attention between swiping the cane and accessing the mobile device [1]. Moreover, previous work has demonstrated that situational impairments worsen the performance during mobile interaction for visually and motor impaired users [11]. Therefore, it is also necessary to consider situational impairments when designing technology to assist permanently impaired users. To address these needs, Kane *et al.* [11] drafted guidelines to support more accessible and empowering mobile device designs. The authors suggest utilising the devices' built-in sensors to identify the user's activity and location, allowing the device to adapt its user interface for an increased usability of the device. To summarise, an important implication of research targeting situational impairments during mobile interaction is that it affects users of all abilities. Mobile interfaces that adapt to contextual changes can therefore benefit all users [11].

In this paper we make two main research contributions. First, we provide a systematic overview of situational impairments that can occur during mobile interaction. Specifically, we examine currently acknowledged situational impairments, how they can be detected, and which design solutions have been proposed to accommodate them. Second, we identify the research gap in the area of situational impairments for mobile interaction. Precisely, we establish those situational impairments that lack investigation, as well as those missing an appropriate detection mechanism. These contributions can benefit researchers working on situational impairments research in the area of HCI, including but not limited to mobile interaction.

2 SITUATIONAL IMPAIRMENTS DURING MOBILE INTERACTION

Situational impairments are known to adversely affect mobile interaction. In the following subsections, we present a detailed literature overview on situational impairments. Based on the available literature, we group our findings by the following impairment categories: ambient temperature, mobile state of the user, encumbrance, ambient light, ambient noise, emotional state of the user (mood), and stress (Figure 1).

Figure 1: The different situational impairments.

2.1 Ambient Temperature

A number of studies have investigated the effect of cold ambient temperature on interaction with mobile devices [10,23]. In the study by Goncalves *et al.* [10], the researchers investigated the effect of cold temperature on smartphone input performance. Participants were asked to complete tapping tasks (based on [15]) with temperature thermistors attached to their fingers. The experiment took place in a controlled laboratory environment, inside a cold room (-10°C) and in a warm room (+20°C) consecutively. Their results show that lower finger temperatures are associated with lower throughput and higher error rate when interacting with the mobile device with two hands. Furthermore, the researchers show that the predictive power of movement time in Fitt's Law [6] could be improved by adding finger temperature as a parameter.

Sarsenbayeva *et al.* [23] expanded this study to focus not only on fine-motor movements, but also on vigilance. The researchers followed an experimental design similar to the one reported in [10]; with the addition of introducing two custom developed applications to measure fine-motor performance (*i.e.*, touch offset, time taken to tap a target) and vigilance (*i.e.*, time taken to find a memorised icon). Interestingly, the results showed that while fine-motor performance was adversely affected by cold temperatures (larger offset and longer time taken to tap a target when compared to warm temperatures), cognitive performance was not affected. However, the researchers argued that vigilance would likely get affected under longer exposure to cold temperatures as reported in [7].

2.2 Mobile State of the User

Several studies aimed to identify the effects of the user's mobile state on mobile interaction. For example, walking has been found to have adverse effect on performance during mobile interaction. In a study by Lin *et al.* [14] participants performed standard target selection tasks while being seated, and walking on treadmill under slow and fast walking conditions. Results of the study did not indicate a significant change in performance in the transition from being seated to being mobile (fast and slow walking). However, in a follow up study, researchers found that task completion time, error rate, and workload measures (*e.g.*, mental and physical demands) differed significantly while performing the tapping tasks under conditions of being seated, walking on treadmill, and free-style walking with obstacles [13]. Researchers established that the obstacle course condition was more challenging for the users compared to the seated condition when completing tapping tasks on mobile devices. Schildbach and Rukzio [25] investigated the negative effect of walking on performance in target selection tasks and reading comprehension. They suggested that the negative effect of walking on target selection tasks can be compensated by increasing the target sizes. Similarly, Mizobuchi *et al.* [17] investigated whether the size of keyboard buttons affected user's text input performance while walking. The results showed that for text input speed, error rate, and subjective ease of use, 2.5 mm is considered the minimum key width on a soft keyboard, with 3.0mm being the preferred key width while walking.

Walking has also been found to cause deterioration in text legibility [18], as well as reading comprehension and cognitive performance, as measured by a word searching task [2].

Moreover, researchers in [27] argue that reading while walking (on-the-go) is limited as it requires the user to divide their attention to handle two tasks in parallel: 1) comprehending the text, and 2) navigating through the environment. In the study by Vadas *et al.* [27] participants were asked to complete reading comprehension tasks in the following conditions: walking and sitting using a speech-synthesis audio display, and walking and sitting using a handheld visual display. The researchers found that audio interface improved participants' navigation within the environment. In addition, participants rated the audio interface as less demanding compared to a visual display when completing the reading tasks. An alternative technique suggested to reduce the situational impairments effect caused by walking is by using gestures. For instance, Bragdon *et al.* [4] compared three types of gestures: bezel gestures, hard button initiated gestures, and soft buttons in sitting and walking modes. They found that bezel gestures were not affected by walking in terms of speed or accuracy during mobile touch-screen interaction.

2.3 Encumbrance

It is common that users interact with their mobile devices while being encumbered with different objects (*e.g.*, handbags, umbrellas, shopping bags, or boxes). Therefore, encumbrance is another situational impairment that can affect mobile interaction. Previous work has highlighted how encumbrance can cause decreases in accuracy while performing target acquisition tasks on mobile devices [20]. They also found that encumbrance affected the user's preferred walking speed, resulting in slower movement speed than the participant's typical rate. In a follow-up study, Ng *et al.* [21] investigated the effect of encumbrance on interaction with mobile device in one- and two-handed interaction modes. They evaluated three postures of holding and interacting with the mobile device: two-handed using index finger, one-handed using thumb, and two-handed using both thumbs. The results of the experiment showed that encumbrance caused a significant deterioration in performance completing tapping tasks for both one- and two-handed interaction modes. Moreover, in [22] the researchers measured performance in completing target acquisition tasks on a mobile phone while encumbered in two conditions: walking on a treadmill and walking on the floor. The results of the experiment did not show any difference in performance of target acquisition tasks.

2.4 Other Situational Impairments

Rich literature exists on such situational impairments as ambient temperature, mobile state of the user, and encumbrance. However, a limited amount of research has been conducted to study the effect of other situational impairments such as ambient light, ambient noise, and the cognitive state of the user (*e.g.* stress, mood) on mobile interaction. Not only walking, but also ambient light has been shown to have negative effect on reading comprehension, and response selection speed, as well as on time taken to find a word [2]. Current mobile devices are equipped with the ambient light sensor that adapts the brightness of the screen according to the light levels of the environment. As the ambient light sensor has proven to accommodate situational impairments caused by ambient light, it might explain why not many studies have investigated the effect of ambient light on mobile interaction.

To the best of our knowledge, there are no studies investigating the effect of ambient noise, emotional state of the user (mood) and stress on mobile interaction from the perspective of situational impairments.

3 RESEARCH ROADMAP FOR SITUATIONAL IMPAIRMENTS IN MOBILE INTERACTION

Going forward, we argue that research on situational impairments and their impact on mobile interaction should follow two main directions: 1) investigate in more detail those situational impairments which have remained underexplored, and 2) propose and develop ways to detect situational impairments, and then offer solutions to mitigate their impact on mobile interaction. With regards to the first point, there are certain situational impairments that have been given significantly more attention (*e.g.*, walking) by the research community than others when considering mobile interaction. In contrast, there are situational impairments that lack investigation altogether (*e.g.*, ambient noise). Therefore, it is necessary to broaden the scope of research for impact of situational impairments, such as investigating the impact of ambient noise or emotion fluctuations during the day [9] on mobile interaction. As for the second point, it is not enough to simply identify such situational impairments as detrimental to interaction with mobile devices. It is also necessary to propose and especially develop mechanisms that could sense situational impairments and accommodate users accordingly. To achieve this, previous work has suggested that user's individual characteristics and information handling strategies should be taken into account when designing adaptive user interfaces on mobile devices [12]. This could potentially improve detection of situational impairments as mobile devices recognize individual behavioural interaction patterns and become more capable to adapt accordingly.

Thus, the successful detection of the presence of a situational impairment is paramount before an appropriate adaptation can take place. As an example, previous work has leveraged the mobile device's built-in battery temperature sensor to detect ambient temperature of the environment, which results in a decrease in performance during mobile interaction at low temperatures, without the necessity for external equipment [24]. The feasibility of detecting the situational impairment is a fundamental step which is often overlooked. Previous work regarding ambient temperature merely identified the effect of cold on performance and suggested some potential adaptations to the interface (*e.g.*, increase in button size, warnings) [10] [23], but did not propose an appropriate method to detect the impairment in the first place. Similarly, previous work has also suggested that assessing grip positions of the hand on a device's surface can be used to detect if a user is encumbered [20].

Table 1: Summary of situational impairments, their effect on mobile interaction, detection methods, and design guidelines.

Situational Impairment	Effect of Situational Impairment	Detection of Situational Impairment	Design Guidelines
Ambient Temperature	Low throughput and high error rates [10] Large touch offset and long time to tap a target [23]	Battery Sensor [24]	Increased button size and warnings [10] [23]
Mobile State of the User	Deterioration in text legibility [18], reading comprehension and cognitive performance [2]	Accelerometer [8]	Increased target size [25] Audio guidance [27] Using bezel gestures [4] Adaptive text-entry system [8] Enlarged soft buttons [12] Audio feedback [5]
Encumbrance	Performance deterioration in target acquisition task [20] [22]	X	*Fat Thumb* [3] *GraspZoom* [16]
Ambient Light	Decrease in reading efficiency [2]	Ambient light sensor	Adaptive screen brightness
Ambient Noise	X	X	X
Mood	X	X	X
Stress	X	X	X

WalkType is another example of appropriate detection, via the accelerometer, of a situational impairment (in this case walking), followed by an adaptive text-entry system for smartphone devices [8]. *WalkType* improved text entry accuracy by considering multiple features of accelerometer data such as displacement, acceleration, and movement inference. The system also incorporates tap location and finger travel distance during taps to eliminate imprecision of the input. *WalkType* significantly improved typing speed by 12.9% and reduced uncorrected error rate by 45.2% compared to the control condition while users were walking. In another example, researchers evaluated an adaptive walking user interface which would enlarge soft buttons when user movement is detected via the accelerometer [12]. Another strategy explored in previous work entails the use of audio feedback to improve touch screen interaction, but only after walking had been detected [5]. The results of the study showed that adding a sound to input buttons significantly improved the usability of standard and small buttons as well as significantly reduced the user workload.

There is a great number of currently available techniques that can be leveraged to improve the interaction with mobile devices, once the situational impairment has been detected. For instance, the *Fat Thumb* technique can be used to improve mobile interaction [3] while the user is situationally impaired due to encumbrance. The researchers suggest two gesture modes to interact with the mobile device: panning and zooming. Using this technique, the type of the gesture is defined by the contact size of the thumb: smaller contact size defined panning, larger contact size defined zooming. Another example is the *GraspZoom* [16] input model that uses pressure sensing to define different gestures with the help of Force Sensitive Resistor, used to determine the strength of the pressure. The interface allows users to zoom in on a particular part of the screen with a long press using their thumb. Zooming out was implemented with sliding gesture followed by pressing the screen. Scrolling action was implemented similar to zoom in. The position of the finger determined the direction of scrolling (*e.g.*, if the user pressed the top of the screen, the interface would scroll upwards).

In Table 1 we present an overview of currently acknowledged situational impairments. We summarise their effect on mobile interaction, existing methods of their detection, and finally, design guidelines proposed by the researchers to accommodate these situational impairments during mobile interaction.

4 CONCLUSION

In this paper, we provide a systematic overview of established situational impairments and their impact on interaction with mobile devices, methods of their detection and design guidelines to accommodate situational impairments. We highlight the situational impairments that require further investigation in any of these three areas.

Ultimately, a better understanding of situational impairments can be useful in discovering whether users with physical impairments and users with situational impairments are affected in similar ways [28]. Previous work has highlighted the need for mobile interfaces to adapt to situational impairments such as ambient temperature, mobile state of the user, encumbrance, ambient light, and ambient noise. As situational impairments affect users of all abilities, design implications and solutions for developing mobile interfaces that adapt to contextual changes are valuable in HCI research as they can benefit all users [11].

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