How changes in context affect human behaviours and performance in mobile computing systems

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Abstract: - Many real world mobile device interactions occur in context-rich environment. Information about how users react to changes in context and perform in context-rich environments is crucial to informing strategies for mobile device design. Thus, the context of use must be considered because there are multiple tasks taking place in many mobile computing interactions. However, few empirical studies on mobile computing regarding changes in context impact users' abilities to perform effectively are conducted to date. In this investigation, context is presumed to be a set of conditions or user states that influence the ways in which a human interacts with a mobile computing device. In order to sense and record relevant contextual factors, the investigations have been conducted to enable a device to sense characteristics of mobility, such as motion and changes in environmental conditions like lighting. The result indicates that the way in which users' behaviour is affected by changes in context is not uniform.

Key-Words: - Mobile computing system, User's contextual behavior, User's performance, Mobile computing interaction, Mobility, Lighting

1 Introduction

Mobile computing is an empowering notion to many people. Different design and evaluation paradigms need to exist for mobile computing devices and environments. The context of use must be considered because there are multiple tasks taking place in many mobile computing interactions. The value that can be added by enabling access to powerful electronic devices in a portable form has yet to be fully realized, but obviously has vast potential in terms of productivity and communication for business, personal, educational, and medical purposes, just to scratch the surface. However, there is currently a large gap between the vision of mobile computing that has been created and the existing state of mobile computing, due in part to the relative youth of the field, but also to the inherent challenge of designing devices that are intended to be mobile. In many mobile computing interactions, there are multiple tasks taking place, often with the mobile task being secondary, which is why the context of use must be considered.

Even though user-centered context is understood to be important in the design and evaluation of mobile devices, and some appliance design approaches even acknowledge that contextual factors, such as ambience and attention, are crucial in device and task design, a surprising number of studies on mobile computing ignore the context of use relevant to the user.

The need for understanding and learning from the design and real use studies is supported by Brewster [1], who, after experimenting with mobile device evaluation in a somewhat realistic situation, noted "a more realistic environment can significantly change the interaction and this must be taken into account when designing and testing mobile devices". He further urges other researchers to employ more appropriate evaluation strategies, while Johnson [2] states a need for new evaluation methods that are specific to mobile computing and specifies the demands of evaluating mobile systems as one of his four problems of HCI for mobile systems.

There is commonly a trade off between mobility and usability, in particular because users' abilities are often hindered by their environment or situation. This can be viewed as the crux of the challenge of user-centered context-awareness. For example, increasing the text size may aid readability on a mobile device, but it also limits the amount of information that can be presented on a single screen and requires more scrolling to view the same amount of information. If this trade off did not exist, devices would remain in their optimal state at all times. But the optimal state for any mobile device is variable because of the wide variety of situations it is commonly used in, and is therefore context dependent.

The effect that environmental and contextual changes can have on mobile device users can be likened to the effects that physical or cognitive impairments can have on users with disabilities. For example, a blind person will typically have difficulty with an interface that was designed for use by a sighted person, like a touch screen. In the same way, a person entering text on a cell phone while walking will have difficulty doing so if the device has not been designed with consideration of a mobile user and device. The concept of situationally-induced impairments and disabilities (SIID) was introduced by Sears et al. [3] to describe some of the side-effects of working with a device in a situation that may impose constraints on the user's ability to effectively accomplish their goals. The added dimension of variable conditions of use when using a mobile device means that the user may face unpredictable, and often less-than-ideal circumstances of use.

Studies have been conducted by varying contextual conditions and recording changes in behaviour in order to sense and record relevant contextual factors. Hinckley et al. [4] added proximity, touch, and tilt sensors to a commercially available PDA in order to allow the device to record important contextual information. Schmidt et al. [5] incorporated orientation and light sensors into a PDA device and specified additional sensors that could be used to retrieve information about conditions of the physical environment, such as acceleration, sound, and temperature.

Sensors can gather information relevant to context, such as location, acceleration, lighting levels, orientation, etc. However, being able to measure and/or record contextual factors that are relevant to the user is only the beginning. With sensors, contextual information can be collected, but the critical question is what to do with that information. The domain of context-awareness is nearing a state where it is faced with an abundance of potentially relevant available data, but a deficit of knowledge of how to use it. Designers may assume that these contextual factors are important, and even intuitively design with them in mind, but what is missing is an understanding of how changes in context affect the user. In most cases, a connection has not been made between the collected data and user behaviour and performance. Bellotti and Edwards [6] provide an elegant anecdote as evidence: "a context aware application can measure temperature, but it cannot tell when a room is too hot and needs to be cooled".

In this study, Reading Comprehension task was assigned to each participant to assess a mobile device user's ability to process information because M-learning (mobile learning) is spreading out thanks to the development of mobile devices and wireless internet technology [7].

Fang [8] introduced the M-learning because it can help through the learning environment of the teachers or the teaching organizations; let the learners have projects to complete learning.

Chang [9] developed a personalized context-aware learning path planner to support individual student doing self-learning in the mobile learning environment according to his/her misconceptions and learning gains.

One of the most important aspects of context in mobile computing is mobility itself. It is variable, complex, and is highly pertinent to mobile computing. Kristoffersen and Ljungberg [10] define three types of mobility: travelling, visiting, and wandering. All three types frequently occur in novel environments. Wandering and travelling are similar, yet differentiated primarily by scale; wandering is conceived of as movement within a place whereas travelling is defined as movement between places. Visiting is the act of being in one place for a limited amount of time and then moving on to another place.

While it is intuitive that changes in mobility context affect a user's interaction with a mobile device, very little is understood about how that interaction is affected. Dunlop and Brewster [11] have cited designing for mobility as the number one challenge to mobile device HCI designers. Yet despite, or perhaps because of, this, most mobile products are evaluated with users in static, highly controlled environments.

In addition to mobility, many other factors are relevant to a user who is interacting with a mobile device. In particular, the combination of mobility and other contextual factors is of interest, as multiple limiting factors are commonly present when the user is moving, such as excess noise, inadequate lighting, stress, inclement weather conditions, as well as changing tasks. One of the most common changing environmental conditions is lighting level. Changes in lighting are frequently encountered by mobile users, especially as they move from indoors to outdoors, but also as they move from room to room within a building or sun to shade while outside. Because information provided by mobile computing devices is almost exclusively visual, any condition that interferes with the visual salience of information displayed is important to examine. This factor is also listed as an important contextual identifier by Bristow et al. [12].

A few recent studies have looked at the context of mobility explicitly, examining either how motion affects the evaluation of mobile computing devices [13,14] or how motion affects performance [15]. Additionally, Pascoe et al. [16] considered device requirements for mobile field workers.

The study described in this paper attempts to build upon this previous work as well as contribute a new level of rigor to the investigation of behaviour in contextually rich environments, enabling deeper discovery of the specific effects of context on mobile device users. Ideally, this investigation will serve to show the benefits that can be obtained by investigating mobile devices in realistic contexts and convince other researchers to consider more realistic contexts during design and evaluation.

2 Methodology

2.1 Study objectives

In this study, two specific contextual factors (motion, and lighting level) were manipulated in order to determine their relative effects on performance of mobile device users. While there has been abundant discussion of strategies for adapting mobile devices to changes in context, the degree to which changes in context impact a user's ability to perform effectively are relatively unknown. Therefore, a clearer understanding of the effects of some of these changes in context on the user can help designers of context-aware tools better focus their efforts, and prioritize their context-sensing projects. The contextual factors studied here are intended to be representative of a subset of particularly relevant aspects of context, but are by no means exhaustive. The goal is to establish a foundation by which the effects of context can begin to be more clearly understood.

2.2 Participants

One hundred and fifty participants were asked to perform a set of tasks on a mobile device while sitting, or free walking along a path around a room. Data from a subset of the participants, those who performed the tasks while sitting ("sitting group") or while walking around the room ("walking group"), are examined in this paper.

The participants considered in the present study (*N*=90) volunteered over the course of one semester from Seoul high school. The participants were primarily juniors and seniors. Basic demographic characteristics were recorded for each participant. These demographic factors between groups are summarized in Table 1.

Group	Sitting (*N*=45)	Walking (*N*=45)
Age	18.1	18.2
Gender	Male=25; Female=20	Male=24; Female=21
Dominant hand	Right=39; Left=3	Right=37; Left=1
Computer use frequency	>1/day=43; ≈ 1/day=2; <1/day=0	>1/day=42; ≈ 1/day=3; <1/day=0
Cell phone owner?	Current=20; Previous=6; Never=19	Current=18; Previous=8; Never=19
Regularly read while walking?	Yes=18; No=27	Yes=16; No=29

Table 1 Demographic comparisons between groups

The experimental tasks were performed on a cell phone, however the tasks were designed such that prior experience with handheld devices was not required, as training was provided for each task and minimal input was needed to accomplish the goals of the tasks.

Each participant was randomly assigned to one of two groups: those who would be performing the tasks on a cell phone while sitting, and those who would be performing the same tasks on a cell phone while walking around a path with obstacles within an observation room.

The two groups were found to be statistically similar in all demographic characteristics.

2.3 Experimental tasks and conditions

Each participant performed the task in each of the two lighting conditions. Participants in the sitting group performed the task while sitting at a table, while participants in the walking group performed the task while walking along a path that contained obstacles.

There was one task used in this study: Reading Comprehension. These were each separate activities with separate goals and instructions.

For the task, participants performed two scenarios; a scenario was a combination of a task and lighting condition. Overall, there were two scenarios used: (1) Reading Comprehension + High-Light; (2) Reading Comprehension + Low-Light; Each scenario consisted of ten trials.

2.3.1 Lighting level

The light level in the observation room was used as a within-subjects variable with two levels. The room that was used for both sitting and walking conditions contained nine sets of overhead fluorescent lights, each with three bulbs. In the High-Light condition all 30 bulbs were illuminated, resulting in an intensity of approximately 270 lux; in the Low-Light condition only the middle bulb for each of the nine sets of lights was turned on, reducing the lighting to an average of 90 lux. For all tasks, the cell phone backlight was turned off. The order in which each lighting condition occurred was randomized for each participant.

2.3.2 Task 1: Reading Comprehension

In order to assess a mobile device user's ability to process information at a relatively deep level, a Reading Comprehension task was assigned to each participant. Given the widespread availability of eBooks [17] and other text document viewers for cell phones, reading comprehension was presumed to be of interest in the domain of mobile computing. The task involved reading paragraphs composed of fictional stories three to five sentences long and answering two multiple choice questions for each paragraph. The questions were taken from a book of standardized reading comprehension questions [18]. The tasks of reading and answering the multiple-choice questions were both carried out using a cell phone. A Samsung Anycall cell phone was used throughout the study for all participants. Participants read through five reading passages, each followed by two multiple choice questions in each of the two lighting conditions, for a total of ten passages of text and 20 questions. The same ten passages and 20 questions were used for all participants, but the order in which they were presented was randomized. Some scrolling was required for most of the reading passages and some of the multiple-choice questions, which could be done using either the up and down physical buttons on the device or by tapping small arrows on the screen with the stylus.

After participants finished reading a text passage they pressed a button at the bottom of the screen labelled "Done", which took them to the first of two questions about the passage they had just read. Participants were not allowed to go back to the passage once they had pressed the "Done" button and were therefore instructed not to move onto the questions until they felt they had sufficient understanding of the content of the passages. Once on a question screen, participants would see the question followed by four radio buttons next to four answer choices. A "Submit" button was at the very bottom of the screen and was used to submit the participant's choice once they had selected an answer from the list. On the first multiple choice screen the "Submit" button would take the participant to a screen with the next question and answer choices, which would then take the participant directly to the next passage of text to read or to a screen which read "Task Finished" if it was the last question in the task.

2.3.3 Condition 1: sitting

Participants assigned to the sitting group performed the task in both lighting conditions while sitting at a table in the observation room. They were provided with no specific instructions as to how to sit or whether or not to touch the table, only that they could not perform the task with the cell phone resting flat on the table.

2.3.4 Condition 2: walking

Participants assigned to the walking group performed the task while walking around a 1-ft wide path that had been taped to a carpeted floor. The path was a loop that wound around tables and chairs in the room, such that users could make multiple laps during a single task scenario. The initial direction that the participants walked along the path was randomly chosen, and then alternated for the remaining three task scenarios of the experiment. The room was approximately 35 ft wide by 35 ft long.

Participants were instructed to keep both feet within the tape on either side of the path and informed that the number of times that they stepped on the tape would be recorded by the experimenter during the task. The number of full and partial laps that participants completed during the task scenario was also recorded by the experimenter, which was converted to distance (in feet) afterwards. There was no restriction on walking speed placed on the participants, only that they needed to keep moving.

2.3.5 Experimental apparatus

In addition to Samsung Anycall cell phone, several other tools were used in this study. In order to better understand the differences in motion experienced by participants in each group, a triaxial accelerometer [19] was attached to the back of the cell phone throughout the experiment. Accelerometer data (*X*, *Y*, *Z*, and "Net", the vector sum of *X*, *Y*, and *Z*) were recorded after each task scenario, resulting in four separate records of acceleration for each participant. Additionally, a laptop computer was used to administer background and post-task surveys to the participants in addition to the NASA-TLX subjective workload assessment [20], which was administered after each of the four task scenarios.

2.4 Procedure

Before the experiment began, participants were given an introduction to the NASA-TLX workload assessment that was to be used in the study and given an opportunity to ask any questions about the meanings of the terms that were used. If the participant had been assigned to the walking condition, the next step was to determine a representative walking speed of that participant by having them walk two laps (one lap in each direction) around the path in the observation room. This was done in order to familiarize the participant with the path, as well as to establish a baseline walking speed to assess how much of an effect performing the task on a cell phone had on their walking speed. Apart from this step, the procedures for participants in the sitting and walking groups were nearly identical.

Participants were given a verbal description of the task they would be performing on Reading Comprehension, accompanied by text instructions on the cell phone and then given a chance to perform practice trials. In the reading comprehension, this consisted of one passage of text, followed by one multiple-choice question. Practice trials were only given before the first scenario within the task. In the walking condition, participants performed the practice trials while walking around the taped path. Once participants verbally stated that they were comfortable with the task, the lighting level was adjusted to the scenarios at hand, and participants were instructed to begin the recorded trials.

Upon completion of the trials, participants filled out the NASA-TLX workload assessment. The lighting level was then adjusted to High-Light if the first scenario had been Low-Light or vice-versa. Participants then began the next set of trials for the same task. The NASA-TLX was then administered again, which completed the first task. Participants were then introduced to the next task and given practice trials before beginning. After the task had been completed, participants filled out a post-task questionnaire that asked them to indicate the degree to which the various factors in the study contributed to the difficulty of the task.

2.5 Experimental measures

Table 2 describes the measures that were recorded during the experiment. Note that for the Reading Comprehension task, the task time was divided into two separate measures. This was done in order to separate the time required to understand and encode the information in the passage (reading time) from the time required to query and recall the information that had been processed during reading (response time). The data from measures only available in walking condition were not included because they cannot be used in comparing sitting and walking conditions.

Task	Measure	Description
Reading Comprehension	Reading time	Average duration covering the time from when the text passage was displayed until the "Done" button was pressed
	Response time	Average time from when the answer screen was

Task	Measure	Description
		displayed until the "Submit" button was pressed
	Scrolls	The average number of times a scroll arrow was pressed, either using an on-screen arrow or a physical arrow button on the device
	Score	The number of correct answers selected (out of 10)
	TLX	The overall TLX subjective workload score (between 0 and 100)
	Acceleration	Acceleration in the *X*, *Y*, and *Z* planes as well as the net acceleration, sampled at 7 Hz
Walking condition only	Baseline walking speed, number of complete and partial laps during each scenario, number of times participant stepped on the tape during each scenario, shoe size of participant	

Table 2 Measures collected during the experiment

2.6 Hypotheses

Since very little previous empirical work has been done investigating the specific effects of task type, motion, and lighting, hypotheses were generated with a broad stroke, presuming that the contextual factors would affect the task and all experimental measures similarly. Casual observation dictated that the effects of motion would be greater than changes in lighting, in general. Therefore, the hypotheses for this study were as follows:

Hypothesis 1 For the *Reading Comprehension* task, the effect of *motion* will yield *strongly significant* differences for all experimental measures.

Hypothesis 2 For the *Reading Comprehension* task, the effect of changes in *lighting* will yield *significant* differences for all experimental measures.

3. Results

In order to facilitate a more in-depth discussion, differences between conditions will be divided into three categories:

Category	*p* value	Description
Not significant	$p>0.05$	The conditions are considered to be equivalent in their effect on the dependent variable
Significant	$0.01<p\leq 0.05$	Differences between conditions are very likely
Strongly significant	$p\leq 0.01$	Differences between conditions are almost certain

Table 3 Differences between conditions

These categories will be designated by * (significant) or ** (strongly significant) in Tables 4,5.

3.1 Task 1: Reading Comprehension

After the data had been collected, correlation tests were run in order to determine if any of the participant demographic factors had possibly influenced the observed values of the experimental measures. Four out of the five experimental measures in the Reading Comprehension task exhibited a high degree of correlation between several demographic characteristics and the observed results. The following factors had a noticeably high degree of correlation with one or more of the experimental measures: *age, dominant hand, and response to "do you regularly read books or other printed text while walking?"* As a result of the relatively large number of demographic factors that likely had influence on the recorded measures, a repeated-measures analysis of covariance (ANCOVA) statistical analysis was used to investigate differences between the independent variables. ANCOVA has the advantage that it is able to disentangle the effects of the independent variables (in this case lighting and motion) from the effects of covariates by including them in the regression model. Each response is therefore decomposed into three parts: that which can be explained by the independent variables alone, that which can be explained by any covariates, and that which cannot be explained by either of the above two (the error). This results in the comparison of responses that have been adjusted in magnitude to account for the effects of the covariates. ANCOVA is also robust to uncertainty about the presence of significant correlation between potential covariates and response variables, so long as there is no dependence between the treatment conditions and the covariates (which holds in this case because participants were randomly assigned to groups).

Participant responses to the NASA-TLX workload assessment were not shown to be significantly correlated with the recorded demographics and were therefore analyzed using a standard ANOVA technique, after verifying that the data met the required assumptions for the test.

3.1.1 Motion

The mean adjusted values for the two between-subjects (motion) conditions as well as the results of statistical comparisons are listed in Table 4. TLX scores are unadjusted because they were not shown to be correlated with participant demographics. All times are in milliseconds.

Measure	Condition	Mean	Standard error	*F*	*p*
Reading time (ms)	Sitting	27,352	1,155	4.748	0.035*
	Walking	31,151	1,220		
Response time (ms)	Sitting	18,372	598	0.390	0.539
	Walking	18,958	625		
Score	Sitting	8.50	0.19	8.610	0.004**
	Walking	7.58	0.20		
Scrolls	Sitting	14.15	0.53	0.306	0.585
	Walking	13.60	0.55		
TLX[a]	Sitting	59.12	1.98	12.100	0.001**
	Walking	68.81	2.07		

An asterisk (“*”) and double asterisks (“**”) denote significant and strongly significant, respectively

[a]These values are the raw means and have not been adjusted for the presence of covariates

Table 4 Adjusted values for experimental measures between motion conditions

3.1.2 Lighting

The same data were analyzed to look at the differences in performance (in both conditions) between the High-Light and Low-Light scenarios. The mean adjusted values for the within-subjects (lighting) conditions are listed in Table 5, along with the results of the statistical analyses.

Measure	Condition	Mean	Standard error	*F*	*p*
Reading time (ms)	High-Light	29,352	890	1.054	0.309
	Low-Light	29,001	931		
Response time (ms)	High-Light	17,628	489	3.985	0.050*
	Low-Light	18,518	449		
Score	High-Light	7.95	0.18	0.128	0.724
	Low-Light	8.00	0.16		
Scrolls	High-Light	13.35	0.48	4.246	0.044*
	Low-Light	14.68	0.51		
TLX[a]	High-Light	60.19	1.64	4.366	0.041*
	Low-Light	63.04	1.48		

An asterisk (“*”) denotes significant

[a]These values are the raw means and have not been adjusted for the presence of covariates

Table 5 Adjusted values for experimental measures between lighting conditions

3.1.3 Motion × lighting interactions

In order for the statistical results in Tables 4 and 5 to be directly interpretable, there must be no indication of a significant interaction between the two independent variables. The results of the ANCOVA motion × lighting interaction are summarized in Table 6

In order to develop a more complete picture of the effects of the two conditions on performance, the graphs in Figs. 1,2,3,4 and 5 illustrate the change in performance as the independent variables were varied at each level. The four data points in each graph represent the adjusted values of the response variables for each of the four scenarios in the Reading Comprehension task.

Measure	Motion condition	Lighting condition	Mean	Standard Error	*F*	*p*
Reading time (ms)	Sitting	High-Light	28,102	1,269	3.246	0.077
		Low-Light	25,385	1,308		
	Walking	High-Light	29,985	1,335		
		Low-Light	30,612	1,375		
Response time (ms)	Sitting	High-Light	17,485	685	1.578	0.215
		Low-Light	17,761	629		
	Walking	High-Light	17,583	723		
		Low-Light	18,848	660		
Score	Sitting	High-Light	8.41	0.26	0.439	0.512
		Low-Light	8.52	0.23		
	Walking	High-Light	7.71	0.27		
		Low-Light	7.48	0.24		
Scrolls	Sitting	High-Light	13.64	0.65	0.022	0.887
		Low-Light	14.90	0.71		
	Walking	High-Light	13.32	0.68		
		Low-Light	14.65	0.74		
TLX	Sitting	High-Light	56.43	2.25	3.574	0.065
		Low-Light	56.71	2.00		
	Walking	High-Light	64.08	2.34		
		Low-Light	68.69	2.09		

Table 6 *F* and *p* values for the motion × lighting interactions

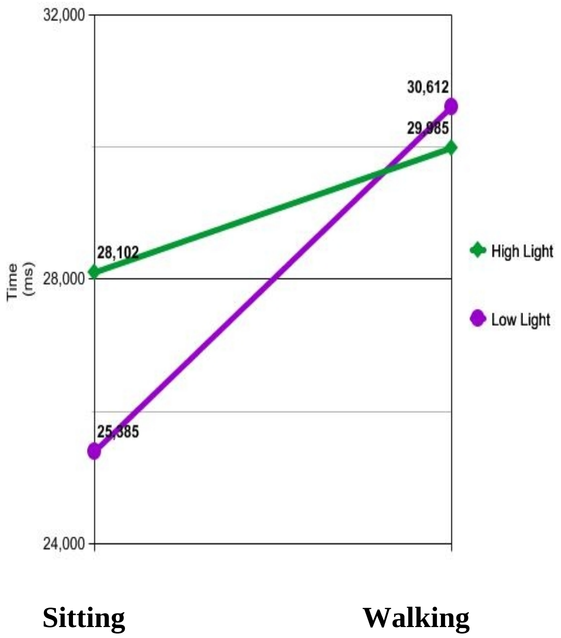
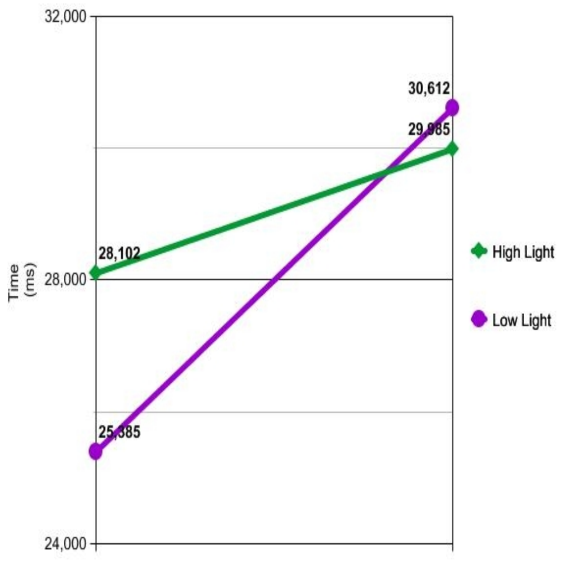
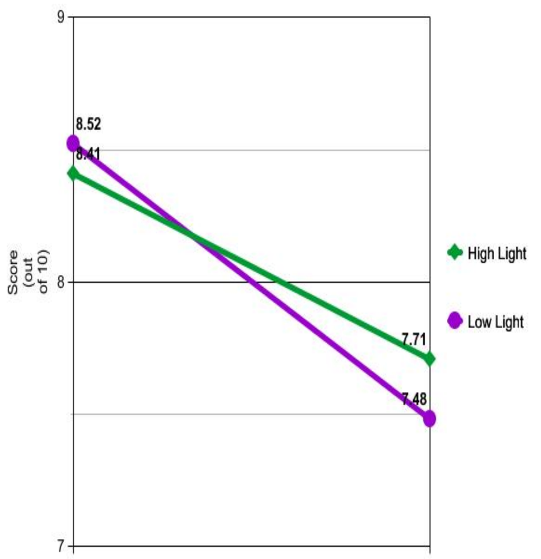


Fig. 1 Reading time motion × lighting interaction



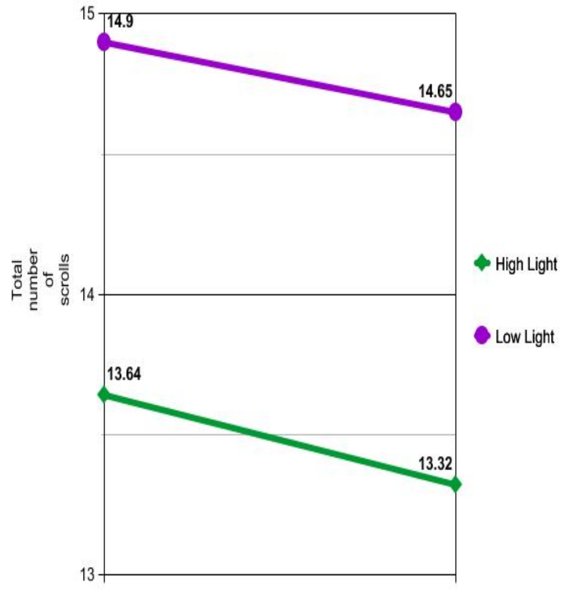
Sitting **Walking**

Fig. 2 Response time motion × lighting interaction



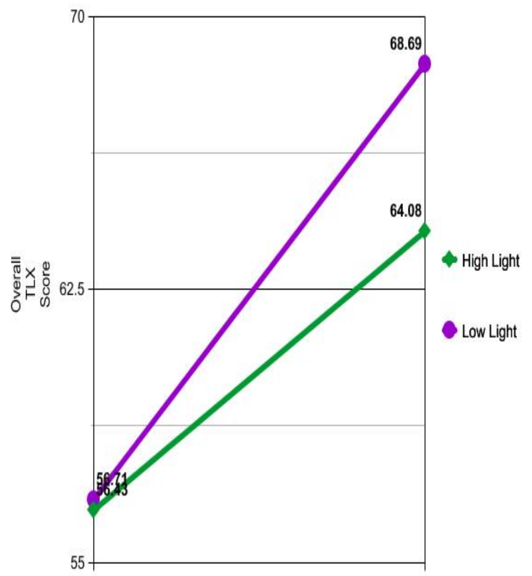
Sitting **Walking**

Fig. 3 Score motion × lighting interaction



Sitting **Walking**

Fig. 4 Scrolls motion × lighting interaction



Sitting **Walking**

Fig. 5 TLX motion × lighting interaction

4 Discussion

The results that were generated are rich with valuable information and have some degree of generalizability because the factors were carefully chosen to be representative of aspects of context encountered on a daily basis. Because context is so complex, it is important to have some degree of control when investigating its effects, therefore incremental advancements in the understanding of context may yield more benefit in the long term than attempts to quantify all effects at once.

Hypothesis 1: In the *Reading Comprehension* task, the effect of *motion* will yield *strongly significant* differences for all experimental measures.

This hypothesis was partially confirmed. Score and TLX were shown to be strongly significant (p=0.004 and 0.001, respectively) between motion conditions, while reading time was significant (p=0.035). Interestingly, response time and scrolls were clearly nonsignificant (p=0.539 and 0.585, respectively). The lack of differences in response time could reveal that users were unable to process the text passages deeply, even though they took more time on them. This could indicate more difficulty in information encoding than information retrieving. Presumably, participants would have spent more time answering the questions in the walking condition than in the sitting condition if they felt that the necessary information was available to them, but was more difficult to access. It could be the case that, even though participants spent more time reading the passages and trying to encode them in the walking condition, the process of encoding was hindered by their motion. Thus, differences in the score measure between motion conditions were caused by inefficient processing of information during the reading phase. The lack of differences in the scrolls measure could indicate that participants were not less efficient in their reading strategy during the walking condition, because they did not use the scroll buttons more frequently.

Hypothesis 2: In the *Reading Comprehension* task, the effect of changes in *lighting* will yield *significant* differences for all experimental measures.

This hypothesis was also partially confirmed. Similar to the results for the effect of motion, lighting yielded significant differences for some measures (response time, p=0.050; scrolls, p=0.044; TLX, p=0.041) and nonsignificant differences for others (reading time, p=0.309, score, p=0.724). Interestingly, the measures that showed up as significant were, with the exception of TLX, the nonsignificant measures in the motion results. This indicates that changes in lighting affected users in a fundamentally different manner than changes in motion. Apparently, lighting affected users in a slightly more superficial way, leading to decreased reading efficiency (noted by more instances of scrolling) and response selection speed, but not accuracy. It is important to note that all noteworthy differences were significant and not highly significant, indicating that the changes in motion are able to influence user behaviour in a more dramatic way than changes in lighting.

Overall, the overarching hypothesis that the independent variables would influence all experimental measures similarly was generally not supported, as some measures, for the Reading Comprehension task, were very significant, while others were quite nonsignificant. This result indicates that common contextual variations can lead to dramatic changes in behaviour. The other overarching hypothesis that users would be impacted similarly in the task was partially supported, as measures of time, score, and workload were significantly different between motion conditions. However, there were some discrepancies in the results for the lighting effects, as well as the degree of significance of the interactions. This is interesting because it indicates some effect of task type on user behaviour even when the device and scenarios are the same.

Additionally, the interactions between the contextual factors, which were not addressed in the initial hypotheses, presented some of the most interesting results. Workload interactions were nearing significance (p=0.077 and 0.065, respectively) for the Reading Comprehension task. When one considers the relatively controlled nature of this study, where most other contextual factors were held constant, the implications of this result for true real world conditions are enlightening. It should be a fairly safe assumption to conclude that the interaction effects would be even more dramatic when the number of variable contextual factors is increased, as in a typical real world mobile interaction scenario. This strongly indicates that mobile device evaluation in a static, seated, environment is likely to elicit far different behaviour from users than they would exhibit in a real world situation.

While this study only examined a small number of contextual factors, the results clearly indicate that common contextual variation (switching from sitting to walking, high light to low light,) has a clear, but diverse effect on the way in which users interact with a mobile device. Similar research looking at other contextual factors, or other levels of similar factors, would yield much needed empirically based insight into human behaviour with mobile devices and allow context to be modelled and designed for much more appropriately.

5 Conclusions

Mobile computing devices can be used in myriad environments where a desktop computer would never be found; in the hands of a standing passenger on a bus, with a doctor who is diagnosing a patient while they are being transported, as a tour guide in a museum, for example. The situational context surrounding the interaction with a mobile device by a human user can greatly influence the user's behaviour and their abilities relating to their mobile device. Even if a mobile device user is not moving, the fact that a mobile device can be taken practically anywhere dictates that it is subject to a wide variety of constraints relevant to the user. In order to overcome the challenge of designing for mobility and context-rich environments, new paradigms, such as the concept of SIID which draws analogies between the impairments generated by contextual factors and those occurring as a result of disabilities, should be investigated as well. For example, existing knowledge about effective strategies for designing for persons with disabilities can likely be leveraged to assist with designing for mobile device users.

In order for mobile computing to meet its grand expectations, it is imperative that contexts of use, particularly as they apply to the user, be considered and that mobile devices be designed with these contexts in mind. Additionally, this study has indicated that creating contextually rich scenarios for mobile device evaluation is not excessively complicated, primarily because context is all around us. And, with the ever-increasing availability of inexpensive, integrated, or compact sensors for mobile devices, measuring and modelling the effects of context is becoming less and less intimidating.

It is important that more research be conducted to investigate the ways in which changes in context impact user behaviour because, as this study has shown, context does not affect people in a uniform way. Beyond that, people have a choice as to how they react in context-rich environments, and their behaviour is often dictated by their own priorities as well as their abilities. The way in which users allocate available cognitive and physical resources when using mobile devices is very important. Users may be able to maintain adequate performance levels on a mobile device, but the expense may be too costly in certain situations. When available attentional resources are scarce, such as when driving or performing other safety-critical, focused tasks, or in time-sensitive situations, consideration of context and the way people manage multiple task demands is especially important. Context cannot be defined by independently considering specific contextual components and adding them together. Context is, by nature, a multifaceted construct, and the ways in which contextual factors interact, combine, and consolidate need to be studied further by both researchers and practitioners.

The results of this project indicate that context is a rich, nuanced, and variable condition. I believe that context is relevant and applicable in almost every situation and that investigations of context will be fruitful in any domain where a user has a specific goal that they are working toward, yet has multiple variables vying for their attention. These investigations should be catered to the domain being studied and should be designed to mirror realistic situations as closely as possible, while still retaining experimental control.

Variable levels of noise may prove worthy of investigation, especially in the context of speech-based interactions. Extensive research has focused on improving speech recognition algorithms, making them more robust in the context of noise, and on developing hardware-based solutions such as noise cancelling microphones. However, little has been reported with regard to user interactions with speech-based solutions under realistic conditions that include variable levels of noise. Ultimately, effective solutions to the challenges introduced by varying context will require a combination of hardware (e.g., noise cancelling microphones), software (e.g., algorithms to stabilize stylus inputs when users are on the move), and careful design.

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