User Experience of Mobile Devices: A Three Layer Method of Evaluation

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Abstract

Mobile devices are an integrated aspect of contemporary society in both business and social contexts. To facilitate the continued development of more effective and efficient user interface designs and devices, it is necessary to employ appropriate Usability Evaluation Methods. However, the changing nature of mobile device interactions has created new and increasing demands on users of these devices. The additional capabilities and features have required increased attention and more complex thought patterns from users to interact effectively and efficiently. For efficient and effective device operation, the 'user experience' needs to be considered at three layers: the hardware; the operating system and other installed applications. This paper presents a task-based review of user experiences while interacting with three different mobile devices, through the novel three layer method of breaking down the user experience, and outlines how this approach is applicable for future research.

Keywords

Human-Computer Interaction, User Experience, Usability, Usability Evaluation, Mobile Computing.

INTRODUCTION

The prevalence of mobile device technologies in modern society is underscored by their rapid adoption for both personal and business use (Dunn et al. 2013). Mobile devices are appealing to users due to their portability, storage capacity, connectivity and ease of personal communication compared to Personal Computers (PCs) and traditional telephones. The increasing adoption of mobile technology use is being largely driven by developments in the power, capabilities and features of these new devices. However, the nature of these developments creates new and additional demands on users of these devices, with the additional capabilities and features requiring increased attention and more complex thought patterns to interact effectively and efficiently. Users need to consider the usability of the actual hardware that they are using, the operating system installed on the device and potentially other applications installed on the device.

The user experience of mobile devices is becoming an increasingly important issue as electronic products continue to converge with a number of other devices, increasing their complexity. As mobile devices have a different feature set to PCs, a major challenge for hardware designers and application developers is to ensure that mobile devices are intuitive, fast and effective. Therefore, the implementation of valid and reliable usability evaluation methods (UEMs) is important for the future of the entire mobile industry (Duh et al. 2006), from the actual hardware to the software running on the devices. Such developments have relied on various aspects of traditional evaluation methods together with the implementation of new evaluation opportunities afforded by the environments in which these devices are used.

The development and popularity of touchscreen mobile devices is affecting the entire technology sector. Manufacturers have replaced the traditional physical keypad with various interaction methods and interfaces that employ the full screen for touch purposes using virtual keys and buttons (Park and Han 2010). While these devices have offered an increased screen size, there are still limits on the dimensions for a full-sized keyboard, and thus the placement of the virtual keys on the touchscreen interface has been considered and virtual solutions developed (Parhi et al. 2006, Kwon et al. 2009). With the introduction of these new devices, new methods of evaluating their user experience are required to provide a structure mechanism for focusing on the devices' benefits and limitations. Manufacturers continue to design devices that allow for greater flexibility in interaction, but ergonomic issues and the constraints of the user are major limiting factors. Mobile devices have greater potential for more varied contextual elements to feature in the user's experience compared to PCs. The need to move beyond the notion of a single user in front of a desktop computer in HCI studies is self-evident (Chi 2009). The transition from traditional PC device characteristics to mobile device characteristics (including mobility, small screen size, the virtual keyboard functions and social interconnectivity) demonstrates how the key element of HCI has moved from system supremacy to personal empowerment (Grudin 2009). As a result, designers and developers are recognizing the importance of focusing on environmental and contextual elements in mobile device evaluations.

Thus, based on the increased interaction with mobile devices the research question becomes: *how should the overall user experience be evaluated for mobile devices?* This paper presents a review of user experiences while interacting with three different devices breaking down the review to consider of the physical device, the operating system and installed applications.

LITERATURE REVIEW

Human-Computer Interaction (HCI) is a discipline that endeavours to understand how and why people interact with devices. Jaimes and Sebe (2007) argue the primary aim of HCI research is to gain deeper insight into how computer technology can be made more usable. Therefore, HCI may also be defined as a study of human factors and machine aspects in the interaction process. Smith (1997) stated that interactive design also requires an appropriate interactive style based on the user's knowledge and tasks. Factors that help determine the interaction style are initiation, flexibility, option complexity and information load, and interaction styles may differ according to individual users (Smith 1997).

One of the most significant factors to impact the concept and practice of HCI during the early 1980s was the emergence of the Personal Computer (PC). This marked the beginning of an era that could potentially see all people in developed nations being computer users (Carroll 2010). In turn, as reported by Carroll (2010), this then led to the emergence of HCI studies to address the usability deficiencies of computers for people seeking to use computers as tools. Thus, during the 1980s HCI research was primarily focused on user interactions with office automation programs including word processing, databases and statistical software, before also including graphical user interfaces during the early 1990s (Lazar et al. 2010). These are all factors that need to be taken into consideration for mobile devices, as they are central to the user experience.

As stated by Chi (2009), HCI as a field of research and study has progressed far beyond the evaluation setting of "a single user sitting in front of a single desktop computer" (p. 1). Traditional HCI researchers have considered new paradigms that recognize mobile computation and the way that it is impacted by environmental and 'context-of-use' factors (Chi 2009). Thus, the challenge for HCI researchers is to design social and mobile application experiments that are "ecologically valid" (Chi 2009, p. 5). The importance of the shift in HCI paradigms towards human interaction with mobile device interfaces is also emphasized by Jaimes and Sebe (2007) who argue that the increased availability of mobile devices is a result of lower hardware costs and the fact that they are becoming more powerful and complex in relation to their computational capacity.

The traditional view of usability that is widely accepted by product developers is that the attributes of the user interface determine the extent to which the product is easy-to-use (Bevan 2009). To best meet the particular needs of different users, there needs to be an appropriate definition of usability formulated which can guide the development of efficient software systems. Dubey and Rana (2010) identified 37 different definitions of usability written during the previous three decades that contained references to a "usability definition and usability attributes" (p. 4726). The attributes most commonly identified in research papers as having the most impact on the usability of a software system included 'learnability' (13.2%), 'satisfaction' (11.1%), 'flexibility' (9.2%), 'efficiency' (8.6%), 'effectiveness' (5.9%), and 'memorability' (5.3%). Thus, when an operational definition of usability is contemplated it will generally be based upon the degree to which the system is effective, learnable, flexible and subjectively pleasing (Dubey and Rana 2010). However, usability is typically only concerned with the devices screen interface rather than the device as a whole.

User Experience Factors

Forlizzi and Battarbee (2004) argue that 'user experience' is associated with a wide variety of meanings from traditional usability factors to the experience that the user gains from interacting with the actual technology. As this study is concerned with an experience with a mobile device that a user holds (ergonomics) and interacts with (aesthetics), it is necessary to consider more than just the traditional usability attributes. Indeed, with the ever-increasing maturity of technology, the interactive element of the product has become more useful, usable and fashionable (Hassenzahl and Tractinsky 2006). With this in mind, research that focuses on user experience in terms of the interactions between people and products is useful to inform product design and extend our understanding of how usability evaluation methods may be used with different products (Forlizzi and Battarbee 2004).

While the terms 'usability' and 'user experience' are sometimes used interchangeably in the literature, researchers such as Heo et al (2009, p. 263) draw a distinction between the two terms. Usability is a much narrower concept than user experience in that it typically just refers to the ease-of-use of the design features of the device. User experience, on the other hand, is defined by Heo et al (2009) as including the user's thoughts and feelings about their interaction with the device as well. Petrie and Bevan (2009) asserted that drawing this distinction between the two terms is valid because the users of many new technologies are not necessarily seeking to achieve a task through their interaction with the device, but may simply be engaged with the device to amuse and entertain themselves. The conceptualization of 'user experience' allows researchers to consider the emerging aspects of technology use from a broader perspective (Hassenzahl and Tractinsky 2006). Hassenzahl and Tractinsky (2006) emphasize the need for the field of HCI research to acknowledge user experience as a "subjective, situated, complex and dynamic encounter" (p. 95) that emerges from the interaction between the user's internal state, the product design characteristic, and the context within which the interaction takes place.

From this review of user experience, six factors that are of importance for this study that have been identified from the literature and are presented in Table 1.

Table 1. User Experience Factors

Factor	Definition
Learnability	Learnability is the degree of ease of learning how to properly engage with a system (Parhi 2007). Leung et al. (2008) argued that learnability is an integral and fundamental attribute related to the user experience because it is important in determining whether the user's actions when using the system are to be successful or not.
User satisfaction	The user's satisfaction with a system will be directly affected by their perception of its performance (Coursaris et al. 2007). That is, the device's performance dimensions of effectiveness and efficiency may be linked to satisfaction measures; the higher the perceived effectiveness and efficiency of the device by the user, the higher the level of user satisfaction.
Efficiency	Efficiency means minimizing the efforts of the user when it comes to productivity. It is the software's capacity to perform in relation to the available resources and conditions (Perez et al. 2004). However, it is hard to determine what the efficiency of user interface relates to. The two clear aspects of efficiency are minimizing the effort required by the user and the quick execution of system processes. According to Galitz (2007), efficiency relates to the pace of interaction and the minimization of time effort. Thus, minimizing the physical effort required by the user is an important part of the interface design process.
Error prevention	Wood (2000) describes errors as incorrect actions performed while accomplishing a task. These may be categorized into four different types: action errors, slip and lapse, mistakes, and accidents. Users often make errors and it is therefore important to have error prevention and management mechanisms in place through the product interface.
Consistency	Consistency in the user experience with systems, either for personal or professional purposes, is an important consideration in the design process (Tilvawala et al. 2011). Consistency can refer to command naming, labels across different screens and the structure of commands (Nielsen et al. 2006). The reason for its importance is that if the same action reveals the same effect every time, then the user becomes more confident in using that action.
Memorability	Memorability is a reference to the ease with which the system can be operated intermittently by casual users (Nielsen et al. 2004). A focus on memorability is designed to assess "the ability of a user to retain how to use an application effectively" (Harrison et al. 2013, p. 4). Users are often required to remember how to use applications and invariably appreciate not having to relearn the process following a time of inactivity. Memorability is generally measured by allowing users to become proficient at performing a series of tasks, recording their proficiency levels, and then assessing the users' proficiency to perform similar tasks following a period of inactivity (Harrison et al. 2013).

A range of user-based Usability Evaluation Methods (UEMs) are available; these include scenario-based tasks, interviews, focus groups, and think-aloud sessions. These methods generally require users to perform realistic tasks which the system or device is designed to support in realistic situations (Petrie and Bevan 2009) each of these methods could be extended to consider the broader factors of user experience. Importantly, by employing user-based methods of evaluation it is possible to overcome the limitations of expert-based simulation evaluations that can never quite replicate the exact nature of user behaviours (Moritz and Meinel 2010).

Another method that has been historically used for considering a systems usability is that of heuristic evaluations. The primary objective of a heuristic evaluation is to identify usability problems in a user interface design by inspecting the interface (de Kock et al. 2009, Biel et al. 2010, Hwang and Salvendy 2010). This inspection method is thought to complement user testing usability approaches in the measures of effectiveness, efficiency and user satisfaction; thus would be a great candidate for exploration with considering the holistic nature of 'user experience'. The heuristic evaluation process is about getting a small number of evaluators to determine the extent to which the dialogue elements of the device match the established usability heuristics (see Nielsen 1994). A recent adaptation of Nielsen's heuristics for touchscreen based mobile devices was created by Instroza et al. (see Inostroza et al. 2012, pp. 664-665). The changes made to the original list included 'Flexibility and efficiency of use' becoming 'customization and shortcuts' which considers allowing the user to increase their user experience with their own device, and the introduction of a heuristic of 'Physical interaction and ergonomics'. Bertini et al. (2006) indicated that the mobile heuristics they applied allowed experts to more easily detect usability flaws than the application of traditional usability heuristics and that are able to provide a more comprehensive evaluation of mobile application usability and reduce the variation among experts.

User testing, generally involves the collection of data on a representative group of users as they perform a number of representative tasks (Lazar et al. 2010). The tests are either formative, i.e. designed to find specific interface problem, or summative, i.e. designed to benchmark the interfaces usability (West and Lehman 2006). The data collected is primarily used to evaluate elements of device structure and design during the development stage. It is therefore a preferred option, when possible, for system and device designers to conduct user-based testing during the early stages of the development process when the costs to make design changes are less (Lazar et al. 2010). Irrespective of the stage of development, the user-based testing process is integral to the design process as it provides an opportunity for system or device designers to understand the user experience and factor this understanding into the design of the interface (Lazar et al. 2010) or future versions of the interface.

METHOD

The review of the literature identified a number of existing gaps around the evaluation of the holistic user experience of touchscreen mobile devices. To properly present and understand issues surrounding HCI, it is necessary to work within a clearly defined research method. Task-based testing is based upon the following five steps (Fichter 2001): determining and describing the tasks; organizing a representative sample; preparing the sample for testing; observing and recording participant task performances; and evaluating the findings.

For this study, three mobile devices were evaluated in the study were: Apple iPhone 4s (iOS 5), Samsung Galaxy Nexus (Android 4.0) and Nokia Lumina 800 (Windows 7.5). The study was conducted from April 2012 to February 2013 with no changes to the devices so all participants has identical experiences. These devices were chosen due to their market share and that they all provided platforms with native operating systems installed allowing for complete evaluation at the three different levels of device interactivity. A number of manufacturers of Android devices install modified interfaces for their products. It should be noted that the mobile device market is one of the fastest paced industries, with new products and operation systems being launched continually; for this reason the purpose of this study was not to focus on an evaluation the user experience of each device, but rather to consider a new method to evaluate mobile devices.

The participants were informed of the order in which they would individually use the devices and told whether to initially perform all the tasks sitting or walking around a pre-defined circuit (to simulate a varied context of use scenario). This was randomly assigned prior to the arrival of each participant. For example, the first participant completed the tasks in the order of Apple, Samsung then Windows; initially all phones were used while sitting and then while moving. There were 12 possible combinations that could have been assigned to participants; all combinations were used throughout the testing. This was conducted to ensure that no recency effects were created. Each participant completed a number of typical tasks with each of the three mobile devices. This followed a task-based testing method (Lazar et al. 2010). The same test script was followed for each mobile device, both while sitting and while walking. The tasks listed in the test script were indicative of tasks that a person would perform as part of daily use of their own mobile device. Based on the tasks specified in the test script, the participant was asked to perform functions including; phone calls; calendar usage; sending a message; reading stored documents; and browsing the Internet. The interactions were recoded with a point-of-view camera capturing how the participants held the device and interacted with it. Participants also employed a simple think-aloud technique stating what they were doing and how it was achieving their goals of completing the tasks. This paper uses the observations by the researchers based on the actions and comments of the participants during their interactions with the devices to provide insight into the user experience of touchscreen mobile devices.

Participants

There were 41 participants that completed the study; this sample was a convenience sample of smartphone users that were students or staff of a university. Demographic data was collected to provide an understanding of the study sample and the extent to which the sample is representative of the broader population. A high-level review of the data shows that the ranges in age, education level, cultural background, and mobile device use of the participants supports the claim that the sample is representative of the broader population of mobile device users.

The distribution data of the demographics of the participants in the study demonstrated that they were typical users of their own device, with 100% of participants reporting owning their own mobile phone and used it daily for making phone calls, sending messages and using the Internet. The most popular phone brand was iPhone, owned by 41.46% (n = 17) of participants, followed by Samsung, owned by 36.58% (n = 15) of participants. Nokia and Blackberry brands were each owned by 7.32% (n = 3) of participants. With regards to the devices operating system 41.46% (n = 17) used iOS and 41.46% used Android (providing equal users of each group).

RESULTS

This section discusses the participants' interactions with the three devices, drawing attention to the main issues associated with the devices. To assist the reader to understand the specific nature of the issues identified, the device entity has been classified according to three 'layers' (see Figure 1 below), it should be noted that only through a holistic understanding of user interacting can areas of improvement be suggested: **Hardware:** including elements such as the size and shape of the device (device physical and ergonomic factors); **Operating System (OS):** including elements such as screen layout and keyboard size; **Application:** running on the OS, (including: a. Created by the OS developer and installed by default on the device (e.g. phone functionality, calendar and messages), b. Third party applications (such as the Adobe application on the Windows device), c. Webpages running in the web browser). Traditional research into HCI focused mainly on layers 2 and 3, as layer 1 (hardware) was in a fixed position (typically a PC). This research extends on the traditional HCI research by also considering the device and the environment in which the device is used.

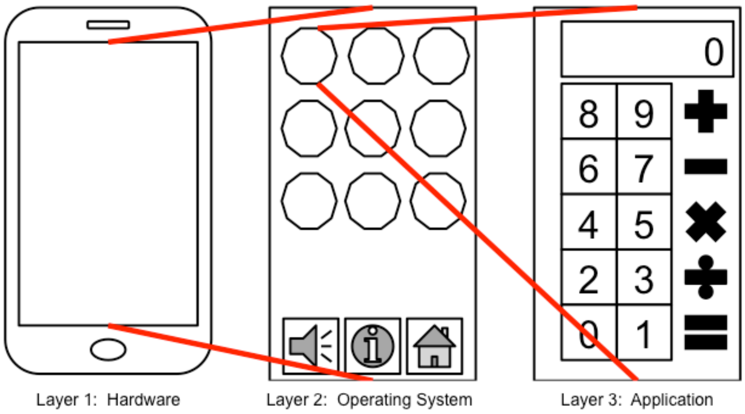

Figure 1. Device interaction layers

For the purposes of the discussion, each layer is initially treated as initially being 'separate' to the other layers, and within each layer the issues pertaining to a range of different elements are identified and discussed. A discussion on the interaction between the three layers is then presented, as the user experience exists when using the device's hardware to interact with the operating system and other applications. The discussion centres on the user experience factors of: *learnability*; *user satisfaction*; *efficiency*; *error prevention*; *consistency*; *functionality*; and *physical interaction*. Also, to inform the discussion, links are established between the observed user experience issues for each layer. These links are identified against Nielsen's usability heuristics considering the adaption by Instroza et al (2012) for mobile devices.

Layer 1: Hardware User Experience Issues

Participants were recorded as they performed the designated tasks as part of the study. During these recordings, it was observed that participants responded differently to the physical and ergonomic aspects of each device. From the literature, usability heuristics have typically avoided discussions of the physical elements of the devices. Although Inostroza et al. (2012) included the concept of 'physical interaction and ergonomics' in their extension to Nielsen's usability heuristics, these two factors result in different user experience issues. For the purposes of this study the observed user (i.e. participant) experience at layer 1 is considered from the perspective of the device's ergonomics, the physical buttons present on the device and the actual touchscreen performance.

When reviewing the ergonomics of the devices, many participants commented that the iOS was "good to hold in one hand" and "is convenient". This was in direct contrast to what was observed with the Windows device, with many participants identifying that the device was hard to operate using one hand, especially during typing. For the Android device, the size of the device was observed to be an issue when the icons at the top of the screen needed to be accessed; this was the largest device in the evaluation. As such, it affected the user-friendliness of the device when one-handed operation was required. However, it was noted that the participants effectively operated the device using either one hand or two hands when needed. It may be worth conducting further research into the possibility of designing the Android and Windows devices to work more effectively as previous research had identified that one-handed device usage was considered as the normal operation method (Karlson and Bederson 2007).

In relation to the physical location of buttons on each device, a generally positive response from the participants was observed for the *'on/off'* button on the iOS device, which was located on the topside of the device. With the Android and Windows devices, during the analysis of the recordings it was observed that it was easy for the participant to inadvertently switch the phone off due to the *'off'* button being obtrusively located at the top of the right-hand side of the phone. It is therefore recommended that the *'off'* button be re-located to a less conspicuous part of the phone considering how users actually hold the device.

The issues identified during the observations of the participants' interactions with the actual mobile device identify the potential significance of the touchscreen mobile device, particularly with the introduction of the heuristic 'physical interaction and ergonomics' by (Inostroza et al.). The principle underpinning this heuristic is that the device elements (such as buttons) should be located in a recognizable position, and the dimensions, shape and user interface elements "should fit the natural posture of the hand" (Inostroza et al. 2012, p. 665). It appears that hardware aspects such as the location of the 'buttons' and the device posture in the participant's hand impacted on user experience in this study.

Layer 2: Operating System (OS) User Experience Issues

The OS of the device includes such elements as the screen layout, keyboard size, information delivery speed, navigational constructs and other operational functions. The initial OS element encountered by the participants was the device's 'unlock' function. It was observed during the analysis that the unlock icon of the iOS device was very easily recognized and operated by the participants. The unlock process on the Android device was not as immediately recognizable to the user, particularly those who had never used the OS. On the 'unlock' screen, the Android device allowed a user to move the lock around a circle, however there were only two areas where a function was actually performed by the device; these functions were unlocking the phone and activating the phone's camera. This was not immediately obvious to all participants. With regard to the Windows device, the participants were given no indication that they were required *scroll up* to open the home screen. In turn, it was observed that the participants instinctively *scrolled down* the first time they used the device, which resulted in them turning the device *off*. The design of the 'unlock' feature affects the user experience, as it is the first interaction that a user has with a new device. The user experience factor of *learnability* was demonstrated with the unlock function, and a clear process for unlocking a device was also shown to prevent errors.

When the participants were operating the keyboard on the Windows device they sometimes mistakenly thought the 'search' function button was the 'enter' or 'send' button. As a result, when the participants pressed the search function icon it took them out of the application they were using. This confusion then lead them to lose the information they had been working on, thereby reducing the efficiency of using the device. This element of the Windows device was not consistent with other devices or applications.

On the iOS device, a grid format is used and the users can easily identify the number of icon pages available to them as the number of pages corresponds to the number of horizontal white dots included on the home page. This ensures consistency across the device. It was observed that the two main screens on the Android device caused the user confusion because each lead the user into an area that required scrolling or swiping when looking for an application. Similarly, it was observed that when using the Windows device many participants did not realize there was a second page when they scrolled up or down to find an *application*. Hence, the design of the device can be improved by ensuring that the second page (complete application listing) is brought to the attention of the user. This is a *learnability* issue; when a user becomes more familiar with a particular device then they will know what content is displayed on each screen and how to customize it to suit their needs. This customization aligns with Nielsen's heuristic of allowing for 'flexibility and efficiency of use'. However, having different applications pages displayed in different ways by default violates the factors of *efficiency* and *consistency* in design and Nielsen's heuristic of 'Aesthetics and minimalist design'. For the Android device, during the analysis it was observed that the participants became confused on the first page because the applications were only identifiable by an icon; on this page the name of the application was not included. In addition, the set-up of the icons on the desktop was not always clear for this device. This is something the designers of the software need to take into consideration when trying to make the software increasingly user-friendly. By having clear icons and labels to distinguish applications, *errors* can be prevented and the amount of learning required by a user is reduced.

For each of the devices, input is primarily performed via the virtual keyboard. It was observed that the keyboard feature on the iOS device was clear and the participants easily recognized the functions. The *'Send'* icon is just one example of how the icons are clearly defined and of an appropriate size. However, the *'Return'* icon was not always clear to the participant and its description does not necessarily relate exactly to its function. Some participants thought that it meant return to the previous page. Typically on PCs the term *'Enter'* is used along with a '↵' symbol. This key was only the '↵' symbol for the Android and Windows devices. All devices used a common *backspace* key of '⌫'.

For the iOS device it was observed that many participants found it difficult to select the advanced auto correct *'word options'* when typing a message as they are automatically activated by pressing the *space bar* and not by selecting the suggested word (as was the case for the other devices). This auto correct function attempts to increase the *efficiency* factor of the device but it actually reduces *user satisfaction* due to frustration and increased *errors* for the iOS device, with pressing the *space bar* supporting two simultaneous actions of its usual duty and editing the previous word typed. To reject an auto correct the user must move their attention away from the keyboard and click on the 'x' next to the word being typed. The way that auto correct was implemented on the other devices allowed a user to select a suggested correction rather than defaulting the word to that option.

The participants' interactions with Layer 2: OS appear to have implications for their cognitive load while interacting with the devices. Some of the functions that they performed were complex and resulted in *errors* that could be avoided with different designs. According to Inostroza et al. (2012), touchscreen mobile devices should "minimize the user's memory load by making objects, actions, and options visible" (p. 664). It is important for the device to have visible and/or easily retrievable instructions to minimize the extent to which a user is required to remember information from one aspect of the task to another. However, the instructional design of the OS in each device may have at times increased the participants' working memory load due to elements being difficult to recognize and/or understand. Observations of participants' interactions with the OS of each device also appear to hold implications for the *'visibility of system status'* usability heuristic. At times, the visibility of OS status for each device appeared to inadequately inform the participant about system processes and changes by not providing specific and timely feedback reducing *efficiency* and *functionality*. All of these factors impact on the overall user experience of using the mobile device.

Layer 3: Application User Experience Issues

With regard to the processes of using the default applications installed on the devices, during analysis it was observed that when the participant opened the calendar they were able to locate the day more easily on the iOS device compared to the other two devices. However, when using the day-change arrow, some participants mistakenly touched the 'add icon' above the day-change arrow, which caused the device to open to a different page when the participant opened the calendar and adjusted the time. In general it was observed that participants liked the facility of the calendar on the iOS that presented the day, times and topic on one page. However, when the participants set the hours and minutes on the iOS device it was observed that the columns were too thin and that errors were made because participants tended to use their thumbs. With regard to the internal processes of both the Android and Windows devices, it was observed that when operating the *calendar* the participants became confused when a new entry was in the process of being added. The multiple steps required increased the time needed to add a new entry (this reduced the *efficiency* of use and the *user satisfaction* of the calendar application); but also, when the *window* for the new entry was finally selected, *Date Selection* and *New Event Selection* were not clear and could not be directly selected from the *primary window* (the potential for *errors*).

In terms of the participant's mental models of interaction, during the analysis it was observed that the Android device was unable to provide a clear pathway (possibly in the form of a titled icon) for choosing contacts when the participant wanted to send a message. The participant's natural reaction in response to this deficiency was to move out of the correct window and find the particular contact from the *'contacts/people application'* window. When the participants accessed their 'contacts' they became confused between the 'message' and the 'call' icons. The icons are identified as pictures; they should also be identifiable through a label. The issue with having to take multiple steps to send a message is that it puts a user in a position whereby there is an increased likelihood of unnecessary *errors*. If these steps could be reduced it would make the sending process more efficient and increase *user satisfaction*.

For the advanced keyboard inputs in different applications, several comments and observations were made. A participant commented about the iOS device "I like .com shortcut. It helps me to make my typing fast and reduce my errors while typing" (this has strong links to the user experience factors of *user satisfaction, efficiency and error prevention*). However, it was difficult for the participants to highlight previous information in the web address and the cursor was also not easy to use to move between the words. When the participants made an error in the *address bar* using the Android device it was observed to be easy to place the cursor over the error and correct it. However, this design could be further improved if the participant is able to easily touch the word directly with the cursor instead of having to drag it.

The participants' interactions with Layer 3: Device applications appear to have particular implications for the user experience factor of *error prevention*. For instance, the inability of participants to sometimes differentiate between old or new messages, the loss of information when using an application, or errors resulting from perceived design flaws in the application point to this conclusion. Similar to layer 2, the *'user memory load'* usability heuristic also appears to be associated with many of the device interaction issues observed in relation to layer 3. For instance, it may be argued that the confusion experienced by some participants when trying to understand the application function, or the inability of some participants to immediately recognize some of the applications, had the potential to increase the users' memory load while using the application.

Overall Perspective

To support a deeper understanding of the various elements which may impact mobile device user experience during interaction, the devices were reviewed according to three independent but interconnected layers: hardware, OS and applications. When each of the layers was then evaluated against user experience factors and usability heuristics for touchscreen mobile devices, four usability heuristics emerged as being of particular relevance to the experiences of the participants during their interactions with the iOS, Android and Windows devices: *'Minimize the user's memory load'*, *'Error prevention'*, *'Flexibility and efficiency of use'*, and *'Consistency and standards'*. The ultimate purpose of this study is to understand the users' overall experience when interacting with a touchscreen mobile device rather than using a particular brand or OS and the suitability of this method for use in future studies. This is argued to be a major contribution as it does not focus on presenting results of a study with technologies that are constantly being updated.

One major area that needs further exploration is consideration of the user experience as a whole. As a user holds the actual device (Layer 1: Hardware) during their interaction, this *physical interaction* is of importance as, and if the device is not comfortable to interact with, the overall experience is affected. For the physical device, the only way to change design issues faced by a user is through the purchase of a new device. For Layer 2: OS, there is the potential that a new version of the OS with new features that may resolve some user experience problems will be able to be installed, and in some situations a Layer 3 (third-party) application can be installed as an alternate application (e.g. for web browsing). The consideration of the device as a whole is of vital as some of the layers can be altered after the user has purchased the device. Users must understand this limitations at the time of purchase and researchers can use this approach when evaluating new versions of an OS (Later 2) and alternate Layer 3 applications.

CONCLUSION

The understanding of users' experience of mobile device touchscreens is enhanced at both a theoretical and practical level as a result of this study. The issues identified consider the content and features of the touchscreen mobile devices' interfaces in combination with the users' perceptions of their experience. As such, the results presented may be used to guide future development of touchscreen mobile device user experience evaluation methods as well as the future design of mobile device interfaces.

Users identified that they experienced difficulty using these devices as the tasks became more complex. Thus, breaking down the operations to the three levels can draw out these issues in more detail; understanding that with mobile devices this is more than a software issue. How information is displayed to the user given that mobile devices have a number of methods for both input and output can have a great effect on the user experience; the memory load placed on the user of the device can be reduced if this is fully understood across the three layers. This was seen when the device vibrated to acknowledge that an operation was successful. Where information is displayed both visually and through text (e.g. the icons of the applications), participants mental models of tasks were supported particularly for those participants who had not used a particular device before. However, when the visual and/or textual representation did not match the participant's mental model (e.g. the compass icon and word 'Safari' for the Internet browser on the iOS device was not recognized by participants that had no experience with Apple devices), participants noted an increase in the effort to be able to complete a task. The prior experiences of users should not be considered lightly; however is there is a complete redesigned of Layer 2:OS then the user could effectively be using a new device with the same hardware (Layer 1).

The method presented in this study in relation to user experiences of touchscreen mobile devices can be applied to both user experience studies in both user experience and design domains, due to the three levels that the results were presented in. As such, the findings in the study may be used to draw out assumptions and implications regarding the structure and complexity of interface designs and how they may best meet the needs of users. Researchers and developers are interested in gaining a better understanding of how people interact with devices in specific contexts so that this level of cognitive demand can be managed, and ideally minimized, breaking down the comparison to the three levels can aid in this understanding. By researchers using this method to understand devices holistically there is the potential for users to have an increased user experience.

REFERENCES

Bertini, E., Gabrielli, S., Kimani, S., Catarci, T., and Santucci, G. 2006. *Appropriating and assessing heuristics for mobile computing*, AVI '06 Proceedings of the Working Conference on Advanced Visual Interfaces.

Bevan, N. 2009. Extending quality in use to provide a framework for usability measurement. *Human Centered Design*. M. Kurosu, Springer**:** 13-22.

Biel, B., Grill, T., and Gruhn, V. 2010. "Exploring the benefits of the combination of a software architecture analysis and a usability evaluation of a mobile application," *Journal of Systems and Software* (83:11), pp 2031-2044.

Carroll, J. M. 2010. "Conceptualizing a possible discipline of human-computer interaction," *Interacting with Computers* (22:1), pp 3-12.

Chi, E. 2009. "A position paper on'living laboratories': Rethinking ecological designs and experimentation in human-computer interaction," *Human-Computer Interaction. New Trends* (5610, pp 597-605.

Coursaris, C.K., Hassanein, K., Head, M., and Bontis, N. 2007. *The impact of distractions on the usability and the adoption of mobile devices for wireless data services*. European Conference on Information Systems, 2007 Proceedings. Paper 28.

de Kock, E., van Biljon, J., and Pretorius, M. 2009. *Usability evaluation methods: Mind the gaps*. In Proceedings of Annual Research Conference of the South African Institute of Computer Scientists and Information Technologists Vanderbijlpark, Emfuleni, South Africa 2009, pp. 122-131.

Dubey, S.K., and Rana, A. 2010. "Analytical roadmap to usability definitions and decompositions," *International Journal of Engineering Science and Technology* (2:9), pp 4723-4729.

Duh, H., Tan, G., and Chen, V. 2006. *Usability evaluation for mobile device: a comparison of laboratory and field tests*. MobileHCI '06 Proceedings of the 8th Conference on Human-Computer Interaction with Mobile Devices and Services Helsinki, Finland, ACM.

Dunn, B.K., Galletta, D.F., Hypolite, D., Puri, A., and Raghuwanshi, S. 2013. *Development of smart phone usability benchmarking tasks*. 2013 46th Hawaii International Conference on System Sciences, IEEE.

Fichter, D. 2001. "Testing the web site usability water's," *Online* (25:2), pp 78-80.

Forlizzi, J., and Battarbee, K. 2004. *Understanding experience in interactive systems*. In Proceedings of the 2004 Conference on Designing Interactive Systems (DIS04): Processes, Practices, Methods, and Techniques, New York, ACM.

Galitz, W. O. 2007. *The essential guide to user interface design: an introduction to GUI design principles and techniques*. USA: Wiley Publishing.

Grudin, J. 2009. "Brian Shackel's contribution to the written history of Human–Computer Interaction," *Interacting with Computers* (21:5), pp 370-374.

Harrison, R., Flood, D., and Duce, D. 2013. "Usability of mobile applications: literature review and rationale for a new usability model," *Journal of Interaction Science* (1:1), pp 1-16.

Hassenzahl, M., and Tractinsky, N. 2006. "User experience: A research agenda," *Behaviour & Information Technology* (25:2), pp 91-97.

Heo, J., Ham, D., Park, S., Song, C., and Yoon, W. 2009. "A framework for evaluating the usability of mobile phones based on multi-level, hierarchical model of usability factors," *Interacting with Computers* (21:4), pp 263-275.

Hwang, W., and Salvendy, G. 2010. "Number of people required for usability evaluation: the 10±2 rule," *Communications of the ACM* (53:5), pp 130-133.

Inostroza, R., Rusu, C., Roncagliolo, S., Jimenez, C., and Rusu, V. 2012. *Usability heuristics for touchscreen-based mobile devices*. Ninth International Conference on Information Technology - New Generations, Las Vegas, NV, IEEE.

Jaimes, A., and Sebe, N. 2007. “Multimodal human-computer interaction: A survey,” *Computer Vision and Image Understanding* (108:1-2), pp 116-134.

Karlson, A., and Bederson, B. 2007. “ThumbSpace: generalized one-handed input for touchscreen-based mobile devices,” *Human-Computer Interaction–INTERACT 2007*, pp 324-338.

Kwon, S., Lee, D., and Chung, M. 2009. “Effect of key size and activation area on the performance of a regional error correction method in a touch-screen QWERTY keyboard,” *International Journal of Industrial Ergonomics* (39:5), pp 888-893.

Lazar, J., Feng, J.H., and Hochheiser, H. 2010. *Research methods in human-computer interaction*. United Kingdom: John Wiley & Sons.

Leung, R., McGrenere, J., and Graf, P. 2008. *The learnability of mobile application interfaces needs improvement*. Proceedings of British HCI Workshop on HCI and the Older Population, British Columbia, Canada, University of British Columbia Vancouver.

Moritz, F., and Meinel, C. 2010. *Mobile web usability evaluation-combining the modified think aloud method with the testing of emotional, cognitive and conative aspects of the usage of a web application*. 9th IEEE/ACIS International Conference on Computer and Information Science, Yamagata, IEEE.

Nielsen, C.M., Overgaard, M., Pedersen, M.B., Stage, J., and Stenild, S. 2006. *It's worth the hassle!: the added value of evaluating the usability of mobile systems in the field*. NordiCHI '06 Proceedings of the 4th Nordic Conference on Human-Computer Interaction: Changing Roles, Oslo, Norway, ACM.

Nielsen, J. 1994. *Enhancing the explanatory power of usability heuristics*. CHI '94 Proceedings of the SIGCHI Conference on Human Factors in Computing Systems Boston, ACM.

Nielsen, M., Störring, M., Moeslund, T. B., and Granum, E. (2004). A procedure for developing intuitive and ergonomic gesture interfaces for HCI. *Gesture-Based Communication in Human-Computer Interaction*. J. Carbonell and J. Siekmann (eds.), Heidelberg, Springer Berlin, 409-420.

Parhi, P. (2007). *Two case studies in the design and evaluation of a mobile interactive system (Diploma Thesis)*, University of Oulu.

Parhi, P., Karlson, A., and Bederson, B. 2006. *Target size study for one-handed thumb use on small touchscreen devices*. MobileHCI '06 Proceedings of the 8th Conference on Human-Computer Interaction with Mobile Devices and Services, ACM Press.

Park, Y.S., and Han, S.H. 2010. “Touch key design for one-handed thumb interaction with a mobile phone: Effects of touch key size and touch key location,” *International Journal of Industrial Ergonomics* (40:1), pp 68-76.

Perez, M., Griman, A., Mendoza, L., and Rojas, T. 2004. *A Systemic methodological framework for IS research*. Proceeding of Trnth Americans Conference on Information System, New York, USA, AMCIS.

Petrie, H., and Bevan, N. (2009). The evaluation of accessibility, usability and user experience. *The Universal Access Handbook*. C. Stephanidis (ed.), London, Taylor and Francis, 20.21-20.14.

Smith, A. 1997. *Human computer factors: A study of users and information systems*: McGraw-Hill, London.

Tilvawala, K., Myers, M., and Sundaram, D. 2011. “Design of ubiquitous Information Systems for digital natives,” *Information Systems Research* (21:4), pp 711-723.

West, R., and Lehman, K. 2006. *Automated summative usability studies: an empirical evaluation*. CHI '06 Proceedings of the SIGCHI Conference on Human Factors in Computing Systems, New York, ACM.

Wood, S.D. 2000. *Extending GOMS to human error and applying it to error-tolerant design*: Doctoral dissertation, University of Michigan.

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