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A Meta-Analytical Review of Empirical Mobile Usability Studies

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Abstract

In this paper we present an adapted usability evaluation framework to the context of a mobile computing environment. Using this framework, we conducted a qualitative meta-analytical review of more than 100 empirical mobile usability studies. The results of the qualitative review include (a) the contextual factors studied; (b) the core and peripheral usability dimensions measured; and (c) key findings in the form of a research agenda for future mobile usability research, including open and unstructured tasks are underutilized, interaction effects between interactivity and complexity warrant further investigation, increasing research on accessibility may improve the usability of products and services for often overlooked audiences, studying novel technology and environmental factors will deepen contextual mobile usability knowledge, understanding which hedonic factors impact the aesthetic appeal of a mobile device or service and in turn usability, and a high potential for neuroscience research in mobile usability. Numerous additional findings and takeaways for practitioners are also discussed.

Keywords

Human Computer Interaction, mobile, usability, efficiency, effectiveness, satisfaction, mobile device, wireless, context, meta-analysis, empirical

Introduction

Mobile devices are becoming increasingly popular, having already reached over one billion mobile subscribers. A recent forecast by the UMTS forum (2005) estimated that the global number of subscribers will be between 1.7 to 2.6 billion for mobile voice and 600 to 800 million for mobile data. As consumers' technology fears and adoption costs are reduced, mobile devices are approaching "mainstream" status around the developed world. Mobile devices propose increasing value to consumers found in "anytime, anywhere, and customized" connectivity, communication, and data services.

Although progress has been made in terms of technological innovations, there are obvious limitations and challenges for mobile device interfaces due to the characteristics of mobile devices (i.e., the size of small screens, low resolutions of the displays, non-traditional input methods, and navigational difficulties; Nah, Siau, & Sheng, 2005). Therefore, usability is a more important issue for mobile technology than for other areas, because many mobile applications remain difficult to use, lack flexibility, and lack robustness.

Research Motivation and Objectives

Usability has been the focus of discussion (Venkatesh, Ramesh, & Massey, 2003) and described by varying definitions (Nielsen, 1993; Nielsen & Levy, 1994; Shackel, 1991) in both academia and industry for a long time. Many of these definitions proposed that the central theme of usability is that people can employ a particular technology artifact with relative ease in order to achieve a particular goal within a specified context of use. The turn of this century marked an increased focus on mobile usability studies for research in the field of Human Computer Interaction (HCI). Although a considerable volume of research on general usability exists, due to the novelty of mobile technology relatively few studies have been conducted focusing on mobile usability. Even worse, only 41% of mobile usability papers are empirical[1] in nature (Kjeldskov & Graham, 2003). Moreover, there is no qualitative study on the usability dimensions considered in such mobile studies. Thus, our research aims to fill this gap and in doing so will also provide a roadmap for future mobile usability studies that will be of value to this relatively young research area. Specifically, this study addresses the following research question: What are the key formation and evaluation dimensions of usability in mobile technology usability studies?

To this end, this paper describes the qualitative review of more than 100 published empirical mobile usability studies. First, following a brief review of a usability evaluation framework in a non-mobile context, a framework of contextual usability for mobile computing[2] is presented. Next, by using the proposed framework a qualitative review of empirical mobile usability studies is presented along with a discussion on the taxonomy used during the coding in this study. The results emerging from the comprehensive review of mobile usability studies are then presented, which include (a) the contextual factors studied, (b) the core usability dimensions defined and measured, (c) the peripheral usability dimensions explored, and (d) key findings in the form of a research agenda. Finally, this paper discusses the contributions and limitations of the research.

Literature Review and a Mobile Usability Framework

Usability studies have their roots as early as the 1970s in the work of "software psychology." Over time, the focus of this body of research has shifted and most recently centered on the relevance of context of use for usability. The concept of *context of use*, as it relates to usability, emerged out of the work of several scholars (Bevan & Macleod, 1994; Shami, Leshed, & Klein, 2005; Thomas & Macredie, 2002) who attempted to identify additional variables that may impact usability. Varied situational contexts will result in emerging usability factors, making traditional approaches to usability evaluation inappropriate. The significance of this area emerges from its importance in yielding a reasonable analysis during a usability study (Maguire,

1 Empirical studies deal with empirical evidence that is derived by means of observation, experiment, or experience. In this study, we further classified empirical evidence as survey, interview, observation, and device/server logs in either a lab, the field, or both settings, as well as focus groups.

2 Even though we mainly focus on mobile usability, our adapted framework can be used for usability studies in general.

2001; Thimbleby, Cairns, & Jones, 2001). Furthermore, during the evolution of HCI mentioned above, the conceptualization of usability has varied extensively. The broad set of definitions and measurement models of usability complicate the generalizability of past studies at the level of the latent usability variable. Therefore, a usability study gains value when it is based on a standard definition and operationalization of usability. In the following section, we review a set of key approaches in evaluating usability as communicated in previous work.

Approaches to Usability Evaluation

Different approaches to usability evaluation have been proposed in different contexts such as websites (Agarwal & Venkatesh, 2002), digital libraries (Jeng, 2005), audiovisual consumer electronic products (Han, Yun, Kwahk, & Hong, 2001; Kwahk & Han, 2002), and many others. In the context of website usability, Agarwal and Venkatesh (2002) presented five categories (i.e., content, ease of use, promotion, made-for-the-medium, and emotion) and subcategories (i.e., relevance, media use, depth/breadth, structure, feedback, community, personalization, challenge, plot, etc.) of website usability evaluation components based on Microsoft Usability Guidelines (MUG ; see Keeker, 1997). They also discussed the development of an instrument that operationalizes the measurement of website usability. Recently, employing the MUG-based model, Venkatesh and Ramesh (2006) explored an examination of differences in factors important in designing websites for stationary devices (e.g., personal computers) versus websites for wireless mobile devices (e.g., cell phones and PDAs). In the context of digital libraries, Jeng (2005) proposed an evaluation model of usability for digital libraries on the basis of the usability definition of ISO 9241-11 (ISO, 2004). The model included four usability evaluation comports: effectiveness, efficiency, satisfaction, and learnability. The satisfaction of digital libraries was further evaluated by the areas of ease of use, organization of information, clear labeling, visual appearance, contents, and error corrections.

In the context of audiovisual consumer electronic products (e.g., VCR, DVD players, etc.), Han et al. (2001; Kwahk & Han, 2002) suggested a usability evaluation framework that was similar to the subsequent work of Hassanein and Head (2003). The framework consisted of two layers: formation of usability and usability evaluation. The formation of usability layer had four contextual-components (i.e., product, user, user activity, and environment) that were well accepted as the principal components in a human-computer interaction upon which good system design depends (Kwahk & Han, 2002; Shackel, 1991). The usability evaluation layer was organized with three groups of variables: design variables (i.e., product interface features), context variables (i.e., evaluation context), and dependent variables (i.e., measures of usability).

Interestingly, there is no usability evaluation framework that yet exists in the context of a mobile computing environment. We believe it is a critical omission and an important topic warranting investigation. The next section looks at the key formative factors of usability as explored in contextual mobile usability studies. From this review, we propose a contextual usability framework for a mobile computing environment.

A Contextual Usability Framework for a Mobile Computing Environment

The work of several scholars (Bevan & Macleod, 1994; Shami et al., 2005; Thomas & Macredie, 2002) who attempted to identify additional variables that may impact usability and subsequently adoption, led to the conceptual emergence of *context of use* (herein referred to as *context*) as it relates to usability, also referred to as contextual usability. Several frameworks encapsulating context have been proposed (Han et al., 2001; Lee & Benbasat, 2003; Sarker & Wells, 2003; Tarasewich, 2003; Yuan & Zheng, 2005). While there may be other usability frameworks that attempt to capture the essence of context, the models cited here provide a representative set of work in this area. From these we adapted the framework proposed by Han et al. (2001) because it offers considerable detail for each dimension they identified.

On the basis of the discussion on approaches to usability evaluation and the framework proposed by Han et al. (2001) and Kwahk and Han (2002), we propose a contextual usability framework for a mobile computing environment. The framework is depicted in Figure 1 and contains three elements. First, the outer circle shows the four contextual factors (i.e., User, Technology, Task/Activity, and Environment) described earlier as impacting usability. Second, the inner circle shows the key usability dimensions (i.e., Effectiveness, Efficiency, Satisfaction, Learnability, Flexibility, Attitude, Operability, etc.). Third, the box on the top of contextual

factors shows a list of consequences (i.e., improving systems integration, increasing adoption, retention, loyalty, and trust, etc.).

Compared to the framework proposed by Han et al. (2001) and Kwahk and Han (2002), there are several advantages of the suggested mobile usability framework. Although the previous frameworks proposed by Han et al. (2001) and Kwahk and Han (2002) are comprehensive, they are difficult to follow due to formation and evaluation dimensions being merged into one diagram. Thus, the suggested framework depicted in Figure 1 represents a simple yet direct way to identify and address the various contextual mobile usability dimensions. In addition, with its central focus on usability, it offers specific guidance on the implementation of any interface/interaction project along with potential outcomes.

In addition, two modifications are introduced in terms of nomenclature for mobile contextual usability. First, "Technology" replaces "Product," as this term helps conceive the system that a user may interact with a greater set of components, instead of simply the device or application itself. One example of this is found in the case of mobile usability where the inclusion of the wireless network is likely in addition to the mobile device (i.e., the product) when studying usability of a mobile product or service. Because mobile usability is mainly related to mobile technology, which continually improves the limitations of mobile interfaces and its applications, the technological factor of a mobile usability framework is an important and unique component that needs to be taken care of. Second, "Task/Activity" replaces "Activity," as the former term appears more commonly in usability literature when describing the nature of users' interaction with the technology. In addition, a list of consequences of usability was added to the framework as an output of usability evaluations.

These four variables (i.e., user, task/activity, environment, technology) were used for the presentation of the qualitative review of previous empirical research[3] that relates to the usability assessment of mobile applications and/or mobile devices. The benefit of using these variables for the literature review is found in both the structure it provides for the discussion to follow, as well as to help highlight any areas that are lacking investigation.

3 Since this study focuses on mobile usability, we only reviewed empirical studies on mobile usability.

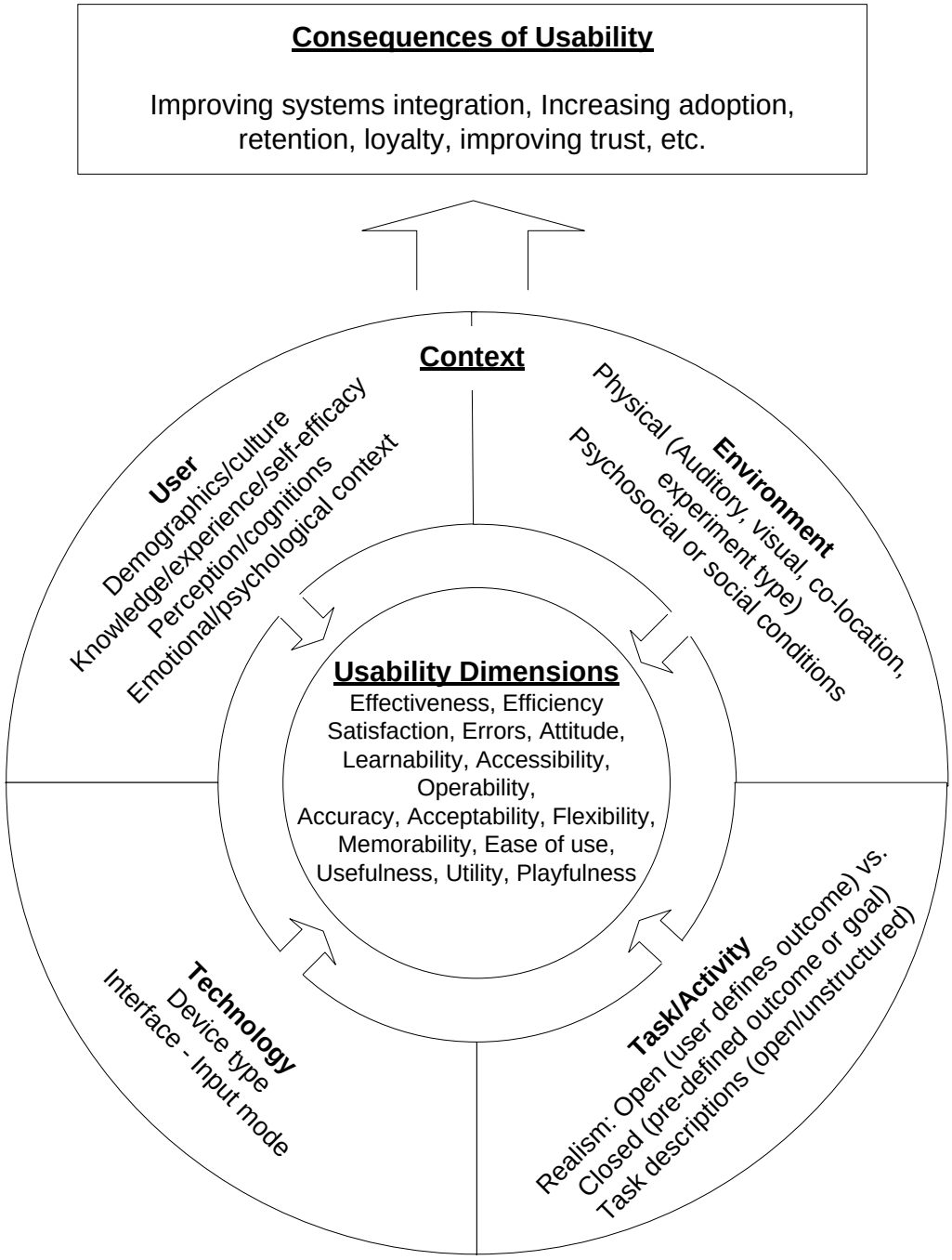

Figure 1. A suggested mobile usability framework

Next, we conducted a qualitative review of empirical mobile usability studies using the framework to demonstrate the validity of the framework. Using the outer and inner circle of the framework in Figure 1, we looked at the contextual factors as well as the key usability dimensions in collected mobile usability studies.

Methods

Through systematic procedures of coding, recording, and computing, a meta-analysis is an organized way to summarize, integrate, and interpret selected sets of empirical studies (Glass, McGaw, & Smith, 1981; Lipsey & Wilson, 2000). The meta-analytical review for this study began with the search for empirical mobile usability studies literature from the year 2000 through 2010. To this end, we used multiple databases to minimize the chance of omitting relevant studies. We continued with cross-referencing the references of the retrieved studies. Hand searching of appropriate journals in this research included journals ranked among the top 10 in terms of perceived quality, as well as journals deemed relevant to the field of usability by the authors. Specific criteria were set for the selection of articles sought in this literature review: (a) a mobile technology was studied, (b) the study was empirical in nature (see footnote 1 of the Literature Review and a Mobile Usability Framework section), and (c) the time frame for included studies was from 2000 through 2010. A conscious decision was made to not limit the reviewed literature to peer-reviewed journal articles, as it would significantly reduce the reviewed articles, given the relative infancy of the mobile usability field. The above procedure resulted in the identification of 100 empirical mobile usability studies. An earlier analysis of the first 45 studies retrieved was presented at a conference in 2006 (Coursaris & Kim, 2006); while most statistics were not reported in that publication, the same analysis was performed on both samples (i.e., studies up to 2006 vs. all 100 studies retrieved by the end of 2010, so as to observe scholarship trends in mobile usability between the two temporal reference points.

Results of Analysis

The literature review of empirical research on mobile usability performed appears in the Appendix. The review results are summarized in terms of the context defined in the study, key usability dimensions measured, research methodology used, sample size, and key findings.

The following sets of analysis pertain to the contextual factors studied among the 100 empirical mobile usability studies reviewed. In doing so, the independent variables studied are described under each of the four contextual framework categories of Figure 1. Overall, empirical mobile usability studies have been focused on investigating task characteristics (47%), followed by technology (46%), environment (14%), and user characteristics (14%; where single-nation populations in studies are not included, albeit one might consider them as cultural studies depending on the frame of reference). (Note: distribution exceeds 100% as multiple areas may have been studied in a single study.) Hence, there is a lack of empirical research on the relevance of user characteristics and the impact of the environment on mobile usability. For example, because on-screen keyboards are now a standard of smartphone technology, it would be important to understand the optimal design of on-screen smartphone/mobile device keyboards according to target user groups and their characteristics.

By contrast with our earlier data set of 45 empirical studies published by 2006, the distribution of research emphasis included research on task (56%), user (26%), technology (22%), and environment characteristics (7%). It is interesting to note that the proportion of studies that considered the environment doubled, and part of this increased emphasis is a result of a number of recent studies that compared and contrasted different usability testing methods and environments. Also, many more articles in this study's larger sample appear to focus on tasks and related technologies far more frequently than on the other two dimensions, i.e., the user and the environment. Thus, it appears that the *human* needs to be entered back in the *Human-Computer Interaction* investigations that focus on mobile usability.

Task characteristics: Open and unstructured tasks, and interactivity and complexity understudied

The framework called for the identification of either closed or open tasks. Closed tasks were used most frequently (58%), and examples would include checking the list of received calls, finding a "Welcome Note" on a mobile website or a mobile app, enabling the vibrating alert, setting the phone on silent mode, and other tasks that have a predefined state or outcome. Open tasks were used in 35% of studies, and examples include interacting with a network of services using verbal or visual information, keeping a pocket diary and filling in forms with each

use of the Internet, logging in to websites and rewriting web diaries that were first written on a pocket diary, and other tasks that do not have a pre-defined outcome (i.e., the outcome is user dependent). Nine percent of reviewed studies did not report on tasks. Hence, there is a relative lack of research involving open and unstructured tasks. Also, effects of task interactivity and task complexity on mobile usability were not investigated. With the increasingly important role of mobile devices in academia, an important question that arises is to what extent can such devices enhance a learner's experience; exploring the potential interaction effect between task interactivity and task complexity can help inform the design and use of mobile technology, applications, and services in the classroom or education environments at large.

This research design pattern is fairly consistent with our earlier analysis from 2006, where closed-open tasks were used 69% and 22% respectively (with 9%, again, not reporting). Hence, the same research gap exists surrounding open and unstructured tasks, and factors such as interactivity, complexity, and others as they relate to mobile usability.

User characteristics: A narrow focus on studied user dimensions is prevalent

The most prominent user-related variable studied in empirical mobile usability research was (prior) experience, focusing on either novices (16%), experts (13%), or both (16%). Culture (3%) and job-specific roles (i.e., physicians, engineers; 8%) were also measured. Disability was only explored twice (i.e., 2%), examining the role of technology in assisting users with visual impairment and memory loss respectively. No empirical mobile usability research studied the role of gender or age, and mobility was investigated in just 6% of studies. From these statistics it becomes apparent that research has been limited in both the range and frequency of user characteristics studied. Examples of such limitations are found in the myriad of disabilities that can negatively impact a mobile user's experience or even prohibit the use of certain services, and yet are extremely underserved.

Comparing these statistics with our 2006 sample, a small shift away from convenient, novice samples (from 25% to 16%) to an examination of the impact of experience (from 9 to 16%) on the dependent constructs appears. Cross-cultural studies did not emerge significantly during this period, which is somewhat surprising considering the uptake of mobile devices around the world; by contrast, work-related context was investigated proportionately twice as much, while convenient samples of students were utilized at similar rates. Thus, the same need and corresponding opportunities for user-centered empirical mobile usability studies still exists.

Technology characteristics: Enabling technology beyond the interface is overlooked in mobile studies

The most popular variable investigated in these studies pertaining to the technology used was the interface. These studies involved mobile phones (44%), PDAs (38%), Pocket PCs (5%), and various interfaces (19%) including a desktop, a tablet PC, a discman, and wearable or prototype devices. Again, these frequencies exceed 100% because a few studies involved multiple devices. The above distribution was quite similar to the 2006 sample. Hence, the lack of research as it relates to technology beyond the interface continues. For example, whether the lack of support for Flash by iOS (available at the time this paper was written) significantly impacts the usability of mobile (iPhone/iPad) users, or to what extent does network interoperability enhances a device's mobile usability would be of significant value particularly among the practitioner community, while extending previously validated research models and theories in the mobile domain.

Environment characteristics: Area with greatest potential for future mobile usability research

Eleven percent of studies explored factors as they relate to the environment. This focus has shown an increase since the 2006 reported research incidence rate of 7%, partly due to an emphasis on usability evaluation methods becoming more relevant and scholars' interest in comparing lab to field-based methods. Lighting and noise levels previously studied were joined by studies on sound, temperature, acceleration, humidity, as well as social aspects. Hence, physical, psychosocial, and other environment-specific factors present a significant opportunity for future research in mobile usability. For example, little is known about the impact of co-location (i.e., a mobile user being in physical proximity to other individuals) on the use of a

mobile device (e.g., which types of applications are more likely to be used when alone vs. collocated with familiar or unfamiliar individuals). Such insight could further advance the contextual designs of mobile devices, whether through user-configured settings, sensors, or other means.

Methodology characteristics: A call for neuroscience research in mobile usability

The final set of analysis pertains to the experiment setup and methodology. Laboratory studies were conducted most often (47%), followed by field studies (21%), while 10% of studies involved both. Hence, lab-tested mobile usability research was dominant, which was also the trend found in our 2006 sample. Next, multiple methodologies were identified in these studies, including questionnaires (61%); device data (33%); direct observation (7%); focus groups (7%); discussions (3%); and voice mail and web mail diaries, as well as Think Aloud Method (each at 2%); and single studies leveraging a usability test/expert, evaluation/participatory, design/card, sorting/task analysis. Frequencies of methodology used exceed 100% because most studies (45%) involved a multi-method approach. Specifically, device data were most commonly triangulated with questionnaire (13%), observation (5%), or interview data (4%). However, with only 13% of the studies being the case, there is limited research that contrasts self-reported data with device data, something that has remained unchanged from the results of our 2006 sample. Lastly, there were no studies involving neuroscience, an area that is of particular importance in mobile usability. With the associated cost of the needed technology to employ related methods, e.g., eye tracking and brain imaging, the area is prime for growth and novel contributions to the field. Knowledge dissemination outlets can both benefit and support the fueling of such research through special calls for related works.

Analysis of Mobile Usability Measurement Dimensions

Because the focus of this study was on the usability dimensions measured in empirical mobile usability studies, we reorganized them in terms of usability dimensions. Table 1 presents a summary of these 31 measured usability dimensions.

Table 1. Frequency of Usability Measures Used in the Reviewed Studies

Original List of Measures			**Collapsed List Of Measures**		
MEASURES	**SOURCES**	**COUNT**	**MEASURES**	**UNIQUE COUNT**	**%**
Efficiency	Barnard, Yi, Jacko, & Sears, 2005; Bohnenberger, Jameson, Kruger, & Butz, 2002; Brewster, 2002; Brewster & Murray, 2000; Bruijn, Spence, & Chong, 2002; Butts & Cockburn, 2002; Buyukkoten, Garcia-Molina, & Paepcke, 2001; Chin & Salomaa, 2009; Chittaro & Dal Cin, 2002; Chittaro & Dal Cin, 2001; Clarkson, Clawson, Lyons, & Starner, 2005; Costa, Silva, & Aparicio, 2007; Duda, Schiel, & Hess, 2002; Fitchett & Cockburn, 2009; Fithian, Iachello, Moghazy, Pousman, & Stasko, 2003; Goldstein, Alsio, & Werdenhoff, 2002; Gupta & Sharma, 2009; Huang, Chou, & Bias, 2006; James & Reischel, 2001; Jones, Buchanan, & Thimbleby, 2002; Kaikkonen, Kallio, Kekäläinen, Kankainen, & Cankar, 2005; Kim, Chan, & Gupta, 2007; Kjeldskov & Graham, 2003; Kjeldskov, Skov, & Stage, 2010; Koltringer &	41	Efficiency	61	33

Original List of Measures			Collapsed List Of Measures		
MEASURES	**SOURCES**	**COUNT**	**MEASURES**	**UNIQUE COUNT**	**%**
	Grechenig, 2004; Langan-Fox, Platania-Phung, & Waycott, 2006; Liang, Huang, & Yeh, 2007; Lindroth, Nilsson, & Rasmussen, 2001; Massimi & Baecker, 2008; Nagata, 2003; Nielsen, Overgaard, Pedersen, Stage, & Stenild, 2006; Olmsted, 2004; Poupyrev, Maruyama, & Rekimoto, 2002; Pousttchi & Thurnher, 2006; Rodden, Milic-Frayling, Sommerer, & Blackwell, 2003; Ross & Blasch, 2002; Ryan & Gonsalves, 2005; Seth, Momaya, & Gupta, 2008; Shami et al., 2005; Sodnik, Dicke, Tomazic, & Billinghurst, 2008; Wigdor, & Balakrishnan, 2003				
Errors	Andon, 2004; Brewster & Murray, 2000; Butts & Cockburn 2002; Cheverst, Davies, Mitchell, Friday, & Efstratiou, 2000; Danesh, Inkpen, Lau, Shu, & Booth, 2001; Fitchett & Cockburn, 2009; Gupta & Sharma, 2009; Huang et al., 2006; James & Reischel, 2001; Jones, Buchanan, & Thimbleby, 2002; Juola & Voegele 2004; Kaikkonen, 2005; Kaikkonen et al., 2005; Kim, Kim, Lee, Chae, & Choi, 2002; Kjeldskov & Graham, 2003; Koltringer & Grechenig, 2004; Langan-Fox et al., 2006; Lehikoinen & Salminen, 2002; Lindroth et al., 2001; MacKenzie, Kober, Smith, Jones, & Skepner, 2001; Massimi & Baecker, 2008; Nagata, 2003; Palen & Salzman, 2002; Ross & Blasch, 2002; Ryan & Gonsalves, 2005; Waterson, Landay, & Matthews 2002; Wigdor & Balakrishnan, 2003	27	Effectiveness	49	27
Ease of Use	Cheverst et al., 2000; Chong, Darmawan, Ooi, & Binshan, 2010; Cyr, Head, & Ivanov, 2006; Ebner, Stickel, Scerbakov, & Holzinger, 2009; Ervasti & Helaakoski, 2010; Fang, Chan, Brzezinski, & Xu, 2003; Fithian et al., 2003; Hinckley, Pierce, Sinclair, & Horvitz, 2000; Hsu, Lu, & Hsu, 2007; Jones, Buchanan, & Thimbleby, 2002; Kim et al., 2002; Kim et al., 2007; Kim et al., 2010; Li & Yeh, 2010; Licoppe & Heurtin, 2001; Mao, Srite, Thatcher, & Yaprak, 2005; Massey, Khatri, &	26	Satisfaction	18	10

Original List of Measures			Collapsed List Of Measures		
MEASURES	**SOURCES**	**COUNT**	**MEASURES**	**UNIQUE COUNT**	**%**
	Ramesh, 2005; Olmsted, 2004; Pagani, 2004; Palen & Salzman, 2002; Pousttchi & Thurnher, 2006; Qiu, Zhang, & Huang, 2004; Roto, Popescu, Koivisto, & Vartiainen, 2006; Ryan & Gonsalves, 2005; Wu & Wang, 2005; Xu, Liao, & Li, 2008				
Usefulness	Bødker, Gimpel, & Hedman, 2009; Chong et al., 2010; Cyr et al., 2006; Ebner et al., 2009; Ervasti & Helaakoski, 2010; Fang et al. 2003; Fithian et al., 2003; Hsu et al., 2007; Hummel, Hess, & Grill, 2008; Kim et al., 2010; Li & Yeh, 2010; Mao et al., 2005; Pagani, 2004; Palen & Salzman, 2002; Pousttchi & Thurnher, 2006; Wu & Wang, 2005; Xu et al., 2008	17	Accessibility	15	8
Effectiveness	Barnard et al., 2005; Bohnenberger et al., 2002; Brewster, 2002; Brewster & Murray, 2000; Chin & Salomaa, 2009; Costa et al., 2007; Duh, Tan, & Chen, 2006; Goldstein et al., 2002; Huang et al., 2006; Kleijnen, Ruyter, & Wetzels, 2007; Liang et al., 2007; Nielsen et al., 2006; Pousttchi & Thurnher, 2006; Ryan & Gonsalves, 2005; Shami et al., 2005; Sodnik et al., 2008	16	Learnability	8	4
Satisfaction	Dahlberg & Öörni, 2007; Ebner et al., 2009; Huang et al., 2006; Hummel et al., 2008; Juola & Voegele, 2004; Kallinen, 2004; Kim et al., 2002; Kim et al., 2007; Kleijnen et al., 2007; Lindroth, 2001; Nielsen et al., 2006; Olmsted, 2004; Palen & Salzman, 2002; Ryan & Gonsalves, 2005; Shami et al., 2005	15	Workload	7	4
Accuracy	Barnard et al., 2005; Burigat, Chittaro, & Gabrielli, 2008; Clarkson et al., 2005; Duh et al., 2006; Keeker, 1997; Koltringer & Grechenig, 2004; Olmsted, 2004; Thomas & Macredie, 2002; Wigdor & Balakrishnan, 2003; Wu & Wang, 2005	10	Enjoyment	4	2
Learnability	Butts & Cockburn, 2002; Dahlberg & Öörni, 2007; Fithian et al., 2003; Kaikkonen et al., 2005; Lindroth, 2001; MacKenzie et al., 2001; Roto et al., 2006; Ryan & Gonsalves, 2005	8	Acceptability	3	2

Original List of Measures			Collapsed List Of Measures		
MEASURES	**SOURCES**	**COUNT**	**MEASURES**	**UNIQUE COUNT**	**%**
Workload	Barnard et al., 2005; Chan, Fang, & Brzezinski, 2002; Chin & Salomaa, 2009; Jones, Jones, Marsden, Patel, & Cockburn, 2005; Li & McQueen, 2008; Seth et al., 2008; Sodnik et al., 2008	7	Quality	3	2
Accessibility	King & Mbogho, 2009; Mao et al., 2005; Pagani, 2004; Palen, Salzman & Youngs, 2001; Suzuki et al., 2009	6	Security	3	2
Reliability	Andon, 2004; Barnard et al., 2005; Costa et al., 2007; Kleijnen et al., 2007; Lin, Goldman, Price, Sears, & Jacko, 2007; Wu & Wang, 2005	6	Aesthetics	4	2
Attitude	Goldstein et al., 2002; Juola & Voegele 2004; Khalifa & Cheng, 2002; Palen & Salzman, 2002; Strom, 2001	5	Utility	2	1
Problems Observed	Kaikkonen, 2005; Kaikkonen et al., 2005; Kjeldskov & Graham, 2003; Nielsen et al., 2006	4	Memorability	2	1
Enjoyment	Cyr et al., 2006; Ebner et al., 2009; Hummel, 2008; Kim et al., 2010	4	Content	2	1
Acceptability	Andon, 2004; Butts & Cockburn, 2002; Juola & Voegele 2004	3	Flexibility	1	1
Quality	Barnard, Yi, Jacko, & Sears, 2007; Bødker et al., 2009; Kleijnen et al., 2007	3	Playfulness	1	1
Security	Andon, 2004; Fang et al., 2003; Kim et al., 2007	3			
Aesthetics	Cyr et al., 2006; Li & Yeh, 2010; Wang, Zhong, Zhang, Lv, & Wang, 2009	3			
Utility	Duda et al., 2002; Hassanein & Head, 2003	2			
Operability	Chittaro, Dal Cin, 2002; Kaikkonen et al., 2005	2			
Memorability	Langan-Fox et al., 2006; Lindroth et al., 2001	2			
Responsiveness	Barnard et al., 2007; Kleijnen et al., 2007	2			
Content	Kim, Kim, & Lee, 2005; Koivumäki, Ristola, & Kesti, 2006	2			
Attractiveness	Lin et al., 2007	1			
Flexibility	Cheverst et al., 2000	1			
Playfulness	Fang et al., 2003	1			
Technicality	Hummel et al., 2008	1			
Availability	Pagani, 2004	1			
Functionality	Pagani, 2004	1			

Original List of Measures			Collapsed List Of Measures		
MEASURES	**SOURCES**	**COUNT**	**MEASURES**	**UNIQUE COUNT**	**%**
Interconnectivity	Andon, 2004	1			
Integrity	Costa et al., 2007	1			

A preliminary inspection of Table 1 shows that the constructs of efficiency, errors, ease of use, effectiveness, satisfaction, and learnability are most commonly measured in empirical mobile usability studies. All of these measures were defined in the work of Han et al. (2001) on the classification of performance and image/impression dimensions with slight variations. The measure of errors was defined by Nielsen (1993) as the "number of such actions made by users while performing some specified task" (p.32). Han et al. (2001) addressed errors through two measures: (a) error prevention (i.e., "ability to prevent the user from making mistakes and errors" p. 147) and (b) effectiveness (i.e., "accuracy and completeness with which specified users achieved specified goals" p.147). With respect to the reviewed literature, mobile usability studies measured the error rate, as opposed to error prevention, associated with the system. Hence, we collapsed the errors, accuracy, and problems observed measures found in this literature review with effectiveness (effectiveness offering a broader definition and operationalization). This broader interpretation of effectiveness may be extended to encompass the extent to which a system achieves its intended objective, or simply put, its usefulness. Hence, the latter may also be collapsed with effectiveness. Similarly, the second order measure of efficiency often attempts to capture the first-order factor of ease of use. This is supported conceptually, because the "easier" a system is to use the less resources are consumed during the task. Hence, ease of use may be collapsed with efficiency. Furthermore, Shackel defined attitude as the "level of user satisfaction with the system" (2009, p 341). Han et al. (2001) defined satisfaction as "the degree to which a product is giving contentment or making the user satisfied" p.147. Hence, attitude (as defined in these usability studies) may be collapsed into the single measure of satisfaction. It should be noted that the frequency count for each collapsed criterion is based on unique counts of a particular publication (i.e., if errors and effectiveness were found in the same study, the publication would count these only once for the unique count). In addition, accessibility had been studied in most cited studies as the degree to which a system was accessible; this was just to clarify from the scope accessibility in the context of vulnerable/disabled users. Hence, other measures found in studies that speak to this concept include reliability, responsiveness, availability, functionality, and interconnectivity, and can be collapsed under accessibility. Lastly, attractiveness speaks to the broader concept of aesthetics, and integrity is a security dimension, so these can be grouped respectively.

Upon review of the measures' relative appearance in the reviewed literature the three core constructs for the measurement of usability appear to be the following:

- Efficiency: Degree to which the product is enabling the tasks to be performed in a quick, effective, and economical manner, or is hindering performance.
- Effectiveness: Accuracy and completeness with which specified users achieved specified goals in a particular environment.
- Satisfaction: The degree to which a product is giving contentment or making the user satisfied.

The above findings are arguably neither surprising nor favorable for the field, as these factors have been set as the standard for more than a decade, regardless of significant technology advances and use settings and scenarios—the usability scholar's lens has gone unchanged. However, the growing popularity of games and similarly engaging and hedonically oriented experiences in the use of mobile devices might suggest that both the factors studied and the definitions set forth for mobile usability may be revisited before too long.

The remaining measures identified in Table 1 reflect the peripheral dimensions measured in empirical mobile usability studies cited in the Appendix, including Accessibility (8%), Learnability (4%), Workload (4%), Aesthetics (2%), Enjoyment (2%), Acceptability (2%),

Quality (2%), Security (2%), Utility (1%), Playfulness (1%), Memorability (1%), Content (1%), and Flexibility (1%).

Recommendations and Conclusion

To the best of our knowledge, this research is the first analysis of the contextual factors and measurement dimensions investigated in the empirical body of knowledge of mobile usability studies published to-date by leveraging a proposed qualitative review framework for mobile usability. The results described earlier enhance our understanding of mobile usability research considerations and serve as the basis for a research agenda in this field. This domain would benefit by having a further emphasis placed on the complexity of contextual usability and answering such research questions as those within and/or between each of the following areas:

- Technology: Beyond the interface—how do mobile technology components beyond the interface (e.g., network connectivity reliability, memory) impact the usability of mobile devices?
- User: Study the *human* factors in HCI—what other user characteristics (e.g., cognitive aptitude, mental models, physical ability) should be considered when studying mobile usability? More research is also needed on variables previously investigated (e.g., experience and efficacy).
- Task/Activity: Real world–real tasks—how do task complexity and task interactivity impact mobile usability? By considering these two dimensions and engaging in research involving open tasks in a field setting approximates real-world situations and results improve in their external generalizability.
- Environment: Usable anytime, anywhere—how do conditions in the environment impact mobile usability? A higher rate of field studies and/or complex lab studies will enhance our understanding of such dynamic factors (e.g., urgency, wind) and their effects on mobile technology.

The results of the meta-analytical review of empirical research on mobile usability identified 31 usability-related measures. The main usability measures studied in mobile usability studies are efficiency, effectiveness, and satisfaction, which are actually consistent with the standard diminutions of other general usability studies (Brereton, 2005; Hornbaek & Law, 2007; Nielsen & Levy, 1994). However, these usability dimensions are more important in mobile applications and technologies because of the inherent characteristics of mobile devices, including small screens, low display resolutions, limited input methods, difficult-to-use interface, and many others. Moreover, the three core dimensions of mobile usability measurements (i.e., effectiveness, efficiency, and satisfaction) reflect the ISO 9241 standard making a strong case for its use in related future studies. The use of this standard would allow for consistency with other studies in the measurement of general usability (Brereton, 2005; Hornbaek & Law, 2007; Nielsen & Levy, 1994).

Beyond the benefit of a standard view of usability, three key findings emerge from the above data. First, any single peripheral usability dimension was measured in fewer than 8% of the studies reviewed. Second, accessibility, in the context of vulnerable populations/disabled users, appears to be one of the most underserved research areas having been studied only twice in this set of 100 mobile usability studies reviewed. This observation may come as a surprise, given the growing popularity of accessibility research in less conventional (e.g., non-IS, non-peer-reviewed) publication outlets, and the increasing levels of legislative support and community interest. Further exploration of this construct, including its role with the remaining usability dimensions, is warranted. Third, aesthetic/hedonic constructs were studied in just 2% of empirical mobile usability studies, even though there is support for the effect of such factors on performance and satisfaction (Coursaris, Swierenga, & Watrall, 2008). These findings in turn call for a critical review of the current operationalization of usability as several dimensions are not captured in the international standard defined by ISO 9241 in 1998.

After more than a decade's worth of research that centers on the standard usability measures articulated by ISO in 1998, our understanding of their inter-relationships is mature. The domain could arguably benefit by extending the defined core by considering a subset of the peripheral dimensions so as to allow for an even deeper understanding of mobile usability. Adding to the

earlier research agenda, the following measurement considerations are outlined for future research: (a) accessibility—increasing research in this area may improve the usability of products and services for often overlooked audiences; (b) hedonics—which factors impact the aesthetic appeal of a mobile device or service, and how do they impact usability?; and (c) usability—what are the relationships between various usability measurement dimensions? Should usability be redefined to reflect additional utilitarian and/or hedonic dimensions?

This study offers several contributions and implications for both researchers and practitioners. On the academic level, first, this breakthrough meta-analytical research is the first attempt, to our knowledge, to offer a comprehensive view of usability dimensions found in empirical mobile usability studies. Second, the identification of a common measurement metric with a review framework would support a future quantitative analysis of mobile usability studies at the construct level (i.e., a meta-analysis of measured usability dimensions in a mobile setting). In turn, this could offer a unified view of empirical mobile usability studies. We hope that the framework and the findings of this study will be used as the basis for continuing research that aims to enhance our understanding of mobile usability considerations and measurement.

This study also provides a couple of important implications for practitioners. First, this study summarizes the existing mobile usability research findings and organizes them based on a set of usability contextual factors and measurement dimensions using a comprehensive mobile usability framework. The results of this study encourage practitioners to pay more attention to the key contextual factors and mobile usability measurement dimensions when they develop their mobile products and/or services. Second, because the current mobile usability evaluation process is more of a "fuzzy art" without a structured framework and there is a need for a more structured approach to evaluate mobile usability, the mobile usability framework identified by this study can be used during a usability evaluation of mobile products and/or services.

As with all research, this study comes with the caveat of the following limitations. First, even though the authors searched intensively for all possible research articles of empirical mobile usability studies, the case may be that relevant articles were omitted in this process. Second, even though the meta-analysis of this study followed the procedures suggested by Glass et al., (1981), Lipsey and Wilson (2000), and Rosenthal (1991), some subjective decisions were made when two mobile usability dimensions were collapsed into a single measure. Although arguments were given, this could be a limitation of a subset of the reported results.

Beyond the benefit of a standard view of usability, an important opportunity for future research arises from the data in Table 1. Accessibility appears to be one of the most underserved research areas. Again, this observation may come as a surprise, given the growing popularity of accessibility research in less conventional (e.g., non-IS, non-peer-reviewed) publication outlets, and the increasing levels of legislative support and community interest. Further exploration of this construct, including its relationship with the remaining usability dimensions, is warranted.

In closing, it is hoped that the above findings and the suggested research agenda will stimulate further research in this domain, the results of which expand both the scholarly body of knowledge, but also have direct and tangible benefits for everyday users of mobile technology.

Practitioner's Take Away

The following are key points raised in this paper:

- Consider the wide range of usability dimensions identified in this study when evaluating the usability of mobile interfaces and applications.
- Design mobile interfaces and applications that fit particular contextual settings, while being flexible to accommodate others.
- Focus beyond the interface—usability is an aggregate experience—when developing applications.
- Study the *human factors* in HCI, and identify cognitive factors and physical abilities that future mobile devices could be designed to accommodate.

- Consider the limitations of the laboratory and conduct research involving real (not simulated) and open tasks through field studies that will offer rich and relevant findings.
- Explore the interplay among dynamic factors (e.g., urgency, noise) and their impact on mobile usability.

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Appendix

Appendix: Formations and Dimensions of Usability

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Appendix

Formations and Dimensions of Usability

Usability studies	Formation of usability				Research methodology* (sample size)	Key usability dimensions/ constructs**	Other variables	Key findings
	User	Task/activity	Technology/ system/product	Environment				
Andon, 2004	N/A Job: Physicians (attending and resident)	N/A	Tablet PCs	Lab & Field	-Focus group -Survey (9)	Errors	Weight, wireless infrastructure, technical support, security, reliability, interconnectivity	Weight→acceptability
Barnard et al., 2005	N/A Undergraduate students	Closed - Users had to perform a set of tasks (reading comprehension, word search) while sitting, walking on a treadmill, or free walking along a path.	Palm m505 (PDA)	Lab Motion & light	-Experiment (126) -Survey -Device data	Reading & response time (therefore efficiency) effectiveness	Salience, Effect of lighting differences, Workload, Score, Scrolls	-Reading time was fastest on a treadmill in high light. -Response time was fastest walking in high light. -Word search time was fastest on treadmill in both high & low light. -Walking caused most mental demand, effort, performance, and frustration. -Subjective measures are more sensitive to changes in conditions then performance measures.

Usability studies	Formation of usability				Research methodology* (sample size)	Key usability dimensions/ constructs**	Other variables	Key findings
	User	Task/activity	Technology/ system/product	Environment				
Barnard et al., 2007	Experts	N/A	Mobile services on mobile phones	N/A	-Interviews (20) -Survey (225) -Age: 18-50+	N/A	Reliability, Responsiveness, Assurance, Empathy, Tangibles, Convenience, Customer perceived network quality	Responsiveness was the best predictor of service quality in cellular mobile context, followed by reliability, customer perceived network quality, assurance, convenience, empathy, and tangibles. Measurement instrument for SERVQUAL and functional quality
Bødker et al., 2009	N/A Culture: Denmark	Open - Used the iPhone for 6 months (email, SMS, Web, Omnipresence, GPS, MP3	iPhone 3G with voice, SMS and data plan	Field	-Experiment -Surveys -Focus groups -Interviews 16 participants	Perceived usefulness	Prior/post use of ICT, Perceived quality, Referent, Context, Perceived appropriateness, and Task medium fit	Perceived quality differences between a new option and the referent impact the decision Context → Perceived Usefulness & Appropriateness of the medium
Bohnenberger et al., 2002	Novices	Open - Shopping	PDA	Field	-Experiment (20) -Survey	Effectiveness Efficiency	Adoption	PDA → less time, effort, cognitive effort, and frustration
Brewster & Murray, 2000	N/A Job: Students	Open - Search trade information, sell shares	Palm V (PDA)	Lab	-Experiment (12) -Device data	Effectiveness Efficiency	N/A	Audio presentation→efficiency, effectiveness

Usability studies	Formation of usability				Research methodology* (sample size)	Key usability dimensions/ constructs**	Other variables	Key findings
	User	Task/activity	Technology/ system/product	Environment				
Brewster, 2002	Novices (students and staff)	Closed - Entering a series of five digit codes using the numeric keypad	Palm III (PDA)	Lab	Experiment (12, 16) -Device data -Survey	Effectiveness Efficiency	The amount of data, button size, sound type, workload	Sonically-enhanced buttons →less workload, more frustration and performance, more data entry; small button→more workload, less data entry
Bruijn et al., 2002	Novices	Closed (navigation to find the answers of questions)	Mobile phone	Lab	-Experiment -Device data (30)	Efficiency	Steps, browser	WAP is more efficient and significantly fewer steps than RSVP
Burigat et al., 2008	N/A	Closed - Navigated large maps & web pages on small screen & used spatial memory acquisition	624 Mhz Pocket PC	Lab	-Experiment -Interview -Device data Undergraduate or graduate students	Accuracy	Driving performance, Preferences	-Grab and drag → Performance in a task involving little navigation -Double scroll bar & zoom enhanced navigation → Performance & user orientation in a task involving larger amounts of navigation
Butts & Cockburn, 2002	Experts	Closed (enter five sentences using each input method to send SMS)	Mobile phone	Lab	-Experiment -Device data -Observation (8)	Efficiency Error Learnability Acceptability	Text entry interface	Reliable differences in efficiency among different text entry interfaces, no learnability difference, acceptability given to certain text entry interfaces over other forms
Buyukkoten et al., 2001	Novice-Experts (computer exp.), level of concentration	Closed (accomplish single-page info, search tasks using different methods)	Palm (PDA) and mobile phone	Lab	-Experiment (15) -Device data	Efficiency	Performance (user and system)	Combination of keywords and single-sentence summaries provides sig. improvements in efficiency.

Usability studies	Formation of usability				Research methodology* (sample size)	Key usability dimensions/ constructs**	Other variables	Key findings
	User	Task/activity	Technology/ system/product	Environment				
Chan et al., 2002	Novices-Experts	Open - Checking & booking a flight, searching and buying a book, stock quotes, etc.	WAP-enabled mobile phones, PDA, & pocket PC	Lab	-Experiment -Device data (6)	N/A	Information overload, depth of site structure, search, connection feedback and latency	Strong relationship between e-commerce and m-commerce
Cheverst et al., 2000	Experts Job: Visitors	N/A	GUIDE prototype	Field	-Interview -Observation (60)	Error, Flexibility Interface friendly (thus, ease of use)	N/A	N/A
Chin & Salomaa, 2009	N/A User motion (and light) Students	Closed - Two tasks (reading comprehension & word search) in high vs. low light, while seated or walking	PDA	-Lab -Light & user motion (sitting, walking on treadmill, walking along a path around a room)	-Experiment (80) -Observation	Completion time (thus, efficiency) Score (thus, effectiveness)	Contextual factors (task type, motion and lighting level), NASA TLX (subjective workload assessment)	Reading comprehension task: Different motion -> reading time Different lighting-> response time, scrolls, and TLX Word search task: Different motion -> all experimental measures (time, score, and TLX) Different lighting-> all experimental measures (time, score, and TLX)
Chittaro & Dal Cin, 2001	Novices Gender	Open - Search and selection	WAP phone	Lab & Field	-Experiment (40) -Survey	Efficiency	Perceived difficulty	N/A
Chittaro & Dal Cin, 2002	Novices	Closed (search and selection)	Mobile phone	Lab	-Experiment -Device data (40)	Efficiency, Operability	Screen interface	Sig. differences in Efficiency and Operability among different screen interface

Usability studies	Formation of usability				Research methodology* (sample size)	Key usability dimensions/ constructs**	Other variables	Key findings
	User	Task/activity	Technology/ system/product	Environment				
Chong et al., 2010	N/A Culture: New Zealand Job: From 10 companies, either m-commerce participants or facilitators	N/A - Asked about their awareness of m-commerce services & adoption barriers	N/A	N/A	-Interview: Face to face or phone -Purposeful sampling 10 participants	- Simplicity in use, User friendliness (interface characteristics, ease of access to relevant information or services; thus, ease of use) - Usefulness (lack of real value-adding m-services, unawareness, fulfillment issue)	Technology Self-efficacy	Usability (learnability, ease of use, usefulness) → m-commerce service adoption
Clarkson et al., 2005	Novices	Closed - Complete 20 sessions in 11 days on Mini QWERTY & full QWERTY -10 phrases in 20 sessions -Typed with thumbs	Dell (Dell Axim) and Targus (Palm m505) Brand Desktop QWERTY	Lab	-Experiment (14) -Demographics -Survey -Device data	WPM (therefore efficiency) Accuracy	Comfort	-Targus group typed faster & typing speeds of users improved over time. -Desktop Qwerty had faster speeds than Mini QWERTY. -Users found the mini-QWERTY marginally comfortable & much less comfortable than full keyboard.
Costa et al., 2007	N/A Job: Architecture Students	Open - Read questions, navigate Web via links, folio, search & scroll for answers, & write in text box	PDA, Touch Screen	Lab	-Experiment (8) -Device data	Efficiency Effectiveness	Integrity, Reliability	Using links is more efficient and effective as a navigation option than scroll, search, and "folio."

Usability studies	Formation of usability				Research methodology* (sample size)	Key usability dimensions/ constructs**	Other variables	Key findings
	User	Task/activity	Technology/ system/product	Environment				
Cyr et al., 2006	Experts Culture: Chinese (30) or Canadian (30) in origin	Open - Choose restaurant on cell phone using bookmarked site (CityGuide), complete survey, and complete open-ended interview questions.	Mobile phone (Nokia 6600 device)	N/A	-Experiment (60) -Survey (60) -Interview (60)	Design aesthetics Usefulness Ease of use	Enjoyment, M-loyalty	Design aesthetics → Perceived usefulness, ease of use, and enjoyment in mobile context Perceived ease of use → Perceived usefulness Perceived usefulness and enjoyment → M-loyalty (user willingness to revisit a site) No significant differences between Canadians and Chinese (living in Canada)

Usability studies	Formation of usability				Research methodology* (sample size)	Key usability dimensions/ constructs**	Other variables	Key findings
	User	**Task/activity**	**Technology/ system/product**	**Environment**				
Dahlberg & Öörni, 2007	N/A Seniors with mild cognitive impairment and/or memory loss	Open - Kept a paper organizer & used their new organizers (called "memory books"). Seniors designed their own mobile phone software for memory support and provided rationales for their design choices.	Organizers (called "memory books"), mobile PDA/phone (iMate K-JAM model)	Lab Geriatric hospital and research center	-Experiment -Observations -Participatory design sessions 6 seniors with MCI 5 normally aged seniors	N/A	Portability, Easy backups, Flexibility and revision, Proactive alarms, Consolidated information, Interactivity, Ease of carrying, Creating a routine of use, Communicatio n support	-Mobile phones were one of the most feasible platforms for memory support technologies. -Commercial phones targeted at seniors should support memory aids and ease of using. -Barriers were poor conceptual design, complexity, hardware designed inappropriately for seniors, radiation & health concerns, fear of changing routines/breaking phone, impersonal nature of tech.
Danesh et al., 2001	N/A Elementary Students	N/A, Transference of data, use album, drawing	Palm (PDA)	Lab	-Experiment -Device data -Observation (14)	Error	N/A	N/A
Duda et al., 2002	Experts Gender (18 male, 18 female)	Open - WAP services exploring	WAP phones	N/A	-Experiment (36) (B2C service) - Survey - Observation - Interview - Age: 29 (av.)	Speed (therefore efficiency) Acceptance (therefore acceptability) Utility Usability	System in- and output (SIO), Feeling of control	In order of importance: Utility → Acceptance Usability → Acceptance SIO → Acceptance Feeling of control → Acceptance Speed → Acceptance Lower cost → Acceptance

Usability studies	Formation of usability				Research methodology* (sample size)	Key usability dimensions/ constructs**	Other variables	Key findings
	User	Task/activity	Technology/ system/product	Environment				
Duh et al., 2006)	N/A Culture: Singapore	N/A	Mobile phones, PDA	Lab & field	-Survey (100) -Experiment -Observation	Effectiveness	Contextual awareness, task hierarchy, visual attention, hand manipulation & mobility, problems observed	There were many more types and occurrences of usability problems found in the field than in the laboratory.
Ebner et al., 2009	Novices-Experts Culture: Turkey	N/A - Mobile Services	N/A	N/A	-Interview 12 interviewees	Ease of use Usefulness	Cost, Mobility, Enjoyment/entertainment, Social influence (external influence), User characteristic, (innovativeness, image, etc.), Content (correctness, quality and delivery time of content)	-Usefulness & Ease of use is most important in m-service adoption. -Service aspect (content and mobility) is more significant than social aspect. -Social influences are more important than user characteristics in terms of social aspects.
Ervasti & Helaakoski, 2010	N/A Culture: Finland	Closed - Register via webpage, download Mora mobile application and use it	Mora mobile service	Field (Campus)	-Experiment (two months) -Survey 52 participants	Perceived usefulness Perceived ease of use	Barriers to use, Utilization of context–specific information, Perceived behavior control, Reference group, Attitude, Intention to use mobile service	PU -> ATT PEOU -> ATT CON -> INT ATT -> INT INT -> USE

Usability studies	Formation of usability				Research methodology* (sample size)	Key usability dimensions/ constructs**	Other variables	Key findings
	User	Task/activity	Technology/ system/product	Environment				
Fang et al., 2003	N/A Adults, alumni, students	N/A - Evaluate characteristics of the devices - Mobile commerce tasks	N/A	N/A	- Experiment (101) - Survey - Age: 20-50	Ease of use Playfulness Usefulness	Perceived task complexity (PTC), Perceived security (PS)	PU, PS. PP. EOU →Intention* positively Mostly PU, PS, PP → Intention* *intention to perform a task
Fitchett & Cockburn, 2009	N/A	Closed - Flick scrolling vs. tilt scrolling Involved a text task & a grid task	iPod Touch	Lab	-Experiment (walking vs. stationary, tilt vs. flick scrolling) 14 postgraduate students -Observation -Survey	Task times (thus, efficiency) Error rates	Scrolling percentage preferred walking speeds, Preferences	Tilt outperformed flick scrolling when stationary (faster task completion times & fewer errors). Both performed similarly while moving, but users preferred and walked faster with flick scrolling.
Fithian et al., 2003	Novices-Experts: Age, experience with stylus and PDAs & with IM & SMS writing	Closed - Locate an individual & send a message, view event details & attendee locations	PDA/phone combination	Field	-Experiment -Survey (9) -Interview -Observation	Ease of use, Learnability, Usefulness, Performance (note: task completion time, therefore efficiency)	Appreciation	Task Completion Time (-)→ Participant's Experience with Stylus and PDAs, and with IM and SMS writing
Goldstein et al., 2002	Novices	Closed - Adding a visit card & make an appointment	PDAs or Smart phone	Lab	-Experiment -Survey (25)	Attitude, Effectiveness, Performance (therefore efficiency)	Proximity between target and questioning source	N/A
Gupta & Sharma, 2009	N/A Culture: Austria	N/A	Mobile smart phone (Qtek S200) (with sensors to capture data)	-Lab Light, Sound Acceleration Temperature Humidity	-Experiment (3 runs: Sitting, moving 1 and moving 2 (differ by kind of task) -Observation	Delay (thus, efficiency) error rate	N/A	User performance (in terms of delay and error rate) decreased, caused by movement and this environmental setup.

Usability studies	Formation of usability				Research methodology* (sample size)	Key usability dimensions/ constructs**	Other variables	Key findings
	User	Task/activity	Technology/ system/product	Environment				
Heyer, Brereton, & Viller, 2008	N/A Culture: Finland	N/A - M-Payment	N/A	N/A	-Focus group -Interview Teens (8), Students (7), Young adults 1 (8), Young adults 2(8), Parents (6), Middle-aged (9)	N/A	Relative advantages, Compatibility, Complexity, Network externality, Costs, Perceived risks and trust in mobile payment service providers, Impact of use situations	M-Payment more important in presence of queues, unexpected need for a payment, time pressure, and lack of cash or loose change. Barriers include the mobile payment market, complex solutions, premium pricing, low adoption rates, perceived risks and perceived incompatibility with large value purchases.
Hinckley et al., 2000	N/A	Closed - Visual tracking (simulate driving)	Palm-sized devices (PDA)	Lab	-Experiment (7) -Device data -Age: 30-50	Errors Ease of use	Sensing Techniques (ST), Design, Usability	- Good Design → EOU - ST → EOU for certain tasks
Hsu et al., 2007	N/A Culture: Finland	Open - Use of the mobile service (Smart Rotuaari)	SmartRotuaari: m-service with wireless multi-access network, middleware, web portal with content provider interface (CPI), & collection of functional context-aware mobile multimedia services/PDA	Field (field-office located on the Rotuaari Pedestrian area in Finland)	-Experiment -Survey Random sample in Finland, but students dominant group 192 Participants	Usefulness Ease of use Satisfaction	Perceived internal resources (skills), Perceived external resources (guidance and support offered), Likelihood of future use, Recommendation to others	Skills, Guidance and support, Usefulness -> Likelihood of future use User satisfaction, Usefulness -> Recommendation to others

Usability studies	Formation of usability				Research methodology* (sample size)	Key usability dimensions/ constructs**	Other variables	Key findings
	User	Task/activity	Technology/ system/product	Environment				
Huang et al., 2006	Novices-experts 11 Nokia users, 8 non Nokia users	Closed - Check received calls, find wireless internet access, find "Welcome Note," turn on vibrating alert, set phone on silent mode	Mobile phones (Nokia Series 40 Developer Platform 1.0)	Lab	-Survey (19) -Experiment (19) -Interview (19) -Focus group [group 1(9); group 2(10)]	Satisfaction Error Effectiveness (and success rate) Efficiency (and time) Number of attempts (thus, accessibility)	-Cell phone's menu selection -Limited size display	Users prefer a less extensive menu structure on a small screen device.
Hummel et al., 2008	Experts Culture: Singapore	N/A - Mobile Internet	Mobile phone	Field	-Survey (online and participants recruited via ads in forums) 161 participants	Usefulness	Perceived fee Perceived value Enjoyment Technicality	-Value perception is a major determinant of m-Internet adoption. -Mediating effect of perceived value on customer's benefit (usefulness and enjoyment) and sacrifice related beliefs (technicality and perceived fee) → Customer's adoption intention
James & Reischel 2001	Novices-Experts	Closed - Text typing (multi-tap and T9)	Mobile phone	N/A	-Experiment (20) -Observation -Age: 18-45	Errors Time (thus, efficiency)	Complexity	Complexity → errors

Usability studies	Formation of usability				Research methodology* (sample size)	Key usability dimensions/ constructs**	Other variables	Key findings
	User	Task/activity	Technology/ system/product	Environment				
Jones et al., 2005	N/A	Closed - Two sets of 24 tasks, Stand scrolling and speed dependent automatic zooming (SDAZ) tasks	Standard desktop Computer and Compaq iPAQ	Lab Scroll vs. Zoom (1-D vs. 2-D vs. SDAZ)	-Experiment (12) -Survey Undergraduate or post graduate students	Efficiency (and task duration, action timings,) accuracy	User interface actions, Workload	Decreased screen space decreased the impact of SDAZ 1-D navigation: normal interface is better than SDAZ 2-D navigation: supports a more accurate target location & longer task completion. SDAZ requires less interface actions & less physical effort than the standard interface .
Jones, Buchanan, & Thimbleby , 2002)	Novices Volunteers (University students, experts)	Closed - 3 scenarios - 3 tourist type - task for each scenario	PDA	Lab	-Experiment (12) -Observation -Survey	Errors Ease of use Time (therefore efficiency)	- WAP interface - PDA interface - Screen size (SS) - Frustration (F)	- Small SS→ errors - PDA interface → EOU - WAP I. < PDA I. - Small SS → TC - Small SS → F
Juola & Voegele 2004	N/A Job: Undergraduat e students (engineering & psychology)	Closed - Establish Bluetooth - Create calendar - Locate document - Add contact entry	Bluetooth devices, mobile phone	N/A	-Experiment (48) -Surveys -Observation (monitoring and recording)	Satisfaction Errors Attitude Acceptability	Make the device work (MTDW), Intention of adoption	Use → Satisfaction Satisfaction → Intention of Adoption MTDV → Errors, half satisfaction Bluetooth → Acceptability (favorable attitude to use)
Kaasinen, 2003	Novices-Experts: Men, women, youth w/ various backgrounds	Closed - Follow instructions using a GPS system	Different GPS devices (PDA, mobile phones…)	Lab & Field	- Experiment (55) - Group interviews - Device data -Age: 14-66	N/A	Location aware features	Location aware features → Enhance mobile services

Usability studies	Formation of usability				Research methodology* (sample size)	Key usability dimensions/ constructs**	Other variables	Key findings
	User	Task/activity	Technology/ system/product	Environment				
Kaikkonen et al., 2005	N/A	Closed - 10 tests	Mobile phone	Lab & field	-Experiment-Device data (40) -Lab study (20) -Field study (20)	Errors Learnability Operability	Navigation and operability problems, other problems listed/ observed	The number of times errors/problems were observed in the two settings.
Kaikkonen, 2005	Novices-Experts (mobile Internet user)	Open - Navigation	Mobile phone (Nokia Series 60 smart phones & occasionally others)	N/A	-Experiment -Survey -Usability tests (6) -Expert evaluations (12)	Errors	Problems observed	Navigation in mobile portals
Kallinen, 2004	N/A	Closed - Read a story on a PDA, with and without listening music	PDA	Field (cafeteria) Noisy Public	-Experiment (30) -Device Data -Survey -Age:15-47	Satisfaction	Immersion, positive/negative emotional response, perceived social richness, surrounding noise, music, attention, time of use	No music → Attention affected by SN Music → Time of use longer Music → Immersion Music → Positive Emotional Response Music → User Satisfaction Music → Perceived social richness
Kargin, Basoglu, & Daim, 2009	N/A Culture: Finland	Open - Order the mobile service following permission-based SMS advertising (communication, information and entertainment) on demand by sending SMS a specified keyword to local short number	N/A	N/A	-Survey: Control group (3047)–no SMS marketing, treatment group (2453)–got SMS marketing	N/A	Content preference (entertainment, information, mixed), Usage class, Average daily expenditure	Permission-based mobile advertising → Increased sales of mobile services, Effectiveness of m-advertising varies between customers with different content preferences (entertainment, information, or mixed) and service usage levels (heavy, medium, or light users).

Usability studies	Formation of usability				Research methodology* (sample size)	Key usability dimensions/ constructs**	Other variables	Key findings
	User	Task/activity	Technology/ system/product	Environment				
Khalifa & Cheng 2002	N/A -Undergrad/ Grad -Students in second (and third) degree	N/A	N/A	N/A	-Experiment (202) -Survey -Age: 18-47	Attitude	Trial, Communication, Observation, Perceived behavioral control, Exposure to mobile commerce, Subjective norms, Intention to adopt	- Trial (mostly), and Communication → Exposure to mobile commerce - Subjective norms → Intention to adopt (ITA) - Attitude → ITA behavioral control → ITA
Kim et al., 2002	Experts (mobile Internet)	Open - Web diaries	Mobile Internet phone	Field: -Noisy and Quiet -Visual cues -Public and alone	- Experiment (37) - Collecting and analyzing data - Comparing paper and e-content - Survey - Device data - Age: 15-40	Errors Satisfaction Ease of Use	Goal (utilitarian/hedonic use), Use in movement/ static, Emotion, Hands availability, Auditory distraction	- Lack of appropriate content over internet → Errors - Use in movement /static + Good Emotion → Satisfaction - Goal → EOU - HA → EOU - UM → EOU - AD → EOU
Kim et al., 2005	Experts Culture: Korea	Open - Keep pocket diary & fill in forms with each use of internet. Log on to website & rewrite web diary, which was written in the pocket diary.	Mobile Phone Model IM-1200 made by SK Telecom	Field	-Experiment (37) -Survey -Web Diaries -Server Log	N/A	Usability (content, navigation, structure, representation) Use contexts (goal & emotion, hand & leg, visual & audio distraction, co-location & interaction)	Mobile internet used primarily: when feeling joyful, had only one hand available for use, and users were alone in a quiet calm environment. Usability problems occurred most often, then navigation issues, representation difficulties, and structure problems.

Usability studies	Formation of usability				Research methodology* (sample size)	Key usability dimensions/ constructs**	Other variables	Key findings
	User	Task/activity	Technology/ system/product	Environment				
Kim et al., 2007	N/A Culture: Finland	N/A – Asked about intention to change payment habits (shifting to electronic and mobile payments)	N/A	Field	Survey development: -Interviews: University students & bank employees - Focus groups: Six groups of MBA master thesis students -Field survey: 948 participants -Random sample -Age: 18=65	Ease of use Generic (efficiency, time)	Benefits, Payment habit specific (purchase, bill payments), Trust (security), Availability of payment transaction information, Independence of time & space (convenience), Social norm, Demo (age, education, experience, profession), Internet use skills, mobile use skills	Mobile payment habit used currently, Education (elementary), Ease of use, Compatibility (large applicability, Profession (upper clerical) -> The acceptance of mobile payments Electronic invoice habit used currently, Ease of use, Internet skills, Profession (upper clerical), Profession (entrepreneur) -> The acceptance of electronic invoices
Kim et al., 2010	Experts (mobile phone users)	Open - Exploratory browsing: Browse photos & videos & select three of them.	Mobile phone: basic, traditional UI (tag-based structure + multi-display button interface) and new UI (folder-based hierarchical structure + fixed-button interface) User generated content m-service	Lab	-Experiment -Survey 33 participants	Perceived usefulness Perceived ease of use Satisfaction	Perceived enjoyment Behavioral intention	New UI enhanced exploratory browsing within mobile UGC services in terms of usefulness, enjoyment, satisfaction, and intention to use the system again. However, there were no statistical differences between mean scores for perceived ease of use of the two UIs.

Usability studies	Formation of usability				Research methodology* (sample size)	Key usability dimensions/ constructs**	Other variables	Key findings
	User	**Task/activity**	**Technology/ system/product**	**Environment**				
King & Mbogho, 2009	N/A Culture: Taiwan Job: Insurance agents	N/A - Self reported survey on performing three major types of insurance tasks with one question for each insurance task	PDA	-Field Insurance industry	-Survey (238) Random sample of agents from one insurance company in Taiwan	N/A	Cognitive style, Computer self-efficacy, Impact on task performance, PDA task-technology fit, Demographic variables (gender, age, education, position experience, and computer experience)	-Different individual traits → different cognitive fit in using PDA -PDA: different degrees of support, different TTF to different tasks -Gender, position experience, computer experience, computer self-efficacy → PDA cognitive fit -Age, education, & agents' cognitive style didn't impact the cognitive fit of using PDA technology for insurance tasks.
Kjeldskov & Graham, 2003	N/A	Closed	PDA, EMS, mobile phones	Lab & Field	-Experiment -Device data -Survey -Observation (48)	Errors Efficiency	Situation (sitting or moving)	Seating at a table→Errors Amount of physical activity→Workload

Usability studies	Formation of usability				Research methodology* (sample size)	Key usability dimensions/ constructs**	Other variables	Key findings
	User	Task/activity	Technology/ system/product	Environment				
Kjeldskov et al., 2010	Novices-Experts Culture: Denmark Job: Female nurses with 2-31 yrs. exp. Novices, but used system for 1 year -Age: 31 - 54	Open - Prior to First study, subjects attended a course on the IPJ system. First usability test: Novices, 7 tasks, Think Aloud; Second test: Nurses had 15 months experience	Desktop PC with hardware used at the hospital, Health care information system (EPR system)/ digital video	Lab	-Experiment (7) -Think Aloud -Observation	Effectiveness Efficiency (completion time)	Usability problems (prevented task solving, frustrated user, not understood by user), Severity rating by evaluator (cosmetic, serious, or critical)	-Experience → Effectiveness -Novices experienced sig. more critical and serious problems -Experts experienced sig. more cosmetic problems. -Experience did not → Efficiency (on complex tasks & critical problems with the EPR) -"Time does not heal usability problems."
Kleijnen et al., 2007	Experts Culture: India Mobile phone users and service providers from the three cities of Lucknow, Kanpur, and Agra (northern India)	N/A	Mobile airtime	N/A	-Interviews -Survey (Consumers and service providers) -Judgmental sampling (70) -Ages: 18-55+	Satisfaction (service and service provider)	Service quality, Service brand image, and customer loyalty, cost, mobile phone number (unchanged) Characteristics of service provider: honesty in billing, reliability, responsiveness, empathy, tangibles, quality of service, cost	Reliable service quality and honesty costs (billing) were the two most important determinants of consumer satisfaction, which lead to customer loyalty.

Usability studies	Formation of usability				Research methodology* (sample size)	Key usability dimensions/ constructs**	Other variables	Key findings
	User	Task/activity	Technology/ system/product	Environment				
Kofod-Petersen, Gransæther, & Krogstie, 2010	N/A Culture: Norway	N/A	FindMyFriends system (developed & installed at the student society building, Samfundet) allowed users to locate each other in different rooms within the building.	-Field Biennial student festival in the society building in Trondheim, Norway	-Experiment -Survey - Registered users (2769) - Respondents to survey (207)	N/A	Number of friends, Frequency of tag use, Use of internal and external terminals (for logging in), Attitude towards citywide location-aware systems, Privacy	- Most respondents used their tags. - Users with the most friends used their tags most often. - Two-thirds used terminals at Samfundet to locate their friends. - Many (55%) would use similar citywide system & most thought it'd be fun. - Primary reason for not using such a system was fear of losing privacy.
Koivumäki et al., 2006	N/A	Open - Used RHUB (system that supported messaging, discussions, user profiles and group management)	Prototype: RHUB (built in Web, IM, SMS and email)	N/A	-Experiment -Device data (108) -Interviews (15) -RHUB-delivered quizzes (102) -Informal conversation (4) -Content analysis (500 random messages from RHUB)	N/A	N/A	- The shift to facilitating group messaging as well as socialization across media engendered specific kinds of use. - Differences in the content and usage habits were across channels (mobile phone vs. computer). - To make a system useful, usability, utility and accessibility should be accounted together.

Usability studies	Formation of usability				Research methodology* (sample size)	Key usability dimensions/ constructs**	Other variables	Key findings
	User	**Task/activity**	**Technology/ system/product**	**Environment**				
Koltringer & Grechenig, 2004	N/A - Students, Univ. employees, staff, researchers & consultants	Closed-Entered text phases and alphabet multiple times on different programs	PDA (PalmOS) Input: Graffiti2 vs. Virtual Keyboard	Lab	-Experiment (12) -Survey -Interview -Device data	Error Accuracy Speed and task load (therefore efficiency)	N/A	Graffiti 2 input is slower and more error prone than with input on Virtual Keyboards, Graffiti 2 preferred (> intuitive).
Kowatsch, Maass, & Fleisch, 2009	N/A Culture: Germany	N/A - Subjects told they own a mobile device capable of identifying products with an RFID-reader & requesting product reviews after touching them with their device	N/A	N/A In-store shopping scenario on a picture	-Survey (scenario based) 116 participants	N/A	Intention to use (product reviews in general, free vs. paid), Intention to prefer a review-enabled store, Maximal amount of the review's fee	Product type → Adoption of product reviews Product review fee (-)→ Intention to prefer review enabled stores Intention to use product reviews → Intention to prefer review-enabled stores
Kurniawan, In Press	N/A >60 year olds	Open - Reviewed brochures and asked to make suggestions on preferred features.	N/A	Field	-Experiment (14) -Delphi Interviews -Focus group -Discussions -Online survey 100 respondents	N/A	Usage patterns, Problems & benefits, Desired & unwanted Features, Roles of phones, Gender	- Women focus on haptic aid and men on perceptual aid. - Older people are passive users. - Characteristics of age friendly phones: memory aids, visual aids, haptic aids, and safety features

Usability studies	Formation of usability				Research methodology* (sample size)	Key usability dimensions/ constructs**	Other variables	Key findings
	User	Task/activity	Technology/ system/product	Environment				
Langan-Fox et al., 2006	Novice	Open - Interactions with a network of services using verbal or visual information	Mobile phone	Lab	-Survey (94) -Focus group -Experiment: Text advance organizer (AO) group (32), graphic AO group (31), control group (31) -Observation	Task performance (inefficiency, proportion correct, total error) Recall performance (thus, memorability, declarative knowledge, procedural knowledge) Cognitive ability variables (verbal reasoning, associative memory)	N/A	The text AO had a facilitative effect for two of the three task performance variables. AOs' utility is highly conditional.
Lee, Cheng, & Cheng, 2007	N/A Culture: Netherlands	N/A - Before survey, provided a short introduction on what mobile transaction services, mobile banking and brokerage were, and several examples of the possibilities involved with mobile services	N/A	-Field (Street)	-Survey (375) -Random sample	N/A	Time convenience (TC), User control (UC), Service compatibility (SC), Risk (RISK), Cognitive efforts (CE), Time consciousness (TC), Value m-channel (MVAL), Perceived value electronic channel (EVAL), Perceived value retail channel (RVAL), Intention to use (INT)	TC→MVAL (positive) UC→MVAL (positive) RISK→MVAL (negative) CE→MVAL (negative) MVAL→INT (positive) RVAL→INT (negative) EVAL→INT (negative) TC x TO→MVAL (positive) RISK x TO→MVAL (positive) CE x TO→MVAL (positive)
Lehikoinen & Salminen, 2002	Novices (students/teachers/engineers)	Closed - Search tasks	Computer	Lab	-Experiment (24) -Device data	Errors	N/A	"BinScroll", a technique to navigate and search for words on mobile devices

Usability studies	Formation of usability				Research methodology* (sample size)	Key usability dimensions/ constructs**	Other variables	Key findings
	User	Task/activity	Technology/ system/product	Environment				
Li & McQueen, 2008	N/A - Four firms: Convenience store, Insurance, Manufacturing, Medical distributor	N/A - Interviewed about their m-apps (each firm implemented mobile technology for > than 1 year)	N/A	N/A	-Interview: C (three applications), D (two applications), A and B (one application)	Performance	Task, Technology (fit), Economic, IT infrastructure, and Organization (viability)	-Organizations aware of task-tech fit importance in choosing m-apps, but might not assess the viability properly. -High fit does not guarantee system success.
Li & Yeh, 2010	N/A Culture: Taiwan	Open - Information retrieval task	Device: Google G1, Services: Three virtual m-vendors with snapshots (buying digital cameras, renting a car for travel from a rental car agency, and booking a hotel)	Lab	-Experiment -Survey 200 participants	Perceived usefulness Perceived ease of use	Trust, Customization, Design aesthetics	Design aesthetics -> PU Design aesthetics -> PEOU Design aesthetics -> Customization Design aesthetics -> m-trust PU -> m-trust PEOU -> m-trust Customization -> m-trust
Liang et al., 2007	Novices-Experts Culture: Japan	Closed - CogTool (user interface evaluation tool)	Based on key layout: Group A's model for CogTool, N905i and N905iμ Group B's model: W61CA, W61H & W53H	Lab	-Experiment (within group, two mobile phone models for each group) -Observation	Task completion time (thus, efficiency), Task execution process (thus, effectiveness)	N/A	-Do not consider multiple mobile phone models with matched interaction sequences as equivalent to the same model. -Tactile key press sensation due to hardware differences between mobile phone models may impact usability.
Licoppe & Heurtin, 2001	N/A Culture: France	N/A	N/A	Lab (for 20 people)	-Survey -Interview (20) -Anonymous traffic database (1,000)	Ease of use, Accessibility	Joinability, Use of a mobile (UOM), Sociological reasons	- Price → UOM - Ergonomics → UOM - Sociological reasons → UOM

Usability studies	Formation of usability				Research methodology* (sample size)	Key usability dimensions/ constructs**	Other variables	Key findings
	User	Task/activity	Technology/ system/product	Environment				
Lin et al., 2007	Novices-Experts Culture: Austria	Closed - Six tasks to find specific information on the web-based Learning Management System	Apple's iPod Touch or iPhone, used by 15 students Nokia's N95, used by 2 students.	Lab	-Experiment -Thinking Aloud Method -Interviews 17 participants	User experience (attractiveness, perspicuity, dependability, efficiency, stimulation and novelty)	Mobile internet design principles: The fat-man-walking-no-narrow-path principle, The free-bird-on-the-fly principle, and the one-handed-bandit-on-the-run principle	The implementation of intelligent pervasive learning environments demands holistic approaches of thinking, design and testing.
Lindroth et al., 2001	Novices-Experts	Closed - Adding a person to the address book, scheduling lessons, creating a card	PDA	Lab	-Experiment -Survey -Device data (12)	Efficiency Errors Learnability Memorability Satisfaction	Weather, interaction situations	Users use device differently in different situations. More satisfaction problems than efficiency and learnability. Must test in the field, using diaries, direct observation, and ethnography.
Ling, 2001	N/A Culture - Youth - Parents	N/A - Use of text messages	N/A	N/A	-Surveys (2007 youth) (1001 parents) -Interviews (12)	N/A	N/A	Social research, no link to usability

Usability studies	Formation of usability				Research methodology* (sample size)	Key usability dimensions/ constructs**	Other variables	Key findings
	User	**Task/activity**	**Technology/ system/product**	**Environment**				
Ling, C., Hwang, & Salvendy, 2006	N/A Culture: Caucasians & Asians in US College Students	N/A - Evaluate five design features (camera, color screen, voice activated dialing, Internet browsing, and wireless connectivity) and rate satisfaction.	Users current mobile phone (8 different brands)	Lab	Survey (2,571)	Satisfaction	Features (camera, color screen, voice activated dialing, Internet browsing, wireless connectivity), Preference level of features, Gender, Ethnicity, Academic major, Mobile phone Mfgr, age, Mobile phone experience	-Phones with color screens, voice activated dialing & mobile internet received higher satisfaction scores. -Female Asians have a higher preference level on color screen. -More males own phones with cameras, Internet browsing, and wireless connectivity. Availability & Experience → Satisfaction
MacKenzie et al., 2001	N/A Students	Closed - Text Typing	PC Concepts KB-5640 numeric keypad	Lab	- Experiment (20) - Observation - Data collection through computer	Learnability Error Rate	Discovery phase (DP), Motor reflex acquisition phase (MRAP), Terminal phase (TP)	DP → high error rate (ER) MRAP → average ER TP → Low ER Learnability → ER
Mallat, 2007	Novices Culture: Africa	Closed - Capture a 2D visual tag and try to use a visual tag application to navigate visual tag-reading systems (for accessing digital library content).	Nokia 6280 camera phone with readers for the visual tags, library collections accessed online & online photographic collection. Visual tags that encode the URL for the photo album.	Lab (simulated university library)	-Experiment -Interview 20 participants (students and non-academic staff from university)	Ease of learning (thus, learnability)	Cost, Education level	The mobile tagging media in educational setting was easy to use and comments from participants showed their high interests about the tagging system. High cost of camera phones and lack of local language support were barriers to adoption.

Usability studies	Formation of usability				Research methodology* (sample size)	Key usability dimensions/ constructs**	Other variables	Key findings
	User	Task/activity	Technology/ system/product	Environment				
Mao et al., 2005	N/A Culture: Turkey and USA	N/A	Mobile phone	N/A	-Survey (273)	Ease of use Accessibility Usefulness	Price, efficacy, personal innovativeness, intention to use	For USA sample: PU →adoption, PEOU →usefulness, Efficacy→ ease of use, personal innovativeness→ PEOU For the Turkish sample: All above and PEOU→ adoption, price→adoption, personal innovativeness→usefulness, personal innovativeness→efficacy
Massey et al., 2005	N/A Job: Students	Open - View websites on two devices & rate sites on content, ease of use, made for the medium, emotion, and promotion.	HP Jonathan 568 PDA	Lab	-Experiment (76) -Survey (35) for Web Usability (41) for wireless Web Usability	Ease of use	Technology Readiness, Made-for-the-medium, Content, Emotion, Promotion	Technology readiness → Importance placed on usability characteristics Technology readiness moderates relationship site type → site ratings
Massimi & Baecker, 2008	N/A	Closed - Used stylus to tap on targets shown in various locations on the display) under 1 of the 4 mobility conditions	PDA, treadmill	-Lab -Seated -Walking -Obstacle course	-Experiment -Observation 64 Students	Error rate Task completion time Target selection time (thus, efficiency)	Mobility condition (seated and walking), Cognitive load	-Obstacle course was not the same as the walking conditions that used a treadmill. -Error rates increased when the participants walked through the obstacle course, even after they reduced their walking speed.

Usability studies	Formation of usability				Research methodology* (sample size)	Key usability dimensions/ constructs**	Other variables	Key findings
	User	Task/activity	Technology/ system/product	Environment				
Merisavo, Vesanen, Arponen, Kajalo, & Raulas, 2006	N/A Culture: China	Closed - Receive SMS mobile ads	Prototype that provided personalized advertisements to mobile users	N/A	-Survey (135) -Experiment and survey (183), (m-ad without personalization vs. m-ad with personalization)	N/A	Personalization (user preference, content, and context), Attitude toward the mobile advertisements, Willingness to utilize the m-advertisements	-The most important factor influencing personalization was the context factor, followed by user preference and content. -Personalized mobile ads were effective & can influence users' consumption behavior.
Nagata, 2003	Experts	Closed - Responded to the phone call, intercom message, or IM notification	PDA, desktop	Lab	-Experiment -Survey -Interview -Device data (8) -Age (25-54)	Efficiency Errors	Anticipation & origin (external & internal) Interruption (unexpected external & internal, expected external & internal)	Sig. difference between the ODA and desktop groups: origin→ Efficiency, anticipation→ Efficiency
Nielsen et al., 2006	Novice	Closed - Transmit data, register	Mobile phone (Sony Ericsson T68i)	Lab & field	-Experiment (14) -Survey (14) -Focus group	Efficiency Effectiveness Satisfaction	Problems observed	Comparison of a field-based and a lab-based usability evaluation of a mobile system
Olmsted, 2004	N/A	Closed - Collect data	Handheld devices (PDA, etc.)	Lab	-Experiment -Observation (14) -Interview (4) -Survey	Efficiency Ease of use Satisfaction Accuracy	N/A	Use of handheld devices to collect census data

Usability studies	Formation of usability				Research methodology* (sample size)	Key usability dimensions/ constructs**	Other variables	Key findings
	User	Task/activity	Technology/ system/product	Environment				
Pagani, 2004	N/A Culture: Italy and USA	N/A	Mobile phone, PDA, i-Pocket PC	Field	-Interview (56) -Focus groups (24 groups) -Phone surveys (1000) -Age: 21-28 -56 users (28 Italy, 28 USA)	Ease of use Accessibility	Mobility, availability, functions, bandwidth, cost, hardware and software functionality, privacy Motivation, degree of service innovation, interest for service, preference, ranking of service	Usefulness most important → adoption, followed by ease of use, price, and speed of use PU → Adoption PEOU → Adoption Price → Adoption Speed → Adoption
Palen & Salzman, 2002	Novices	Open - Phone calls - Explore the functionalities of the phone	Wireless Telephone (N/A)	Field Everyday life	- Experiment (19) - Observation - Interviews - Age: 16-75	Errors (software/ hardware) Ease of use Attitude Satisfaction Usefulness	Network, Geographical terrain, Interior/ exterior call, Building material, Call traffic, Phone antenna, Weather	Other Variables → EOU Other Variables → PU Other Variables → Errors Errors → Satisfaction, Attitude (underutilization)

Usability studies	Formation of usability				Research methodology* (sample size)	Key usability dimensions/ constructs**	Other variables	Key findings
	User	Task/activity	Technology/ system/product	Environment				
Palen, Salzman, & Youngs, 2001	Novices	N/A - Talk about their experience	Mobile phones	Lab	-Interview Voice mail diaries -Calling behavior data (19) -Ages: 16-75	Accessibility	Right price, Business reason, Job-related reason, Safety, Security, Social, Special event, Mobility, Net of safety /proximity, Freedom	- Right price → Adoption - Business reason → Adoption - Job-related reason → Adoption - Safety → Adoption - Security → Adoption - Social → Adoption - Special event → Adoption - Device → Increased mobility, accessibility, safety/proximity - Device→Share resource, Freedom
Poupyrev et al., 2002	N/A All male	Closed - Scroll a text list	Palm (PDA)	Lab	-Experiment -Survey	Performance (therefore efficiency)	N/A	Tactile feedback→efficiency
Pousttchi & Thurnher, 2006	Novices Job: IT service technicians	Closed - Selecting info about customers previous problems -Search a location -Search a problem solution suggestion -Reading docs	PDA, pocket PC	Lab & field	-Experiment (30) -Log files -Video capturing -Survey -Interviews	Effectiveness Ease of use Time for solving a task (therefore efficiency), Usefulness	Use of context mobility	Which tasks are suitable for mobile application support, which personnel is most likely to benefit from mobile tool support, and what improvements on business metrics are to be expected
Qiu et al., 2004	Novices-Experts	Open - Web tasks	PDA	Lab	-Experiment -Observation -Interviews (27) -Graduate students	Ease of use	Zooming, semantic, conversion, presentation, optimization	Zooming → Ease of Use Semantic Conversion → Ease of Use

Usability studies	Formation of usability				Research methodology* (sample size)	Key usability dimensions/ constructs**	Other variables	Key findings
	User	Task/activity	Technology/ system/product	Environment				
Rodden et al., 2003	Experts (computer background)	Open & Closed - 12 tasks (web browsing & search)	Pocket PC	Lab	-Experiment -Survey (24) -Age: 20-42	Efficiency	N/A	Performance between tasks and interaction between browser and task
Ross & Blasch, 2002	N/A Severe visual impairment	Closed - Cross three intersections	Wearable device	Field	-Experiment -Interview -Device data (15) -Age: 62-80	Error Efficiency	Hesitations, Confusion episodes, Preference	interface→ veering performance, less hesitation, need to improve interfaces to increase performance (time/less veer)
Roto et al., 2006	Novices-Experts Divided into two groups of similar age, background and cell phone internet use	Open - Used Minimap browser first and then switched to narrow layout browser after 8 days to complete given tasks.	Nokia 6600 phone	Lab & field	-Lab study (8) -Field study (20) Longitudinal Usability Study (20) -Diary -Group discussion -Survey	Ease of use Learnability	Preference	-Most preferred Minimap: easier to use, pages looked more familiar -Minimap better on pages with big data tables or simple layouts -Neither browser suitable in a hurry -Familiar pages easier to browse then unfamiliar ones
Ryan & Gonsalves, 2005	Novices Culture: Australia	Closed - tasks on list on all four applications	Mobile phone (smart phone) PC web based(HTML), PC device based (AT), mobile web based (XHTML), mobile device based (AWT)	Lab	-Survey (12) -Experiment (12)	Errors Satisfaction, Learnability Efficiency (and time) Ease of use	Context awareness	Client-side processing & location context → Mobile device-based application = PC-based objective performance and subjective usability measures Mobile web-based application → lowest quantitative performance

Usability studies	Formation of usability				Research methodology* (sample size)	Key usability dimensions/ constructs**	Other variables	Key findings
	User	Task/activity	Technology/ system/product	Environment				
Seth et al., 2008	Experts Culture: Korean Job: Usability practitioners working for a mobile phone company in Korea	Closed - Taking a picture and related operations Evaluate the mobile phone using the usability tests	Two mobile phones (similar functionality)	N/A	-Experiment -Case study with 8 Practitioners -Card Sorting -Task Analysis -Meta-Review	Task based (efficiency of procedure, support of operation sequence, stability of use, cognitive burden of execution)	Indicator level: Visual support of task goals, Support of cognitive interaction, Support of efficient interaction, Functional support of user needs, Ergonomic support Critical level: LUI based (information architecture, wording, function options), PUI based (ergonomic consideration, contextual consideration), GUI based (icon, font, display style), and task-based (see left)	-Framework for evaluating the usability of mobile phones to support task-based and interface-based usability evaluation. -Hierarchical model of usability factors, four sets of checklists, a quantification method, and an evaluation process
Shami et al., 2005	N/A Job: Medical-dental students, assessors	Closed - Clinical exam (paper vs. e-checklists)	PDA	N/A	-Experiment -Device data -Survey (43)	Effectiveness Efficiency Satisfaction	Form of assessing checklists (paper, electronic)	PDA checklist→efficiency, PDA checklist→effectiveness, PDA checklist→satisfaction

Usability studies	Formation of usability				Research methodology* (sample size)	Key usability dimensions/ constructs**	Other variables	Key findings
	User	Task/activity	Technology/ system/product	Environment				
Sodnik et al., 2008	N/A	Closed - Five tasks on a mobile phone in a car simulator (write text message, make call, change profile picture, delete image, play song)	Nokia 60 Series	Lab	-Experiment (18) -Survey -Interviews -Device data	Effectiveness Efficiency (and task completion time) Satisfaction	Driving performance, Workload	-Auditory interfaces were effective to use in a mobile environment, but weren't faster than visual interface. -Using auditory interfaces increase driving performance and perceived workload.
Strom, 2001	N/A	N/A	Mobile phone, PDA, walk/disc man, camera	Field	-Interviews -Observation (7)	Attitude	Use, Social attractiveness	Use → Less social attitude
Suzuki et al., 2009	Novices-Experts Culture: Taiwan	N/A	MMS	Field	-Survey 207 respondents	Ease of use	Compatibility Triability Image Result demonstrability Voluntariness Visibility Relative advantage	-(Except for laggards) Relative advantage → MMS adoption -Compatibility also key in motivating the adopters and potential adopters -Ease of use, triability, result demonstrability, visibility, image, & voluntariness: varied effects for different categories of adopters, potential adopters, and users

Usability studies	Formation of usability				Research methodology* (sample size)	Key usability dimensions/ constructs**	Other variables	Key findings
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Svanæsa, Alsosa, & Dahla, 2010	N/A	Closed - Eight designs tested by a physician using a bedside terminal to show X-ray images to a patient (e.g., select and drag X-ray image to a terminal icon on the PDA vs. PDA as a remote control to navigate menu on the bedside terminal).	Digital Noldus video-recording solution with roof-mounted/remote control/stationary/ wireless "spy" cameras, wireless mics, audio mixer, software for remote "mirroring" of content on mobile devices, PDA, PC Patient terminal	Lab Usability lab for m-ICT in medical setting	-Experiment -Usability testing Experiment 1: Combining handheld devices & patient terminals Experiment 2: Automatic identification of patients at point of care -Interview	N/A	Graphical user interface (GUI) usability, Physical and bodily aspects of usability (screen size, body movement and the use of hands), Social aspects of usability (private vs. public, face to face dialogue), Contextual nature of usability	Ergonomic aspects: social aspects & factors related to how well the system integrates with existing work practice → usability of m-ERP
Wang et al., 2009	N/A Culture: China	Open - Used every function of the system and record any confusion & problems encountered	Software: "Mobile Learning Center, Curriculums" (from parts of the lessons from *College English Intensive Reading* of Shanghai Foreign Language Education Press) Device: PPC of Dopod CHT9000, which has a T-flash Card of 2G capacity (mobile device)	N/A	-Experiment -Survey -Interview 20 freshmen and 20 sophomores in Software Engineering	N/A	Survey: English learning tools, Curriculum content, Media types, Learning fragment duration, Function preferences, & implement mode Interview: Individual requirement, Updating information timely, Rich referential content	System design of a college English m-learning system

Usability studies	Formation of usability				Research methodology* (sample size)	Key usability dimensions/ constructs**	Other variables	Key findings
	User	Task/activity	Technology/ system/product	Environment				
Waterson et al., 2002	N/A	Closed	PDA	Lab & Field	-Experiment Lab (5) Field (5) -Observation -Device data -Survey (10)	Errors	N/A	This testing technique can more easily gather many content related issues, but device-related issues are more difficult to capture.
Wigdor & Balakrishnan, 2003	N/A	Closed - Entered short phases of text	Mobile phones	Lab	-Experiment -Device data (10)	Efficiency Errors	Text entry interface	Sig. effects for the technique Different efficiency increase for different users, error rates higher for TileText than for MultiTap
Wu & Wang, 2005	N/A Culture: Taiwan	Open - Engaged in online transactions via B2C Mobile Commerce (MC) for personal use	N/A	Lab	-Experiment (310) -Survey -Interview	Accuracy Ease of use Usefulness	Perceived risk, Cost, Compatibility, Behavioral intention to use, Actual use, Reliability	B.I. to use MC→ Actual use usefulness & risk → BI to use Cost (-) → BI to use MC 26.8% were familiar with MC Compatibility, most important effect on BI & 2nd most important effect on actual use

Usability studies	Formation of usability				Research methodology* (sample size)	Key usability dimensions/ constructs**	Other variables	Key findings
	User	Task/activity	Technology/ system/product	Environment				
Xu et al., 2008	N/A Job: Guests of the Beijing Olympics	Open - Used suite of mobile Web services and applications at Beijing Olympics	Nokia N82 mobile phone, applications used Olympics guide, Menu Reader, English-Chinese-English phrasebook, Sports Tracker, Photo sharing on Ovi, and Nokia Maps application.	Field	-Experiment -Device data -Survey 158 participants	Ease of use Helpful (thus, usefulness)	Number of times used, Continuance intention	Study suggested how usage patterns can be used to determine when to use the applications and how user activity and environment can be used to improve the applications as well as to develop personalized mobile Web applications.

Note:
* Research methodology: How (Observation, Interview, Focus group, Survey, Device data) and Where (Lab study, Field study)
** Key usability dimensions: Effectiveness, efficiency, satisfaction, ease of use, usefulness, learnability, flexibility, attitude, operability, errors, memorability, accuracy, accessibility, acceptability