Situational Impairments during Mobile Interaction

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1 INTRODUCTION

Non-conventional contextual and environmental factors are known to adversely affect mobile interaction leading to *situational impairments*. The term *situational impairments* was first introduced by Sears [20], where the term was used to describe the relationship between the user, the nature of the 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. Due to their ubiquitous nature, smartphones are often used in situations, where the user is situationally impaired *e.g.,* due to contextual and environmental factors, such as cold ambience [6, 15], ambient noise [17], motion [5, 7, 19], or being encumbered [13, 14]. Therefore, one of the challenges within the Ubicomp community is to enhance the capabilities of mobile devices to detect these situational impairments and accommodate them.

Moreover, the effects of some of the situational impairments have been established during mobile interaction (*e.g.,* cold environments [6, 15], ambient noise [17], motion [5, 7, 19], and encumbrance [13, 14]). However, other situational impairments (*e.g.,* emotional state of the user, and stress [1]) remain underexplored. Hence, it is valuable to the Ubicomp community to know the effects of underexplored situational impairments on mobile interaction, in order to develop the detection mechanisms and adaptive interfaces to accommodate them.

Our research has three main objectives. The first objective of our research is to understand the effect of underexplored situational impairments (in particular, ambient noise, mood or emotional state of the user, and stress). The second objective of our research is to develop mechanisms for detecting situational impairments (*e.g.,* ambient temperature). Finally, our research aims to provide design guidelines and recommendations for building interfaces to adapt the interaction by accommodating the situational impairments.

2 OVERVIEW OF SITUATIONAL IMPAIRMENTS DURING MOBILE INTERACTION

Situational impairments have been shown to have a negative effect on mobile interaction. Our findings on situational impairments are grouped in the following categories: ambient temperature, mobile state of the user, encumbrance, ambient light, emotional state of the user (mood), stress, and ambient noise.

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2.1 Ambient Temperature

Several studies investigated the effect of cold ambient temperature on mobile interaction [6, 15]. In the study by Goncalves *et al.* [6], the researchers investigated the effect of cold ambience on smartphone input performance. Participants completed target acquisition tasks [9] with temperature thermistors attached to their fingers. The experiment took place in a controlled laboratory settings, inside a cold room (-10°C) and in a warm room (+20°C). Their results show that lower finger temperatures are associated with lower throughput and higher error rate when interacting with the smartphone with two hands. Furthermore, the researchers show that the predictive power of movement time in Fitts' Law [3] could be improved by adding finger temperature as a parameter.

Sarsenbayeva *et al.* [15] 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 [6]; with an addition of introducing two custom developed applications to measure fine-motor performance (*i.e.,* offset size and target acquisition time) and vigilance (*i.e.,* visual search time). Their results showed that while fine-motor performance was adversely affected in cold environment (larger offset and longer target acquisition time), cognitive performance was not affected. However, the researchers argued that vigilance would likely get affected under longer exposure to cold temperatures as reported in [4].

2.2 Mobile State of the User

Several studies investigated the effect of the user's mobile state on mobile interaction. For example, walking has been shown to have an adverse effect on performance during mobile interaction. In a study by Lin *et al.* [8], participants performed standard target selection tasks while being seated, and walking on a 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. However, in a follow up study, researchers found that task completion time, error rate, and workload (*e.g.,* physical and cognitive demands) differed significantly while performing the tapping tasks under the conditions of being seated, walking on a treadmill, and free-style walking with obstacles [7]. Researchers established that the obstacles course condition was more challenging for the users compared to the seated condition when completing tapping tasks on mobile devices. Schildbach and Rukzio [19] established the negative effect of walking on performance in target selection tasks and reading comprehension. They suggested that the adverse effect of walking on target selection tasks can be compensated by increasing the target sizes. Similarly, Mizobuchi *et al.* [10] 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 3.0 mm being the preferred key width while walking.

Walking has also been found to cause deterioration in text legibility [11], as well as reading comprehension and cognitive performance, as measured by a word searching task [1]. Moreover, researchers in [21] 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.* [21] 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.* [2] 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 [12]. 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.* [13] 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 [14] 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 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 emotional state of the user (mood) and stress on mobile interaction from the perspective of situational impairments [16].

Ambient noise was one of the underexplored situational impairments; however, as part of our research, we conducted a study investigating the effects of ambient noise on mobile interaction. The details of the study are presented in the Contribution section.

3 RESEARCH METHODOLOGY

In total, there are four studies planned to investigate the effect of situational impairments on mobile interaction.

Study 1 builds on our previous work that identified a significant effect of cold ambience on mobile interaction [15]. This study aims to develop a detection mechanism to sense cold-induced situational impairments during mobile interaction using built-in sensors of a smartphone. We conducted two experiments to 1) assess the effect of a cold environment on the battery temperature of several smartphone models, and 2) investigate the relationship between smartphone battery temperature and human finger temperature. Regarding point 1, we conducted a comparative study of changes in battery temperature over time using multiple handsets. Our objective was to investigate whether different phones and batteries behave similarly in cold settings. Then, our objective was to investigate, if smartphone battery temperature and human finger temperature co-vary when exposed to changing ambient temperature. The experimental design was adopted from previous work by Sarsenbayeva *et al.* [15].

Study 2 aims to investigate the effect of different ambient noise types on mobile interaction. This research question was explored in a lab study, where we quantified mobile interaction in terms of three common activities conducted on smartphones: target acquisition, visual search, and text entry. We used two software applications as experimental tasks, TapCircle and FindIcon, previously used to investigate the effect of cold-induced situational impairments on mobile interaction [15]. This allows for direct comparison of our results to previous findings. Additionally, we developed a new custom software called TypeMe. The tasks presented by TapCircle measures users' fine-motor performance during target acquisition, the task in FindIcon measures users' cognitive performance during visual search [15], and the task in TypeMe measures users' text entry performance.

Study 3 aims to investigate the effect of emotional state of the user (mood) on mobile interaction in terms of smartphone usage. Furthermore, the study will examine if applications trigger particular emotions in users. This study will also focus on detection of the user's emotional state based on the smartphone sensors (*e.g.,* applications use). This will be an in-the-wild study as the required data needs to be captured in naturalistic settings, where a custom software will be built to collect smartphone usage data. The software will collect participants emotions (from facial expressions and self-reported values) and smartphone app usage data. We will look into correlations between the app usage data and emotional state of the user. Furthermore, we will examine if user's emotional state can be predicted from the application usage, as well as if user's application usage can be predicted from their emotional state. When building predictive models, we will take into consideration other variables than app usage, such as battery, notifications, network, screen status, and self reported emotional state.

Study 4 is planned as a lab study, and aims to examine the effect of stress on mobile interaction during the three common activities: target acquisition, visual search, and text entry. The objective of the study is to investigate the effect of stress on interaction performance in terms of target acquisition time, target acquisition precision, visual search time, errors during the search, time per character in text entry task, and text entry error rate. The software from the Study 2 will be reused in order to compare the effect of stress to previously acknowledged situational impairments (*e.g.,* cold, ambient noise). Empathica E4 [1] wearable sensor will also be used in this study to collect participants physiological data, such as heart rate variability and electrodermal activity. Sensor data will be used as a ground truth for participants stress levels.

4 CONTRIBUTION

4.1 Current contribution to the Ubicomp research

4.1.1 Study 1. Two main studies have been conducted so far since the beginning of the PhD. In Study 1 [18] we developed a method to infer changes in finger temperature of a smartphone user. Particularly, we show that smartphone battery temperature works as a reliable measure to determine changes in finger temperature, when a user is interacting with their smartphone in a cold environment. The Study 1 consisted of two parts. In the first part of the study, we examined how four smartphones (that varied in manufacturer, size, battery capacity, body material, and weight) behave in the environment with changing temperature. Our results showed a statistically significant positive correlation between the battery temperatures of all four devices.

In the second part of the Study 1, we investigated the relationship between the smartphone battery temperature and human finger temperature when exposed to changing ambient temperature. We followed the experimental design presented in [15], we asked our participants to complete target acquisition tasks in cold (-10°C) and warm (+20°C) environments in two interaction modes: 1) using their index finger, 2) using their thumb. We measured their finger temperature using external thermistors. A Pearson product-moment correlation coefficient was calculated to assess the relationship between participants' finger temperatures (index and thumb) and the phone's battery temperature. A positive correlation was observed for both fingers (index: $r = 0.86$, $p < 0.01$; thumb: $r = 0.85$, $p < 0.01$).

Our findings demonstrate that changes in smartphone battery temperature can be used to infer changes in users' finger temperature. This is an important finding as it shows that cold-induced situational impairments can be predicted using off-the-shelf smartphones built-in sensors. This information can then be used to adapt

[1] https://www.empatica.com/en-eu/research/e4/

mobile interfaces to overcome cold-induced situational impairments or simply to provide warnings to the user on over-exposure to cold environments.

4.1.2 Study 2. The next study (Study 2) was conducted to examine the effect of ambient noise on mobile interaction. To the best of our knowledge, it was the first study to investigate the effect of different ambient noise types (*e.g.,* fast and slow tempo music, indoor and outdoor urban noise, meaningful and meaningless speech) on mobile interaction during target acquisition task, visual search task, and a text entry task. To investigate whether mobile interaction was affected by ambient noise, we built generalised linear mixed-effect models to describe participant performance in the above mentioned tasks.

We again followed the experimental design presented in [15]. The performance was measured in terms of target acquisition time and offset size (target acquisition task), time taken to memorise and find a target (visual search task), and time per character entry (text entry task). Our results show that the target acquisition time decreased in both music and both urban noise conditions. Offset size was significantly larger in the music with slow tempo condition. Further, participants spent significantly less time on memorising a target in the urban indoor noise condition. In addition, participants produced significantly more errors in urban outdoor noise condition when searching for an icon. Finally, the time per character entry was significantly longer in the urban outdoor noise and meaningful speech conditions. We also compared the magnitude of noise-induced situational impairments to the cold-induced situational impairments. Our results showed that the mean values for target acquisition time and visual search time (time to memorise an icon, time to find an icon) were smaller under noise conditions compared to a cold environment. Our findings enhance the understanding of noise-induced situational impairments on mobile interaction and contribute towards accumulating knowledge in situational impairments research.

4.2 Expected future contribution to the Ubicomp research

In the remaining part of the PhD, we will focus on cognitive situational impairments and fulfil the following research objectives. First of all, it is important to investigate the effect of emotional state (mood) of the user on mobile interaction. The mobile interaction will be assessed in terms of applications use, and the research question we are investigating in this study is: *"What is the effect of the emotional state of the user on applications usage during mobile interaction?"* We will examine if applications can be used to identify the user's emotional state and mood. Furthermore, we will compare the emotional state of the user (mood) to already acknowledged situational impairments to quantify the magnitude of its effect on mobile interaction.

We also plan to examine the effect of stress on mobile interaction. The effect of stress will be studied on the target acquisition, visual search, and text entry tasks during mobile interaction. Then the results will be compared to the results obtained from previous studies: the effect of cold- and noise- induced situational impairments on mobile interaction. To the best of our knowledge, no studies have been conducted to investigate the effect of stress from the perspective of situational impairments. Finally, we will compare stress to already acknowledged situational impairments to quantify the magnitude of its effect on mobile interaction. Research questions we ask in this study are:

1. How does stress affect interaction performance with smartphone?

2. Can stress be detected using smartphone and wearable sensors?

We believe our research will contribute to the field of UbiComp/HCI in terms of enhancing the knowledge base on situational impairments, as well as building smarter ubiquitous technology, that is able to detect situational impairments and adapt the interface accordingly.

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REFERENCES

[1] Barnard, L., Yi, J. S., Jacko, J. A., and Sears, A. Capturing the effects of context on human performance in mobile computing systems. *Personal and Ubiquitous Computing 11*, 2 (2007), 81–96.

[2] Bragdon, A., Nelson, E., Li, Y., and Hinckley, K. Experimental analysis of touch-screen gesture designs in mobile environments. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, CHI '11, ACM (New York, NY, USA, 2011), 403–412.

[3] Fitts, P. M. The information capacity of the human motor system in controlling the amplitude of movement. *Journal of experimental psychology 47*, 6 (1954), 381.

[4] Flouris, A. D., Westwood, D. A., and Cheung, S. S. Thermal balance effects on vigilance during 2-hour exposures to- 20 c. *Aviation, space, and environmental medicine 78*, 7 (2007), 673–679.

[5] Goel, M., Findlater, L., and Wobbrock, J. Walktype: Using accelerometer data to accomodate situational impairments in mobile touch screen text entry. In *Proc. of the SIGCHI Conference on Human Factors in Computing Systems*, CHI '12, ACM (New York, NY, USA, 2012), 2687–2696.

[6] Goncalves, J., Sarsenbayeva, Z., van Berkel, N., Luo, C., Hosio, S., Risanen, S., Rintamäki, H., and Kostakos, V. Tapping task performance on smartphones in cold temperature. *Interacting with Computers 29*, 3 (2017), 355–367.

[7] Lin, M., Goldman, R., Price, K. J., Sears, A., and Jacko, J. How do people tap when walking? an empirical investigation of nomadic data entry. *International journal of human-computer studies 65*, 9 (2007), 759–769.

[8] Lin, M., Price, K. J., Goldman, R., Sears, A., and Jacko, J. Tapping on the move-fittsâĂŹ law under mobile conditions. In *Proc. IRMA*, vol. 5 (2005), 132–135.

[9] MacKenzie, I. S., and Isokoski, P. Fitts' throughput and the speed-accuracy tradeoff. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, CHI '08, ACM (New York, NY, USA, 2008), 1633–1636.

[10] Mizobuchi, S., Chignell, M., and Newton, D. Mobile text entry: Relationship between walking speed and text input task difficulty. In *Proceedings of the 7th International Conference on Human Computer Interaction with Mobile Devices &Amp; Services*, MobileHCI '05, ACM (New York, NY, USA, 2005), 122–128.

[11] Mustonen, T., Olkkonen, M., and Hakkinen, J. Examining mobile phone text legibility while walking. In *CHI '04 Extended Abstracts on Human Factors in Computing Systems*, CHI EA '04, ACM (New York, NY, USA, 2004), 1243–1246.

[12] Ng, A., Brewster, S. A., and Williamson, J. The impact of encumbrance on mobile interactions. In *Human-Computer Interaction – INTERACT 2013*, P. Kotzé, G. Marsden, G. Lindgaard, J. Wesson, and M. Winckler, Eds., Springer Berlin Heidelberg (Berlin, Heidelberg, 2013), 92–109.

[13] Ng, A., Brewster, S. A., and Williamson, J. H. Investigating the effects of encumbrance on one- and two- handed interactions with mobile devices. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, CHI '14, ACM (New York, NY, USA, 2014), 1981–1990.

[14] Ng, A., Williamson, J. H., and Brewster, S. A. Comparing evaluation methods for encumbrance and walking on interaction with touchscreen mobile devices. In *Proceedings of the 16th International Conference on Human-computer Interaction with Mobile Devices & Services*, MobileHCI '14, ACM (New York, NY, USA, 2014), 23–32.

[15] Sarsenbayeva, Z., Goncalves, J., García, J., Klakegg, S., Rissanen, S., Rintamäki, H., Hannu, J., and Kostakos, V. Situational impairments to mobile interaction in cold environments. In *Proceedings of the 2016 ACM International Joint Conference on Pervasive and Ubiquitous Computing*, UbiComp '16, ACM (New York, NY, USA, 2016), 85–96.

[16] Sarsenbayeva, Z., van Berkel, N., Luo, C., Kostakos, V., and Goncalves, J. Challenges of situational impairments during interaction with mobile devices. In *Proc. of the 29th Australian Conference on Computer-Human Interaction*, ACM (2017), 477–481.

[17] Sarsenbayeva, Z., van Berkel, N., Velloso, E., Kostakos, V., and Goncalves, J. Effect of distinct ambient noise types on mobile interaction. *Proc. of the ACM Interact. Mob. Wearable Ubiquitous Technol. 2*, 3 (2018).

[18] Sarsenbayeva, Z., van Berkel, N., Visuri, A., Rissanen, S., Rintamaki, H., Kostakos, V., and Goncalves, J. Sensing cold-induced situational impairments in mobile interaction using battery temperature. *Proc. ACM Interact. Mob. Wearable Ubiquitous Technol. 1*, 3 (Sept. 2017), 98:1–98:9.

[19] Schildbach, B., and Rukzio, E. 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, ACM (New York, NY, USA, 2010), 93–102.

[20] Sears, A., Lin, M., Jacko, J., and Xiao, Y. When computers fade: Pervasive computing and situationally-induced impairments and disabilities. In *HCI International*, vol. 2 (2003), 1298–1302.

[21] Vadas, K., Patel, N., Lyons, K., Starner, T., and Jacko, J. 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, ACM (New York, NY, USA, 2006), 219–226.