ABSTRACT

Title of Document: ACCESSIBILITY IN CONTEXT: UNDERSTANDING THE TRULY MOBILE EXPERIENCE OF USERS WITH MOTOR IMPAIRMENTS

Maia R. Naftali
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Directed By: Leah Findlater, Assistant Professor, College of Information Studies

Touchscreen smartphones are becoming broadly adopted by the US population. Ensuring that these devices are accessible for people with disabilities is critical for equal access. For people with motor impairments, the vast majority of studies on touchscreen mobile accessibility have taken place in the laboratory. These studies show that while touchscreen input offers advantages, such as requiring less strength than physical buttons, it also presents accessibility challenges, such as the difficulty of tapping on small targets or making multitouch gestures. However, because of the focus on controlled lab settings, past work does not provide an understanding of contextual factors that impact smartphone use in everyday life, and the activities these devices enable for people with motor impairments.

To investigate these issues, this thesis research includes two studies, first, an in-person study with four participants with motor impairments that included diary entries and an observational session, and, secondarily, an online survey with nine respondents. Using case study analysis for the in-person participants, we found that mobile devices have the potential to help motor-impaired users reduce the physical effort required for everyday tasks (e.g., turning on a TV, checking transit accessibility in advance), that challenges in touchscreen input still exist, and that the impact of situational impairments to this population can be impeding. The online survey results confirm these findings, for example, highlighting the difficulty of text input, particularly when users are out and mobile rather than at home.

Based on these findings, future research should focus on the enhancement of current touchscreen input, exploring the potential of wearable devices for mobile accessibility, and designing more applications and services to improve access to physical world.

ACCESSIBILITY IN CONTEXT: UNDERSTANDING THE TRULY MOBILE EXPERIENCE OF USERS WITH MOTOR IMPAIRMENTS

By

Maia R. Naftali

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Advisory Committee:

Assistant Professor Leah Findlater, Chair

Associate Professor Jennifer Golbeck

Assistant Professor Marshini Chetty

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Chapter 1: Introduction

"Limitations only go so far." - Robert M. Hensel.

We are in transition to a new computing paradigm. Touchscreen interaction and voice commands are taking over traditional input methods based on keyboards and mice, as small and portable devices are being used for tasks traditionally performed by desktop computers. In this shift, mobile technologies like tablets and smartphones have become an important source of information access by users with motor impairments.

Several studies have explored the accessibility of mainstream mobile devices for users with motor impairments, finding advantages as well as challenges in their use. In terms of advantages, touchscreen-based devices have been found to require less physical strength required compared to input methods based on physical buttons [19]. As well, compared to traditional assistive devices, the use of mainstream technology (e.g., smartphones, tablets) has shown more acceptance and increased perception of independence in social contexts [29,44,48]. On the other hand, several documented challenges affect the use of mobile devices by motor-impaired users. Basic gestures like zooming or tapping have been found difficult or impossible, increasing required effort to complete a task [2,16,20,30,55]. In addition, the context in which the mobile phone is used also brings challenges to motor-impaired users, sometimes preventing use of the device in a mobile (in transit) context or when restrictive clothing is worn [29].

A number of solutions have been studied to address these limitations. Pointing mechanisms that use the borders of the device as a guide [16], design guidelines for accessible interfaces[19,29], and interfaces that adapt to each user's abilities [17,23] have improved input performance for people with motor impairments on touchscreen devices. Yet, most of the research related to mobile accessibility takes place in a laboratory setting and does not provide an understanding on the use of mobile devices in everyday life. While laboratory studies allow us to learn about the low-level interaction of touchscreen devices in controlled quantitative assessments, field studies are needed to explain how devices are being used, reasons for adoption, and challenges encountered in practice This understanding of the needs of motor-impaired users can help in designing technologies that provide truly mobile information access—access anytime, anywhere.

Mobile device adoption in the United States has increased in recent years. According to U.S. Census Bureau [67], in 2012, 91% of adults had a cellphone, 45% of whom owned a smartphone. Similarly, a 2014 Pew report on mobile technology shows that 42% of adults in the U.S. also have tablets [70], whereas 34% of Internet users goes online mostly using their phones. In this mobile paradigm, it is essential to understand the adoption of such devices and the challenges that still persist in providing equal access to information for people with disabilities. Designing accessible mobile technologies can also present an opportunity for motor-impaired users to be more independent and connected [1].

1.1 Research Objectives and Approach

The goal of this research is to understand how smartphones are being used by people with motor impairments in everyday life, examining use both in and outside of the home. The primary research questions are:

- **Q1:** How are people *integrating* smart mobile devices on a daily basis into activities such as communication, transit, and shopping? In what *contexts* are mobile devices being used and are these contexts truly *mobile*?

- **Q2:** What *real-world accessibility challenges* arise that affect how these devices are being adopted (e.g., ability to use a smartphone in a busy café or on the street)?

- **Q3:** What are the activities that smartphones have *enabled* to users with motor impairments that were previously difficult or even impossible?

To address these questions, I conducted two studies: an in-depth, in-person study with four participants to study their use of a smartphone *in situ*, and, to triangulate findings from that study, a small online survey with nine participants with motor impairments. The in-person study consisted of three parts: an initial interview, a two-week diary study, and a three-hour contextual session that included a performance assessment of standard mobile input, a contextual interview, and neighborhood activities during which participants used the phone. The data collected in this study was analyzed using a case study approach, with four individual case studies followed by a cross-case analysis. The main emerging themes from this analysis were *enablement*, *challenges*, *wishes* and *personalization.* Following the in-person study, the online survey examined similar questions from a broader population of users with motor impairments. Despite the sample size of the survey, it offers preliminary additional evidence to support the themes found in the in-person study.

1.2 Contributions

This thesis makes the following primary contributions:

- Confirming in a field study previous findings on the challenges of touchscreen use by people with motor impairments that had been identified largely in lab-based settings.
- Extending research on situational impairments to encompass people with motor impairments, in particular, showing that movement and restrictive clothing can be a barrier to accessibility even after years of experience.
- Identifying and characterizing how smartphones are being used by people with motor impairments to overcome physical accessibility challenges.

1.3 Organization

This thesis is organized as follows. Chapter 2 provides an overview of related work. Chapters 3 and 4 represent the bulk of the research and cover the method and findings from the in-person study, respectively. Chapter 5 presents the survey method and analysis. Finally, Chapter 6 provides a discussion of the overall research and ideas for future work.

Chapter 2: Related Work

In this chapter, I introduce accessible computing for users with mobility impairments, including research on input methods, accessibility of touchscreen-based and mobile devices, and adaptive interfaces. This is followed by a review of diary studies as a research method in HCI, specifically applied to mobile computing.

2.1 Background on Motor Impairments and Technology

Motor impairments affect a considerable portion of the population in the US. Approximately 8.2% of adults have difficulties with physical tasks relating to upper body functioning, including lifting and grasping, and nearly 6.7% use wheelchairs. [68]. People with physical disabilities experience several difficulties accessing computers and interacting with input devices such as keyboards, levers, switches, and pointing devices. Some of the difficulties can impede computer use when upper body functioning or hand dexterity is affected [7,12,37]. For instance, Parkinson's disease can cause slowness of movement known as bradykinesia, making it difficult for an individual to lift their fingers off a keyboard quickly [37]. As another example, multiple sclerosis can cause numbness in fingers and tremor in extremities, which may cause unwanted movements while operating a device [37]. Similarly, a person with high spinal cord injury may not have sufficient movement to press keys at all [37].

2.2 Design Approaches to Accessible Computing

Providing access to technology to every user with a disability has been a matter of concern in academic research and for governments, many of whom have enacted legal frameworks to ensure accessibility rights. For instance, in the United States, Section 508 amendment of the Rehabilitation Act requires federal agencies to make their electronic and information technology accessible [69].

A primary question with accessible design [58,64] is: *Should people with disabilities be required to use additional interfacing tools to operate a system*? *Or should the technology instead adapt to each user*? While today's approach to accessibility largely focuses on having mainstream technologies accommodate and adapt to users, it has not always been this way. Vanderheiden, one advocate of Universal Usability, classified different strategies applied to the design of accessible technology into: (a) change the individual, (b) provide them with tools they can use, or (c) change the environment [57]. Focusing on strategies (b) and (c), several approaches emerged with the common goal of creating accessible technology [64]. Assistive Technology and Rehabilitation Engineering are examples of those that provide users with special tools. On the other hand, Universal Design, Universal Usability [49,58], Ability-based Design, and Extraordinary Human-computer interaction [41] are examples of design approaches that change the environment.

The main disadvantage of strategies that provide individuals with special tools—instead of integrating accessibility into mainstream technology—is that they can stigmatize users with disabilities, especially those who would rather not use a dedicated technology [44,48]. For instance, the use of special keyboards or mouth sticks by motor-impaired users to press keys suggests that they are not able to use a standard keyboard. In that sense, mobile devices have shown advantages, as they integrate accessibility to the mainstream technology instead of leveraging a separate solution for users with disabilities access.

Figure 2.1: A keyboard with raised areas between keys for users with tremors or spastic movements [60].

Figure 2.2: a mouth stick to press keys. From WebAim [60] .

2.3 Accessibility of Traditional Computer Input

Many accessibility concerns and input improvements that apply to mobile touchscreen devices build on accessibility research with traditional computers. A variety of input methods have been studied to allow motor-impaired users access to computers, including keyboards, pointing devices such as mice, and joysticks. Prior to 1992, research on accessible input methods centered on designing assistive devices, while accessibility was not integrated in the majority of mainstream technology [59]. Glinert and York compiled emerging studies from that period, and suggested moving “assistive technology from specialized devices [hardware] into software” by means of virtual keyboards and word prediction [12] and customization of keyboard functions [7]. This led to a number of subsequent studies aiming to provide accessible computing to users with motor impairments by means of software implementations [13], adaptive interfaces (those that change automatically based on knowledge of user needs) and adaptable ones (those that offer mechanisms for users to customize the interface) [15,61].

A considerable part of accessible technology research has focused on analyzing keyboards for motor-impaired users, which present difficulties such as hitting adjacent keys involuntarily, or performing multi-keystrokes, among others [7,54] . Since Glinert and York[18], a number of studies have focused on accessible keyboard and pointing input for users with motor impairments. Trewin and Pain quantified low-level interaction of keyboards and mice, concluding that participants with motor impairments took three times as long as the control group for both mouse and keyboard tasks, and encountered difficulties in dragging, pointing and long keystrokes [53,54]. A subsequent study proposed a self-configuring keyboard that monitors the user's keystrokes and automatically adjusts key repeat delay to accommodate input errors [56]. Also using a virtual a keyboard, more recent work has proposed the use of a head tracking pointer using a Wii Remote control and Infra-Red LEDs attached to a pair of glasses [22]. Some research also suggests alternative input methods to keyboards, such as joysticks and haptic devices [26,65]

Interaction with pointing devices has also been studied for users with motor impairments, showing challenges in selecting small targets, performing accidental clicks, and pointing and clicking with mice [14,27,32,52,54]. Similar to keyboard studies, initial research aimed to understand low-level interaction of mouse movements, accuracy on target acquisition operations [25,32], and performance comparisons between trackballs and mice [63]. Trewin et al. proposed a method for cursor assistance that freezes the cursor during clicks to improve clicking problems [52]. With the goal of facilitating pointing on small targets, Findlater et al. introduced enhanced area cursors that rely on magnification and goal crossing using standard mice [14]. In the same way, Hurst et al. developed a technique that collects pointing performance data in a real context of use to classify users and adapt pointing tasks [24]. Another recent implementation of adaptive systems applied to target acquisition and pointing tasks proposed a software that detects motion near a target and accommodates device's speed [9]. While these studies focus on traditional input methods, many of the findings on pointing devices are important to understand touchscreen interaction. For instance, both traditional and touchscreen interaction create challenges for people with motor impairments in pointing to small targets.

2.4 Situational Impairments

One important characteristic of mobile computing is that environments move along with users, allowing them to operate systems and perform tasks on the move even in hazardous conditions, but also introducing new constraints to interaction and connectivity [46,51]. This fact of motion has a considerable impact in how we interact with mobile devices compared to desktop computing, as the physical context is always changing and users cannot devote their attention to the screen. In addition, input and output capabilities are reduced or constricted [36]. Sears at al. defines the presence of *Situationally-induced Impairments and Disabilities* (SIID) or *Situational impairments* when there are contextual factors that affect how users interact with a device [47]. These factors can be *environmental* (lighting conditions, glare, noise, vibrations, temperature, rain, weather), *attentional* (social interactions, divided attention, device out-of-sight, physical obstacles) and *physical* (clothing, baggage, occupied hands) [30].

A number of studies have analyzed the effects of SIID on input accuracy with mobile devices. Barnard et al. examined the effects of movement and lighting while sitting or walking, finding that motion significantly affected task performance [3]. Similarly, Lin. et al. studied stylus-based tapping operations on PDAs while walking on a treadmill, standing and walking in an obstacle circuit [34]. The study found that users under the most extreme conditions of the obstacle circuit had to reduce their walking speed by up to 90% to maintain tapping accuracy. They also found that larger targets were selected more quickly than small ones for all the experimental conditions, and confirmed that the treadmill and obstacle course increased error rates for target selection [34]. Other studies have examined the impact of walking on text legibility with mobile device, showing that visual performance is affected [40], and that users compensate by sacrificing walking speed[35]. Conversely, Perry and Hourcade [45] studied one-handed thumb interaction, finding that movement did not significantly affect performance.

To accommodate situational impairments, adaptive interfaces and pointing techniques have been explored. Kane et al [30] evaluated the feasibility of *walking user interfaces* that adapt their layout when the user is moving, enlarging target size. The findings confirm Lin et al. study [34] about the effects of movement, suggesting that enlarging target size may be effective for reducing the negative effects of target acquisition while walking. Similarly, to minimize the impact of situational impairment by walking Goel et al. [3] designed and evaluated a model that adapted text-entry systems for users on-the-go. By using the smartphone's accelerometer to compensate for movement, their final adaptive keyboard resulted in a 45% decrease in errors. Bragdon et al. [5] investigated the impact of situational impairments on touch-screen gestures. The study confirmed that gestures that used physical edges—bezel and mark based—were more accurate and less demanding for the context.

The majority of the studies presented in this section analyze the impact of situational impairments through laboratory experiments that simulate contextual factors. Moreover, they largely do not focus on people with motor impairments. This thesis differs, in that I studied use *in situ*, through field studies and observations to understand the impact of situational impairments in a more realistic way.

2.5 Accessibility of Touchscreen Devices and Mobile Phones

Mobile computing presents advantages for motor-impaired users, but also challenges. Users with motor impairment who lack of dexterity in their hands can find it difficult or even impossible to press physical buttons [2,16,20,30,55], but touchscreen devices provide an opportunity for these users, as they require less physical strength to use. However, despite being less demanding than regular keypads for the reduced strength required, touchscreen input still presents challenges in gestures like target acquisition [16,20,31,55]. Research has focused in understanding and measuring how people with physical impairments use touchscreen mobile devices, and how to adapt the phone to overcome challenges.

The accessibility of different touchscreen gestures for motor-impaired users has been studied from a quantitative approach, measuring accuracy and performance of tasks. Target acquisition was found to be challenging [20,38], and the use of physical edges as a guide has been proven to increase accuracy and stability [5,62,66]. As an example of physical edge use, Froehlich et al.[16] proposed and evaluated a target acquisition technique with a stylus that uses the physical edges of a PDA's screen as a guide, suggesting that users with limited fine motor control increased their accuracy. Also, Guerreiro et al. [20] measured the accuracy of tapping, crossing, exiting and directional gesturing operations with users with tetraplegia, finding that targets located at the bottom of the screen and next to the preferred hand were the easiest to select. As for multi-touch gestures, Trewin studied found that users with motor impairments encountered difficulties in pinching and performing three-finger slides [55].

A number of techniques have been studied to enhance the accessibility of touchscreen devices for motor-impaired users, including adaptive interfaces and assistive technologies. Montague et al. [39] analyzed adaptive interfaces using a user model shared across devices for touchscreen user interfaces. The study showed that adaptive interfaces may be particularly useful for people with severe disabilities, but also that minor adaptations can be helpful for users with less severe disabilities, such as age-related vision loss. As examples of customization, Borges et al. [4] configured a mobile device for a user with cerebral palsy using participatory design, suggesting that minor modifications to mainstream applications input allowed for use of the device. Also using participatory design, Carrington et al. designed an arrangement of mobile devices to power wheelchair, exploring placement and form factor [8].

Similarly, by observing nearly 190 user-generated YouTube videos, Anthony et al. analyzed how users with physical disabilities operate and adapt mobile devices such as tablets and smartphones [2]. The study found that, despite the challenges found on multi-touch gestures, users were abl1e to use mainstream touchscreen devices and considered them empowering. It also proposed a characterization of interaction styles, use cases, challenges and home-made solutions, together with design implications to improve touchscreen usability for people with physical impairments. Finally, it emphasized the potential of touchscreen mainstream devices in terms of adaptation capabilities.

Another aspect that has been analyzed besides performance is how users with motor impairments use and adapt mobile devices. Five years ago, Kane et al. studied how people with motor impairments use mobile phones in the wild, what are the challenges and situational impairments found, and how are such devices selected and adapted. The study found that participants were able to use mainstream devices despite the challenges encountered, and the most frequent adaptations that users implemented were text resizing, the use of screen readers, and custom holders or hooks for the device. It also suggested that the situational effect of movement on people with motor and visual impairments might be drastic, as participants reported they were unable to use a phone while walking [29].

From a different perspective, Shinohara and Wobbrock [48] interviewed individuals with motor and visual impairments using mainstream mobile devices to study assistive technology acceptance and how technology use is affected by social and professional factors. They found that "functional differences between assistive technologies and their mainstream counterparts influenced misperceptions" that support stereotypes that (1) users with disabilities cannot use mainstream technology, and that (2) "people with disabilities would be helpless without their devices". The study recommends that accessible technologies should be part of mainstream devices and not treated as separate components, also confirming what the Universal Usability [49,58,59], Ability-based Design [64]and Extraordinary Human-Computer Interaction [41] frameworks envision. The authors suggest that such technologies should address not only function, usability, and cost, but also aesthetics and social acceptance [48].

The study I performed shows similarities and differences from Kane et al. [29]. While both studies analyze the impact of situational impairments and mobile adoption of users with motor impairments using a diary study method, this thesis focuses only on smartphone devices (more widely adopted today) and users with motor impairment, and uses contextual sessions to complement diaries with observations.

2.6 Diary Studies in Human-computer Interaction Research

This thesis employs a diary study method, among other approaches. The use of diary studies in human-computer interaction comes from sociology and history fields [33]. While diaries can be general—on non-temporal bases—or timed, the latter are the most common in HCI research because of the focus on frequency of application use [33]. Diaries can help connect the gap between observations in a naturalistic setting, and controlled laboratory studies isolated from the context, by providing records of the field that can be used later in a more controlled method [28]. The two primary types of diary studies are *feedback*, which focuses on events that researchers want to retrieve and provides instructions or questionnaires for entries, and *elicitation*, which prompts users to create entries when they find an event relevant [33]

In recent years, diary studies have been used in HCI to evaluate mobile technologies, as mobile interaction takes place mostly in uncontrolled settings [6,9,11,29,42,43,50]. Most closely related to this thesis is a 2-week diary study by Sohn et al. [50] conducted a 2-week diary study with mobile phone users to analyze their information needs when they were away from home, as well as the strategies used to address needs, and the contextual elements that prompted each need. This study used both elicitation diaries through SMS, and feedback diaries through a web form, finding that contextual factors affect how mobile users access information from their devices

2.7 Summary

Different approaches to accessible computing were reviewed, exposing the disadvantages dedicated assistive devices in comparison to accessible mainstream technology for users with disabilities. Context of use is an important factor to consider, as situational impairments like movement can affect how tasks are performed. However, most of the accessibility research on mobile devices for users with motor impairments is experimental and takes place in a controlled setting, in contrast to the research conducted for this thesis.

Chapter 3: In-person Study Method

This chapter describes the research design of this study, as well as procedure details and general aspects of the data analysis performed. Data was collected through initial interviews, a 2-week diary and contextual interviews.

3.1 Rationale

The most important goal of this research is to understand how smartphones are not just operated, but adopted on a daily basis by users with physical disabilities, and what challenges are encountered. I performed an in-depth methodology that combined diaries with contextual interview and observation sessions. Diary studies can be an effective method to collect data about habits during a specific period [33], while applying triangulation with contextual methods can provide a better understanding of the real use of smartphones in any environment.

3.2 Procedure

I performed an in-depth multiple case study analysis, followed by a survey to collect data from a wider community with motor impairments. As shown in Figure 3.1, the in-person part of the study consisted of three portions: initial interview, diary and contextual session.

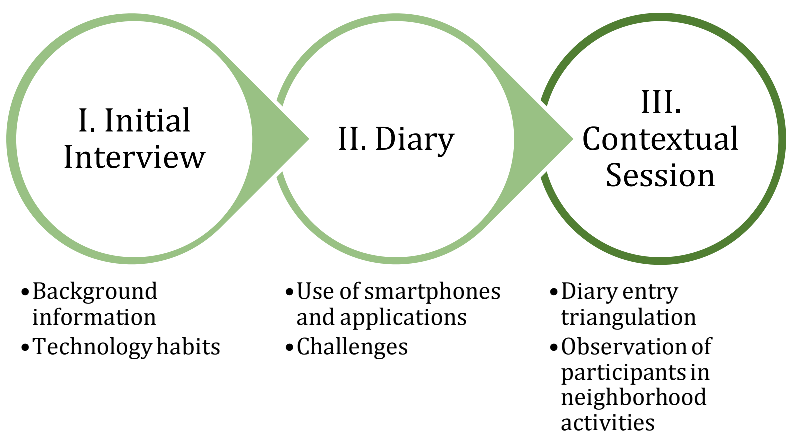

Figure 3.1: The in-person method procedure included an initial interview, a diary study, and a contextual session

3.2.1 Initial Interview

The goals of the initial interview were to collect background information and technology habits from participants, and also to explain study procedures. Smartphone users with motor impairments were interviewed through a 30-minute structured questionnaire that was audio recorded and transcribed. Questions covered participants' demographic information, diagnosed medical conditions, smartphone model, frequency of use of smartphones, and assistive technologies used. At the end of the interview, the diary study portion was explained and participants were able to choose between voicemail and a web form to perform their daily entries.

3.2.2 Diary Entries

The objective of the diary portion was to collect evidence about the use of the phone in different contexts, minimizing the observer and recall effects that can appear in methods like interviews or focus groups [9,33] by capturing events closer to their occurrence, and allowing users to provide the information by themselves. Through their daily entries, participants provided data about use of their phone: what applications were used, positive or negative experiences, challenges encountered, and when the phone was useful for activities performed outside home.

Participants were required to complete at least 10 entries over a 2-week period received a reminder at 7 p.m. each day for 14 days by either email, SMS, or voice message, and completed a questionnaire taking approximately 10 minutes. The questionnaire consisted in two multivalued questions and four open-ended questions. For accessibility, participants could complete entries in one of three formats: a Google form, email and voicemail. Entries could be completed up to one day late, but no later.

Each entry had the following six questions:

- For which of the following tasks did you use your phone today? (Select all that apply)
- What activities did you do outside the home today?
- For what activities was the phone especially helpful today inside or outside the home?
- What are the worst experiences you had with the phone today?

- (Optional) Were there other accessibility issues you encountered today not involving the phone? If so, please explain.
- (Optional) Please share any other comments or ideas you have about your phone experience.

3.2.3 Contextual Session

Following the diary entry portion, I scheduled a 3-hour contextual session with each participant. The goal of using this session was to observe users in their real context and, at the same time, collect in-depth information about mobile use beyond the diary entries. The contextual sessions consisted in in-person interviews, demonstrations and observations in public places with participants to: (1) triangulate data from diary entries; (2) get information about use of smartphones outside from home, including encountered challenges and SIID; (3) collect evidence about use of mobile devices in daily activities. These sessions have similarities with contextual interviews, as participants are observed with their devices in their context of use, and were also asked to demonstrate specific tasks with their devices in order to understand their difficulties and intrinsic knowledge [33].

I arranged with participants place, time of day, and neighborhood activities to perform during the session based on their regular habits (e.g. as reported in the diary entries). Each session was structured into three parts:

1. Assessment of touchscreen operations using a ten-task test. 10 minutes.
2. Semi-structured interview about use of the smartphone, including participant's demonstrations of smartphone use and challenges, and general aspects of mobile adoption and wishes. Three parts of up to 45 minutes each.
3. Neighborhood or out-of-home activities, different for every participant. Between 40 and 60 minutes.

Data were collected using video, images, audio recordings and notes.

1. Assessment of touchscreen operations - Ten-task test

To detect difficulties with touchscreen operations, the session began with an assessment of the participant's performance on a set of common smartphone tasks. All the tasks were performed using the same phone (Samsung Exhibit II 4G 2.7", Android 2.3.2.):

1. Strength A: Grab the phone and lift it
2. Strength B: Press power button
3. Long slide: unlock screen
4. Pointing A: Tap right upper corner icon
5. Pointing B: Tap in the center
6. Pointing C: Tap lower corner icon
7. Slide A: Scroll a text, vertical
8. Slide B: Scroll a map, horizontal
9. Pinch: map zooming in and out
10. Hold tap and swipe: icon moving

Participants were asked to repeat each task twice with their dominant hand and were permitted to attempt the task three times if they initially failed. At the start of each task, the phone was placed on a table in front of the participant. A video camera located in front of the starting phone position to record the interaction, and I took notes of the observations. See Appendix A for a detailed description of testing procedures.

2. Contextual Interview

The goal of the contextual interviews was to triangulate data from the participant's diary and to collect in-depth information about use in a non-laboratory setting. During this part of the session, participants were interviewed in a semi-structured questionnaire, and were asked to demonstrate specific tasks they perform with smartphones that had been reported in their diary. The contextual interview was split into three portions of 45 minutes or less each. The first part of the interview covered aspects of the use and adoption of the phone, and the second part covered challenges encountered. Finally, the last part covered general aspects of mobile adoption, as well as elements to improve in current mobile phones, and wishes about future technology, with the following six questions:

[1] How do you think your day would change if you didn't have the phone?
[2] How do you think the **activities** you're able to do in a day would change if you didn't have your phone?
[3] How do you think the activities you're able to do in a day would change if your phone would be **more accessible**?
[4] Has the phone **changed** how you do **things at home** or do the internet?
[5] What are the things that you **would like to have** in your phone to make a great experience?
[6] How would your **ideal phone be**, if you could design it as you wanted?

3. Neighborhood Activities

This portion of the session collected data about everyday use of phones outside the home, and the effects of situational impairments due to weather, movement, restrictive clothing and divided attention, among others. Depending on reported habits, participants were taken to the selected locations, such as coffee shops, groceries or metro stations, to perform activities they usually do. For instance, one activity could be to navigate included through a grocery store to find and purchase an item, or another activity could be to check the train schedule while traveling to the metro station. Participants and the interviewer agreed in advance on the set of activities and locations.

Data collection included images, video, audio recording and notes. Participants wore a small audio recorder, while the interviewer took notes or video recorded the activities performed.

3.2.4 Recruitment

I recruited participants with motor impairments affecting their use of the phone, who had also owned smartphones for at least 18 months. Participants from DC, Maryland and Northern Virginia were invited through a combination of listservs to which belong, publicly available listservs and bulletin boards targeting people with disabilities, advertisements through organizations that work with people with disabilities, and word of mouth.

3.2.5 Data Collection and Analysis

Part	Devices used	Data Collected
Initial Interview	Audio recorder, redundant audio recorder, Google Form	Audio, notes
Diary	Google Form per use	Diary entries
Contextual Session	Audio recorder, redundant audio recorder, video camera, camera, backup camera, notebook	Audio, video, observation notes, images.

Table 3.1: Types of data collected during the in-person study

The information collected was stored on the primary researcher's computer and external drive, and using University of Maryland servers. All collected audio was transcribed, while portions of the videos were used to take observation notes and extract images.

For the contextual session, an HD video camera was mounted to a portable tripod focusing the screen to record participant's interaction with the device. Interview audio was recorded using a portable recorder on participant's side, and also using a redundant device located between me and the participant. Notes were taken during the entire interview, as well as photos of participants interacting. During neighborhood activities, a small audio recorder was located on participant clothes, while pictures and videos where taken with an HD portable camera by the interviewer.

The in-person study will be presented using a multiple case study analysis method. The data collected in diaries and the audio transcripts from the in-person sessions were analyzed with initial coding on a first pass, and codes were subsequently grouped in a hierarchy. After another pass on the coding, the emergent categories were selected for an axial coding analysis.

The coding process was validated using pair-review with one external reviewer not on the research team and myself. Excerpts from interview sessions and diary entries were collected from six different categories out of eighteen, three of them randomly selected (activities, organization, transport), and the other three chosen by relevance to the research questions (situational impairments, social acceptance, physical world control). The external reviewer read through all excerpts that had been coded for each of those six categories, and marked agreement or disagreement about whether the excerpt belonged in that coding category and the correct code was applied. Finally, both coders reviewed instances of disagreement. See Appendix A for the final code set.

Chapter 4: In-person Study Findings

In this chapter, I first introduce each participant from the in-person study and their background. Then, I present the four participants as separate case study analyses, focusing on themes of physical use of the phone, enablement, challenges and situational impairments, and use and personalization. Finally, I summarize the overall findings. Data reported here comes from the initial phone interviews, the diary entries, and the contextual session with each of the participants.

Four smartphone users with motor impairments from the DC/VA/MD area were recruited between October and December 2013. Table 4.1 shows participant's background information, and Table 4.2 summarizes their use of technology, including smartphone model, frequency of use and applications being used. Table 4.3 shows the results of the ten task assessment with observation notes.

	P1	**P2**	**P3**	**P4**
Gender	Male	Male	Male	Male
Age	46	24	30	29
Occupation	Transportation employee	Technology consultant	Designer, unemployed	Technology and accessibility consultant
Diagnosed condition	▪ Muscular dystrophy ▪ Partial use of hand and arms ▪ Limited walk with braces ▪ Photophobic ▪ Limited visual acuity in right eye ▪ Nearly blind in left eye.	▪ Cerebral palsy ▪ Mobility impairments ▪ Lack of dexterity on left hand ▪ Speech affected	▪ Quadriplegic ▪ Poor hand dexterity	▪ Cerebral palsy ▪ Mobility Impairments
Starting since	Birth	Birth	6 years ago	Birth
Frequency of going out	Every day: commuting to work, and weekend errands	Every day: commuting to work, and weekends/after hours	Only on weekends and social events	Every day: commuting to work, and weekends

Table 4.1: Background information of study participants.

	P1	P2	P3	P4
Frequency of computer use	Every day	Every Day	Every Day	Every Day
Computer applications used	Microsoft Office, browsing, Skype	Microsoft Office, browsing, Skype, work applications	Adobe products, email, browsing, maps	Microsoft Office for Mac, browsing
Smartphone model	**LG Google Nexus**	**Samsung Galaxy S4**	**IPhone 5 iOs7**	**IPhone 5s iOs7**
Time using smartphones	4 years	7 years	~2 years	8 years
Plan type	Family, unlimited	Family, data shared	Family, unlimited	Personal, unlimited
Frequency of smartphone use	Every day, 2 hours a day	Every day, multiple times a day	Every day, more than 2 hours	Every day, multiple times a day
Tasks performed with smartphone	▪ Phone calls ▪ SMS ▪ Reading, Kindle app ▪ Games ▪ Navigation ▪ Camera ▪ Plugins for desktop appearance	▪ SMS ▪ Email ▪ Navigation ▪ Social networks	▪ Audio podcasts and books ▪ Social networks ▪ SMS ▪ RSS feeds ▪ Camera ▪ Remote control ▪ Games ▪ Reminders and notes	▪ Phone calls ▪ SMS ▪ Authentication ▪ Online shopping ▪ Work ▪ Transportation
Accessibility technology used	▪ Dragon Naturally Speaking ▪ Darwin ▪ Magnification tools ▪ SVOX (voice-to-text)	None	▪ Assistive Touch ▪ Siri for dictation	▪ Dragon Naturally Speaking ▪ Siri
Could you use a smartphone without assistive tools?	"Having them [assistive tools] it will be easier.. it will certainly be more convenient"	"Yes."	"I would still be able to use it. It will just be slower... And ... especially when pressing the physical buttons I usually have to kind of pin the phone... hmm… so it doesn't move...."	Yes. "Anything I can do to reduce the amount of time that I have to touch the phone…"
Devices used outside home	Smartphone	Smartphone, laptop only for work	Smartphone	Smartphone

Table 4.2: Use of technology.

	P1	P2	P3	P4
1. Grab the phone and lift it	Participant uses the table to make the phone fall in the palm of the right hand, and move it to the front of the lap. Then, he uses the leg to return the phone to the table	No issues observed. Might use left hand as a support to rotate the phone.	No issues observed	No issues observed
2. Press power button	Use of legs and both hands to position the phone on his left hand, and rotate the phone to turn on the button. The small button presented some difficulty	No issues observed	No issues observed. Using left hand as a buffer	No issues observed
3. Long slide	No issues observed	No issues observed	No issues observed	No issues observed
4. Tap upper corner target	No issues observed	No issues observed	No issues observed.	No issues observed
5. Tap center target	No issues observed	No issues observed	No issues observed.	No issues observed
6. Tap lower corner target	No issues observed	No issues observed	No issues observed.	No issues observed
7. Vertical slide	No issues observed. Using thumb finger.	No issues observed	No issues observed.	No issues observed
8. Horizontal slide	No issues observed. Using thumb finger.	No issues observed	No issues observed.	No issues observed
9. Pinch	First locates the thumb in the center, and moves the index left or right.	Using both hands.	Using middle and ring finger for small areas, but two hands for bigger areas.	No issues observed
10. Long tap and swipe	No issues observed	No issues observed. Using left hand to prevent the phone to slide on the surface.	No issues observed.	No issues observed
Dominant Hand	Right	Right	Right	Right

Table 4.3: Ten-task assessment results.

4.1 Case One: P1

Participant P1 is a 45-year-old male works in the transportation industry and lives with his wife and kids. P1 was diagnosed with muscular dystrophy since birth, having partial use of hand and arms, and limited ability to walk with braces. He also has limited visual acuity and photophobia in his right eye, and is nearly blind in the left eye. P1 uses a power wheelchair only when he feels tired or needs to carry weight. In his spare time, he loves cooking and organizing meals at home, and also enjoys practicing sports, reading, and following soccer leagues.

P1 acquired his first smartphone, a Google Nexus Android, four years before the interview. He uses desktop computers equipped with Dragon Naturally Speaking software and magnification tools for browsing, working with Microsoft Office and talking on Skype. Despite feeling confident about being able to use computers without assistive technology, P1 feels that not having those tools would be more complicated for him.

P1 completed 15 diary entries over a period of 17 days. The most commonly used applications reported were: (1) communications via email, phone and SMS; (2) weather reports; (3) books; (4) calendar and scheduling (Figure 4.1). As for activities outside of home, the most frequent were: (1) travelling around town and commuting; (2) work; (3) shopping and groceries; (4) sport and social (Figure 4.2).

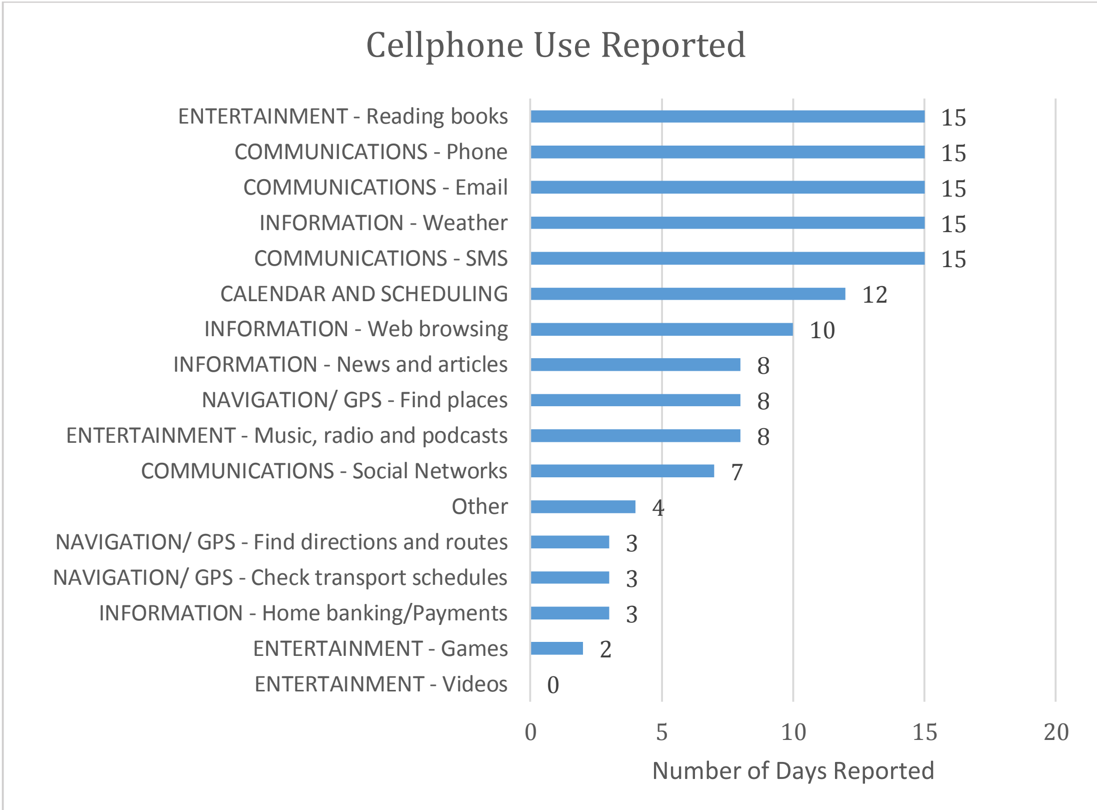

Figure 4.1: P1 cellphone use reported.

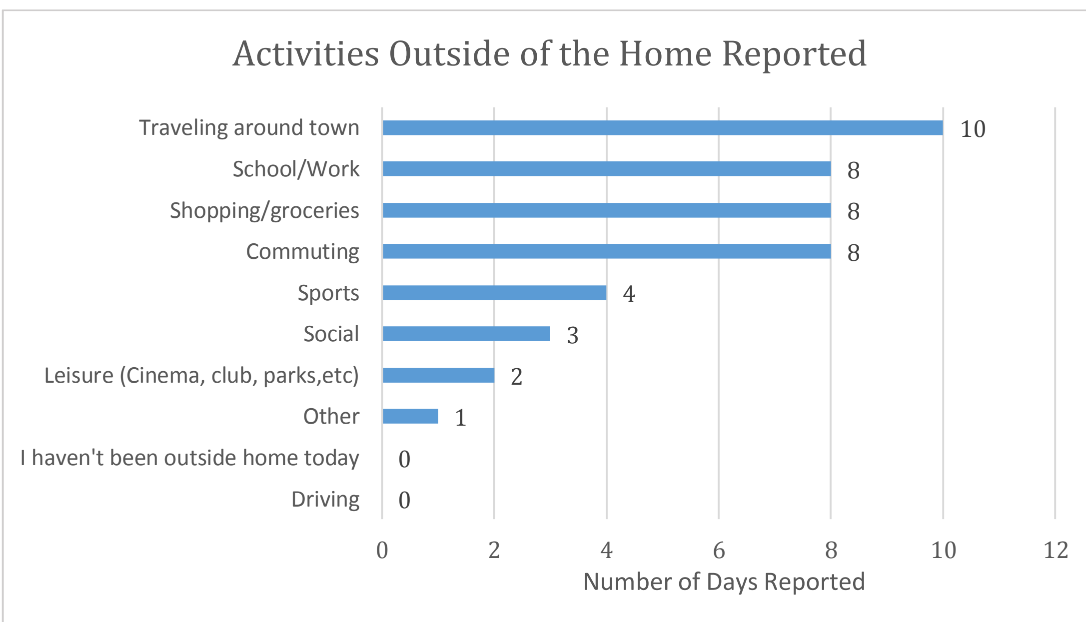

Figure 4.2: P1 activities outside of the home reported.

4.1.1 Contextual Session

The contextual session with P1 took place on a Sunday morning in a coffee shop in a busy urban area. After analyzing P1's diary, the questionnaire of the contextual interview was customized to include questions and demonstrations of his use of smartphones while doing errands, cooking, travelling, reading and accessing information on-the-go.

P1 showed how he uses his phone to share files on Dropbox, check sports information, read books, play word games, answer and send SMS from voice control, use social networks (Facebook), and correct text. This portion of the session took 110 minutes.

Neighborhood activities included a short walk to a pharmacy and a visit to a Metro station. As it was snowing with a temperature near 0°C, these activities took place indoors. In the pharmacy store, the activity assigned was to purchase batteries, to find out how to commute from that area to College Park, and to look up the current temperature. After getting to the Metro station and entering the system using a contactless card, the activity was to get the waiting time for the next train.

4.1.2 Findings

4.3.5.6 Case summary – P1

Enablement	• Home activities (e.g. cooking and groceries) • Gaming • Reading (books, newspaper) • Personal organization (e.g. calendar, notes, reminders) Better capability of keeping up with things • Accessing information on-the-go(web, payments, files) Feeling more productive • Communication with his family
Challenges	***On phone use*** • Grabbing and holding the phone outside of the home • Lengthy text input on touchscreen • Voice to text accuracy on the phone, and text correction • Reading small/low contrast text ***Situational impairments impact*** • Movement or walking • Impeding clothing • Weather
Use	• Communications • Transportation

	• Entertainment • Reading • File sharing
Wishes	• More accuracy on voice commands and dictation (voice-to-text) • More accessible experience with Facebook app to share images • Change color and font size on apps for a better readability

Table 4.4: P1 case summary.

4.1.2.1 Physical Use of the Phone

P1 manipulates the phone by holding it with his left hand on his lap (Figure 4.3). When he is not using it, the phone is stored in a pocket or held on his neck from a small hook at the top of the plastic protective case (Figure 4.4).

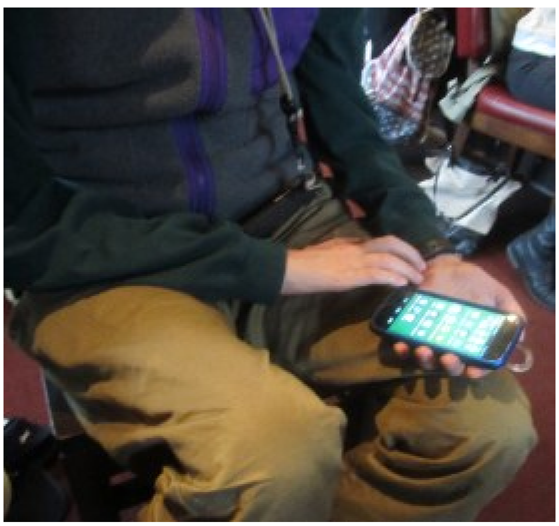

Figure 4.3: Using the smartphone.

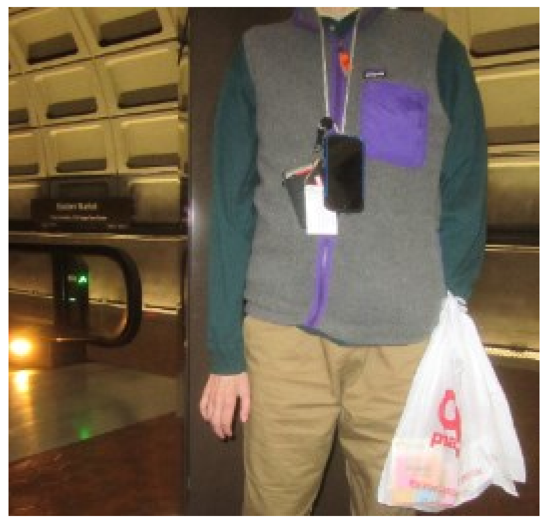

Figure 4.4: storing the smartphone for moving around.

At the beginning of the contextual session, P1 completed the ten performance tasks, with the following results. P1 was able to perform all touchscreen gestures necessary to operate a smartphone, even if he sometimes adapted the techniques to suit his abilities. For instance, to grab the phone, he moved his right hand on to the table by initiating movement from his shoulder. Performing small movements with his right hand with the help of his torso, he moved the phone to the edge of the surface and let it fall on his left hand, which was located below the edge. To return the phone to the table, P1 used his left leg to elevate his left arm and let the phone fall to the surface (Figure 4.5). During the session, the phone fell to the floor once as his left hand released it before the arm was over the table. As for multitouch gestures, P1 first tapped with his thumbnail or index finger near the target, then swiped the middle finger of the same hand left or right to zoom in or out (Figure 4.7).

Figure 4.5: P1 moving the phone to the edge of the table.

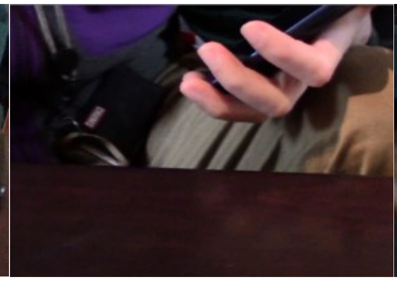

Figure 4.6: P1 grabbing the phone after letting it fall from the table.

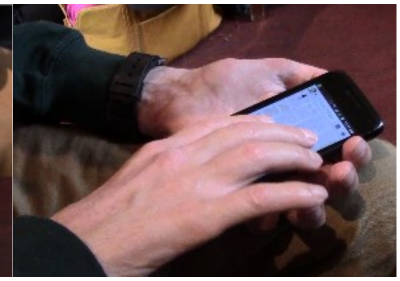

Figure 4.7: P1 showing a pinch gesture in two stages.

Grabbing and operating the phone for P1 requires him to be seated and to have both hands free. When he needs to take out his phone from a pocket or remove it from the hook around his neck, he first needs to find a place to sit and bend. If the phone is on the hook, he might use his mouth to hold it for more stability while his right hand takes it off the hook and grabs it.

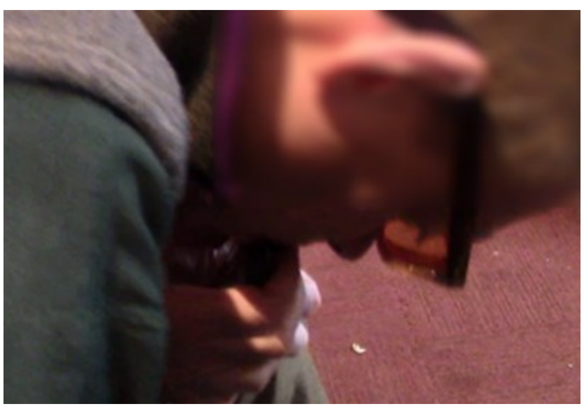

Figure 4.8: P1 taking the phone off the hook with his mouth.

Figure 4.9: P1 holding his phone in a hook.

4.1.2.2 Enablement

Using a smartphone enabled P1 (1) to be more communicative with his family; (2) to take care of home activities like meal planning and laundry; (3) to read more; (4) to organize his day using calendars and notes; (5) to access information on-the-go.

P1 uses his phone to take an active role in housework activities such as meal planning and laundry. For instance, he prepares meals by using the Kindle app to access recipes when he is in the kitchen, being able to find recipes by ingredient. He also uses his phone to manage groceries by keeping track of shopping lists, to-dos and calendar entries. As he commented:

> *"And even at home because I have a disability I am not doing the physical work of the house, my job is meals. Meals planning. Keeping a calendar straight. It would be more difficult for me to do that without the phone."*

The phone also allows him to read books and newspapers because he can enlarge the text in the Kindle App and reverse the colors, or use voice to text. In addition, he commented that he usually accesses books in the Darwin app (a book reader). In discussing the difficulties he previously had in reading and how the phone helps, P2 commented:

> *"I've already tried very, very hard to read prints because there wasn't as much available and now 90% of the books are available in electronic format… So I actually read more now than I read 4 years ago… just because of the accessibility… and I read a lot more now because of the phone..."*

While P2 has difficulty with physical writing due to lack of strength in his hands, he can enter text on the touchscreen. Being able to enter text on a mobile device allows him to take notes for scheduling meals and making lists for personal organization. During the session he commented that he finds calendars on the phone useful because he can add events at any time instead of waiting to get home and access the computer.

Accessing information on-the-go helps P1 to avoid challenges from the real world when moving around or doing errands. For example, the metro fare machines are not accessible for P1, but he adds funds to his metro card on the mobile website. He can also check if a place is open before attending, or perform online payments from his mobile device:

> *"[without the phone] I will have to be more cautious about preparing for the activities I am going to do during the day, and that would limit extraordinarily... that could be something as simple as not knowing to go to a store that might be a couple of blocks away because you wouldn't know whether it was open or not."*

4.1.2.3 Challenges and Situational Impairments

Touchscreen Input and Phone Use

Input is an important challenge for P1. He finds that voice-to-text on his phone is not as accurate as Dragon in his desktop computer, requiring him to correct the words that have errors. It is so inaccurate as "*not to be useful*". P1 also prefers his computer to his phone for lengthy text input because of the physical effort required for him to tap, and because of the speed and accuracy of the input. As he commented:

> *"You noticed the open ended questions [of the diary]? I was reluctant to respond because they required too much typing…"*

However, physical effort is not an obstacle at all for P1 to play word games and reorganize icons on his phone, reporting that he feels productive doing so. He can be playing about 20 minutes until he feels tired: *"I get more tired in my back because I hunch over… yeah… but I like playing with my phone… you know, it is fun technology".*

Privacy and Social Contexts

Privacy is not as important for P1 on the smartphone as it is with a laptop, where he showed his concern about having his screen observed in public places. He prefers having text-reader mode enabled rather than taking his phone out of his pocket. Any time he gets a new SMS or email, the phone reads aloud the content of the message. During the contextual session, he commented:

> *"One, time, I was in a meeting at work, and usually I will turn off my phone, and I forgot to ensure not to get a text… "*

Situational Impairments

When P1 is moving around, situational impairments make it impossible to control the phone. He must first sit. Despite having a screen reader enabled, he can't answer calls or read emails if his phone is in his pocket, which happens in cold weather. Weather and restrictive clothing also make it more difficult to remove the phone from his pocket:

> *"It can be difficult for me to carry the mobile phone. When it is warm out I can carry it in my shirt pocket and access it. When it is cold I have to carry it in my jacket pocket. I am afraid I will drop it. And, it is more difficult for me to access the mobile phone while wearing a jacket."*

In the same way, taking out his phone is challenging when he is walking or in public transport. Before departing, he makes sure to use the phone and communicate as he knows he will not be able to access the device until he gets to his destination. Deciding whether to use the phone or not while on public transit depends on how much time is available. Taking out the phone and storing it again requires a considerable physical effort, so for short trips or walks P1 does not use his phone: *"If I were on the Green Line, because its trip is long… I would take it out, and I will read emails"*. If he reads emails while in public transportation, he decides whether to respond or not based on the length of the message. For longer messages he waits until he gets to his desktop computer.

4.1.2.4 Wishes

P1 reported he would like to have better voice commands from his phone, longer lasting batteries, and that any app could have its font size enlarged or colors inverted. He also wishes to use the Facebook app more to connect with family and friends and share images, but finds the experience inaccessible because he can't use the camera and text is not legible for him.

4.2 Case Two: P2

4.2.1 Participant Description

P2 is a 24 year-old male professional who works as an IT consultant in DC/MD/VA area, and also volunteers remotely on a committee. P2 has cerebral palsy (since birth), which affects his mobility, speech, and left hand dexterity. He moves around in a power wheelchair or "scooter". He enjoys going out, travelling, attending after-hour events with colleagues, and dining out.

P2 acquired his first smartphone seven years ago in 2007, and he currently uses a Samsung Galaxy S4 with Android OS. He uses desktop computers and an iPad tablet every day at home and at work for browsing, talking on Skype, and accessing work applications. None of his devices—phone, computers, iPad—have assistive technologies installed.

4.2.2 Data Collection

P2 completed diary entries over a period of 10 days. The most commonly used applications reported were: (1) communications using SMS, social networks services, email and phone with the same frequency; (2) web browsing; (3) personal organization (calendars and reminders); (4) payments (Figure 4.10). As for the activities outside of the home, the most frequent were (1) shopping and groceries (2) travelling around town and commuting; (3) work; (4) social (Figure 4.11).

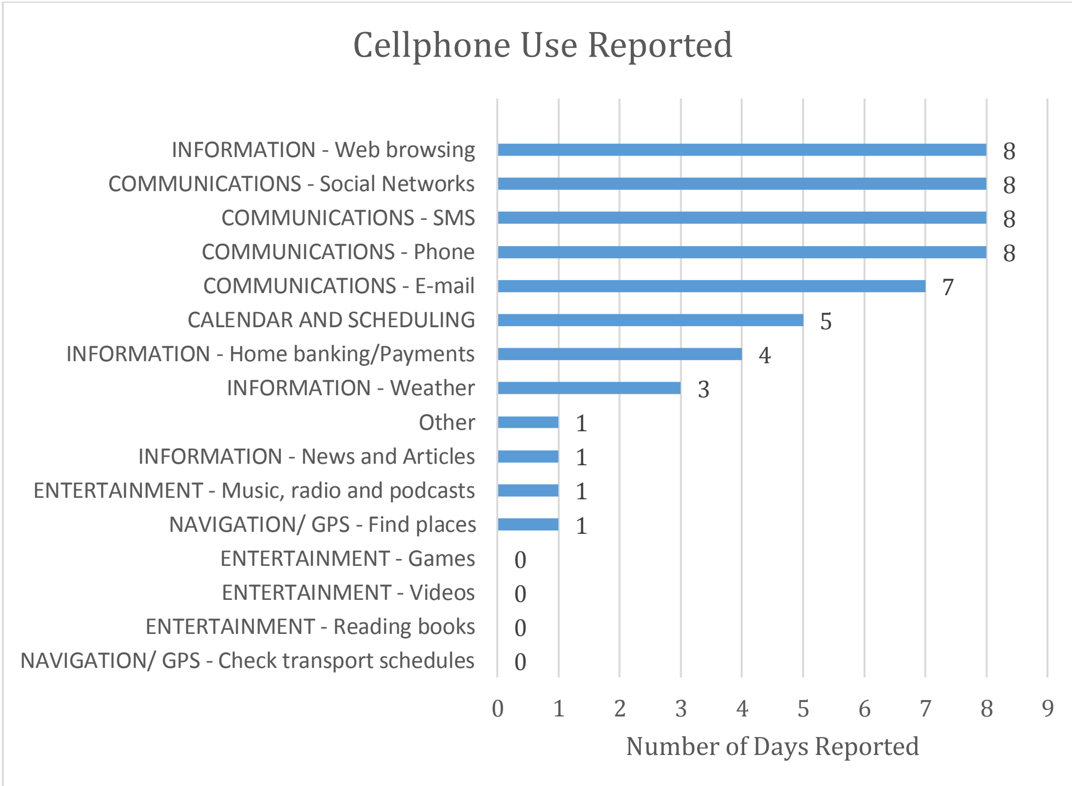

Figure 4.10: P2 cellphone use reported.

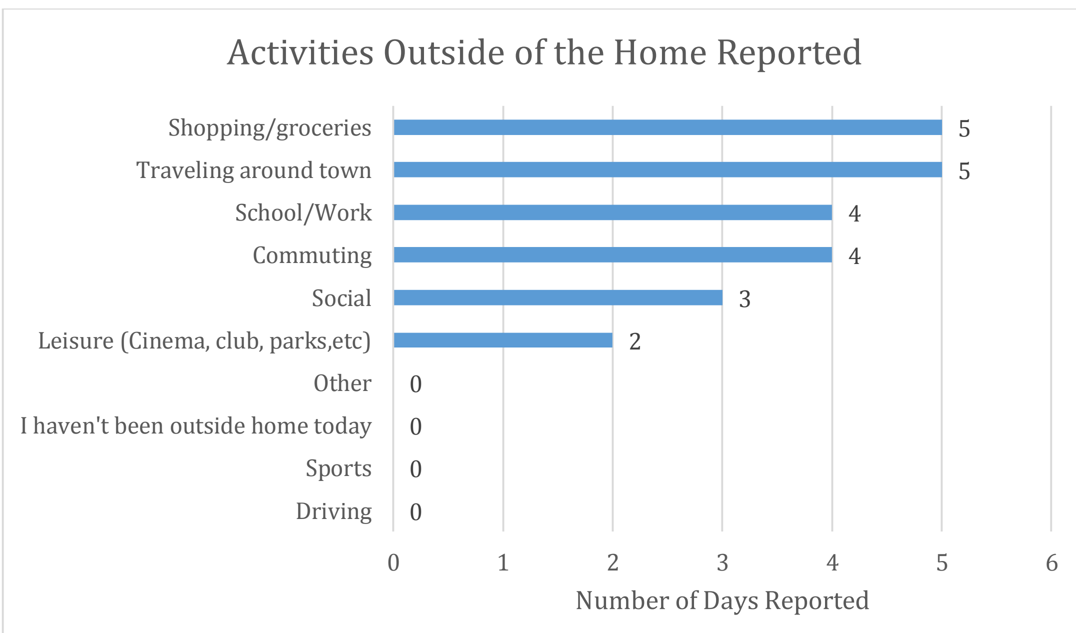

Figure 4.11: P2 activities reported outside of the home.

4.2.2.1 Contextual session

The session with P2 took place on a weekday evening in an urban neighborhood and lasted nearly three hours. The contextual session was customized based on P2's diary to include questions and demonstrations on use of the smartphone during social activities, working, travelling, and accessing information on-the-go. P2 demonstrated his use of the phone for personal organization with calendars and emails, web browsing, online shopping, use of social networks, use of restaurant coupons, use of tourism apps to book hotels, and use of the phone for communications. He also explained challenges with text correction and pinch-to-zoom. This portion of the session took 90 minutes with short breaks.

Following the interview portion, neighborhood activities included a short walk to a mall—as the temperature was nearly -2°C and sidewalks still had snow and were slippery—a visit to a pharmacy and a visit to a coffee shop. In the pharmacy, the activity assigned was to purchase some chocolate and look up the current temperature on the phone. At the coffee shop, the activities were to buy a coffee, answer a phone call and check transportation schedules. In addition, the participant spontaneously demonstrated his use of social networks for sharing images and using the web.

4.2.3 Findings

4.3.5.6 Case Summary – P2

Enablement	• Work • Personal organization and writing (e.g. calendar, notes, reminders) • Communication with family, friends and colleagues • Accessing information on-the-go(shopping, payments, web) • Travelling
Challenges	***On phone use*** • Lengthy text input on touchscreen • Multitouch gestures • Text correction • Speech recognition not working ***Situational impairments impact*** • Weather: rain and snow • Impeding clothing: pockets
Use	• Communications • Work • Travel • Personal organization • Social
Wishes	• Wireless or inductive charger • Not having to plug the phone

	• No multitouch gestures (e.g. pinch) • Using se voice commands

Table 4.5: P2 case summary.

4.2.3.1 Physical Use of the Phone

P2 operates his phone by holding it on a table or holding it with his left hand (Figure 4.12). When he moves around, the phone is located on his lap or in his scooter table (Figure 4.13). P2 does not use his pocket because he can't take out the phone when he is moving around, so when it rains or snows he stores the device in a bag in his scooter container. The only customization he reported applying to the phone is a standard plastic protective case.

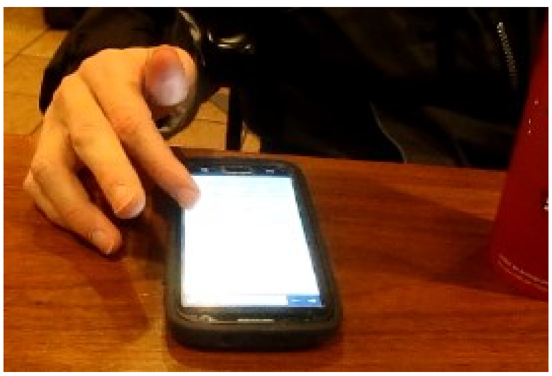

Figure 4.12: P2 using a smartphone.

Figure 4.13: P2 using the phone when moving around.

At the beginning of the contextual session, P2 completed the 10 performance tasks, with the following results: P2 was able to perform all touchscreen gestures necessary to operate a smartphone, but found it difficult to perform one-hand multitouch gestures. To zoom in and out, he used both hands for the pinch gesture, requiring the phone to be on a surface (Figure 4.14). P2 does not use any assistive technology. He tried to use Dragon Naturally Speaking for voice recognition in his computer, but his speech was not recognized by the software.

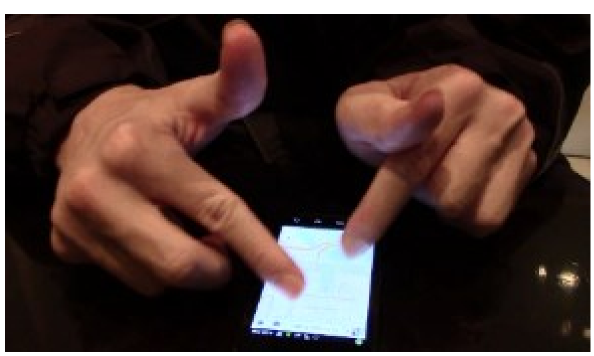

Figure 4.14: P2 performing two-hand pinch gesture.

4.2.3.2 Enablement

Using smartphones enabled P2 to (1) work remotely; (2) to be connected with his family, friends and classmates; (3) to use information on-the-go for different purposes, such as shopping; (4) to share pictures with friends; (5) to organize his day.

P2 finds his phone especially useful for working remotely, and has used it for his last three positions. He likes the convenience of working at any place and at any time, and having the information synchronized on all the devices: *"I would go in my scooter, reading and working from there... so I would work whenever"*. He also reported that when he was at college and had a job at the same time, he used to send and respond work emails while on campus. As he commented: "*I do IT work…so all I need is a computer and my phone and I have my own desktop...and internet..."*

For Communications

P2 finds important the immediacy of mobile devices to be important. Having information access at any time allows him to plan or adapt his daily activities when an incident occurs. For instance, he commented on his diary on one morning with inclement weather that: *"I coordinated with my co-workers and taxi driver to make sure I could safely get to work on my phone before I even got out of bed".* Mobile phones also allow him to maintain contact with friends and family, for instance, using Facebook to share images with when he is on a trip or at a social event. He mentioned during the session:

> *"[about not having the phone] I wouldn't be that connected ...I do a lot of work from the phone, so I talk to people ... at Boston, the committee at Seattle, I wouldn't be in CONSTANT contact to all the people"*

Personal Organization

Another advantage of the phone for P2 is that it allows him to write and to organize his activities, as he finds it difficult to physically write on paper. This finding is similar to P1. As reported in his diary, P2 *"…took some quick notes on my phone instead of writing on paper because writing is difficult for me."* P2 also uses the phone to write reminders, manage contacts, and use calendars. To do that, he relies on Google email drafts, calendars, and spreadsheets that he accesses from all his devices. For instance, he mentioned that when he goes grocery shopping, he takes notes from his iPad at home, emails them, and accesses them from the phone at the store. As he commented:

"I don't write very well... I don't write... I have always use an online calendar since high school… now, my outlook is connected to my Google calendar, so they are all in sync …"

Finally, the phone also supports P2 in shopping tasks. Having defined himself as an active online shopper, he has an Amazon Prime membership account. He also uses his phone to buy flight tickets and hotels, being able to check last-minute deals using different mobile apps.

4.2.3.3 Challenges and Situational impairments

Touchscreen Input and Phone Use

While P2 was able to operate his smartphone as-is, he reported challenges in text correction, copy-paste, multitouch gestures and plugging in the phone. Touchscreen input becomes challenging when he needs to type fast: *"With my tight schedule, trying to hurry and quickly dial into a call is frustrating because I make mistakes".* As for text correction, P2 experienced frustration when the touchscreen keyboard on his device was upgraded and he was not able to hit the space bar to skip word correction (Figure 4.15). He explained that after the update, to prevent a word from being corrected, he found it difficult to tap a small arrow for each word. For long text input, P2 prefers to use different devices, saying: "*typing a lot on my phone can get difficult so I use my laptop and iPad to type when I can*".

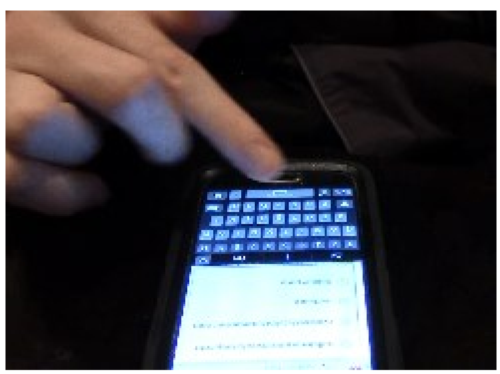

Figure 4.15: P2 showing touchscreen text correction.

This participant finds multitouch gestures to be difficult, and prefers to avoid them. If he has to zoom in or out, he first tries using a double-tap gesture, which he still finds challenging. For this reason, he prefers to use the Facebook app instead of the mobile website because "*…you don't have to zoom in and out while in the app*". P2 also found copying and pasting difficult, commenting that he has to double tap to select text. He also reported in his diary that charging the phone after a long day was difficult because he was too tired to plug the phone in himself. During the session he commented: *"I give it to my girlfriend to plug in... it's a lot of work.*

Privacy and Social Context

Despite using his phone several times a day for multiple tasks, P2 prefers not to use it when he is a social context like a special dinner. During the interview he commented that he would check his e-mail when he is waiting for someone, but then he turns his phone into vibration mode and puts it on his lap so he can know when a message comes. For example:

> *"…even if I have it at the table, in a happy hour, even if I had it at the table and someone calls, I can check over, see who's calling, and get back to what I'm doing. So in my mind I have "so, john X has called", but I can ignore … I can see and then decide if I am taking it or not."*

P2 uses the speaker mode of his phone considerably, but only on private places. He reported he used the speaker at home or at work, so he can type in his computer and also have a hand free to talk.

Situational Impairments

P2 uses his device on his lap when he is moving around, being only affected by weather (Figure 4.16 and Figure 4.17). Rain and snow can be problematic, as he has to protect his phone and he will not be able to take it out easily, for example:

> *"I got caught in freezing rain. I cannot easily use pockets, so I have trouble finding a place to put my phone where it won't get wet."*

Figure 4.16: P2 with his phone on his lap on public places.

Figure 4.17: P2 with his phone on his lap when moving around.

4.2.3.4 Wishes

P2 likes touchscreen devices, and generally finds them to be accessible. In terms of enhancements, he mentioned alternative gestures to multitouch that use tapping instead, and better speech recognition. *"I would like Dragon to get better for typing"*. He also envisions cordless smartphones and inductive charging to avoid plugging phones. As he summarized during the session: *"Not have to plug it in, no power, and no power cord. The web would be more accessible. No pinches…"*

4.3 Case Three: P3

4.3.1 Participant Description

P3 is a 30-year-old industrial designer from a suburban area, currently unemployed and working on personal projects. P3 was diagnosed with quadriplegia six years ago, affecting his hand dexterity and mobility. He uses a power wheelchair, and drives a car that he can enter independently using a ramp. Most of his time is spent at home, where he has a bedroom with integrated living room and work areas. P1 occasionally goes out on weekends to dine with friends or visit family. His hobbies are photography and video editing, for which he has a professional camera and an Apple workstation.

P3 acquired his first smartphone—an iPhone 5—nearly two years before the research. He is an advanced user of Apple computers and Adobe products for media editing. The assistive technologies he uses on his phone are Assistive Touch and Siri (for dictation). His phone has a case that attaches to a tripod, which in turn offers a hook that he uses to grab the phone. Despite feeling confident about being able to access his iPhone without assistive technologies, P3 reports that pressing physical buttons would be difficult.

4.3.2 Data Collection

P3 completed 13 diary entries over a period of 14 days. The most commonly used applications reported were: (1) videos, music, radio and podcasts for entertainment; (2) access to email; (3) access to social networks; (4) browsing, and reading news and articles (Figure 4.18). As for activities outside of the home, P3 reported that he spent much of his time at home during the diary period (Figure 4.19).

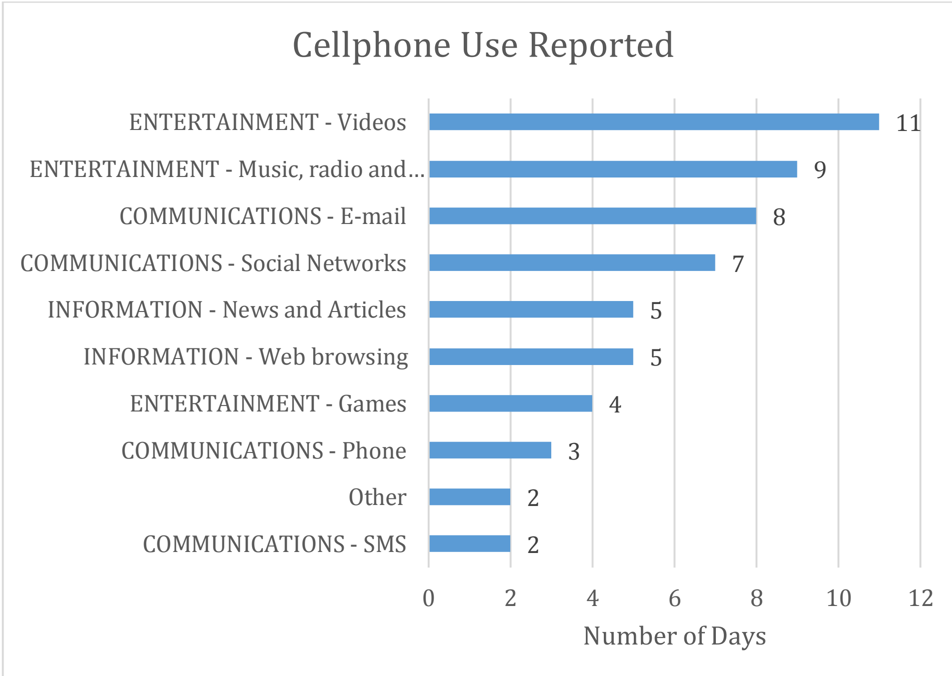

Figure 4.18: P3 cellphone use reported.

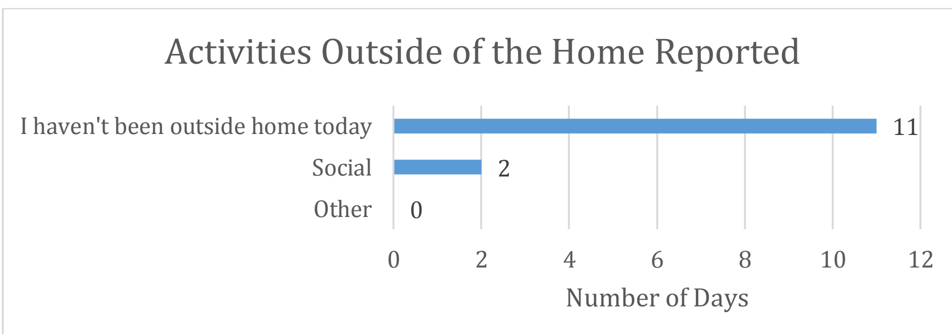

Figure 4.19: P3 activities outside of the home reported.

4.3.2.1 Contextual Session

The contextual session with P3 took place on a weekday morning at his house. The format of the session was adapted based on P3's diary entries. As he reported few activities outside of the home, and because his house is in a rural area, the session was adjusted to include a driving demonstration (Figure 4.20) and use of GPS for navigation instead of neighborhood activities. The contextual interview included questions and demonstrations of operating his workstation remotely from the phone, accessing podcasts and videos, using Assistive Touch, and entering text with Siri and the iPhone keyboard. The session lasted nearly 150 minutes, with short breaks.

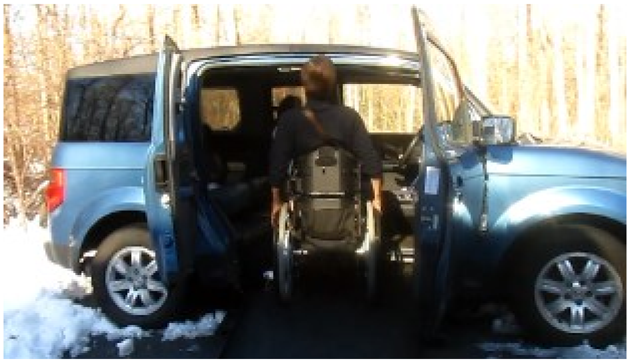

Figure 4.20: P3 getting into his car.

Figure 4.21: P3 in driving position.

4.3.3 Findings

4.3.3.1 Case summary – P3

Enablement	• Entertainment • Work/remote control • Personal organization and writing • Communication with family, friends and colleagues • Accessing information on-the-go(shopping, payments, web) • Travelling
Challenges	***On phone use*** • Lengthy text input on touchscreen • Think before you dictate: Short time offered by Siri • Multitouch gestures • Text correction ***Situational impairments impact*** • Privacy on social contexts
Use	• Entertainment • Communications • Work • Personal organization
Wishes	• Body integration • Self-drive cars • Advanced image edition applications • Easy to grab size

Table 4.6: P3 case summary.

4.3.3.2 Physical Use of the Phone

P3 operates his phone by holding it on his left hand. His case offers a stand for tripods on the border that goes between his fingers, allowing him to relax his left hand and (Figure 4.22). When he moves around on his wheelchair, the phone is placed on his lap or inside a bag (Figure 4.23). He uses Assistive Touch to do one-handed pinch-to-zoom and to control the volume.

Figure 4.22: P3 holding the phone from the case.

Figure 4.23: P3 holding a smartphone when moving around.

During the ten performance tasks, P3 was able to perform all the touchscreen gestures necessary to operate a smartphone, but found it difficult to zoom in and out. To zoom, he started with a one-handed pinch (Figure 4.24) using his ring and middle finger with small movements. When that did not work he used both hands, which required him to have the phone on a table (Figure 4.25).

At the beginning of the contextual interview, I was able to observe how P3 operates a touchscreen smartphone and what are the challenges encountered: P3 is able to perform all the touchscreen gestures necessary to operate a smartphone, but finds it difficult to zoom in and out. When he has to zoom in, he starts with a one-handed using his ring and middle finger with small movements. If that does not work he uses his both hands, which requires him to have the phone on a table (Figure 4.25).

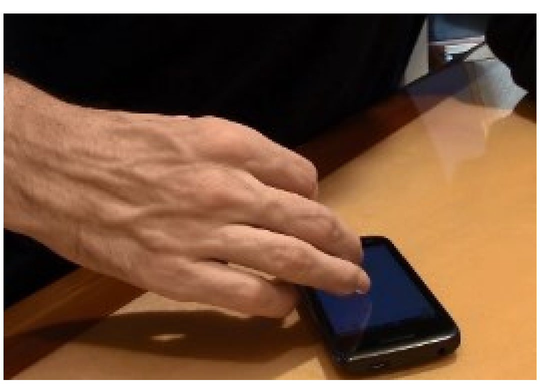

Figure 4.24: P3 performing a one-handed pinch.

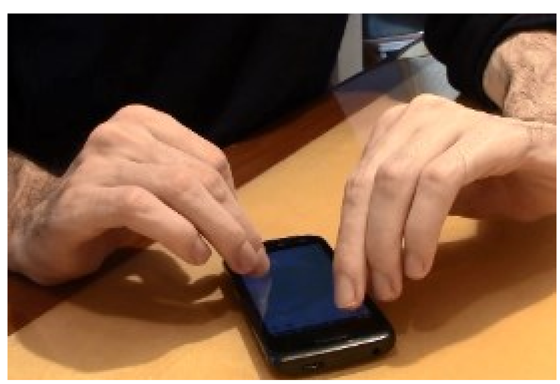

Figure 4.25: P3 performing a two-handed pinch.

The only customizations that P3 had installed is the tripod mount, as shown in Figure 4.22, and Assistive Touch.

4.3.3.3 Enablement

P3 spends most of the time at home, where using smartphones enabled him (1) to be entertained during his daily routine; (2) to be connected with his family and friends; (3) to control his workstation remotely; (4) to be organized; (5) to access information quickly. He reported that the phone provides him a sort of freedom in routine tasks: *"[About not having the phone] I wouldn't have been kind of free to do that wherever I wanted to".* For instance, he mentioned the convenience of being able to create reminders whenever he needs help with housework activities, like changing bed sheets. *"That kind of immediacy is really the best thing".* Another feature used by P3 are reminders and notes, mostly from Siri. As he commented:

> *"[About having the phone] it makes a way more flexible if I'm thinking. I'm writing something down or add something to a list, or look something up to the Internet...as I'm thinking about it...I don't have to make a note to look it up later…*

Routine and Entertainment

P3 most commonly used the phone for entertainment, as described above. During the session, he explained that every morning at the same hour spends two hours on a required physical program in the bathroom, where he brings the phone with him to help pass the time. Previously, he had used the laptop:

> *"Before I have the phone… … I used to drag my laptop in …to the bathroom with me!! …set it up on my sink and ... listen to Google videos and things like that … …The phone has completely replaced that"*

Waking up every morning for the program is an issue for P3. One of his strategies is browsing or playing games like Lumosity on his phone from the bed. As he reported during the session, browsing and using the phone as a replacement for an alarm helps him to get out of bed "*because I don't exactly hop out of bed*". Often times when he is browsing, he shares the content he likes with his friends too, or browsers their Facebook accounts.

Physical World Accessibility

P3 uses Pocketcloud to remotely control his workstation from his phone for rendering videos or listening to music. From the bed or from a couch, he can manage video processing without having to use his wheelchair to get his desktop. His video rendering processes are often controlled from the sofa, and he can turn off his workstation without moving whenever the task ends. He also commented that he uses the remote connection to control the music from his computer speakers: *"I'll get the cloud, turn off the music or something like that...so that's great..."*

Communications/Social

During the session, P3 commented that he uses text messages he keeps in touch with friends and family. He enjoys showing images and accessing the web from his phone while visiting with family. He also shares popular things he finds on the Internet with friends. Despite having a single lens reflex camera mounted to a tripod, he prefers to use his smartphone for to take pictures on social settings.

> *"It's really fun that when you get a reaction out of a friend… when you show them a picture or something funny that they haven't seen before…some article you were reading perhaps."*

4.3.3.4 Challenges and Situational impairments

Touchscreen Input and Phone Use

Besides multitouch gestures as commented on section 4.3.3.1, P3 finds it difficult to select small targets. For example, he demonstrated the difficulty of tapping targets and making accidental taps in Assistive Touch. Problems with tapping small elements also appear when he has to correct text by placing the cursor within a block of text.

As for voice-to-text, P3's experience using Siri can be summarized into "Think before you talk". While this participants uses Siri to write reminders and messages he still finds it difficult to use Siri dictation to write an email because he has to know in advance what to say exactly to avoid correcting the message.

> *"There's usually one word that's wrong. I generally find this to be true but... I'm trying to speak clearly and concise, and that's one of the things where before I open the dictation I usually take a second to think about what I'm going to say. I don't think it is naturally for me to think out a whole sentence that's grammatically correct."*

Situational Impairments

Social context and privacy affect how P3 uses his phone to communicate. He does not regularly get phone calls when he is out. He commented that sometimes he can't take the phone out of his bag, but he prefers anyway to retrieve phone calls later: "*I'd just wait until I have a moment where I have some quiet or peace or I can lock my wheelchair...*" P3 also explained that he does not want to be constantly distracted by the phone. When he is with friends, for instance, he does not get phone calls.

4.3.3.5 Wishes

P3 envisions future mobile devices integrated with our bodies. Aesthetics and immediacy were important attributes for him: "*It would be always on your person you know... It wouldn't be something that you have to even think about*." He also commented that he would like to have self-driving cars. Additionally, he would like to have more applications like the Adobe Creative Suite on his phone for instant image editing.

4.4 Case Four: P4

4.4.1 Participant description

Participant P4 is a 29-year-old male working as technology consultant. He has cerebral palsy since birth, and has a mobility impairment and hand tremors. He uses a power wheelchair with a lift. In his spare time, he visit friends and travels.

P4 acquired his first smartphone—a Blackberry—seven years ago in 2006, and he currently uses an iPhone 5s. He uses a Mac laptop and a desktop computer equipped with Dragon Naturally Speaking for voice control and dictation. He is able to use these devices without assistive technology, but he commented that doing so would increase the physical effort required.

4.4.2 Data Collection

P4 completed 14 diary entries over a period of 16 days. His most commonly used applications were: (1) access to information (weather, web, news and articles); (2) communications using SMS, phone, email and social networks; (3) navigation; (4) personal organization (Figure 4.26). As for the activities outside of home, the most frequent were: (1) travelling around town and commuting; (2) social; (3) work; (4) leisure; (5) shopping (Figure 4.27).

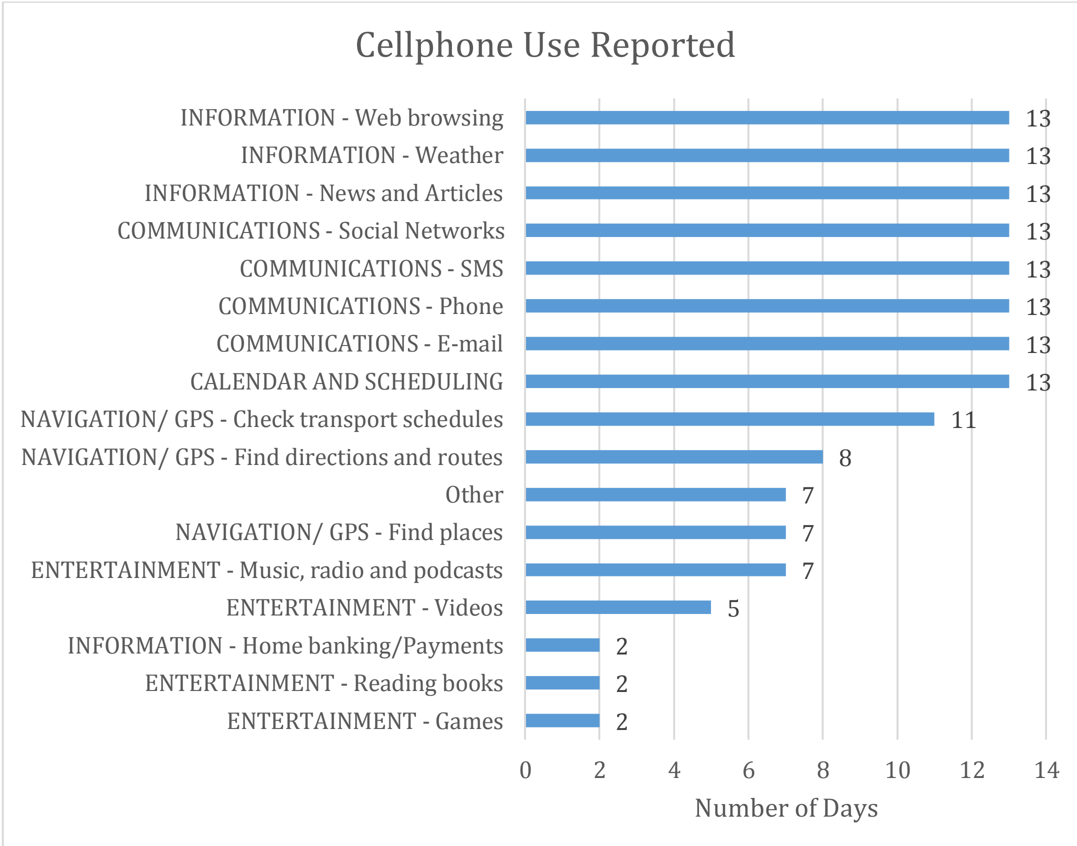

Figure 4.26: P4 cellphone use reported.

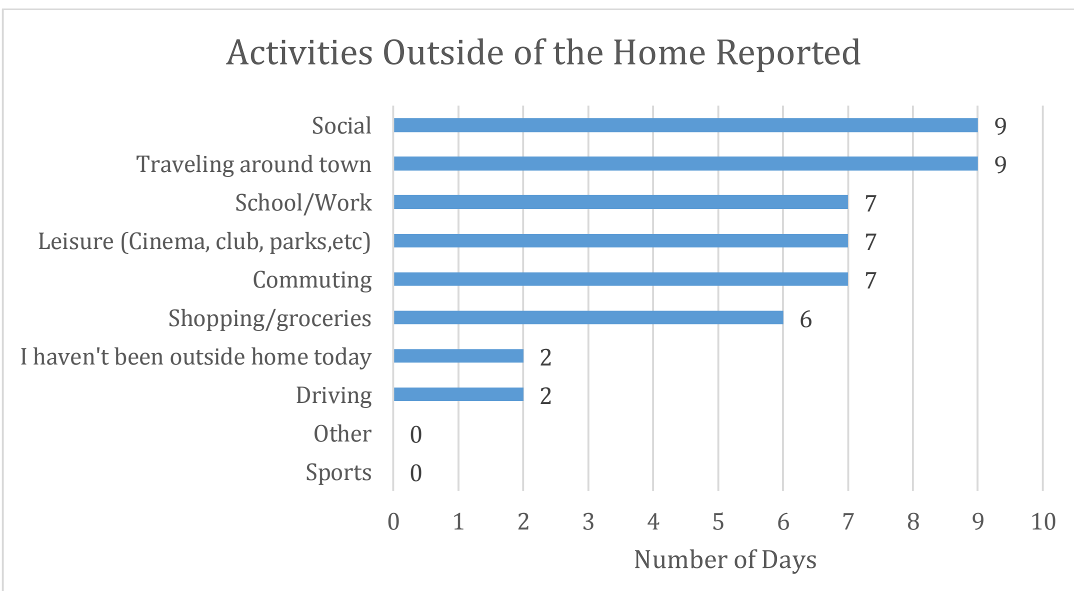

Figure 4.27: P4 activities outside of the home reported.

4.4.2.1 Contextual Session

P4's contextual session took place on a Saturday morning in a coffee shop in a busy urban area. The questions and demonstrations were customized based on P4'sdiary. At the coffee shop, in addition to the ten performance tasks and answering interview questions, P4 showed how he uses his phone for sharing files on Dropbox, checking sports information, reading books, playing word games, answering and sending SMS from voice control, using social networks (Facebook), and correcting text. This portion of the session lasted 140 minutes.

Neighborhood activities then included a visit to a pharmacy, a walk within a shopping mall (it was snowing and -1°C), and use of an elevator. In the pharmacy, the activity assigned was to buy some chocolates, and to find out how to commute from that area to College Park.

4.4.3 Findings

4.3.5.6 Case Summary – P4

Enablement	• Travelling and commuting • Work • Personal organization and writing (e.g. calendar, notes, reminders) • Communication with family, friends and colleagues • Accessing information on-the-go(shopping, payments, web) • Entertainment
Challenges	***On phone use*** • Think before you talk: Siri • Tapping small targets • Holding heavy phones ***Situational impairments impact*** • Connection • Privacy of voice readers • Divided attention • Noise
Use	• Size and form factor
Wishes	• Remote control for house elements • Voice recognition enhancements (Google Now) • Voice control on appliances

Table 4.7: P4 case summary.

4.4.3.1 Physical Use of the Phone

P4 operates his phone by holding it in his right hand. When he moves around, the phone is in his pocket or in his hand (Figure 4.28 and Figure 4.29). No assistive technologies were installed on the phone and P4 commented that he does not like cases because he considers them “bulky”.

Figure 4.28: P4 using a smartphone when moving around.

Figure 4.29: P4 holding a smartphone with right hand.

For the ten touchscreen performance tasks at the beginning of the session, P4 performed all successfully, although he had to use his right hand to hold the phone for the slide gesture. However, he finds it difficult to select small targets. He reported in the diary that he occasionally uses a stylus for text input due to hand tremors or spasms. For that reason, he aims to perform the fewest touchscreen operations possible, by using Siri to enter text.

4.4.3.2 Enablement

Using smartphones enabled P4 (1) to be able to take public transportation more efficiently; (2) to work from his phone at any place (3) to organize his day using calendars and reminders; (5) to extend voice-control from his phone to other devices.

P4 uses his phone to avoid accessibility challenges in the physical world. From his smartphone, he is able to work remotely, use public transportation efficiently, shop, control his TV, and connect with friends: “*So I mean, having the mobile access just reduces the physical effort so much.*”

P4 defines himself as a frequent user of the web from his mobile device. Access to information is important for him for work. His phone is configured to work remotely for his company, which makes him feel more productive. Often when he can’t commute to work due to inclement weather he works from home. As he reported in his diary:

"With mobile access I don't have to worry about that. I don't need to go to this inaccessible place to get my job done".

Transportation

Access to information was crucial for transportation. P4 demonstrated an application for the Metro that he uses every day to check the elevator status. For him, this app is critical because he can know in advance when the elevators at his station are broken, and get off the station after or before to avoid delays. P4 also uses GPS navigation and maps for long trips. The device is a way to mitigate challenges in public space. As he comments: "*It's being able to anticipate elevator outages, and being able to plan outside your routes on public transit and being able to have weather alerts*".

Shopping and Payments

P4 prefers to do online shopping to in-person shopping, as he finds grocery store aisles narrow and difficult to navigate. Online payments allow him not to commute. During the session, he told that some time before he received a check and found convenient to use an app to deposit it, not having to physically go to a bank. He also finds online payment transactions easier than taking out his wallet and credit card. As he commented: *"Shopping online enables my independence. Shopping in the physical world... well, let's just say I'm a happy Amazon Prime customer."*

Personal Organization and Entertainment

P4 uses notes, reminders and calendars on his phone for personal organization, finding them to be intuitive. At the session he reported that he uses reminders from Siri synchronized with his calendar and his other devices. As for games, he prefers mobile games to modern desktop video games, as he finds them simpler and better designed for contexts where users are constantly being distracted, and also require less dexterity and memory to remember game commands. He commented that he plays frequently when he is commuting, or whenever he wants to pass the time.

Physical World Accessibility

P4 had his TV and stereo speakers connected to his iPhone so that he can remotely control the TV via voice commands and send it content. This means he does not have to use standard remote controls.

4.4.3.3 Use and Preferences

Portability is a key aspect for P4. He selects his devices by his size and weight. He is also aware of headphones for the iPad, but he prefers to use the phone as-is and not add bulk. For that reason, he commented that he does not use headsets because they make the experience less mobile. Size and weight is another primary factor P4 considers before acquiring a mobile device because he has to be able to grab and lift it. As observed in the session and commented by the participant, he does not use any case because he considers they add weigh and bulk. As he commented during the session.

> *"The headset is just one more thing to remember, and by the time you're like taking all this extra stuff with you... You are not really mobile..."You know, you have to actually make it deliberated decided to hook it on a headset"*

4.4.3.4 Challenges and Situational impairments

Touchscreen Input and General Phone Control

P4 finds the touchscreen keyboard on his phone to be challenging for long text input: "*How do I compose an email in my phone? Short!"* Whenever he has to write a long response, he waits until he gets home and uses his computer with speech dictation. He also finds problems with small target acquisition, such as selecting small areas in a file list or when correcting text.

He also finds it difficult to hold the phone. For instance, he commented in his diary that he mistyped a password twice due to hand tremors and ended up having to use a stylus to enter the numbers. He also has trouble holding the phone due to the hand tremors.

One challenge of using Siri for P4 is the 20-second window he has to dictate a message, which limits the type of emails he writes on the phone.

Situational Impairments

While P4 is able to use his phone while moving around, the lack of signal can be impeding for him, as he relies on information about transportation. For instance, he reported that oftentimes in the metro reception cut out while he was retrieving information about elevator status.

P4 also commented that divided attention affects the use of the phone when he is in public places. If he has to answer an email or answer a phone call when he is around or in public places, he decides based on the length of the message and his status. As he explained: *"Do I want to take my attention away from what I'm doing at the moment to address this mobile alert?*" He also mentioned that noise can also affect his use of mobile devices. As an example, he commented that in a recent road trip he tried to use the speech recognition in a car while the GPS was turned on, and he could not perform the task.

His attitude towards use of mobile phones in public is diverse. He considers that voice readers are a detriment to privacy: *"The reason I don't use voice over whatever... because I mean... There's not a lot of privacy there.*"

4.4.3.5 Wishes

P4 envisions mobile devices capable of being fully commanded by voice. He would also like to be able to control any item from his house using voice commands from the phone. As he suggested in the session, he would like to control his TV and elements in his living room using Siri. "*Hey, TV, ON!" That would be awesome".*

4.5 Cross-case Findings

4.5.1 Enablement

4.5.1.1 Physical Accessibility

Participants use smartphones to improve their access to everyday activities that present physical obstacles—such as commuting, shopping, doing payments, or writing reminders—while they also find smartphones useful for entertainment, remote working, personal organization, and being connected to significant others.

Information accessed from their phones has been found critical for using public transportation and for planning their daily commute to work. For instance, P4 reported that he depends on ElStat, a mobile website and app that informs the elevator status of every Metro station, to take public transportation and be able to exit from the network. P1, P2 and P4's diaries also showed that navigation apps are among the most frequently used apps, including GPS for road trips and apps for online transport schedules.

The ability to work remotely from their phones reduced the physical effort of commuting to work, sitting on a desk, or using laptops. For example, P4 reported that since he can access his work environment from the phone, he can work from his couch and avoid the inconveniences of taking transportation to get to his building, or even require to use his laptop.

Online shopping and mobile apps for home banking were found advantageous by three participants. During the session, I was able to observe real-world challenges that appear with on-site shopping, such as navigating through aisles, carrying bags, and waiting for assistance before they pay.

4.5.1.2 Personal Organization

All participants used their smartphones as personal organizers, using calendars, reminders and lists. Physical writing was found to be difficult or impossible by all of them, and mobile devices provide an accessible alternative to hard-copy notepads and calendars. Making notes or other entries as they arise was found to be important for time management and organization, either at home or at work, for all the participants.

4.5.1.3 Control of Physical Elements

Mobile devices were also used to control other devices from their houses, reducing the physical effort required to operate them in-situ. P3 reported that he controls his workstation from the phone, allowing him to operate it from different locations of his house without requiring him to sit in the wheelchair and move between his desk and couch multiple times. In a similar way, P4 also reported that he sends videos to the TV or audio to the speakers by using Siri on his phone, which extends the experience of voice control to other devices.

4.5.1.4 Use of Smartphones in Social Contexts and Communications

In terms of communications, all participants confirmed that their phones allow them to connect to their families and friends. Three of them also reported that in certain social contexts they share information accessed on-the-go with others, like images, articles or videos. For instance, one participant commented that sharing content and links with friends and family was a way to connect with them or have a fun conversation. This use of the mobile Web for social facilitation confirms Church and Oliver's [10] study about mobile use, suggesting that access to mobile Web access is also a social activity and not an event solely motivated by an information need.

4.5.1.5 Use of Smartphones Inside and Outside from Home

The use of mobile phones was found important either inside or outside the house, as participants found smartphones to be more portable than tablets or laptops. As a consequence, all of them reported that part of the interaction that they typically performed on their desktop computers was now taking place on their phones. For instance, P1 reported that he carries the phone to the kitchen for checking the recipe while cooking. P3 also explained that he now brings the phone instead of his laptop to the bathroom to be entertained in his daily 2-hour routine. However, there are extra needs for information access when outside of the home, mostly related to mobility, work and entertainment.

4.5.2 Challenges of Smartphone Use

Lengthy text input, use of voice-to-text and target acquisition on small elements was challenging for all participants, and all of them experienced frustration with text correction regardless the smartphone model. Despite being able to use a touchscreen keyboard, all the participants reported that they prefer to use their desktops or tablets when they have to write lengthy text, as touchscreen input on their phones was found to be slow (P1), and frustrating (P2). As for the ten performance tasks during the contextual session, only one participant was able to perform multitouch gestures with one hand. For participants who expressed difficulties on multitouch gestures, two of them used both hands when a large gesture was required (e.g. a zoom in a big area), while one had Assistive Touch of iOs enabled. These findings confirms prior research on touchscreen gestures [2,16,20,39,55], suggesting that challenges on touchscreen input still persist in advanced smartphone users with motor impairments.

P3 and P4 found Siri inadequate for dictation as it only provides a 20-second window to talk. This window forces them to think in advance to prevent input errors, and limits the length of the dictations. P1, P3 and P4 mentioned that their desktop software (Dragon) was more accurate than voice-to-text technologies from phones.

As for text correction, all participants found it challenging and frustrating, and both iOs and Android users are required to tap small elements to correct words. Participants that used iOs explained that tapping a small bubble multiple times or pointing to a position to correct text was difficult. In a similar way, those participants using Android found frustrating to tap an arrow multiple times.

In terms of privacy, participants had several concerns about using speakers and voice-to-text technology. As opposed to help with privacy concerns, the use of external devices such as headphones was found a detriment to portability by three of the participants. This confirms again Shinohara et al. [48] study that claims that users would prefer using mainstream devices, and that designing successful accessible technology must also address aesthetics and unobtrusiveness.

4.5.3 Impact of Situational Impairments

Confirming what Kane et al. suggested in [29], situational impairments still affect motor-impaired users in mobile conditions. Walking, restrictive clothing, weather, noise and lack of connectivity were found to impact how participants use their mobile devices.

Restrictive clothing and inclement weather also affected how participants used their phones. When moving around town, P2, P3 and P4 held phones on their laps. However, during inclement weather the phone was stored in a bag (P2, P3) or pocket (P1, P4), making it difficult to access. Consequently, answering phone calls at these times was challenging for all the participants. For instance, P1 reported that he has to sit to use his phone when he is out.

4.5.4 Personalization

The four users in this study had applied none or few assistive technologies and customizations to their devices—including software, cases, and hooks—confirming observations made by Trewin et al. [55], where smartphone users with motor impairments also had few customizations on their phones. In addition, although three participants used phone cases, none of these cases were specially designed for accessibility. This finding also confirms what Shinohara et al. [48] suggested in their study about preferences of use of mainstream technology instead of separate solutions.

4.5.5 Wishes for Future Technologies

Participants proposed enhancements to current mobile technology, as well as features they would like to have. From the enhancements, three participants suggested more accuracy on voice-to-text and voice control from the phone. Other suggestions collected were: more accessible social apps to share images, cordless battery charging, and apps for image edition as powerful as their desktop version. In terms of desired features, P3 mentioned he wished to have body augmentation ("*you will have a toot implant, and that would be your internal speaker*"), while P4 proposed to control devices from his house remotely (e.g. thermostat, coffee machine, TV) using voice commands from the phone.

4.6 Summary

The in-person study analyzed four smartphone users with motor impairments, finding that (1) challenges in multitouch gestures still persist, such as pinch; (2) there are difficulties in text input and correction; (3) the impact of situational impairments in motor impaired users can prevent them from using their phones when out of the home; (4) access to information can improve the access of motor-impaired users to the physical world (5)

Chapter 5: Online Survey

To analyze challenges found in smartphone use and adoption trends with a wider range of users with motor impairments, I conducted an online survey. Note that the survey has a small sample (8 users), but offers some preliminary additional evidence to triangulate the case study findings.

5.1 Rationale

The goal of the survey was to understand general aspects of smartphone adoption, challenges and real impact of the context of use in a wider range of participants with motor impairments. After a preliminary analysis of the in-person study data, I selected the most recurrent problems and themes for the survey: (1) similarities and differences in use and adoption of mobile devices when at home versus out; (2) difficulties in basic touchscreen operations, like performing multitouch gestures, entering and correcting text; (3) participants' visions for future technology. Mobile phone users who did not own a smartphone were also included in the target population to understand their reasons for not adopting smartphones.

5.2 Survey Method

Participants were recruited through different channels, including distribution lists targeted to users with motor impairments, online forums, local chapters, Facebook and Twitter. The survey was hosted on SurveyGizmo and was designed to take 20-25 minutes. Participants could opt into a drawing for a $100 Amazon gift certificate.

There were two versions of the survey to cater to different participants: (1) smartphone users; (2) regular cellphone users. Before deployment, both versions were piloted by respondents with and without motor impairments. See Appendix A for the complete set of survey questions.

The survey for smartphone users consisted of 26 questions, both open-form and close-form. Questions covered general background (e.g. age, gender, diagnosed medical conditions), type of mobile device owned, different contexts where the device is used, and challenges found with basic touchscreen operations (e.g., text input and correction, multitouch gestures). As well, to compare at-home phone use versus use around town, an identical set of questions about device use, physical setup, and challenges encountered was included for each of these contexts. Whether the at-home questions were asked first or the around town questions were asked first was randomized.

Non-smartphone users completed 17 questions, with 10 extra questions if they owned a touchscreen device other than a smartphone (e.g., tablet). As with the smartphone user version, questions covered general background, tasks performed with the phone, and difficulties encountered. However, the survey also asked about reasons for not adopting a smartphone. The touchscreen device questions included physical device setup, tasks performed, difficulties encountered, and desired technology improvements.

5.2.1 Survey Responses

A total of 24 responses were submitted worldwide, and nine additional responses were partially completed. Because of cultural and regional differences, only responses from the US were considered for the analysis (15), while responses that did not indicate motor impairments were not counted (6). For the nine remaining valid responses, the average completion time was 14.22 minutes.

Participant Demographics

From nine (9) valid responses, one (1) was not a smartphone user but reported tablet use, and eight (8) reported smartphones. Of these nine participants—six female and three male—all were adults over 18. Respondents reported a range of disabilities, including one (1) with muscular dystrophy, two (2) with neuropathy and arthritis, four (4) with cerebral palsy, one (1) with multiple sclerosis, and two (2) with other motor impairments. Seven (7) reported one disability, while the other two (2) reported two. From the nine (9) surveyed participants, five (5) use a wheelchair, three (3) do not use a wheelchair, and one (1) does so only occasionally. The majority of participants reported that their motor impairment affects their use of the phone, either substantially (4 participants) or to some degree (2). Two (2) participants reported very little impact, while one (1) reported no impact at all.

5.2.2 Use of Mobile Devices

Eight participants out of nine use their devices from home, five (5) from the street, work, and car, four (4) on public transit, and two (2) in other places. Most participants used their phones often, with four (4) using it at least hourly, three (3) at least once every few hours, one (1) once a day, and one (1) once every few days. Only two participants reported they use voice-to-text assistive technologies on their phones and software tools to support accessibility (e.g. Assistive Touch, switch input).

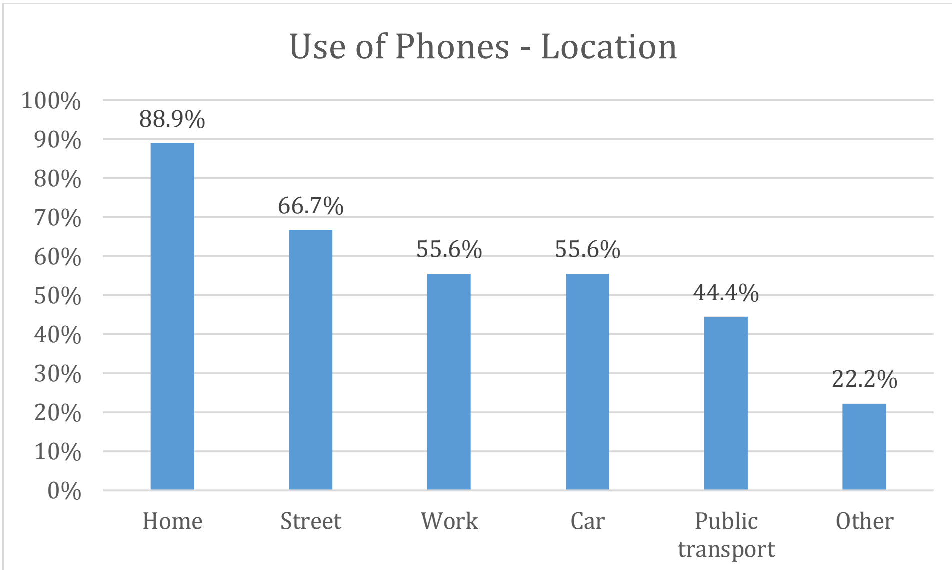

Figure 5.1: Use of mobile phones reported by location (N=9).

Use at Home and Out

For the following analysis, the non-smartphone respondent was excluded, leaving 8 responses. I focus on differences in mobile device use between home and outside of home scenarios.

There were differences in physical use of the phone at home versus out. The preferred positions for the phone when at home were: lying flat on a table (3 responses), lying on lap (2 responses), mounted to a wheelchair or using a table. When out, the preferred position was lying on the lap (respondents), followed by "someone else holds it" (3 responses).

As for the applications used when home and out, participants reported similar use patterns in both contexts, except from navigation (Figure 5.2). For navigation, which includes transportation, GPS and maps, six (6) participants reported use when out, while only three (3) reported use from home.

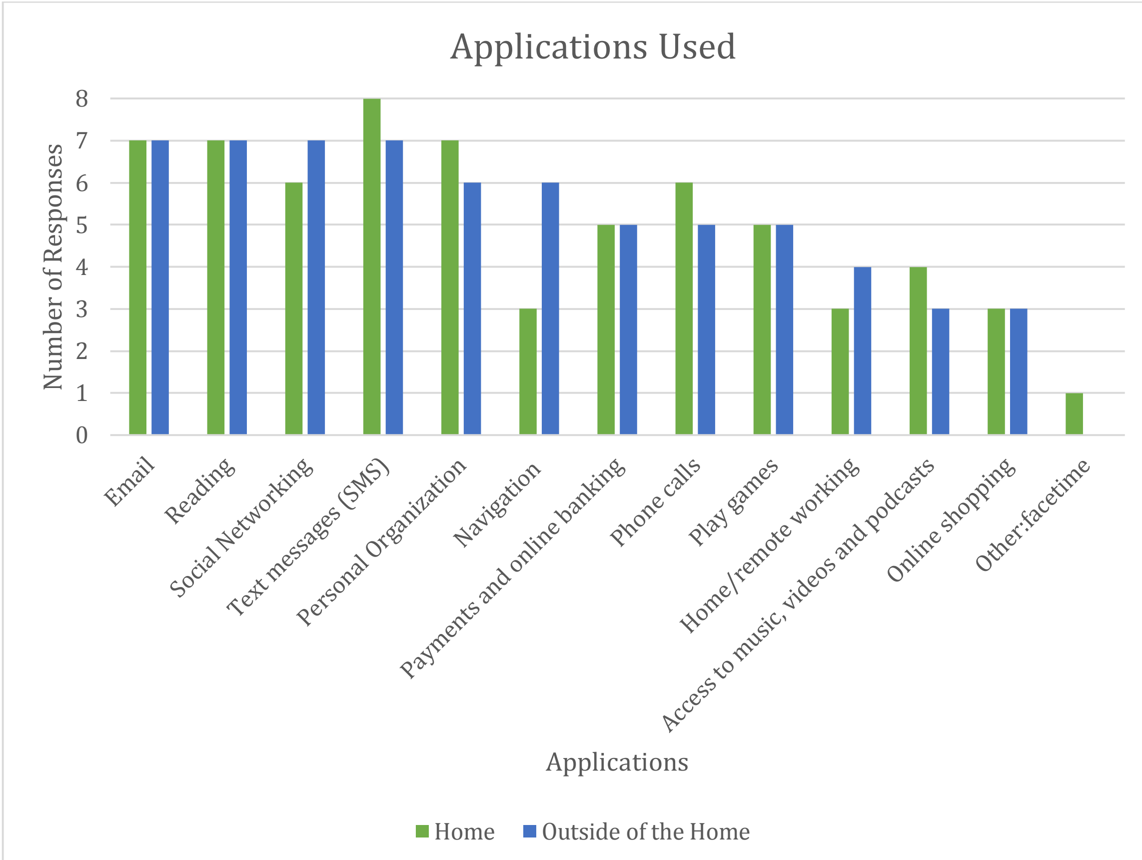

Figure 5.2: Applications used on the phone when home and when out, as reported by smartphone users in the survey (N = 8).

5.2.3 Challenges

As shown in Table 5.1, text input in mobile devices (both smartphones and tablets) was found to be "difficult" and "very difficult" by the majority of the respondents, confirming in-person study results. Entering text was found to be "difficult" by 3 participants out of 9, and "very difficult" by 1, but correcting text was considered "very difficult" by 4 participants, and "difficult" by 2. Multitouch gestures were found "very difficult" by 4 participants out of 9.

Rating	Entering text	Correcting text	Multitouch gestures
Very easy	1	0	2
Easy	2	3	1
Neutral	2	0	2
Difficult	3	2	0
Very difficult	1	4	4

Table 5.1: Reported difficulties from survey respondents in completing touchscreen input tasks that in-person participants had found to be challenging (N = 9).

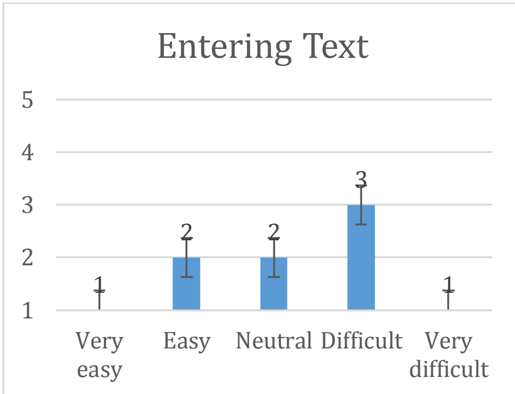

Figure 5.3 - Reported difficulties from survey respondents in entering text (N=9).

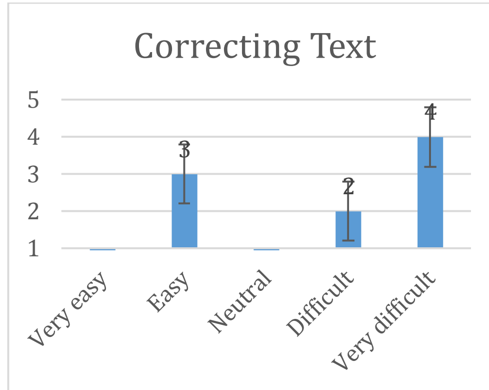

Figure 5.4 - Reported difficulties from survey respondents in correcting text (N=9).

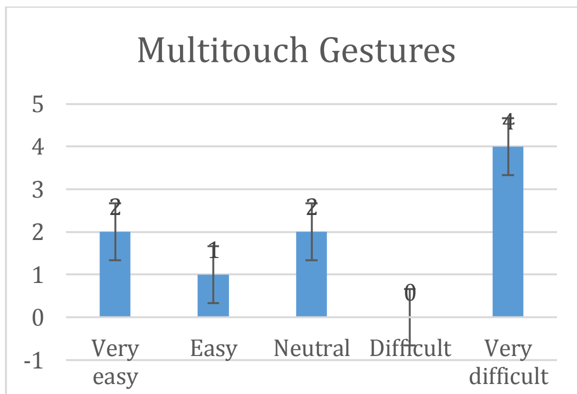

Figure 5.5 - Reported difficulties from survey respondents in performing multitouch input (N=9).

Comparing challenges in smartphone use at home versus when out, challenges in the latter were higher or equal to challenges at home, except for speech input. Seven participants out of eight found it difficult to grab and lift the phone when out, while four indicated the same when at home (see Figure 5.6).

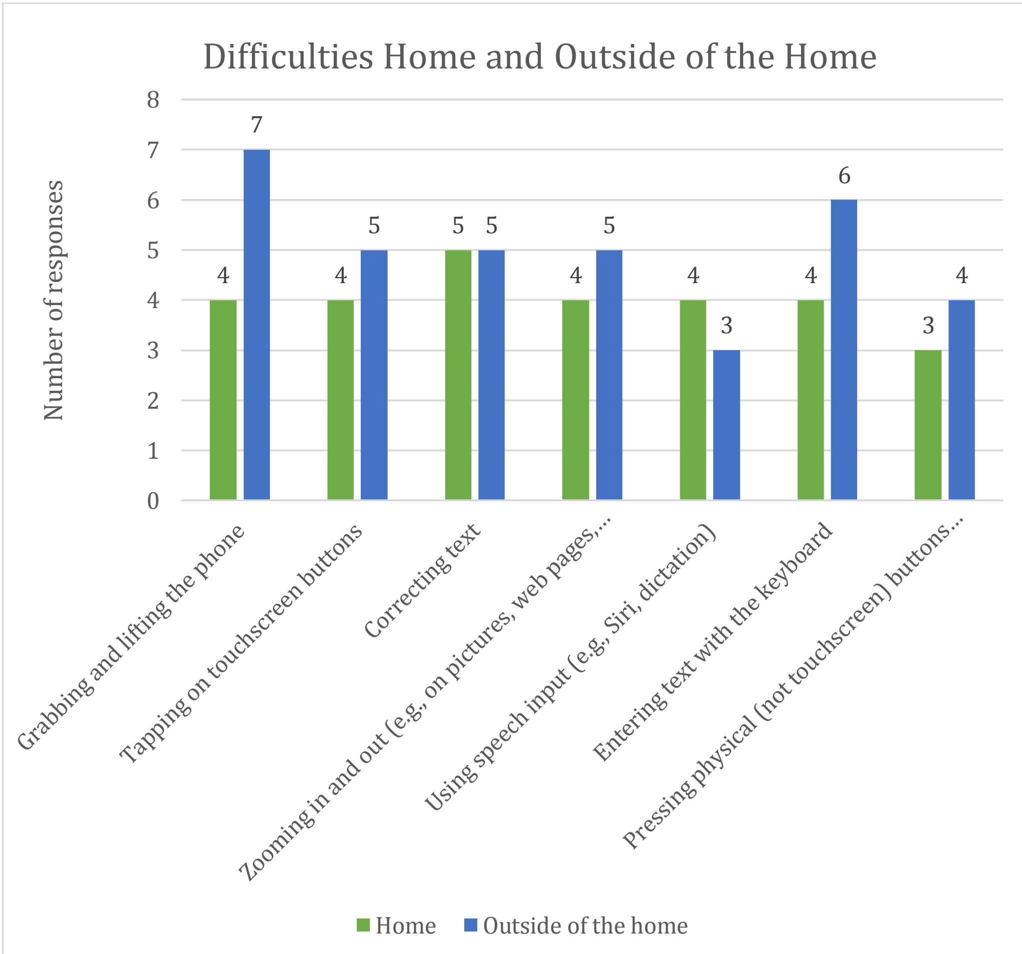

Figure 5.6: Difficulties in smartphone use when using the device at home versus when out, as reported by survey respondents with smartphones ($N = 8$).

5.3 Summary

While the survey results are only preliminary due to the small number of respondents at this point, the data provides some conformation for findings from the in-person study, particularly with challenges in touchscreen gestures and text input, and about broad aspects of smartphone use. Respondents indicated difficulties in entering and correcting text, while the impact of challenges outside the home was higher than difficulties encountered at home. However, a larger sample is necessary to reach a strong conclusion.

Chapter 6: Conclusions

This thesis reports on the experiences of smartphone users with motor impairments. The primary goal was to understand how smartphones are being adopted, what challenges still persist, and what activities these devices enable. This study addresses limitations of prior experimental work in laboratories by studying and providing an understanding smartphones in the context of use. This chapter discusses the findings and presents ideas for future work.

6.1 Discussion

Using different field study methods, this work (1) confirms prior research on challenges found in touchscreen use by people with motor impairments, and also confirms research on assistive technologies and aesthetics;(2) finds new challenges on movement and restrictive clothing, extending prior research on situational impairments performed with mobile phones ; (3) identifies and characterizes how smartphones are being used by people with motor impairments to overcome physical accessibility challenges, reaffirming that mobile devices increase the independence for these users.

Physical World Accessibility

A contribution of this research is to characterize how mobile information access for users with motor impairments is being used to *reduce the physical effort of everyday activities*, both at home and when out. Mobile applications provide users with alternative ways of dealing with physical obstacles found in commuting, on-site shopping, payments, and writing, but also help them reduce their physical effort while at home. For example, when out, participants in the in-person study used mobile apps and the mobile web to take instant notes and manage calendars, buy products with online-shopping, and improve their access to public transportation by anticipating schedules and elevator outages. When at home, two participants also used their phones to control other devices (a desktop computer and a TV).

Extending to more areas this idea observed from participants of using accessible personal devices to interface with other devices or avoid challenges, can significantly improve their access to physical world. It also confirms Anthony et al.'s[2] and Kane et al.'s[29] suggestions that mobile devices can bring empowerment to users with motor impairments by allowing them to do activities that are otherwise difficult.

Challenges and SIID

Challenges of touchscreen use for motor-impaired users still persist, even for experienced users. The in-person and the survey studies both ratify documented difficulties on tapping small elements, performing multitouch input, and entering text, which have been thoughtfully analyzed in previous work [2,19,29,39,55]. Additionally the in-person study found new challenges in voice-to-text technologies for the phone and word correction, the latter being confirmed by the survey study as well. Participants found mobile voice-to-text not adequate enough for text input, and less accurate than the desktop version; word correction was also found to be challenging regardless of the phone model because it required participants to tap small elements multiple times.

In addition to touchscreen input challenges, difficulties introduced by situational impairments confirm Kane et al.'s [29] diary study of mobile device use from five years ago, finding that movement, weather and restrictive clothing drastically affect how users access their devices. Answering phone calls was found to be difficult on-the-go in Kane et al.'s research and in this work as well: two participants from the in-person portion commented that they postpone their phone calls. Moreover, all users from the in-person study reported difficulties when accessing emails while moving about or in public environments, having to wait until they get a desktop computer to write long responses. This suggests that input with touchscreen devices is accessible, but not yet considered efficient by motor-impaired users.

Assistive Technologies and Aesthetics

We have confirmed in this work the role of aesthetics in the design accessible technologies to avoid stigma [44,48,64], as well as the preference for using mainstream technologies instead of separate assistive solutions [41,48,49,59,64]. Smartphones are today widely adopted portable devices, and this represents an opportunity for accessible computing researchers and designers to develop mainstream applications that can help users with motor impairments overcome physical world challenges.

6.1.1 Implications for Design

Considering suggestions from participants and observations from the analysis, as well as challenges found, I identified the following opportunities to enhance mobile accessibility and accessibility of the physical world for motor-impaired users:

Physical Space Accessibility

The use of information on-the-go (e.g. messages, SNS, GPS) and virtual spaces (e.g. online shopping) to avoid physical world challenges facilitated routine tasks or social interaction for the case study participants. Therefore, designers of *physical* spaces should consider how they can provide online information to improve the accessibility of the physical space. Likewise, designers of appliances or technologies for the home could enhance their accessibility by creating "pluggable" devices that could interface with mobile computers, for example, over the wireless network. Such alternative access would allow users to select a control modality that works for their abilities—controlling the device directly, using the touchscreen, or using voice control.

Touchscreen Text Input

Text input on mobile phones was inefficient for all participants in the in-person study, particularly in terms of text correction, selection and copy-pasting; these findings were confirmed in the survey. As a suggestion, text input with a touchscreen keyboard should not require users to tap small targets while entering text, selecting individual words, and copy-pasting words, as happens in current solutions.

Allowing text positioning in two taps (one for selection and another for adjustment that can render an enlarged area), or using alternative controls to navigate through the text (e.g. sliders), might facilitate text selection and positioning. As for text correction, the controls for selecting an alternate spelling should be enlarged or allow for using long taps to facilitate replacing incorrect words.

Voice-to-text Configurability

Challenges with voice-to-text included accuracy of recognition and problems with pausing the input stream, requiring participants to think in advance about what to say, and to perform manual corrections. One design implication is to allow voice-to-text pauses to be configurable and adaptable to users, also enabling them to pause and navigate through different chunks of text using voice commands. These more advanced features already exist in current voice-to-text technology for desktop computers (e.g. Dragon), and should make phones more accessible if they are incorporated into mobile devices' mainstream voice-to-text as well. In addition, using a dictionary with suggestions might also increase accuracy and reduce the amount of tapping required to fix errors.

Wearables to Lower the Impact of Situational Impairments

Touchscreen input should be distributed and extended to other input methods and devices, such as small wearables (e.g. rings, watches), voice control, and human body, to reduce the impact of situational impairments that can be blocking for users with motor impairments. Delegating basic touchscreen operations to external components will allow the user to operate a phone when it is in a pocket or while they are moving, as it will not be necessary to pull out the phone. Those wearable devices still have to be unobtrusive and aesthetic.

6.1.2 Limitations

This research is limited in the number of participants involved and their background. Having four expert mobile phone users, all male between 25 and 45, and US residents, might not unveil additional challenges that appear with more novice users from different locations, ages, and genders. Additionally, the participant sample in this study was biased in that we recruited only participants who *can* use mobile devices. The findings should generalize to other users with similar levels and types of impairments, but not, for example, to users who have more severe impairments.

For the in-person study, the diary method was efficient for collecting information about use and challenges in context. However, this method also requires self-reporting and user elicitation, and participants might complete entries partially. The contextual session attempted to balance this self-report data with observations. One overall limitation, however, was the lack of a standardized performance assessment of each user's motor abilities and ability to use the mobile device. To overcome that issue to some degree, the study assessed a set of ten basic mobile phone tasks.

The survey aimed to address many of the sampling limitations of the in-person study through a broader set of respondents. However, difficulties were encountered in recruiting a large number of participants. While the survey findings thus provide some additional evidence to triangulate the in-person study findings, they should be considered preliminary.

6.2 Future work

Results from this study can inspire future work on mobile accessibility that will further improve access of motor-impaired users to the physical world, as well as address current challenges in touchscreen interaction.

Focusing on the challenges reported, a first approach will be to improve current text and voice input on touchscreen smartphones. One possible application could be the use of unobtrusive wearable technology to overcome the limitations of touchscreen input on movement conditions, inclement weather or restrictive clothing, by triggering a specific task (e.g. answering a phone call). Another application could be to explore context-aware adaptive user interfaces for smartphones that accommodate to user needs [30]. For instance, such applications would resize targets based on the context, adjust brightness, and modify text-readers to silence on meetings or according to user's calendar and coordinates.

In terms of enablement, this study has shown the importance of accessing information to enhance physical world mobility. Another direction could be to extend the implementation of context-aware "urban apps" and websites to help both motor-impaired and body-abled users to navigate and overcome physical world challenges. These ideas have been explored by Hara et al. [21] for users with visual impairments. For instance, such applications would pull information about transportation, stores opened, directions to restaurants and hotels that are accessible, or navigation that provides the shortest accessible paths to save wheelchair battery.

Based on participants' experiences at their home, I also found that control of household elements with mobile phones has the potential to reduce physical effort for motor-impaired users for everyday tasks. For instance, it could allow one to open doors, control air conditioning systems, control stoves, or turn on door alarms. Remote control from phones will also extend touchscreen input and voice-commands to every controlled device.

6.3 Conclusion

This study has analyzed smartphone use and challenges for users with motor impairments *in situ*, finding evidence that access to information improves physical world access, while documented challenges in touchscreen input still persist. For the participants in this research, portable touchscreen devices were generally accessible, but there are still challenges ahead. Whether if touchscreen or voice is the right way to address user input for this population, there are opportunities for improving current mainstream touchscreen devices that can translate to further independence. Research on wearable technology, adaptive input, and social apps will have the potential to eliminate current challenges.

Appendices

Appendix A: In-person Study Procedure

I. Initial Interview Method

Length	30 minutes
Method	Phone
Objectives	• Collect participant's demographic information, and more details about their disability • Collect habits of use of technologies • Explain the study procedure
Background questions	**General** • Age • Gender • Occupation • Diagnosed conditions • Year of onset • Type of impairment • Frequency of activities out of home **Technology** • Frequency of use of computers and Internet • Smartphone model and plan • Applications used • Assistive technologies used, if any • Locations of smartphone use
Data collected	Notes, audio recordings.

II. Diary Method

Length	14 days; 10 minutes per entry at most.
Platform	Email; web forms; voicemail;

Objectives	• Collect evidence about the use of the phone on different contexts:
	    • Applications used
	    • Use of smartphones outside home
	    • Challenges and problems encountered
	• Get information about habits of use, while **minimizing the observer and recall effects**
	• Support future data collected in observations and interviews.
	• Allow participants to provide details about real use as it happens

Diary Type	• Feedback: every day, for at least 10 days, participants completed predefined questions. A reminder was sent via SMS, e-mail or instant message (GTalk/Facebook/MSN/Skype/Whatsapp), according to the preference of each participant.

Questions	• For which of the following tasks did you use your phone today? (Select all that apply) • What activities did you do **outside the home** today? • For what activities was the phone especially helpful today **inside or outside the home**? • What are **the worst experiences** you had with the phone today? • (OPTIONAL) Were there **other accessibility issues** you encountered today not involving the phone? If so, please explain. • (OPTIONAL) Please share any other **comments** or ideas you have about your phone experience.

III. Contextual Session Method

Length	3 hours
Location	Participant's area of choice out of their home
Objectives	1. Get insights of the participants in their environment. 2. Explore to what degree situational impairments affect users with motor impairments in a real scenario. 3. Triangulate with diary data. 4. Have a better understanding of attitudes towards the use of the device.
Parts	1. Assessment of touchscreen operations. 2. Contextual interview. o Use of mobile o Challenges o Neighborhood activities.
Description	The session combined observations and interviews in the context of use. Participants were asked to: • Perform their everyday activities, such as doing groceries, commuting, finding places, enjoying the landscape, etc. • Answer questions about the use • Show examples or demos of how they use their phone
Data collected	Audio; notes; pictures; video recording.

IV. Coding Dictionary

Initial Code (Open coding)	Category	Area
Cooking activities related to cooking or kitchen	**Activities**	**Enablement**
Shopping/ groceries acquiring physical and virtual things making a payment		

Reading reading online content, books, newspapers		
Multitasking doing two or more things at the same time , like checking emails and listening to music or eating		
Payments/ Banking activities related to bank institutions, either online or not		
Photography taking pictures with the phone		
Working doing any task related to personal projects, schoolwork or current job		
Remote control controlling any device with the phone (e.g. computer)	**New interactions**	
Apple TV extending siri can be merged with remote control		
Remote work/remoting also working, but requiring to be connected		
Immediacy the quality of having information on-the-go, at any time	**On-the-go access**	
File sharing		
Email		
Web		
Reminders and lists use of any application to generate reminders and lists	**Organization**	
Calendar		
Note taking the action of taking notes		
Mobility the action of physically moving from one place to another	**Transport**	
Tourism moving to another place for leisure		
Navigation use of references to get a destination (e.g. GPS)		
Public transport use of public transportation		
Share experiences the action of sharing a personal evidence of a past event (e.g. pictures of a party)	**Social**	
Events occurrences of social gatherings (e.g. afterhours)		
Communications use of communication channels for social purposes (e.g. call a friend)		
Connecting to others the action of getting in touch with other humans		

Games or gaming use of software catalogued as a game for leisure purposes	**Entertainment**	
Reading		
Other		
Social networks use of social networks (e.g. Facebook) for leisure		
Speech recognition accuracy	**Mobile input/operation**	**Challenges**
Text correction when fixing words that have not been entered as expected during a text input		
Lengthy input when users have to enter chunk of text that they consider long		
Text input entering text in a keyboard		
Plugging/battery problems with energy sources, either plugging or managing the power		
Screen size anything related to screen size		
Voice-to-text feature that synthetizes speech		
Tap pointing acquisition operation on a touchscreen device		
Multitouch(gestures) any gesture that requires more than one contact point		
Slippery when the object has not a steady grip	**Form**	
Size		
Weight		
Movement any SIID caused by moving conditions, like walking, taking a transport, or riding	SIID contextual factors that affects how users interact with mobile devices	
Weather SIID caused by weather		
Clothing SIID caused by clothing that impedes normal movements		
Connectivity SIID caused by poor connectivity to network (e.g. no wireless connection)		
Movement/transport not necessarily related to mobile devices. General issues when moving around	**Physical world**	
Text to speech -privacy privacy aspect of voice readers	Social Acceptance	
Use/non-use in social contexts		

Aesthetics	(also under “other”)	
Use of headphones/add-ons use of external objects with the phone		
“Hyper connection” limits self-imposed restrictions to the unrestricted use of technology (e.g. I turn off the phone when I'm on a dinner)		
Voice-to-text enhancements to technology	**Mobile enhancements**	**Wishes** what participants envision about technology
Form related to mobile form/shape		
Visual related to visual output or screen		
apps new apps or new features on existing apps		
Alternative to multitouch gestures applications installed that offer an alternative to multitouch (e.g. Assistive Touch)		
Remote control controlling any device with the phone (e.g. computer)	**Physical world control**	
Wireless		
Case	**Customization**	**Use** general aspects of applications used and customization
No-case the fact of not having a case		
Hook an object to hang the device		
Assistive technologies		
Attitude towards e-mail (ATE) what users do then they receive an e-mail	**Preferences**	
Phone-computer		
App-web		
Portability	**Features**	
File sharing	**Applications**	
Games		
Privacy	**Other**	
Other		
Other	Other	**Other**

V. Interview Questionnaire

Part I – Demographics

- Age
- Gender
- Occupation
- Could you describe any mobility, visual or visual impairments that you have?
- When did they start?

- Do you have any diagnosed medical condition associated with these impairments? If so, what is the diagnose?
- How often do you go outside home?
    - Less than once a week
    - Once a week
    - A few days a week
    - Almost every day
    - Every day

Part II: Use of technology

- How often do you use computers/laptops?
    - I don't use computers or laptops
    - Once a week or less
    - A few days a week
    - Almost every day
    - Every day
- What are the computer application and games you regularly use?
    - Games, utilities, browsing, communications
- What services do you use from the Internet?
    - Web, e-mail, SNs, File sharing, Maps, Audio and video others
- What smartphone model do you have?
- What type of plan do you currently have on your phone?
- When did you get your first smartphone?
- How often do you use your mobile phone?
    - Once a week
    - A few days a week
    - Almost every day
    - Every day
- In a day, how frequently do you use your mobile phone?
- What type of tasks do you regularly do with your phone?
- Do you use any accessibility app or device? If so, which ones?
- Would you be able to use your phone without these features?
- When you are outside home, what are the devices you regularly use? (Mobile phone, laptop, GPS, watch…)

Appendix B: Survey Questionnaire

Part I: Background Questions

1) What kind of mobile phone do you own?*

( ) Smartphone (e.g. Android, Blackberry, iPhone, Windows Phone)
( ) Cell phone with touchscreen
( ) Regular cell phone
( ) I don't own a mobile phone
( ) I have a mobile phone but am unsure of what kind

2) What is your age?*

( ) 18-24
( ) 25-34
( ) 35-44
( ) 45-54
( ) 55-64
( ) 65+

3) What is your gender?*

( ) Male
( ) Female
( ) Other

4) What is your occupation? If you are a student, please say so along with your area of study.*

5) Do you have any of the following diagnosed medical conditions? Check all that apply.

[ ] ALS (Lou Gehrig's Disease)
[ ] Arthritis
[ ] Cerebral palsy
[ ] Essential tremor
[ ] Multiple sclerosis
[ ] Muscular dystrophy
[ ] Neuropathy
[ ] Parkinson's disease
[ ] Repetitive stress injury (RSI)
[ ] Spina bifida
[ ] Spinal cord injury
[ ] Other (Please specify)

6) How long have you had this condition?
( ) Since birth
( ) Less than a year
( ) Less than 5 years
( ) 5-10 years
( ) More than 10 years

7) Do you use a wheelchair?*
( ) Yes
( ) Only occasionally
( ) No

8) How much does your motor impairment impact your ability to use the smartphone?
( ) Not at all
( ) Very little impact
( ) Some impact
( ) Substantial impact

9) Do you have any of the following impairments? Check all that apply.
[ ] Visual impairments that *cannot* be corrected with glasses or contact lenses
[ ] Hearing impairments
[ ] Speech impairments
[ ] Other (Please specify):

10) Where do you regularly use the mobile phone? Check all that apply.
[ ] Home
[ ] Work
[ ] Street
[ ] Public transport
[ ] Car
[ ] Other (Please specify):

Part II: Survey for Non-smartphone Users

11) Have you ever tried to use a smartphone?

( ) Yes

( ) No

12) If yes, what model did you try?

13) What factors have prevented you from acquiring a smartphone? Check all that apply.

[ ] Costs

[ ] Safety

[ ] Difficulties learning new technologies

[ ] Unneeded

[ ] Weight

[ ] Shape or size

[ ] Difficulties using it

[ ] Other (please specify

14) Do you want to use a smartphone?

( ) Yes

( ) No

( ) Maybe

15) What tasks do you generally do with your cellphone? Check all that apply.

[ ] Communications (E.g. Phone calls, SMS)

[ ] Access to music or videos

[ ] Browse the web

[ ] Emails

[ ] Camera

[ ] Other (Please specify)

16) What difficulties do you encounter when using your cellphone? Check all that apply.

[ ] Pressing physical buttons

[ ] Holding the phone

[ ] Lifting the phone

[ ] Entering text

[ ] None of the above

[ ] Other (Please specify):

17) Do you have any of the following touchscreen devices? Check all that apply.

[ ] iPad

[ ] Android tablet (e.g. Google Nexus, Samsung Galaxy Tab)

[ ] Microsoft Surface

[ ] iPod touch

[ ] Other (Please specify):

Part IV: Survey for Non-smartphone Users – Tablets

18) Do you ever use your device for any of the following? Check all that apply.

[ ] Email

[ ] Navigation (e.g., looking up a location or route)

[ ] Social networking (e.g., Facebook, Twitter)

[ ] Personal organization (e.g., notes, calendar, reminders)

[ ] Home/remote working

[ ] Online shopping

[ ] Payments and online banking

[ ] Music, videos and podcasts

[ ] Games

[ ] Reading (e.g. news, articles, books)

[ ] Other (Please specify): ____

19) How do you usually set up your device? Check all that apply.

[ ] Mounted to a wheelchair

[ ] Lying flat on a table, desk, or wheelchair tray

[ ] Someone else holds it

[ ] Lying on your lap

[ ] Propped up with a stand

[ ] Other (please specify):

20) Are there any tasks that you can complete more easily now that you have a touchscreen device (e.g., checking email, looking up information online)? If yes, please provide examples.

21) Which of the following do you find difficult to do when using your touchscreen device? Check all that apply.

[ ] Grabbing and lifting the phone

[ ] Tapping on touchscreen buttons

[ ] Correcting text

[ ] Zooming in and out (e.g., on pictures, web pages, maps)

[ ] Using speech input (e.g., Siri, dictation)

[ ] Entering text with the keyboard

[ ] Pressing physical (not touchscreen) buttons such as power and volume

[ ] Other (please specify)

22) Do you ever find certain tasks physically impossible to do on your touchscreen device? If yes, please provide examples.

23) Is there anything else you wish you could do with your touchscreen device (e.g., something currently impossible or just difficult)? If yes, please describe.

Part III: Survey for Smartphone Users: Use of Touchscreen Devices at Home

Please complete this section telling us how you use your touchscreen device when you're home.

18) Do you ever use your device for any of the following? Check all that apply.

[ ] Email

[ ] Navigation (e.g., looking up a location or route)

[ ] Social networking (e.g., Facebook, Twitter)

[ ] Personal organization (e.g., notes, calendar, reminders)

[ ] Home/remote working

[ ] Online shopping

[ ] Payments and online banking

[ ] Music, videos and podcasts

[ ] Games

[ ] Reading (e.g. news, articles, books)

[ ] Other (Please specify):

19) How do you usually set up your device? Check all that apply.

[ ] Mounted to a wheelchair

[ ] Lying flat on a table, desk, or wheelchair tray

[ ] Someone else holds it

[ ] Lying on your lap

[ ] Propped up with a stand

[ ] Other (please specify)

20) Are there any tasks that you can complete more easily now that you have a touchscreen device (e.g., checking email, looking up information online)? If yes, please provide examples.

21) Which of the following do you find difficult to do when using your touchscreen device? Check all that apply.

[ ] Grabbing and lifting the phone

[ ] Tapping on touchscreen buttons

[ ] Correcting text

[ ] Zooming in and out (e.g., on pictures, web pages, maps)

[ ] Using speech input (e.g., Siri, dictation)

[ ] Entering text with the keyboard

[ ] Pressing physical (not touchscreen) buttons such as power and volume

[ ] Other (please specify)

22) Do you ever find certain tasks physically impossible to do on your touchscreen device? If yes, please provide examples.

23) Is there anything else you wish you could do with your touchscreen device (e.g., something currently impossible or just difficult)? If yes, please describe.

Part III: Survey for Smartphone Users: Use of the Smartphone when you're out around town

Please complete this section telling us how you use the smartphone when you're out around town (not at home). You're more than halfway done!

34) Do you ever use your phone for any of the following *when you are out around town*? Check all that apply.

[ ] Phone calls

[ ] Text messages (SMS)

[ ] Email

[ ] Navigation (e.g., looking up a location or route)

[ ] Social networking (e.g., Facebook, Twitter)

[ ] Personal organization (e.g., notes, calendar, reminders)

[ ] Home/remote working

[ ] Online shopping

[ ] Payments and online banking

[ ] Music, videos and podcasts

[ ] Games

[ ] Reading (e.g. news, articles, books)

[ ] Other (Please specify):

35) How do you usually set up your phone when using it *out around town*? Check all that apply.

[ ] Mounted to a wheelchair

[ ] Lying flat on a table, desk, or wheelchair tray

[ ] Someone else holds it

[ ] Lying on your lap

[ ] Propped up with a stand

[ ] Other (please specify):

36) When you're *out around town*, are there any tasks that you can complete more easily now that you have a smartphone (e.g., checking email, looking up information online)? If yes, please provide examples.

37) Which of the following do you find difficult to do when using your phone *out around town*? Check all that apply.

[ ] Grabbing and lifting the phone

[ ] Tapping on touchscreen buttons

[ ] Correcting text

[ ] Zooming in and out (e.g., on pictures, web pages, maps)

[ ] Using speech input (e.g., Siri, dictation)

[ ] Entering text with the keyboard

[ ] Pressing physical (not touchscreen) buttons such as power and volume

[ ] Other (please specify)

38) When you're *out around town*, do you ever find certain tasks physically impossible to do on the phone? If yes, please provide examples.

39) When you're *out around town*, is there anything else you wish you could do with the phone (e.g., something currently impossible or just difficult)? If yes, please describe.

Basic touchscreen experience

Please indicate how easy or difficult you find the following tasks on your touchscreen device, from 'Very easy' to 'Very difficult'.

40) Entering text using the keyboard.

( ) Very easy ( ) Easy ( ) Neutral ( ) Difficult ( ) Very difficult

41) Correcting text you already entered

( ) Very easy ( ) Easy ( ) Neutral ( ) Difficult ( ) Very difficult

42) Performing gestures that require two fingers (e.g. zooming in and out)

( ) Very easy ( ) Easy ( ) Neutral ( ) Difficult ( ) Very difficult

43) Do you encounter any other challenges in using your touchscreen device? If yes, please describe.

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