The Disability Continuum: Investigating Health and Situational Induced Impairments and Disabilities

Hugo Nicolau Joaquim Jorge

IST / Technical University of Lisbon / INESC-ID
{hman, jaj}@vimmi.inesc-id.pt

Abstract. Recent advances on mobile technologies are blurring the frontiers between able-bodied and disabled users. Indeed, mobile settings have a negative impact on motor abilities. Mobile users' bodies are prone to vibrations, resulting in hand tremors, which hinder target selection accuracy. These users seem to share some problems with elderly people, who experience increased physiological tremor. However, this hypothesis has yet to be thoroughly researched. In this work, we propose to bridge the gap between different domains, allowing designers to build more inclusive and comprehensive solutions using recent touch-based devices. We present two evaluations comparing situational- to health-impaired users and report on the main differences and similarities we found on text-entry tasks. Our results show that while elderly users are more likely to commit cognitive errors, both user groups experience similar substitution errors. We found that the increased demands of mobility and type of device seemingly induce a "*disability continuum*", where both situationally- and health-impaired users' performance is interleaved.

Keywords: Text-entry, Mobile, Tablet, Touch, Elderly, Walking, Tremor.

1 Introduction

Over the years, solutions targeted at disabled people have demonstrably benefitted all users. A good example is the T9 text-entry method [4]. Still, accessibility largely remains a research area for minorities. The very distinction between accessibility and usability attests to this. Our work suggests that there are situations where the distinction between able-bodied and disabled users is not so clear. We thus argue that there is not a clear-cut line separating usability from accessibility, which we regard as different points in a continuum of disabilities. Our observations of mobile users operating touch-based devices likely support this concept. Indeed, mobile able-bodied users often face demands that compete for the same resources they need to operate electronic devices, leading to situational impairments and disabilities (SIID) [5]. For instance, walking both engages visual attention and induces hand oscillations, making text-entry on mobile devices a much harder task [3]. Indeed, keying accuracy decreases, cognitive workload increases, while walking performance suffers [1]. Other research found that interaction challenges can be either induced by health conditions or by contextual factors, blurring the line between able-bodied and disabled users.

adfa, p. 1, 2011.

Wobbrock [6] proposed investigating whether situational and health induced impairments and disabilities affect users in similar ways as a useful means to address a wide range of abilities. Bridging the gap between these two domains brings several advantages to the research community. First, it avoids duplication of work. Second, it promotes reusing knowledge between accessibility and mobile research areas. Third, it leverages creating broader solutions. Fourth, it may reduce costs and increase availability. Last but not the least, it could remove the negative connotations of the word accessibility.

Previous research by Yesilada et al. [8] confirmed that problems encountered between motor-impaired and situational-impaired users do indeed overlap and that either domain could benefit from similar solutions. However, these findings are restricted to physical mini-qwerty keyboards. We focus our research on touch-based devices, the current trend of mobile devices. Our goal is to empower designers to build tailored solutions to cope with a wide range of abilities. Other feature of our work lies in the target users: we intentionally focused our analysis in tremor impairments, observing comparable disabilities between elderly citizens, who experience increased physiological tremor and walking people, who suffer from situationally induced tremor.

We aim to bridge the gap between the two domains by providing both empirical knowledge and a comparative analysis. Particularly, we set out to answer two main research questions: First, what are the main similarities between situational impaired and elderly users' performance? Identifying common issues will allow us to provide the tool for informed design. Second, we seek to identify the main differences between user groups, so that future solutions can provide inclusive designs. However, one major challenge lies in fairly comparing different users' abilities. How can we model and compare these? Although we acknowledge that elderly and situational impaired users show many differences, we compare them at a functional level, modeling their abilities through observed input accuracy [7]. In what follows, we discuss our experience to measure text-entry performance, describing the experimental setup and drawing conclusions from observed performance. We the present guidelines for inclusive design as well as avenues for future work.

2 Investigating Text-Entry Performance

Historically, accessibility and usability have been regarded as distinct research domains. However, recent advances in mobile technologies have the potential to unify these communities into Mobile Accessibility. However, it is not yet clear whether and how they overlap. Thus we seek to describe the main differences and similarities between user groups and allow designers to build effective solutions for a wide range of abilities. To this end, we study text-entry performance with both situational and health impaired users.

2.1 Participants

Twenty two participants, 3 females and 19 males, took part in the first user study. Their age ranged from 23 to 40 with a mean of 26.5 years old. They were recruited from our university. None of the participants had visual or motor impairments and all of the participants owned a mobile phone whereas only 15 of them used touch screen technology regularly. All participants were right-handed. This user group will be called *SIID group*.

For the second study we recruited fifteen participants (11 females and 4 males) from a local social institution. Their age ranged from 67 to 89 with a mean of 79 years old. All participants were right-handed. None of them had severe visual impairments and were able to see screen content. Twelve of the participants owned a mobile phone, however they were only able to receive and make calls. Only one participant had used touchscreen technology before, but has never entered text. Regarding QWERTY familiarity, six participants had used this type of keyboard whether in typing machines or computers. This user group will be called *HIID group*.

2.2 Apparatus

An HTC Desire and ASUS EEE Pad Transformer TF101 with a capacitive touch screen were used during the user study. A QWERTY virtual keyboard, similar to android's SDK keyboard, was used in both devices; for the HTC Desire each key was 10x10mm on landscape mode and 7x10mm on portrait mode, while for the tablet each key was 20x10mm (landscape). A letter was entered when the user lifted his finger from the key. Neither word prediction nor correction was used. Acceleration data was capture through the mobile device's accelerometer for posterior analysis.

2.3 Procedure

SIID study. At the beginning of the experiment participants were told that the overall purpose of the study was to investigate how text-entry performance was affected by walking conditions. Subjects were then informed about the experiment and how to use our evaluation application. We evaluated the participants' performance in two mobility settings: sitting and walking at average human pace (2 steps per second). The experiment was conducted in an indoor test track built-up at the university campus (without obstacles). In both walking conditions, we asked participants to follow a pacesetter while entering text. Although other designs could be chosen, we opted to keep a fixed pace rather than measure it as a dependent variable in order to ensure a comparable level of walking demand across trials. The experimenter instructed participants to stay within 2 meters of the pacesetter as he walked. If the participant fell behind by more than 4 meters, the experimenter logged a walking deviation for that trial. The pacesetter carried a mobile phone, which gave him feedback through vibration about the intended pace. Before each mobility condition participants had a 5 minute practice trial to get used to the pace and text-entry task. For each mobility setting, subjects were asked to enter text with 3 hand conditions (chosen randomly) using their thumbs: one-hand/ portrait, two-hand/ portrait, and two-hand/ landscape. For each condition participants copied seven different sentences (first two sentences were practice trials), resulting in 42 different sentences per participant. Both sentences and mobility conditions were chosen randomly to avoid bias associated with experience.

HIID study. At the beginning of the study, participants were told that the overall purpose was to investigate how text-entry performance is affected by the type of device. We then explained and exemplified to them how to use a virtual keyboard. Before the evaluation phase, we assessed the participants capabilities regarding tremor (postural and action tremor) applying two different methods (Archimedes spiral test and capturing accelerometer data). Subjects were then informed about the experiment and how to use our evaluation application. We evaluated the participants' performance with two devices: mobile phone and tablet. Before each condition participants had a 5 minute practice trial to get used to the virtual keyboard. We did not force participants to interact with a specific finger, thus they were allowed to choose the most comfortable typing strategy, as long as it was consistent during that condition. For the mobile phone condition, participants had to hold it in their hand, since it is a handheld device; for the tablet device condition, it was placed on the table in front of them. For each evaluation condition, participants copied five different sentences (first sentence was a practice trial). The order of conditions was counter balanced to avoid bias associated with experience. Each subject entered a total of 10 different sentences.

In both studies sentences were displayed one at a time, at the top of the screen. Copy typing was used to reduce the opportunity for spelling errors and to make error identification easier. Participants were instructed to type as quickly and accurately as possible. Error correction and word prediction was not available, since we wanted to measure the quality of transcribed sentences without correcting strategies. All sentences were extracted from a written language corpus, each with 5 words, an average size of 4.48 characters per word, and a minimum correlation with the language of 0.97.

2.4 Dependent Measures and Analysis

We measure performance during text-entry tasks by several quantitative variables: words per minute (*WPM*), minimum string distance (*MSD*) error rate, and character-level errors (*substitutions*, *insertions*, and *omissions*). We also gathered tremor-related measures for each trial in order to characterize participants' level of impairment and applied Shapiro-Wilkinson tests to observed values in *WPM*, *MSD error rate*, and types of errors. We applied parametric statistical tests, such as repeated measures ANOVA and t-test, for normally-distributed dependent variables or non-parametric tests (Friedman and Wilcoxon) otherwise.

3 Results

Our goal in this work is to understand and bridge the existing gap between health- and situational-induced disabilities. Detailed results of each user study are reported in [3, 2]. In this section, we focus our analysis in the comparison of both user groups, highlighting their main differences and similarities in text-entry accuracy. This knowledge will enable designers to take into account their abilities and provide effective solutions for a broader target population.

3.1 Input Accuracy

The quality of the transcribed sentences was measure using the *MSD error rate*, calculated as *MSD(required sentence, transcribed sentence) / mean size of alignments x 100*. Fig. **1** illustrates participants' *MSD error rate* across all conditions. The mobility effect can be clearly seen in *SIID group*, from seated (*m*=5.1% *sd*=4%) to walking (*m*=7.5% *sd*=7%) conditions, resulting on a significant main effect [$F_{1.244,26.115}$=4.962, *p*<.05]. This result confirms that indeed users were situationally impaired by mobility. Nevertheless, their *MSD error rates* were still lower than *HIID's group*. In fact, when comparing *SIID* upper bound (walking two-hand portrait: *m*=16.5%, *sd*=11.9%) and *HIID* lower bound conditions (tablet: *m*=8.7%, *sd*=8.3%), we found a statistically significant difference [Z=-2.598, *p*<.01], suggesting that elderly participants face additional difficulties compared to situationally impaired users.

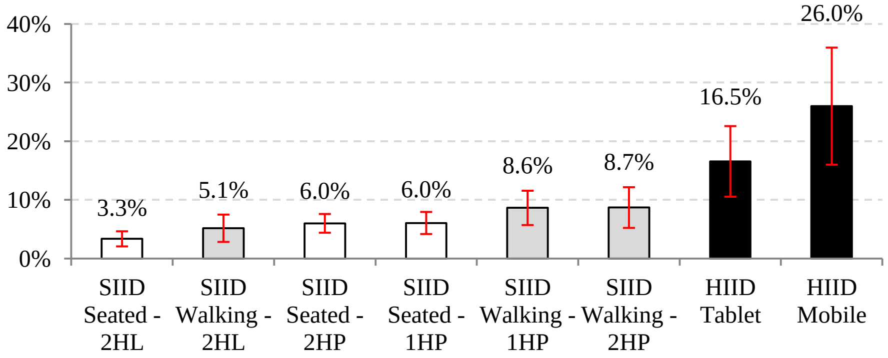

Fig. 1. *MSD error rate* across all conditions (2HL – Two Hand Landscape, 2HP – Two Hand Portrait, 1HP – One Hand Portrait). Error bars denote 95% confidence interval.

3.2 Types of Errors

In addition to overall *MSD error rate*, we performed a more thorough analysis of errors in order to better understand the performance gap between *HIID* and *SIID* groups. In this section we present a fine grain analysis of errors, categorized by type: *insertions* – added characters; *substitutions* – incorrect characters; and *omissions* – omitted characters. Also, we report the absolute and relative magnitude of each type of error for all conditions (Table 1). As the name suggests, the absolute magnitude consists in the mean error rate; while the relative magnitude corresponds to the mean error rate expressed as a comparison to the overall magnitude of *MSD error rate* (*error rate / MSD error rate *100*), which illustrates the importance of an error type for that user group.

	Absolute (%)			Relative (%)		
Condition	***Ins***	***Subs***	***Omi***	***Ins***	***Subs***	***Omi***
SIID Seated 1HP	1.1	4.3	0.6	18.6	71.4	9.8
SIID Seated 1HP	1.1	3.8	1.1	18.3	63.4	18.3
SIID Seated 2HL	0.7	1.7	1.0	20.7	50.6	28.4
SIID Walking 1HP	1.0	7.0	0.6	11.4	81.3	7.3
SIID Walking 2HP	1.4	5.5	1.8	16.5	62.9	20.4
SIID Walking 2HL	1.0	3.0	1.2	18.8	59.1	22.3
HIID Mobile	5.5	7.8	12.6	21.2	30.1	48.7
HIID Tablet	3.8	3.7	9.0	22.9	22.6	54.5

Table 1. *Insertions, substitutions,* and *omission error rates* across all conditions.

The *relative insertion error magnitude* is very similar across user groups, suggesting that *insertion errors* have a similar relative importance for both *HIID* and *SIID* participants. On the other hand, some types of errors are more relevant to one user domain than another. While *omissions* are the most common error type of *HIID* group, *substitutions* account for the majority of errors of situationally impaired users. This result illustrates the differences in the relative importance of each error type.

Regarding absolute error rates, both *insertion* and *omission* errors follow the same pattern of *MSD error rate*; that is, *HIID* participants obtained higher error rates than *SIID* users. When comparing *SIID* upper bound (worst result) with *HIID* lower bound (best result), we still found significant differences on *insertion* [Z=-2.511, p<.05] and *omission* error rates [Z=-3.093, p<.005]; that is, health-induced disabilities introduce additional *omission* and *insertion* errors when compared to walking conditions.

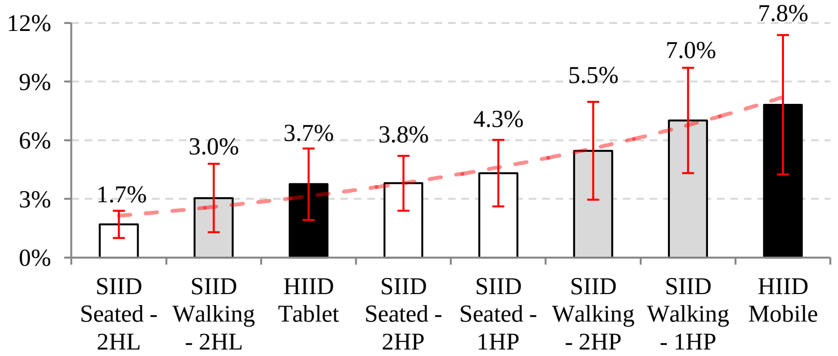

Fig. 2. *Substitution error rates* across all conditions. Error bars denote 95% CI.

Nevertheless, differences between *HIID* and *SIID* groups concerning *substitutions* are more blurry (Fig. 2). In fact, elderly users' performance with *tablet* device is very similar to *SIID seated* conditions (no significant differences were found). This suggests able-bodied users are disabled by mobile devices. Moreover, whilst walking, the *SIID* group's performance was similar to elderly performance with mobile device, showing that the increased demand of mobility results in a similar level of disability between user groups. We called this effect the "*disability continuum*", since there is not a clear distinction between health- and situational-induced disabilities. Instead there is a continuum of disabilities that is revealed with the increased demand of each condition. Overall, *HIID* and *SIID* groups revealed similar *substitution errors*; however, elderly participants committed additional *insertion* and *omission* errors.

3.3 *Substitutions* in Detail

In this section we perform a more detailed analysis on *substitution* errors, since this was the type of error with most similarities between *HIID* and *SIID* groups.

Substitution patterns. For situational impaired users, most frequent errors were at the right/left of intended keys. This finding may be related with key height in portrait mode; that is, keys are slightly higher than wider (7x10mm). Nevertheless, in landscape mode this pattern remained unchanged. For elderly participants we also found a consistent substitution pattern: right-bottom errors. Hit points were slightly deviated in right-bottom direction, which may be related to hand dominance and one-hand interaction mode. Overall, both user groups presented a consistent substitution pattern. Adjacent keys were commonly touched instead of intended keys. While same-row errors are common whilst walking, right and bottom substitutions are more frequent for elderly participants.

Cause of errors. S*ubstitution* errors have two main causes: poor aiming or finger slips. A finger slip consists in a correct landing on target and incorrect lift (i.e. users lift the finger on a nearby key), which originates a substitution. On the other hand, poor aiming errors occur when users land and lift their finger on wrong keys. Average slip error rate was below 10% and 14% for mobile users and elderly participants, respectively. Overall, most *substitutions* were due to poor aiming for both user groups, illustrating the importance of compensating hit points on touch typing.

One of the main differences between user domains regards cognitive errors. Some *HIID* participants consistently performed *substitutions* such as: p→q, m→w, i→j. We believe these to be cognitive errors: users had an improper model of the letter and have confused it with a similar one. This finding suggests that *substitutions* are not due to motor errors alone. Nevertheless, motor-based errors were more frequent.

4 Bridging the Gap

After analyzing both groups' performance, we are now able to identify their main differences and similarities, which should be used in future keyboard designs.

Cognitive abilities take an important role on elderly performance. One of the main differences between SIID and HIID groups were their cognitive abilities. Indeed, cognitive errors, namely confusion between similar letters and omission (i.e. forgetfulness) errors were very common among elderly participants.

Similar (relative) magnitude of insertion errors. Dealing with insertion errors shows to be equally important for both situational and health impaired users. We believe this type of error to be easily identifiable and automatically discarded by monitoring typing patterns. Nonetheless, personalization may play an important role in this solution as users' typing patterns may vary [2].

Substitutions continuum. We found substitution errors to be the most similar error type between user groups. In fact, SIID and HIID participants were equally affected with the increased demand of conditions, suggesting that designers will be able to reuse and leverage existing knowledge towards more inclusive solutions.

5 Conclusion and Future Work

We have investigated text-entry performance of both situational and health impaired users on touch-based devices and report their main differences and similarities. Our goal was to raise awareness and provide the knowledge to develop more broader and effective solutions. Indeed, results suggest that with the advances of mobile technologies there is not a clear distinction between able-bodied and disabled users, but rather a *"Disability Continuum"*. Elderly users experience common substitution errors with mobile users; however, they are also more amenable to cognitive errors. Following this work, we intend to analyze hand tremor features that were captured through the devices' sensors and develop touch models that can be applied in both user domains.

6 Acknowledgements

This work was supported by FCT: individual grant SFRH/BD/46748/2008; project PEst-OE/EEI/LA0021/201; and project PAELife AAL/0014/2009.

7 References

1. MIZOBUCHI, S. ET AL., D. Mobile text entry: relationship between walking speed and text input task difficulty. In *Proc. of Mobile HCI'05* (2005), 128.
2. NICOLAU, H., AND JORGE, J. Elderly text-entry performance on touchscreens. In *Proc. of ASSETS'12* (2012). *To appear.*
3. NICOLAU, H., AND JORGE, J. Touch typing using thumbs: understanding the effect of mobility and hand posture. In *Proc. of CHI '12* (2012), 2683–2686.
4. PAVLOVYCH, A., AND STUERZLINGER, W. Model for non-expert text entry speed on 12-button phone keypads. In *Proc. of CHI'04* (2004), 351–358.
5. SEARS, A., AND YOUNG, M. Physical disabilities and computing technology: An analysis of impairments. The Human-Computer Interaction Handbook: Fundamentals, Evolving Technologies and Emerging Applications. Lawrence Erlbaum (2003), 482–503.
6. WOBBROCK, J. The future of mobile device research in HCI. In *CHI'06 Workshop Proceedings: What is the Next Generation of Human-Computer Interaction* (2006), 131–134.
7. WOBBROCK, J., ET AL. Ability-Based Design: Concept, Principles and Examples. ACM Transactions on Accessible Computing (2011).
8. YESILADA, Y., ET AL. A simple solution: solution migration from disabled to small device context. In *Proc. of W4A'10* (2010), 27-29.