Under the development of mobile devices, users start to use smartphones to take care of daily tasks in different situations and by variable ways. The objective of this study is to get a deeper understanding of motivations, approaches, and methodologies on the usability research of mobile applications. Thirty-two recent articles are studied in the first phase literature review study and the result shows that interface elements, user interactions and usage contexts are major interface elements, and the ease of input entering is the major concern. Motivated by that, twelve UNC-CH SILS students are recruited to conduct the second-phase empirical study and the statistics indicate that handedness has obvious influence on usability. Other mobile interface design suggestions are given at the end of the study.

Headings:

Application software -- Mobile device applications

Computer software -- Mobile device application development

Systems design -- User interfaces (Computer systems)
A USABILITY EVALUATION OF PERSONAL TASK-MANAGING APPLICATIONS IN ONE-HANDED THUMB TOUCHING MOBILE INTERFACE

by

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A Master’s paper submitted to the faculty of the School of Information and Library Science of the University of North Carolina at Chapel Hill in partial fulfillment of the requirements for the degree of Master of Science in Information Science.

Chapel Hill, North Carolina
April 2014

Approved by

Bradley Hemminger
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Introduction

The growing usage of smartphones and mobile applications in many scenarios is projected to bring more opportunities for application developers. According to Global Mobile Statistics 2013, as of September 2013, 147.9 million people in the U.S. owned smartphones, and both Apple and Google have more than 800,000 third-party apps in their online markets (mobiThinking, 2013). Mobile applications have played important roles in numerous application areas such as email, social networking, entertainment, and E-commerce, and smartphone users have more choices than ever before.

However, competitions also exist due to the high similarity among a large number of apps. As of July 2013, Android’s Google Play users have downloaded over 50 billion apps (Mashable, 2013). When searching key word “task management” in Apple’s App Store, more than 1,500 results are returned. Users typically have a choice between several apps with similar functionality. Competition to capture smartphone users’ attention and generate profit from mobile applications is tremendous.

Apps need to deliver great user experience in order to be competitive. Although on app markets, evaluation indexes such as rating, reviews, and rank could affect users’ first impression on an application, user experience is still the dominant factor to shape the user evaluation of an application and keep user using the application. The mobile app entrepreneur believes that the true essence of mobile applications is to allow users to get an immediate outcome to their problem or need, which means it should be easier and
more convenient to use than a desktop computer (Gary, 2013). Not only engineers in industry, but also researchers in academia believe that usability is a crucial way to attract and retain users in addition to functions (Terrenghi, Kronen & Valle, 2005). Mobile applications target a wide audience that desire to operate an intuitive system without direct training and support. Researchers also regard usability as one of the most important characteristics for mobile applications. As a result, the current situation is that usability of mobile system is challenging while the cost of abandoning an application is low for users, which makes the competition of mobile application development fiercer.

To evaluate usability of mobile applications, special targeted mobile-wireless metrics need to be designed and applied because of the specialization of mobile applications (Spriestersbach & Springer, 2004). Researchers (Gafni, 2009) develop a matrix by which displays the usability metrics according to the specific problems in mobile systems, such as display load, clarity of operation possibilities, completeness of operation menu, and display self-adjustment possibilities, their purpose and method of calculation (Table 1). The table also links these measures to three types of wireless mobile-related problems—network, device, and mobility.

The metrics are developed based on the insight that the usability of mobile systems can be analyzed from four aspects—understandability, learnability, operability, and attractiveness. These four aspects are further refined and explained. Figure 1 shows their detailed manifestation in the process of using mobile applications.
Table 1. Usability Metrics Mapped According to Mobile-wireless Problems

<table>
<thead>
<tr>
<th>Source of problems:</th>
<th>Network</th>
<th>Device</th>
<th>Mobility</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Narrow Band</td>
<td>Connection stability</td>
<td>Security</td>
</tr>
<tr>
<td></td>
<td>Connection stability</td>
<td>Digital standards</td>
<td>High costs</td>
</tr>
<tr>
<td></td>
<td>Security</td>
<td>High costs</td>
<td>High costs</td>
</tr>
<tr>
<td>Matrices</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Display load</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Clarity of operation possibilities</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Completeness od operation menu</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Display self-adjustment possibilities</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Message conciseness</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Ease of input entering</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ease of output use</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Parameters self-adjustment possibilities</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Ease of use--displays per output</td>
<td></td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Ease of use--displays per task</td>
<td></td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Tasks based on user location</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 1. Metrics Mapped According to Usability Characteristic & Sub-characteristics
In this study, the mutual sub-characteristics of operability and learnability—the ease of input is focused due to two reasons. First, physical constraints of mobile devices, especially small screen size, make the input method of mobile applications drastically different from the input method of traditional software such as desktop applications. As the screen size of mobile device is relatively small, navigating the entire information space on smartphone is not an easy task. If all the information is squashed into one screen, it will cause problems in perceptibility or readability, as the size of the information such as text or image might become too small (Chung, Lee & Jeong 2011). So smartphone applications usually require frequent navigation such as tap or drag to cover the entire information space. The space for such navigation or other interaction with the information is also small due to the limited screen size.

Second, such difference of input method on mobile applications brings difficulties to users. First, entering data on a phone is tedious and annoying (Longoria, 2001). Certain level of proficiency is required to input data on smartphone. Users’ effectiveness and efficiency in entering data are limited by small buttons and labels limit. Such inefficiency may further reduce the input speed and increase errors. Previous studies also suggest that usability can be affected by the use of different data entry methods (MacKenzie & Zhang, 1999; S. X. Zhang, 1998). It’s important to investigate the ease of input for the new data entry method of mobile applications.

Studying the usability of mobile applications in general is no longer sufficient because the use case in real life is more complicated. Research starts to focus on more detailed and specific area in mobile application usability for example handedness, environment, and special scenarios like driving. In this paper, we focused on study the
difference of the usability of smartphone application under different context of its use. Context can be defined as “any information that characterizes a situation related to the interaction between humans, applications, and the surrounding environment” (Dey, Salber, & Abowd, 2001). As applications become more “mobilized”, they are infiltrated into every aspect of lives in recent years. Users are more likely to use their mobile devices under different situations. Most mobile device use is in everyday life situations with many distractions, and the user may be multitasking (walking, talking, watching TV, etc while using device). Interactions under such scenarios could bring more usability problems because users are more easily to be distracted by surroundings.

In this study, walking situation is addressed because such scenario best reflect the mobile application usage based on location and context. Smartphone can be taken to any location and be used immediately, even on the go. Walking is a frequently occurred scenario when user did not have access to PCs. It is common that users answer phone calls, reply messages, and browse webpages on their mobile phones while walking. Such on-the-go scenario is especially important for usability testing as it provides two unique requirements for the smartphone applications. First, user could only spent a relatively small portion of their time to interact with the smartphone application while walking. Second, walking while using a mobile device can further exacerbate the data entry problem.

These devices allow for single-handed interaction, which provides users with the ability to place calls and access information when one hand is otherwise occupied. A dominant hand could be one example of users’ heterogeneities that could affect the usability of a product, especially when related to users’ hands. The assumption of
choosing the preferred hand as the user selection variable in the research of usability testing is that a preferred hand generally performs better than a non-preferred hand. Hoffmann (1997) has studied the arm movements and concluded that the preferred hand performed more accurately than the non-preferred hand and that no significant difference exists between right- and left-handed individuals when using their preferred hands.

As mentioned earlier, the data entry requires dexterity and proficiency of users and users are more comfortable to operate with preferred hand in a static state. So it seems natural to assume that people should perform better (faster and more accurate) in their interactions with mobile applications when using their preferred rather than their non-preferred hand, but it is unclear if the differences are large enough to justify including these as variables when evaluating interactions or developing guidelines. This study aims to collect and summarize the empirical evidences of the differences and provide suggestions to future research.

The purpose of this two-phase sequential mixed method is to get a deeper understanding of improving usability of task management mobile applications. In the first phase, quantitative research questions address the comparison of the target acquisition error rate between preferred hand participants group and non-preferred hand group under two circumstances—sitting and walking, and using two different kinds of interfaces—text-entering interface and option-based interface. In the second phase, qualitative interviews will be used to probe participants’ experience with the interfaces they have used in the first phase. The reason for following up with qualitative research in the second phase is to better understand and explain how handedness, environment, and interface type influence the usability of mobile task management tools, and generate
more insights that can be applied as guidelines to assist application designers in future design.

The literature review study is designed to investigate two research questions:

RQ1.1: What usability issues are major problems to compromise the usability of mobile applications?

RQ1.2: What kinds of approaches/methodologies are proposed to address/investigate usability issues, and how different approaches/methodologies are used to address the same usability issue?

The empirical study is designed to investigate three research questions:

RQ2.1: Do handedness and walking status affect usability?

RQ2.2: What approaches/design rules could enhance the user experience for non-preferred hand using situation and walking status?
Literature Review Study

In previous work, Gafni (2009) define new metrics of usability in order to measure the quality level of usability of mobile applications. Unfortunately, there exists no literature-survey that categorizes the usability problems in mobile applications using these metrics, or identifies the challenge faced to mitigate these usability problems. To fill such a significant gap, we provide a literature review on usability problems in mobile applications. This literature review investigates how usability problems such as uncomfortable input entering compromise usability characteristics such as operability, and which existing techniques are proposed to deal with such technical problems. This literature review also investigates the pervasiveness of the usability problems and how well existing techniques can address such problems.

Study Setup

In our literature-survey study, we survey the literature from a comprehensive bibliography of articles on usability problems of mobile applications. We manually collect the articles from conferences in recent years. The articles are published in a wide range of venues in human computer interaction (e.g., SIGCHI, UIST, UbiComp). The bibliography consists of 32 papers in total (Appendix A).

Study Design

For each article in the bibliography, we use usability issue metrics, specific interaction/design elements and contexts of the usage to characterize then. We first
classify the articles based on different usability issues the articles addressed. We use
metrics defined by Gafni (2009) to characterize the usability issues. We then summarize
the specific interactions or design elements that the articles investigate. Last, we extract
the scenarios that the techniques or study can apply to.

We calculate the percentage of the articles that propose techniques to deal with
different usability issues. Such data can help draw conclusions on how usability issues
may compromise usability characteristics. We also summarize the approaches that
articles take to address certain usability issues. This categorization can indicate not only
which technique is frequently used to address certain usability issue, but can also identify
which study strategy is widely used across different usability issues.

**Research questions of Literature Study**

In this literature study, we survey 32 articles in total. Table 2 shows the number of
articles we survey for each usability issues.

RQ1.1: What usability issues are major problems to compromise the usability of
mobile applications?

The design of an application need to consider various interface elements (e.g.,
Layout, Size, Hierarchy etc.), user interactions (e.g., Touch, Gestures etc.) and usage
contexts (e.g., Walking, Lying down, Face-to-face etc.) The answer to this question can
help understand which of these factors would need to specifically address usability
issues.

RQ1.2: What kinds of approaches/methodologies are proposed to address/
investigate usability issues, and how different approaches/methodologies are used to
address the same usability issue?
In addition, we study the advantages and disadvantages of different kinds of techniques, providing guidelines on choosing techniques for different usability issues.

**Usability Issues in Various Elements, Interactions, and Contexts**

Table 2 shows the usability issues addressed by surveyed articles. Seven out of 11 metrics mentioned in Gafni (2009) have been addressed in the literature of our survey. In the process of the literature survey, we find that the original definition of these metrics are limited. The original scope of the metrics mainly focus on the potential impact of small screen size and hardware constrains of mobile applications. By surveying the literature, we find that the use cases of mobile applications are much broader, and much more factors need to be taken into account when considering the usability of mobile applications. So, we redefine the related eight metrics here: (1) Clarity of operation possibilities, which measures the degree of accessibility to all the possible operations that apps can perform. (2) Completeness of operation menu, which measures the degree of completeness of menus possibilities and rationality of its hierarchies. (3) Display load, which measures the burden degree of the displays as well as the informativeness and orderliness of the displays. (4) Ease of input entering, which measures the ratio of easy to provide input or start command of the application/system. (5) Ease of output use, which measures the level of convenience when user manipulate the output. (6) Ease of use, which measures the degree in which the system performs minimum interactions. It depends on the number of interactions and interfaces involved in a task. (7) Tasks based on user location, which measures the degree of usage of task based on user location, to minimize inputs. It reflects how adaptive the application can be based on different locations of users.
Ease of Input Entering

As we can see in Table 2, ease of input entering is the most important usability metrics among the 8 metrics we defined. Thirteen out of 32 papers have addressed the usability issues related to the ease of input. The ease of input is commonly related to the interactions such as touch, text entering, and gestures. The keyboard and haptic feedbacks are the main design elements involved in the input activities. This because the virtual keyboard on the touch screen is the most common way for user to enter inputs.

Nevertheless, HCI community endeavor to break constrains of the touch screen to enter inputs. Novel elements such as 3D gestures and deformation-based gestures are developed to meet users’ needs to enter special inputs. Furthermore, to increase the usability when user enter the inputs, researchers enhance the user experience of haptic feedback to ensure the users that the specific UI elements has been pressed.

Researchers also investigate the usability of input activities in various contexts. Walking and entering special texts (e.g., CAPTCHA, password etc.) are the most frequent contexts that have been investigated. This result is intuitive because walking and entering special texts are common usage scenarios of smartphone applications. In these contexts, users have special needs to the interface as the interactions in these contexts are different from normal usage scenarios such as entering texts in static status. In addition, some research also concerns about the input convenience of the motor impairment. Unlike reading output on the screen, traditional entering input interfaces post higher standards for the physical capabilities of users. These research investigates the behaviors of users with motor impairment and tries to customize input interfaces for these users.

Last, other research provides solutions to launch favorite command in a more intuitive way. Because the segments of time spent by users on mobile applications are often
shorter than desktop applications, the research would enable users to launch the functionalities of mobile applications much faster.

Table 2. Usability Issues Addressed by Surveyed Articles

<table>
<thead>
<tr>
<th>Usability Metrics</th>
<th># Articles</th>
<th>Usage Contexts</th>
<th>Interactions/Design Elements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clarity of operation possibilities</td>
<td>1</td>
<td>Cross-device tasks</td>
<td>Taskflow</td>
</tr>
<tr>
<td>Completeness of operation menu</td>
<td>1</td>
<td>Menu traversal</td>
<td>Menu Hierarchies</td>
</tr>
<tr>
<td>Display load</td>
<td>5</td>
<td>Navigate; Browse; Select; Read output without eyes</td>
<td>Touch; Display; Icon; Notification Message</td>
</tr>
<tr>
<td>Ease of input entering</td>
<td>13</td>
<td>Walking; For motor impairments; Entering CAPTCHA/password/text/3D virtual content; Launch favorite command;</td>
<td>Touch; Text Entering; Keyboard; 3D gestures &amp; input; Deformation-based gestures; Haptic feedback.</td>
</tr>
<tr>
<td>Ease of output use</td>
<td>3</td>
<td>Lying down; Multi-touch rotation</td>
<td>Screen rotation</td>
</tr>
<tr>
<td>Ease of use</td>
<td>6</td>
<td>Smartphone launcher; Face-to-face interaction; Unlock phone; Launch favorite command; Browse; Web use</td>
<td>Layout; Home screen; Co-located interaction; Viewing Image; Browser design</td>
</tr>
<tr>
<td>Tasks based on user location</td>
<td>3</td>
<td>Walking; Search; Map use</td>
<td>Touchscreen Gestures; Interaction while walking; Search</td>
</tr>
</tbody>
</table>

Ease of Use

Ease of use is the second frequently discussed usability metric. Six out of 32 papers have discussed the usability issues related to ease of use. To increase the ease of use, the central theme of the research is to minimize the user interactions in order to accomplish tasks. Among all the topics, layout and home screen are design elements that frequently discussed in the literature concerning ease of use. This is mainly because the strategy to minimize interactions varies for applications in different categories, while the strategy to minimize the interactions before entering into a specific application is more
So researchers tend to focus more on layout and home screen to solve the more general usability issue. Besides, the research concerning the ease of use inside the application also exists. The approaches of the research focus on specific usage scenarios. Some research develop technique to facilitate the ease of use when viewing panorama pictures. Other research investigate the ease of use when user surfing the web with mobile browsers. These works develop techniques or make the suggestions to the design elements to enhance ease of use for specific tasks.

Researchers also investigate the ease of use in different contexts. Some research develop technique for the ease of use for frequent tasks, such as launch favorite commands and unlock the mobile devices. These tasks are essential for mobile systems and user perform these tasks quite frequently. Some other research investigate the ease of use of mobile devices when users are communicating face to face. The researchers argue that the interactions with mobile devices could serve both for the communication with mobile devices and the resources of real world interactions.

**Display Load**

Display load is also frequently investigated in the surveyed articles. Six out of 32 papers have discussed the usability issues related to display load. The display load becomes a main usability topic for smartphone application because of two reasons. First, the devices’ screen size is limited. The content that could be displayed on desktop applications could not be fully and properly presented in smartphone applications. Second, the users need to enter input or read output in a rather shorter time slot, so too much information on the screen become serious issue when users try to differentiate each part of information on the screen in a short time. The issues caused by display load can be
categorized into two sets, issues related to input task and issues related to output task. First, from perspective of input, heavy display load increase the difficulty to accurately hit the UI components. The corresponding interactions and design elements addressed in literatures are touch and icons. Second, from perspective of output, heavy load increase the difficulty for user to extract information. The corresponding interactions and design elements addressed in literatures are displays and notification message.

Researchers also investigate the display load in various contexts. In addition to the common contexts such as navigate, browse, select, researchers particularly focus on the context when users don’t have enough time to read output or enter input. In the literature, this context is called “eyes free” scenarios. Numerous techniques are developed to enable user to enter input or read output in the eyes-free scenarios.

**Tasks Based on User Location**
Tasks based on user location is one of the usability metrics that is unique for mobile applications. Three articles that we surveyed have addressed the usability issues related to this metric. It is worth noted that the less frequent interactions such as gestures and walking interactions are primary concerns in this metric. This is because the location-based services are often used in the scenarios that users frequently change their locations. Map use and use of applications while walking are the contexts that frequently discussed for this metric. Additionally, the interactions of searching are also common subjects for the research in this metric. One possible explanation is that the search functionality in smartphone applications usually leverage the location data to rank the list of return results for the searching.
Ease of Output Use

Ease of output use and display load are both metrics concerning output, but they have different focus. Display load focuses on the manifestation of the output, while ease of output focus more on the convenience of manipulation of the output. The research for this metric is mainly focus on screen rotation. Screen rotation is a unique functionality for mobile devices because only small handheld device could be rotated during the daily use. Various contexts have been investigated for screen rotation. Research shows that users use smartphone applications quite frequently when lying down. Researchers have tailor the screen rotation to increase the usability of smartphone applications when users are lying down. Also, research also investigates the scenarios when user operate tablet on the table with one hand. For this use case, researchers customize the multi-touch screen rotations.

Other Usability Issues

Two usability issues have only been mentioned in one article: clarity of operation possibilities and completeness of operation menu. These usability metrics are important ones for both smartphone and desktop applications. One possible reason why less research focuses on these topics is that these metrics may not have many unique challenges on mobile platform. Despite the fact that the number of mobile-related challenges of these problems is less, the problems that the two articles have addressed are mobile-unique.

The articles addressing the clarity of operation possibilities investigate the task flows on mobile devices. Particularly, it studies the cross-device tasks and task flows. Cross-device tasks become very common in smartphone applications. For example, a top rank application in Chinese app market called WeChat require user to use smartphone
applications to scan the QR code on computer screen to log in. The tasks of this kind
require user to manipulate multiple devices collaboratively. The clarity of the operation
possibilities of these tasks become very important as user need very clear indication or
instructions to perform cross-device operations. The article addressing completeness of
operation menu discusses the design of a very specific UI element, the menu hierarchies
of mobile applications. Because of the screen size limitation, the mobile applications
often have multiple levels of menus instead of menus on desktop applications that have
less levels in the menu but more options on each level. One takeaway from both articles
is that the difference between usage scenarios of mobile and usages scenarios of desktop
should be taken into account in every design details. The slight difference in the interface
could have huge impact on the user experience.

Summary
These results show that 6 unique usability metrics of smartphone applications are
major topics that HCI community concern about. For each usability metric, we also
briefly illustrate the involved interactions and interface elements, as well as the main
contexts that existing research focus on.

Approaches Used to Address Usability Issues
To address the RQ1.2, we summarized the approaches used in the surveyed
literature. Table 3 shows the approaches used in surveyed articles to address the usability
issues we mentioned. 21 out of 32 papers propose at least one technique to address the
mentioned usability issues. Overall, we summarize 9 commonly used approaches used in
these 20 papers to address usability issues. Noted that multiple techniques could be
adopted by one article. We briefly illustrate each of them in the following paragraphs.
Table 3. Approaches Used in Surveyed Articles to Address Usability Issues

<table>
<thead>
<tr>
<th>Approach</th>
<th>Usability Issues</th>
<th># Articles</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adaptive interfaces (e.g., keyboard, screen rotation)</td>
<td>Ease of input entering; Ease of output use</td>
<td>5</td>
</tr>
<tr>
<td>Novel interaction with auxiliary part of mobile devices (e.g., benzel, back cover)</td>
<td>Ease of input entering; Ease of use</td>
<td>2</td>
</tr>
<tr>
<td>Voice input</td>
<td>Ease of input entering</td>
<td>1</td>
</tr>
<tr>
<td>Depth camera/sensor</td>
<td>Ease of input entering; Tasks based on user location</td>
<td>2</td>
</tr>
<tr>
<td>Predicting user behavior</td>
<td>Ease of input entering; Ease of use; Tasks based on user location</td>
<td>4</td>
</tr>
<tr>
<td>Eyes free output (e.g., Haptic/Gesture /Electrical stimulation feedback)</td>
<td>Ease of input entering; Display load</td>
<td>4</td>
</tr>
<tr>
<td>Gestural input</td>
<td>Ease of input entering</td>
<td>2</td>
</tr>
<tr>
<td>Offload content to space around</td>
<td>Display load</td>
<td>1</td>
</tr>
<tr>
<td>Deformable user interface</td>
<td>Ease of input entering</td>
<td>1</td>
</tr>
</tbody>
</table>

**Adaptive interfaces**

The adaptive interfaces are self-adjusted interfaces based on different user postures. 5 articles have adopted this technique to address ease of input entering issues or ease of output use issues. The proposed approaches first infer the users’ posture by monitoring the physical locations of users’ interactive body parts such as the fingers grasping the device, hands or faces. Then they construct models that define the best relative positions between interfaces and human postures. Last, the interfaces adapt themselves based on the user postures and the models. Such technique is generally suitable to enhance user experience in mobilized contexts.
**Predicting user behavior**

Mobile applications could leverage the prediction of user behavior to provide customized functionalities and user interfaces. The prediction of user behavior is used in the same way as the user gestures in the previous approach. The prediction of user behavior facilitate the construction of a model indicating the best user interfaces or functionality options provided to users at certain steps of the user operation. This technique improves the accessibilities of the desired functionalities and enhance the ease of use of the applications.

**Eyes-free output**

We mentioned the notion of eyes free output when describing the surveyed articles addressing the usability issues related to display load. Four articles adopt this technique to resolve the issues related to display load and ease of input entering. The eyes-free output notify users certain information mainly by haptic feedback, either through electric stimulation or gesture-like movements. A representative example of eyes-free output are ringtone or vibration when we receive phone call. The eyes-free output developed in the literature (e.g., haptic gestures) could convey more detail information than simple notifications by vibrations.

**Other approaches**

Various other approaches have been adopted by surveyed literature to address usability issues. It is worth noted that the ease of input entering could be addressed by 8 out of 9 approaches proposed. We infer that the input entering is the most important user interactions for mobile applications. Based on such inference, the empirical study performed in this dissertation will further investigate how usability varied by different
design of user input entering, and how proposed approach in the literature would alleviate existing usability issues.

**Study methodologies Used to Investigate Usability Issues**

*Table 4. Study Methodology Used in Surveyed Articles to Investigate Usability Issues*

<table>
<thead>
<tr>
<th>Study Methodology</th>
<th>Usability Issues</th>
<th>#Articles</th>
</tr>
</thead>
<tbody>
<tr>
<td>Log-based data collection</td>
<td>Ease of input entering; Ease of use</td>
<td>3</td>
</tr>
<tr>
<td>Study &amp; analyze video/screenshot data</td>
<td>Ease of input entering; Tasks based on user location; Ease of use; Display load</td>
<td>4</td>
</tr>
<tr>
<td>Model/theory-based evaluation</td>
<td>Ease of use; Completeness of Operation Menu; Display load</td>
<td>3</td>
</tr>
<tr>
<td>Study physical data</td>
<td>Ease of input entering; Ease of output use; Ease of use</td>
<td>3</td>
</tr>
</tbody>
</table>

To address RQ 1.2, we also summarized the study methodologies of surveyed articles. Twelve of 32 articles are empirical studies or new theories investigating the research metrics. As shown in Table 4, four general study methodologies have been adopted by the surveyed literature. We select two representative methodologies to illustrate how these study methodologies were used in the articles.

**Log-based data collection**

Many novel ideas have been adopted during the log-based data collections in surveyed literature. A representative example is in an article studying the users’ typing behaviors, the authors developed a typing game to log the users’ typing behaviors. Such methodology generates a significant amount of data for authors to analyze, which improve the authenticity and credibility of the study results.
**Study & analyze video/screenshot data**

Online video websites such as Youtube provide a promising repository for HCI researchers to analyze user behaviors from user generated video. User studies carried out in the lab are both expensive and unreliable. Users are aware of the situation that they are being studied, thus could present different behaviors. Empirical studies through user-generated videos not only save the cost of hiring participants, but also generate results with higher authenticity because the videos used in the studies can reflect the user behaviors in real scenarios. Additionally, some studies that set special requirements on participants (e.g., studies on motor impairments) have difficulties to recruit participants that meet the special requirements. User-generated videos provide great flexibility for researchers to select qualified candidates from large amount of videos.

**Summary**

We discussed various approached and study methodologies that have been proposed to address usability issues. We find that those approaches and methodologies actively leverage information from user interactions (e.g., patterns of user behaviors, user postures) to guide the design of better user experiences. We also find that the important usability issues such as ease of input entering has been addressed by most of approaches. Such fact motivates the empirical study of this dissertation to reveal the essence of the user interactions. The study results are desired to explain how different approaches would alleviate the usability issue.
**Method of Empirical Study**

This empirical study sought to answer two research questions via quantitative experiments followed by a semi-structured interview. In the experiment phase, participants were given two task management tools to perform 4 tasks. After that, they were asked to take part in a semi-structured interview to answer 7 questions about their feelings of the previous experiment and mobile phone using experience in daily life. Participants’ interactions with device during the experiments were recorded by screen recording app running at the back end and their answer to interview questions were taken as notes by investigator for further analysis.

**Participants**

Twelve UNC-CH SILS students were recruited via email to take part in this study voluntarily. They are all using or have used a touchscreen mobile phone before. Choosing experienced users have two advantages. First, it can eliminate interaction errors caused by the unfamiliarity of basic operations on touchscreen mobile devices. Second, it can decrease the learning time of those two task management tools in the experiments. SILS student is a suitable group to be studied. The average age of SILS students is between 18-26, and most of them have good learning ability and are familiar with new technologies. Thus the learning curve of using new application is not steep. Except that, there are no other restrictions on participants’ gender, nationality, handedness and major because a large variety of participants can decrease the influence of side effects caused by specific
group of people. Web designers have proved that female users have higher expectation on artistic quality of a web page but male users prefer a clear structure (Marcus & Gould, 2000). Since such factors are not focused in this study and thus there is no emphasis on these aspects during the recruitment process.

**Experimental Apps Description**

Two task management applications are used in this study. The first one is called EnterTask, which provides five textfields—Title, Date&time, Priority, Category, and Description for users to describe an event. The design principle of this tool is to make it extremely concise and clear, look like a piece of paper (Figure 2). This tool forces users to enter all content by typing because there are no word association functionalities, calendar choosing component, and entering limitation.

*Figure 2 Interface of EnterTask*
The word association functionality provided by Android system is also disabled. Users have to operate keyboard to enter every character. The design purpose of this tool is to catch as many users’ behaviors as possible. In addition, such design is different from most task management tools in the market. Feedback on the design is expected to be collected from semi-structured interviews.

The second application is called ChooseTask, which is developed based on the prototype of a task management app called Anydo. ChooseTask provides the same functionalities as EnterTask but it has a more mature user interface (Figure 3). ChooseTask uses icon buttons, enables word association, and provides more operation gestures such as dragging and sliding. ChooseTask pops up associated word to help users to refine their input (Figure 4). For example, when user enter “go to” in the title textfield, ChooseTask pops up several options “go to sleep”, “go to gym”, and “go to bank” to stimulate more completed item information.

![ChooseTask Interface](image)

*Figure 3 Interface of ChooseTask.*
Another difference of ChooseTask is that it provides calendar for users to choose date and time, a button to choose priority, and a dialog box to create and select categories. Such design decreases the frequency of using keyboard but also reduce the flexibility of input. In addition, more shifting between pages is involved in this app and thus sometimes users have to navigate back and forward. As a comparison to EnterTask, the design purpose of this tool is to investigate users’ feedback on multi-page interfaces and semi-complete widgets.

Figure 4 Automatic Inputs Refine of ChooseTask.

Procedures
This study is composed of a four-task experiment and a semi-structured interview. At the beginning of the study, all participants were given one informed consent (informed consent is attached in Appendix B) to read and sign, which contains purpose, procedures, benefits, and other nature of this study.
After agreeing and signing the informed consents, the participant was randomly assigned into one of two groups. Participants in Group A use their preferred hand during the whole experiment process and those in Group B use non-preferred hand. All participants were divided into two groups, 6 people for each group. Each participant was given a number as identification. Number 1 to 6 is assigned to participants in Group A, and participants in Group B use number 7 to 12 to identify.

Then the participants were given a brief introduction on two tools and tasks they would conduct during the experiment. They were also given one sample task to do under the help of investigator. Such design is to make sure that participants have basic understanding on experimental tools before they conduct the true experiment. In addition, it is very important that they are familiar with basic functionalities because the error interactions caused by unfamiliarity with the tool are noisy data for this experiment. After these steps, participants are fully prepared to perform 4 tasks (task guide is attached in Appendix C).

For the first task, participants were asked to insert a reminder into EnterTask while sitting in SILS Library. Then they used ChooseTask to insert another reminder in the same environment. After these two tasks, participants were led to SILS lobby and asked to insert the third reminder into EnterTask while walking in their normal speed in SILS lobby. For the last task, they used ChooseTask to insert one more reminder while walking in SILS lobby. The results of two groups can be analyzed to investigate the difference of target acquisition error rate and task finishing speed caused by handedness. In addition, the result of tasks one and three can be used to compare with the result of task two and
four to explore two kinds of interface design. Last but not least, the first two tasks are designed as benchmarks for the other tasks to explore how walking affects usability.

After experiments, a semi-structured face-to-face interview was conducted with participants (interview guide is attached in Appendix D). The interview is mainly focused on three aspects. First, do participants find problems when using the applications while walking during the experiments and in their daily lives? Second, do participants in Group B feel obvious discomfort during the experiments and under which circumstance do they use non-preferred hand to operate their mobile phone? Third, do they have preferences to the two different tools they have used and why?.

Data Collection Method

Two dataset are collected in this study corresponding to two phases—experiments and semi-structured interview. In the first phase, each participant conduct tasks under four circumstances—using EnterTask when sitting, using ChooseTask when sitting, using EnterTask when walking, and using ChooseTask when walking. For each circumstance, investigator records the time each participant spends to finish the task by reviewing video recorded by screen recording app and mark it as $T_{ij}$, the total time participant $i$ spends to finish task $j$ ($i \in [1,12], j \in [1,4]$).

In addition to $T_{ij}$, other statistics including $E_{ij}$ (total error touch of participant $i$ in the jth task), $C_{ij}$ (total touch of participant $i$ in the jth task), and $ER_{ij}$ (the percentage of error touch f participant $i$ in the jth task) are counted from screen record manually and recorded. To answer the first research question, $\overline{ER}_{i1} - \overline{ER}_{i3}$ ($i \in [1,6]$) and $\overline{ER}_{i1} - \overline{ER}_{i3}$ ($i \in [7,12]$) are calculated.
All data collected in the semi-structured interviews are transferred into digital files and stored. All statistics are recorded in MS Excel Spreadsheet. All files are saved without name identification and original screen record files are deleted from the mobile device after statistics are recorded.
Results

To assess the influence of walking status, handedness and interface design under each circumstance, time spent by each participant on each task $T_i$ (i stands for the number of the task) is measured (Table 5). Although all tasks are designed to be in the same complexity level, the total touches (tabbing, sliding, and dragging) times $C_i$ varies from each participant (Table 6). Because of the big difference on total touch times, time spent on each task is not sufficient to indicate usability. Thus, the average time spent on each touch is also measured (Table 7) to evaluate participants’ behaviors under each circumstance. Another indicator of usability is the acquisition error rate (Table 8), which is calculated by total errors and total touch times.

**Handedness Affects Usability**

For each task, Group A spends more time than Group B in average according to Table 5. Because the only difference between group A and Group B is that participants use different hands to operate the device, the result suggests that using non-preferred hand actually improves users’ efficiency on performing tasks using EnterTask and ChooseTask by decreasing the time spent on each task. Although the difference is not obvious on all tasks—for all tasks, the difference between two groups is less than 6 seconds. It is surprising that participants need more time to finish tasks when using their preferred hand. However, we discover that participants in Group A performs more touches for task
2, 3, and 4, and such difference could explain why Group A uses more time on each task (Table 6).

Table 5 Time Spent on Tasks by Participants

<table>
<thead>
<tr>
<th></th>
<th>T1</th>
<th>T2</th>
<th>T3</th>
<th>T4</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Group A</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>P1</td>
<td>156</td>
<td>218</td>
<td>90</td>
<td>176</td>
</tr>
<tr>
<td>P2</td>
<td>101</td>
<td>104</td>
<td>62</td>
<td>66</td>
</tr>
<tr>
<td>P3</td>
<td>101</td>
<td>156</td>
<td>131</td>
<td>165</td>
</tr>
<tr>
<td>P4</td>
<td>130</td>
<td>146</td>
<td>88</td>
<td>143</td>
</tr>
<tr>
<td>P5</td>
<td>145</td>
<td>198</td>
<td>121</td>
<td>155</td>
</tr>
<tr>
<td>P6</td>
<td>151</td>
<td>235</td>
<td>80</td>
<td>96</td>
</tr>
<tr>
<td>AVG</td>
<td>131</td>
<td>176</td>
<td>95</td>
<td>134</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>T1</th>
<th>T2</th>
<th>T3</th>
<th>T4</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Group B</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>P7</td>
<td>82</td>
<td>143</td>
<td>121</td>
<td>129</td>
</tr>
<tr>
<td>P8</td>
<td>140</td>
<td>170</td>
<td>103</td>
<td>168</td>
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<td>P9</td>
<td>137</td>
<td>188</td>
<td>81</td>
<td>98</td>
</tr>
<tr>
<td>P10</td>
<td>132</td>
<td>201</td>
<td>90</td>
<td>123</td>
</tr>
<tr>
<td>P11</td>
<td>120</td>
<td>165</td>
<td>89</td>
<td>144</td>
</tr>
<tr>
<td>P12</td>
<td>119</td>
<td>143</td>
<td>76</td>
<td>96</td>
</tr>
<tr>
<td>AVG</td>
<td>122</td>
<td>168</td>
<td>93</td>
<td>126</td>
</tr>
</tbody>
</table>

Table 6 Total Touch Times for Each Task

<table>
<thead>
<tr>
<th></th>
<th>C1</th>
<th>C2</th>
<th>C3</th>
<th>C4</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Group A</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>P1</td>
<td>76</td>
<td>120</td>
<td>100</td>
<td>54</td>
</tr>
<tr>
<td>P2</td>
<td>105</td>
<td>108</td>
<td>80</td>
<td>123</td>
</tr>
<tr>
<td>P3</td>
<td>76</td>
<td>101</td>
<td>53</td>
<td>56</td>
</tr>
<tr>
<td>P4</td>
<td>89</td>
<td>120</td>
<td>76</td>
<td>78</td>
</tr>
<tr>
<td>P5</td>
<td>77</td>
<td>99</td>
<td>103</td>
<td>82</td>
</tr>
<tr>
<td>P6</td>
<td>95</td>
<td>134</td>
<td>80</td>
<td>105</td>
</tr>
<tr>
<td>AVG</td>
<td>86</td>
<td>114</td>
<td>82</td>
<td>83</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>C1</th>
<th>C2</th>
<th>C3</th>
<th>C4</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Group B</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>P7</td>
<td>122</td>
<td>82</td>
<td>56</td>
<td>88</td>
</tr>
<tr>
<td>P8</td>
<td>65</td>
<td>51</td>
<td>74</td>
<td>46</td>
</tr>
<tr>
<td>P9</td>
<td>86</td>
<td>52</td>
<td>45</td>
<td>58</td>
</tr>
<tr>
<td>P10</td>
<td>99</td>
<td>70</td>
<td>62</td>
<td>76</td>
</tr>
<tr>
<td>P11</td>
<td>78</td>
<td>99</td>
<td>55</td>
<td>55</td>
</tr>
<tr>
<td>P12</td>
<td>82</td>
<td>55</td>
<td>83</td>
<td>87</td>
</tr>
<tr>
<td>AVG</td>
<td>89</td>
<td>68</td>
<td>63</td>
<td>68</td>
</tr>
</tbody>
</table>

Although participants in Group B spend less time on each task, they actually need more time to perform one touch behavior (Table 7) for most tasks. Group B spends
70.3%, 24.77%, and 7.77% more time on each touch behavior for task2, 3, and 4. In this experiment, the average time spent on each touch is more persuasive than total time spent on each task because participants’ interactions with the device are not strictly limited. Participants are free to navigate content that is irrelevant to tasks in the device. This result suggests that using non-preferred hand decreases the speed of operating mobile device by 16.27% (median of four tasks).

Table 7 Average Time Spent on Each Touch

<table>
<thead>
<tr>
<th>Group A</th>
<th>T1/C1</th>
<th>T2/C2</th>
<th>T3/C3</th>
<th>T4/C4</th>
</tr>
</thead>
<tbody>
<tr>
<td>P1</td>
<td>2.053</td>
<td>1.817</td>
<td>0.900</td>
<td>3.259</td>
</tr>
<tr>
<td>P2</td>
<td>0.962</td>
<td>0.963</td>
<td>0.775</td>
<td>0.537</td>
</tr>
<tr>
<td>P3</td>
<td>1.329</td>
<td>1.545</td>
<td>2.472</td>
<td>2.946</td>
</tr>
<tr>
<td>P4</td>
<td>1.461</td>
<td>1.217</td>
<td>1.158</td>
<td>1.833</td>
</tr>
<tr>
<td>P5</td>
<td>1.883</td>
<td>2.000</td>
<td>1.175</td>
<td>1.890</td>
</tr>
<tr>
<td>P6</td>
<td>1.589</td>
<td>1.754</td>
<td>1.000</td>
<td>0.914</td>
</tr>
<tr>
<td>A</td>
<td>1.546</td>
<td>1.549</td>
<td>1.247</td>
<td>1.897</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Group B</th>
<th>T1/C1</th>
<th>T2/C2</th>
<th>T3/C3</th>
<th>T4/C4</th>
</tr>
</thead>
<tbody>
<tr>
<td>P7</td>
<td>0.672</td>
<td>1.744</td>
<td>2.161</td>
<td>1.466</td>
</tr>
<tr>
<td>P8</td>
<td>2.154</td>
<td>3.333</td>
<td>1.392</td>
<td>3.652</td>
</tr>
<tr>
<td>P9</td>
<td>1.593</td>
<td>3.615</td>
<td>1.800</td>
<td>1.690</td>
</tr>
<tr>
<td>P10</td>
<td>1.333</td>
<td>2.871</td>
<td>1.452</td>
<td>1.618</td>
</tr>
<tr>
<td>P11</td>
<td>1.538</td>
<td>1.667</td>
<td>1.618</td>
<td>2.618</td>
</tr>
<tr>
<td>P12</td>
<td>1.451</td>
<td>2.600</td>
<td>0.916</td>
<td>1.103</td>
</tr>
<tr>
<td>B</td>
<td>1.457</td>
<td>2.638</td>
<td>1.556</td>
<td>2.025</td>
</tr>
</tbody>
</table>

Unit: second

Integrating participants’ answers in semi-structured interviews, we conclude two reasons for the inefficiency on speed. First, the dexterity of non-preferred hand is not as good as preferred hand. All participants in Group B express their comfortableness of using non-preferred hand to operate the device in the interview. Second, using non-preferred hands extracts users’ attention from the screen to their hand and thus they have to re-browse the screen frequently to find the next point they would like to touch.

In addition to speed, the error rate when using non-preferred hand is also higher for task 1, 2, and 3 according to Table 8. Group B made 73.07%, 14.81%, and 65.00%
more errors than Group A for these three tasks. However, task 4 is an exception.

Participants in Group B made 20.33% less errors than those in Group A. By reviewing the screen record, we find that Group A makes 66 acquisition errors in task 4, in which 24 acquisition errors occur when the participants try to touch a button at the top left corner using their right hand.

Thus, the experiment result shows that using non-preferred hand not only causes the user to take more time but also increases the acquisition error rate. This result improves that using non-preferred hand brings usability issues and may reduce users’ interest in apps.

*Table 8* acquisition Error Rate for Each Task

<table>
<thead>
<tr>
<th></th>
<th>E1/C1</th>
<th>E2/C2</th>
<th>E3/C3</th>
<th>E4/C4</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Group A</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>P1</td>
<td>0.013</td>
<td>0.025</td>
<td>0.020</td>
<td>0.111</td>
</tr>
<tr>
<td>P2</td>
<td>0.048</td>
<td>0.028</td>
<td>0.013</td>
<td>0.203</td>
</tr>
<tr>
<td>P3</td>
<td>0.013</td>
<td>0.030</td>
<td>0.038</td>
<td>0.036</td>
</tr>
<tr>
<td>P4</td>
<td>0.022</td>
<td>0.025</td>
<td>0.013</td>
<td>0.141</td>
</tr>
<tr>
<td>P5</td>
<td>0.026</td>
<td>0.030</td>
<td>0.010</td>
<td>0.085</td>
</tr>
<tr>
<td>P6</td>
<td>0.032</td>
<td>0.022</td>
<td>0.025</td>
<td>0.133</td>
</tr>
<tr>
<td>A</td>
<td>0.026</td>
<td>0.027</td>
<td>0.020</td>
<td>0.118</td>
</tr>
<tr>
<td><strong>Group B</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>P7</td>
<td>0.033</td>
<td>0.024</td>
<td>0.036</td>
<td>0.148</td>
</tr>
<tr>
<td>P8</td>
<td>0.062</td>
<td>0.039</td>
<td>0.027</td>
<td>0.043</td>
</tr>
<tr>
<td>P9</td>
<td>0.035</td>
<td>0.038</td>
<td>0.022</td>
<td>0.052</td>
</tr>
<tr>
<td>P10</td>
<td>0.030</td>
<td>0.029</td>
<td>0.032</td>
<td>0.039</td>
</tr>
<tr>
<td>P11</td>
<td>0.064</td>
<td>0.020</td>
<td>0.055</td>
<td>0.164</td>
</tr>
<tr>
<td>P12</td>
<td>0.049</td>
<td>0.036</td>
<td>0.024</td>
<td>0.069</td>
</tr>
<tr>
<td>B</td>
<td>0.045</td>
<td>0.031</td>
<td>0.033</td>
<td>0.086</td>
</tr>
</tbody>
</table>

Another finding from the interview is that most participants sometimes use non-preferred hand to operate their mobile phone in daily lives. The most frequent situation is that they want to check their mobile phone when they are operating a mouse by preferred hand. P10 mentions that she used to take subway to work every morning. She was accustomed to use non-preferred hand to operate her mobile phone because her preferred
hand was used to hold the handrail. Although they all operated mobile phone by non-preferred hand before, they just make phone calls, send messages, and do other simple tasks. None of them have used non-preferred hand to perform complicated tasks such as playing games.

**Walking Affects Usability**

To evaluate the influence of walking status, the statistics of task 1 and task 3 are compared to statistics of task 2 and task 4. In terms of speed, walking does not add burden on participants as expected. In contrast, participants actually spend less time on each touch for both task 3 and task 4 (Figure 5).

![Figure 5 Line Chart of Average Time Spent on Each Touch by Group](image)

However, it is not rigorous to make assumption that walking does not affect usability because of three limitations of this study. First, learning curve may counteract the influence of walking. After using both apps in task 1 and task 2 could help participants to get familiar with the apps and increase their operation speed. As a result, they spend less time on task 3 and task 4. Second, the walking environment in this study
is not real. Participants are walking in SILS lobby where the environment is quiet, safe, and without disturbance. However, a real walking environment such as walking on a busy street is more complicated and exactable. Last but not least, the walking speed of participants is not controlled strictly.

Although walking does not affect operation speed according to the statistics, walking brings much higher error rate for ChooseTask. According to Figure 6, the A of task 4 is 337.03% higher than task 2 for Group A, and 177.41% higher for Group B. The result also indicates that there’s no evidence that walking increase the gap of acquisition error rate caused by handedness.

![Figure 6 Line Chart of Acquisition Error Rate for Each Task by Group](image)

**Figure 6** Line Chart of Acquisition Error Rate for Each Task by Group

**EnterTask VS ChooseTask**

Another problem remained is that Group A performs more touch behaviors.

According to screen record, 4 out of 6 participants in Group A never use word association functionality during the experiment even if ChooseTask returns the same expression as
they use. They always type in every letter by using keyboard. This phenomenon is also verified by their answers in the semi-structured interview. Those 4 participants in Group A are not attracted by the word association functionality. One possible reason is that they focus on the keyboard section and neglect the associated word returned by ChooseTask. As discussed above, Group B spends more time between two touch behaviors on re-browsing the screen. They are more likely to notice the change on the screen. Thus we believe that word association function is more important to users when they use non-preferred hand to operate device.

Although ChooseTask is designed to be more user-friendly, it does not get much more compliments in the interview. Participant P1, P3, P4, P6, and P7 prefer EnterTask instead of ChooseTask. P1 mentions that he likes the simple interface of EnterTask because he can see all widgets in one screen. He is confident about the next step he is going to do when using EnterTask and he does not have to navigate among several pages to find the item he need. P3 prefers the interface of EnterTask because it does not have confusing buttons. He exactly knows the usage of each part of the screen. P4 and P6 also prefer EnterTask because they both believe EnterTask already provides all functionalities that they expect a task management tool should have. It’s light and flexible, which can save a lot of space for device. In addition, learning curve of EnterTask is steadier because it’s easy to use. ChooseTask also gets negative comments from other participants. They think the interface is so simple that makes the app look unreliable.

For ChooseTask, all participants agree that the interface is nicer and more comfortable. P9 especially likes the icon ChooseTask uses and she thinks they perfectly simplify and enhance the layout. P2, P8, P10, P11, and P12 all mention the word
association functionality and calendar component of ChooseTask, which save a lot of
typing time when doing task 2 and task 4. Negative reviews on ChooseTask focus on
page navigation. “It is annoying to shift back and forward when using ChooseTask
because it is just a simple task. I don’t think it is necessary to have so many pages,”
commented P7.
Discussion

In this paper, we carry out a two-phase study to investigate the usability issues in smartphone applications. Particularly, we focus on the ease of input entering on mobile applications. The study consists of a literature review study and an empirical study.

In the literature review study, we survey 32 articles of the Human Computer Interaction domain in recent years. We analyze motivations, approaches, and methodologies of these articles and asked two questions.

First, what are the major usability issues that affect users’ experience with mobile applications? In order to characterize those usability issues, we define 8 usability metrics of mobile applications based on original metric proposed by Gafni (2009). In our characterization, we focus on interface elements (e.g., Layout, Size, Hierarchy etc.), user interactions (e.g., Touch, Gestures etc.) and usage contexts (e.g., Walking, Lying down, Face-to-face etc.). The answer to this question can help understand which of these factors would need to specifically address usability issues.

Second, what are the common approaches and methodologies in these literatures to address/investigate of those usability issues? We summarize nine approaches and four study methodologies from the surveyed articles. We illustrate how these approaches and study methodologies can be leveraged across different usability issues. We also investigate how different approaches and methodologies could be used to address/investigate the same usability issue. Particularly, we find that the ease of input
of entering information is the major concern addressed by various approaches and methodologies in the articles. This fact motivates us to carry out a detailed empirical study on the ease of input entering to reveal the essence of user interactions.

In the empirical study, we recruited 12 participants to take part in a four-task experiment followed by a semi-structured interview. We measured operation speed, and acquisition error rate, and analyzed interview notes to answer three questions.

First, do handedness and walking status affect usability? The statistics indicate that handedness affects usability in both operation speed and acquisition error rate. We analyze possible reasons and invalidity threats. However, no obvious evidence proves that walking status affects usability in this study. We suspect that this is caused by the authenticity of experimental scenario.

Second, what approaches/design rules could enhance the user experience for non-preferred hand using situation and walking status? We provide two suggestions according to the study result. (1) page shifting should be decreased in order to pursue a simple interface; (2) word association functionality and built-in components that can decrease users’ interaction with keyboard are highly recommended for apps that are frequently used by non-preferred hand.
Related Work

Our work in this study falls into the general category of usability study of ease of input entering. A variety of empirical studies have investigate the ease of input of small touchscreen mobile devices. Small devices deserve more attention because interface design on small screens is more difficult than large screen due to lack of screen space (Brewster, 2002). Previous works have analyzed and evaluated the usability of small touchscreen mobile devices from numerous perspectives. This literature review summarizes those previous works and draws a conclusion on the novelty of this study and its importance.

One major difference of small touchscreen mobile device from desktop is its lack of screen space. As a result, size of widgets is adjusted to fit the screen size. However, such adjustment brings problems. For example, direct presentation of most World Wide Web pages on small mobile devices can be difficult for users to read, causing poor user experiences (Bickmore & Schilit, 1997) because users cannot always clearly read the content and hit the spot they would like to touch.

Researchers have investigated numerous ways to decrease the influence of small screen in order to improve the usability of mobile application usability. Brewster (2002) tries to improve target acquisition rate by applying sonically-enhanced buttons. He conducts an experiment with 16 participants, asking them to perform serials of button touching tasks on mobile device. Result shows that sonically-enhanced buttons improve
touching accuracy of normal sized buttons by 50.8% in laboratory environment. His experiment proves that sound has a positive impact on the usability of button. He also suggests that button size could be too small because it is too hard to be touched even enhanced by sound.

Parhi, Karlson & Bederson (2006) conducts a two-phase empirical study to explore optimal target sizes for one-handed thumb use of mobile touchscreen devices. They explored required target size for single-target pointing tasks, such as tabbing buttons and checkboxes, in the first phase experiment and widget size for tasks that involve a sequence of taps, such as text entry, in the second phase.

Since holding a device in one hand constrains thumb movement, we varied target positions to determine if performance depended on screen location. The results showed that while speed generally improved as targets grew, there were no significant differences in error rate between target sizes $\geq 9.6$ mm in discrete tasks and targets $\geq 7.7$ mm in serial tasks. Along with subjective ratings and the findings on hit response variability, we found that target size of 9.2 mm for discrete tasks and targets of 9.6 mm for serial tasks should be sufficiently large for one-handed thumb use on touchscreen.

A number of studies that consider appropriate target sizes for touchscreen use have already been conducted on small touchscreen devices such as PDAs (Brewster, 2002; Mizobuchi et al, 2002; Sears & Zha, 2003) and smartphones (Perry & Hourcade, 2008; Park, 2010). We differentiate the study in this dissertation from the existing work by three perspectives.

First, the input method studied by existing work is outdated. Although existing works are using the same platform as we do, most of them focus on two-handed stylus
input (Mizobuchi et al, 2002) and single-handed thumb input (Perry & Hourcade, 2008), which is not comprehensive. One the one hand, using stylus is different from using a finger or a thumb. According to experiment results from Mizobuchi et al (2002), error rate of using a pen instead and a cursor key are almost the same when the target size is bigger than 5 mm. However, the contact area of finger and thumb is much bigger than a stylus, and thus such result is insufficient for thumb-input interface design because it requires lower resolution and accuracy. On the other hand, research on single-handed thumb interactions fails to declare whether participants use preferred-hand or non-preferred-hand. We consider that there’s difference in the need of target size if users use non-preferred-hand instead of preferred-hand. Thus, claiming target size without indicating handedness is not consolidated.

Second, the contexts in which the existing studies being performed is limited. Our studies cover broader contexts. The experiments in previous studies are usually conducted in a standstill environment, where participants use devices when sitting down in a silent space—usability-testing laboratory. However, result could change if participants have to use touchscreen devices while walking because related work in Psychology has revealed that human beings are likely to be distracted if they focus on more than one single event (Lindenberger, Marsuske & Baltes, 2000). Mizobuchi et al (2002) also suspect that usability of a mobile device could be significantly reduced when user is in a more realistic situation such as walking outside and holding something in one hand. Bergstrom-Lehtovirta, Oulasvirta & Brewster (2011) conducted an empirical study and find that accuracy of target acquisition decelerated by 20–40% if participant is walking in his/her favored speed.
Third, the specific requirement set in the existing studies may not reflect the real usage scenarios in daily smartphone use. Different kinds of requirements of applications may lead to different user behaviors. Mizobuchi et al (2002) focus on in-vehicle touchscreen and they create and prove that their interaction schema, which contains new interaction gestures and pie-menu display instead of traditional touch behavior and list-menu, is significantly faster and safer. However, this result may not be applicable to other systems because in-vehicle system requires shorter gesture using visual cues. Sears and Zha (2003) investigate data entry task on PDA, which is another popular topic. They carry out an empirical study with 30 participants, asking them to do 6 tasks involving data-entry process, and they surprisingly find that data entry rates and error rates are not affected by keyboard size. These previous studies indicated that experiment results in one setting might not be applied to another setting.

Limitations

This study utilizes college students as participants, who are young and facile with using their hands to operate their smartphones. It is likely that the group of subjects tested is not representative of the population as a whole. One would expect older subjects to exhibit poorer performance and less dexterity especially while moving or multitasking as compared to this study’s participants.
References


Dunlop, M., & Levine, J. (2012, May). Multidimensional pareto optimization of
touchscreen keyboards for speed, familiarity and improved spell checking.


### Appendix A—Characteristics of articles in Literature Review

<table>
<thead>
<tr>
<th>Year</th>
<th>Conference</th>
<th>Title</th>
<th>Study/Technique</th>
<th>Approach</th>
<th>Interaction or Design Elements</th>
<th>Metrics</th>
<th>Context</th>
<th>Device</th>
</tr>
</thead>
<tbody>
<tr>
<td>2006</td>
<td>CHI</td>
<td>A Role for Haptics in Mobile Interaction: Initial Design Using a Handheld Tactile Display Prototype</td>
<td>Technique</td>
<td>new display platform</td>
<td>Touch</td>
<td>Display load</td>
<td>Navigate; Browse; Search; Map</td>
<td>Smartphone</td>
</tr>
<tr>
<td>2013</td>
<td>CHI</td>
<td>Analyzing User-Generated YouTube Videos to Understand Touchscreen Use by People with Motor Impairments</td>
<td>Study</td>
<td>Study video</td>
<td>Touchscreen</td>
<td>Ease of input</td>
<td>Usages of motor impairments</td>
<td>Smartphone</td>
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<td>2013</td>
<td>CHI</td>
<td>iPhone in vivo: video analysis of mobile device use</td>
<td>Study</td>
<td>Study video and interactions</td>
<td>Touchscreen</td>
<td>Tasks based on user location</td>
<td>Search; Map</td>
<td>Smartphone</td>
</tr>
<tr>
<td>2013</td>
<td>CHI</td>
<td>A Study on Icon Arrangement by Smartphone Users</td>
<td>Study</td>
<td>Study screenshots</td>
<td>Layout; Homescreen</td>
<td>Ease of use - per task</td>
<td>Smartphone launcher</td>
<td>Early-Age Cell Phone</td>
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<tr>
<td>2004</td>
<td>CHI</td>
<td>Model-based Evaluation of Cell Phone Menu Interaction</td>
<td>Study</td>
<td>Evaluation</td>
<td>Menu Hierarchies</td>
<td>Completeness of Operation Menu</td>
<td>Menu traversal</td>
<td>Early-Age Cell Phone</td>
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<tr>
<td>2012</td>
<td>UbiComp</td>
<td>Understanding and Prediction of Mobile Application Usage for Smart Phones</td>
<td>Technique</td>
<td>Dynamic home screen study</td>
<td>Homescreen</td>
<td>Ease of use - per task</td>
<td>Search to use an app</td>
<td>Smartphone</td>
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<tr>
<td>2010</td>
<td>CHI</td>
<td>Mobile Taskflow in Context: A Screenshot Study of Smartphone Usage</td>
<td>Study</td>
<td>Study screenshots; Diary study</td>
<td>Taskflow</td>
<td>Clarification of operation possibilities</td>
<td>Cross-device tasks</td>
<td>Smartphone</td>
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<tr>
<td>2013</td>
<td>CHI</td>
<td>iGrasp: Grasp-based Adaptive Keyboard for Mobile Devices</td>
<td>Technique</td>
<td>Adaptive keyboard</td>
<td>Keyboard</td>
<td>Ease of input</td>
<td>Text Entry when grasping device</td>
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<td>UIST</td>
<td>iRotate Grasp: Automatic Screen Rotation based on Grasp of Mobile Devices</td>
<td>Technique</td>
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<td>Gestures and Widgets: Performance in Text Editing on Multi-Touch Capable Mobile Devices</td>
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<td>Text entering</td>
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<td>Text Entry</td>
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<td>AD-Binning: Leveraging Around Device Space for Storing, Browsing and Retrieving Mobile Device Content</td>
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<td>Offload mobile content to space around</td>
<td>Display</td>
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<td>CrashAlert: Enhancing Peripheral Alertness for Eyes-Busy Mobile Interaction while Walking</td>
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<td>Interaction while walking</td>
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<td>Muscle-Propelled Force Feedback: Bringing Force Feedback to Mobile Devices</td>
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<td>Designing and Theorizing Co-Located Interactions</td>
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<td>iRotate: Automatic Screen Rotation based on Face Orientation</td>
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<td>Looking At You: Fused Gyro and Face Tracking for Viewing Large Imagery on Mobile Devices</td>
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<td>Observational and experimental investigation of Typing Behaviour using virtual Keyboards for mobile Devices</td>
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<td>multidimensional Pareto optimization of Touchscreen Keyboards for speed, familiarity and improved spell checking</td>
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<td>Touch Typing using Thumbs: Understanding the Effect of Mobility and Hand Posture</td>
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</table>

**Technique**

- Study
- Technique
- Theory

**Study Parameters**

- Study physical parameters of gestures
- Study display
- Study analysis of naturalistic video data
- Study of user touch in a typing game; adapted shift function
- User Study

**Ease of Use**

- Ease of output use
- Ease of input
- Ease of use - per task
- Ease of use - per output
- Ease of input
- Ease of input
- Ease of input

**Devices**

- Smartphone
- Tablet
- GPS
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<th>Technique</th>
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<td>CHI</td>
<td>WalkType: using accelerometer data to accommodate situational impairments in mobile touch screen text entry</td>
<td>Technique</td>
<td>Using Accelerometer Data</td>
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<td>Predicting future location</td>
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<td>2012</td>
<td>CHI</td>
<td>Characterizing Web use on smartphones</td>
<td>Study</td>
<td>Naturalistic and longitudinal logs-based data collection</td>
<td>UI design &amp; functionality</td>
<td>Ease of use - per task</td>
<td>Web Use</td>
<td>Smartphone</td>
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Appendix B—Informed Consent

University of North Carolina-Chapel Hill

Consent to Participate in a Study

Consent Form Version Date: March 4th, 2014

Title of Study: A Usability Evaluation of Personal Task-managing Applications in One-handed Thumb Touching Mobile Interface

Principal Investigator: Yan Zhao, Dr. Bradley Hemminger

UNC-Chapel Hill Department: School of Information and Library Science

UNC-Chapel Hill Phone number: 919-962-8366

Study Contact Email Address: yan.zhao@unc.edu

Study Contact telephone number: 919-260-8884

This study is to support master paper completion for principal investigator Yan Zhao. This study has been reviewed by IRB. What are some general things you should know about studies?

You are being asked to take part in a study. To join the study is voluntary. You may refuse to join, or you may withdraw your consent to be in the study, for any reason, without penalty. You may not receive any direct benefit from being in the study. We do not anticipate any risks to you for participating in this study other than those encountered in day-to-day life.

Details about this study are discussed below. It is important that you understand this information so that you can make an informed choice about being in this study. You will be given a copy of this consent form. You should ask the researchers named above, or staff members who may assist them, any questions you have about this study at any time.

What is the purpose of this study?
The purpose of this two-phase sequential mixed method will be to get a deeper understanding of improving usability of task management mobile applications.

Are there any reasons you should not be in this study?

You should not be in this study if:

1. You are younger than 18 years old.

2. You are not a student in UNC Chapel Hill

3. You are not fluent in speaking and writing English.

4. You are not familiar with mobile devices such as smart phones.

How many people will take part in this study?

If you decide to be in this study, you will be one of 20 people in this study.

How long will your part be in this study last?

Participation will consist of two experiments and one interview that will last about 45 minutes.

What will happen if you take part in the study?

If you agree to participate, you will be arranged to take part in a short orientation for 5 minutes. You will be given a Galaxy 3 installed with EnterTask and ChooseTask, which are two mobile task management applications. Investigator will give you a sample task and show you an instruction video about how to use these apps. After that, you will be given two designed tasks and you need to insert them using the apps with your preferred/non-preferred hand when sitting in SILS Library. Then you will be given another two designed tasks and inserting them into the phone when walking in a normal speed in SILS lobby. These two steps will last for about 20 minutes. Finally, you will be invited to attend a 20-minute semi-structured interview with the investigator to talk about your experience in the previous two-step experiment. For any reason, you may choose not to answer any question that is part of the study. All interviews will be audiotaped and taken down as notes.

What are the possible benefits from being in this study?

You may not benefit personally from being in this research study. However, you may expect possible fun of exploring and using two new mobile applications.

What are the possible risks or discomforts involved from being in this study?
The risks in this study will be no more than those encountered in everyday life. There may be uncommon or previously unknown risks. You should report any problems to the researcher. How will your privacy be protected?

No identifiable data will be collected during this study. In written reports, your name and any identification information will not be used and the investigators will make additional efforts to analyze data. The data collected may be transformed into digital files and stored on server of the School of Information and Library Science in UNC Chapel Hill. After the analysis for this project is completed, all originally collected data will be deleted and/or destroyed.

Participants will not be identified by name in any report or publication about this study. Although every effort will be made to keep research records private, there may be times when federal or state law requires the disclosure of such records, including personal information. This is very unlikely, but if disclosure is ever required, UNC-Chapel Hill will take steps allowable by law to protect the privacy of personal information. In some cases, your information in this research study could be reviewed by representatives of the university, research sponsors, or government agencies (for example, the FDA) for purposes such as quality control or safety.

What if you want to stop before your part in the study is complete?

You can withdraw from this study at any time, without penalty. The investigators also have the right to stop your participation at any time. This could be because you have had an unexpected reaction, or have failed to follow instructions, or because the entire study has been stopped.

Will you receive anything for being in this study?

You will not receive anything for taking part in this study.

What if you have questions about this study?

You have the right to ask any questions you may have about this study. If you have questions about the study (including payments), complaints, concerns, or if a study-related injury occurs, you should contact principal investigators of this study—Shumeng Gu and Dr. Bradley M. Hemminger. If you have any questions or concerns regarding your rights as a subject in this study, you may contact the University of North Carolina at Chapel Hill (UNC-CH) Behavioral Institutional Review Board, IRB_subjects@unc.edu, Tel: 919-966-3113. You may be given a copy of this form to keep for your records. The principal investigators will keep this consent form for at least three years beyond the end of the study.

Title of Study: A Usability Evaluation of Personal Task-managing Applications in One-handed Thumb Touching Mobile Interface  Principal Investigator: Yan Zhao, Dr. Bradley Hemminger
Participant’s Agreement:

I have read the information provided above. I have asked all the questions I have at this time. I meet the qualifications for the study. I voluntarily agree to participate in this research study.

_________________________________________           ______________________
Signature of Research Participant                    Date

_________________________________________________
Printed Name of Research Participant

_________________________________________           ______________________
Signature of Research Team Member Obtaining Consent             Date

_________________________________________________
Printed Name of Research Team Member Obtaining Consent
Appendix C—Task Guide

Tasks Guide for Study

A Usability Evaluation of Personal Task-managing Applications in One-handed Thumb Touching Mobile Interface

Estimated Length – 20 minute

Task 1

In this task, you will be asked to insert a new to-do item into an app, called EnterTask, while sitting in SILS Library. You have sufficient time to do the task. When you finish all steps, return the device to investigator. Please do not quit this application and other applications running at the back end.

For this task, you would like to set up a reminder for your upcoming mid-term examination review of course INLS 760. The due date is Mar 24, 2014 and it is very important. You have to go through all slides and course materials provided by the professors, which can all be downloaded from your dropbox space. According to your own habit, inserting this reminder into EnterTask. You must include all information provided above.

Task 2

In this task, you will be asked to insert a new to-do item into an app, called ChooseTask, while sitting in SILS Library. ChooseTask has a different UI compared to
EnterTask. When you are typing, it will show you several options related to the characters you just typed in. You can choose from those options or enter the whole sentence on your own. Choose a comfort way and enjoy the experiment. You have sufficient time to do the task. When you finish all steps, return the device to investigator. Please do not quit this application and other applications running at the back end.

For this task, you would like to set up a reminder for your literature review assignment of course INLS 512, which will be due on Mar 27, 2014 at 5:00 pm. It is your most important task of this coming week. Basic requirements of this task are to come up at least 8 pages and submit them via sakai before the due date. Detailed requirements can be downloaded from the course webpage. According to your own habit, inserting this reminder into ChooseTask. You must include all information provided above.

Task 3

In this task, you will be asked to insert another new to-do item into EnterTask, but walking in SILS Lobby. You have sufficient time to do the task. When you finish all steps, return the device to investigator. Please do not quit the application and other applications running at the back end.

For this task, you would like to set up a reminder for a fun night on this coming Saturday, March 21, 2014. You will take part in Happy Hour at Milltown. Although this is quite fun, it will not be so important to you if you have other tasks to do at that time because it’s just an entertainment. And your friend Bob asked you to pick him and his friends at cobb deck on your way to Milltown. According to your own habit, inserting this reminder into EnterTask. You must include all information provided above.

Task 4
In this task, you will be asked to insert a new to-do item into an app, called ChooseTask, while sitting in SILS Library. ChooseTask has a different UI compared to EnterTask. When you are typing, it will show you several options related to the characters you just typed in. You can choose from those options or enter the whole sentence on your own. Choose a comfort way and enjoy the experiment. You have sufficient time to do the task. When you finish all steps, return the device to investigator. Please do not quit this application and other applications running at the back end.

For this task, you would like to set up a reminder for a fun night on this coming Saturday, March 21, 2014. You will take part in ILSSA Happy Hour at TRU DELI + WINE!. Although this is quite fun, it will not be so important to you if you have other tasks to do at that time because it’s just an entertainment. And you were asked to bring some new friends. Thus you decided to ask your friend Mary White to join you. According to your own habit, inserting this reminder into ChooseTask. You must include all information provided above.
Appendix D—Interview Guide

Interview Guides for Study

A Usability Evaluation of Personal Task-managing Applications in One-handed Thumb Touching Mobile Interface

Estimated Length – 20 minute

Hello __________________. My name is Yan Zhao from the University of North Carolina at Chapel Hill. Thank you for agreeing to be interviewed as part of the A Usability Evaluation of Personal Task-managing Applications in One-handed Thumb Touching Mobile Interface interview.

First let me tell you a bit about the study. The study consists of a pilot testing experiment and a series of interviews designed to further explore the usability of task management applications on smartphones. The result of this study will be used in my master paper to demonstrate and solve my research questions.

Your responses to the interview questions are confidential. Only summary data will be reported and no individual name will be used. Before we begin, let me review the consent form and ask for your verbal consent.

Thank you. Let’s go ahead with the interview now.
Interview Questions

1. Do you feel uncomfortable when using your non-preferred hand to operate the smartphone during experiments?

2. Have you ever used your non-preferred hand to operate a smartphone and do you think it’s easy to operate?

3. Thinking about the two applications you just used, do you have preference on any of them? Why?

4. Why you don’t like the other application/ both of the applications?

5. Do you often use your smartphone while walking? In what situation will you use your smartphone while walking? What apps you usually use while walking?

6. Do you feel apps are more difficult to use while walking?

7. What kind of suggestion you will give to application designers in terms of interfaces?

Thank you for your time. Your responses will be combined with those of others to provide information about their experience with mobile task management tools.