Mobile distractions that affect usability but not performance, and vice versa

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ABSTRACT
Mobile HCI is at a very exciting time. Mobile devices are using state of the art technology to become powerful computers as well as handheld communication devices. This not only presents fantastic opportunities, it also presents many issues that must be overcome. Specifically as mobile devices become more powerful, more complex applications are being run on them in more distracting environments.

This paper explores the nature of these issues and presents an experiment that shows that there are two types of distractions that a mobile user can experience. One such distraction can affect usability and not performance, and the other type of distraction can affect performance and not usability. Finally these distractions are discussed and this paper concludes with a reinforced argument for a cognitive load aware system.

Author Keywords
Mobile Usability; Mobile HCI; Cognitive Load Theory; Cognitive Science.

ACM Classification Keywords
H.5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous.

General Terms
Human Factors; Design; Measurement.

INTRODUCTION

Mobile devices are challenging HCI in many new and unexpected ways. Many of these challenges can be seen to stem from two main aspects:

Firstly, mobile devices are becoming powerful and this is allowing increasingly complex software to be used on them.

S*econdly,* mobile devices are being used in far more complex environments.

Examples of these phenomena can be seen, for example, in mobile learning software, where one of the main issues facing the usability of these types of applications was suggested to be cognitive load [1].

Cognitive Load Theory explains how the human mind interacts with instructional materials for learning and has several guidelines that are used to assist in the design of instructional material used for learning [2]. Cognitive Load Theory is highly relevant to all aspects of HCI but is especially relevant to Mobile HCI due to the nature of differing environments that a mobile device is used in.

This paper will present the results of an experiment (the final experiment of a series of five) which investigates the relationship between Cognitive Load Theory and Mobile HCI. This experiment suggests that there are two different types of distraction which uniquely affect performance and usability separately.

LITERATURE REVIEW

Usability is defined by the ISO as "*the effectiveness, efficiency and satisfaction with which specified users can achieve specified goals in particular environments.*" [4]. A usable system should be easy to use (utility) and easy to learn (learnability) [3].

In recent years the notion of 'ease of use' has been applied to Usability where the general philosophy is based on making things 'easy' for the user. This approach stemmed from work done by Miller [5] which determined that human cognitive resources were limited. Miller's work led, in part, to the development of Cognitive Load Theory.

Cognitive Load is the demand for mental resources associated with processing information in working memory. HCI attempts to reduce the inputs that humans had to process; making things easier (less Cognitive Load) meant making things more effective, efficient and satisfying to use. Research [2, 6, 7, 8, 9] suggests that our Cognitive Load can and will vary depending on the characteristics of the task and those of the user.

Cognitive Load Theory was developed primarily as a theory for learning, specifically to help understand problem solving [6, 8, 10].

Previous research [12] suggested that there were many unconsidered extraneous distractions that a mobile user would face and presented a model of these distractions.

They suggested that distractions can occur from 1) the content itself 2) the application 3) the system software 4) the device hardware and 5) the greater environment (Figure 1, below).

By combining several methods of balancing Cognitive Load [2, 13, 14, 15] instructional designers can ensure that the learner's Cognitive Load is at the suitable level with regard to the content only. HCI must then consider how to ensure the correct Cognitive Load is portrayed based on the application, system, device and environment.

These new concerns demand that efforts be made to understand how these distractions affect the usability of mobile devices.

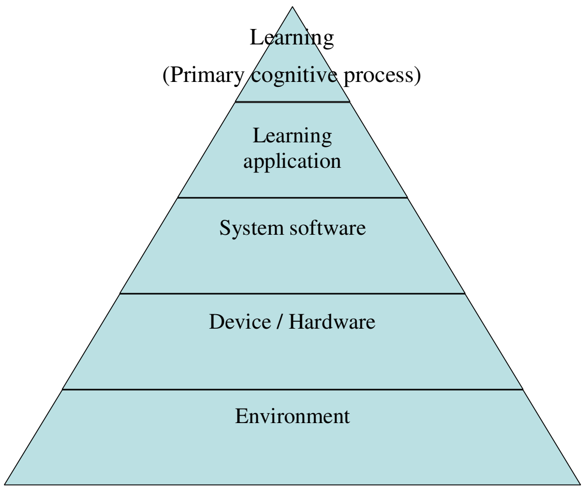

Figure 1 Sources of Cognitive Load

EXPERIMENT

This experiment builds on four previous experiments [21, 22, 23] and attempts to find an observable link between distraction and performance. Previous work [23] found that distraction had an effect on usability but there was no apparent effect on performance.

This experiment will build on that experiment by increasing the distraction to see if performance can become affected. As such the hypotheses for this experiment were similar to previous work.

H1: There is a significant effect of distraction on performance.

H2: There is a significant effect of distraction on Usability.

The experiment will be explained in more detail below.

Method

Participants

129 participants were recruited from the online site Mechanical Turk[1]. Several recent studies have found Mechanical Turk to be a valid source of participant recruitment for behavioral and user studies [cf. 16, 17, 18, 19]. Some studies suggest that the representative demographic characteristics of Mechanical Turk may be at least as diverse as, and more representative, than traditional college or online based recruitments [16, 17].

Each participant was paid approximately $0.25 to complete the task which took approximately 5 minutes. Each participant agreed to give their consent to this experiment and were given a one page briefing before the experiment took place.

Materials

Participants were expected to have a home computer and access to broadband in order to sign up to the experiment. After this stage the participants were expected to have a mobile phone/device capable of displaying web pages. The application was written in HTML, CSS, PHP and SQL and, as such, was not native to any particular device. The following devices were used: Android (59), iPhone (42), Symbian (16), iPod (7), Windows phone (4), Blackberry (1). The learning task was a series of 10 mathematical problems in which the participant needed to add or subtract three "two" digit numbers. The answer would always be two digits and fall between 25 and 90.

Procedure

A primary distraction was inflicted on all the participants as they completed this experiment. This distraction was designed to bring the participant close to a state of cognitive overload. There were two levels to this distraction, easy (low Cognitive Load) and hard (high Cognitive Load). Referring back to Miller's work [5], it was decided that the distraction would be a memory task which ran simultaneously to the learning task. The actual distraction was unimportant (for this experiment at least) as long as it inflicted a similar cognitive load on the participants. The distraction required the learners to remember how many apples are displayed at the top of various pages throughout the primary task of completing the mathematical calculations (see figure 2, an example of the first task with a low cognitive load distraction).

The low cognitive load distraction was to remember seven apples over the ten mathematical tasks and the high cognitive load distraction was to remember seventy apples over the ten mathematical tasks.

1 http://www.mturk.com/

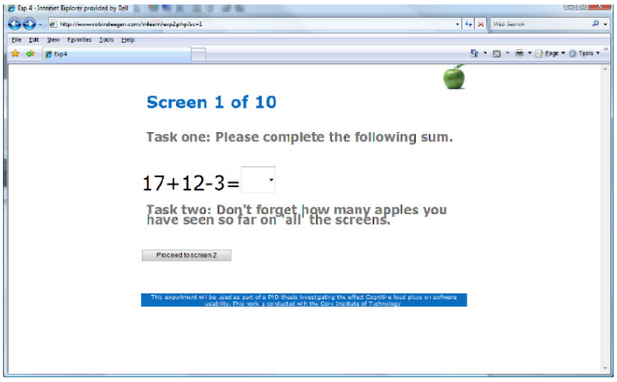

Figure 2. Example of the mathematical task and distraction

Approximately half of the group would then be exposed to a secondary and more difficult distraction in addition to the primary distraction. This distraction is designed to bring the participant to a complete stop e.g. a state of cognitive overload. It was predicted that all of the participant's cognitive resources, at that point, will go towards dealing with this distraction.

This more difficult secondary distraction took place in the middle of the primary task and it effectively '*paused*' the primary task. The secondary distraction was a challenging puzzle displayed below (figure 3). The participant had to count the correct number of triangles (including combinations of triangles) present within one large triangle. When they reached a decision (e.g. dealt with the distraction) they resumed the primary task.

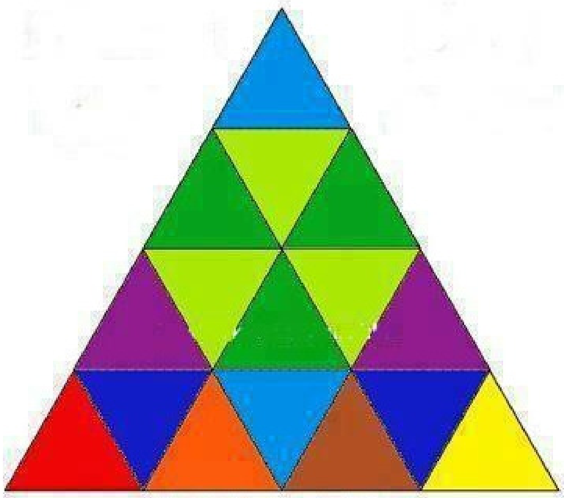

Figure 3. Example of the secondary puzzle distraction

Each participant was randomly assigned to one of four conditions automatically, by the software, a) Easy primary distraction, no secondary distraction (n=30) b) Hard primary distraction, no secondary distraction (n=32) c) Easy primary distraction, with secondary distraction (n=38) d) Hard primary distraction, with secondary distraction (29).

Performance was measured by calculating the accuracy of the primary task. Cognitive load was measured by self report methods using a 9 point likert scale developed by Paas [11]. This scale is widely accepted as being an accurate measure of cognitive load [2]. Cognitive load measurements for primary task, primary distraction and interface (e.g. usability) were taken.

Results

As stated, the analysis focused on the cognitive load, expressed as mental effort, and performance associated with the mathematical learning task and the mental effort associated with the primary distraction (e.g. remembering the apples) and using the interface.

The number of distractions and difficulty of the primary distraction level were the independent variables with two levels each, respectively. The dependent variables were the primary task performance, the primary task cognitive load, the primary distraction cognitive load and the cognitive load associated with the interface/usability. The data was normally distributed and assumptions of variance-covariance were met. As such a two way MANOVA was used to analyze the data.

Using Pillai's trace, there was no combined effect of number of distractions and primary distraction level on performance or cognitive loads $V=0.08$, $F(4,122)=0.236$, $p=0.92$, η^2 (partial eta squared)$=0.00$, observed power of 0.10. Excluding the difficulty of the primary distraction there was also no effect of number of distractions on performance or cognitive loads $V=0.06$, $F(4,122)=2.02$, $p=0.09$, $\eta^2=0.06$, observed power of 0.59. Furthermore, excluding the number of distractions there was an observed effect of difficulty of primary distraction on the performance and cognitive load $V=0.20$, $F(4,122)=7.81$, $p=0.00$, $\eta^2=0.20$, observed power of 0.99.

Follow up contrast and univariate analysis revealed that level of difficulty had a significant effect on the primary distraction related cognitive load rating ($F(1,125)=29.51$, $p=0.00$, $\eta^2=0.19$) and interface related cognitive load rating ($F(1,125)=6.98$, $p=0.01$, $\eta^2=0.05$). Also, the number of distractions had a significant effect on the performance of the primary task ($F(1,125)=6.97$, $p=0.01$, $\eta^2=0.05$).

Discussion

It is immediately apparent that there does not appear to be any significant relationship between the severity of the primary distraction and number of distractions on the performance or cognitive load results. This is slightly surprising as it was assumed that a series of distractions would be combined as one 'source' of distraction. This does not appear to be the case. Delving deeper into the analysis can begin to explain why this may be the case.

Varying levels of distraction difficulty

Initially the level of distraction was observed to have a significant effect on the dependant variables.

Contrasts revealed that this effect occurred on the primary distraction related cognitive load rating and the interface related cognitive load rating. It is obvious that any distraction is going to have a certain portion of cognitive resources directed to dealing with that distraction, and likewise it is clear that when this distraction's difficulty is increased the portion of cognitive resources dealing with this distraction increases also. To that end the increase in cognitive load ratings associated with this distraction was expected (Figure 4).

However, it was unusual that the cognitive load rating for the interface also significantly changed with the increase in distraction difficulty (Figure 5).

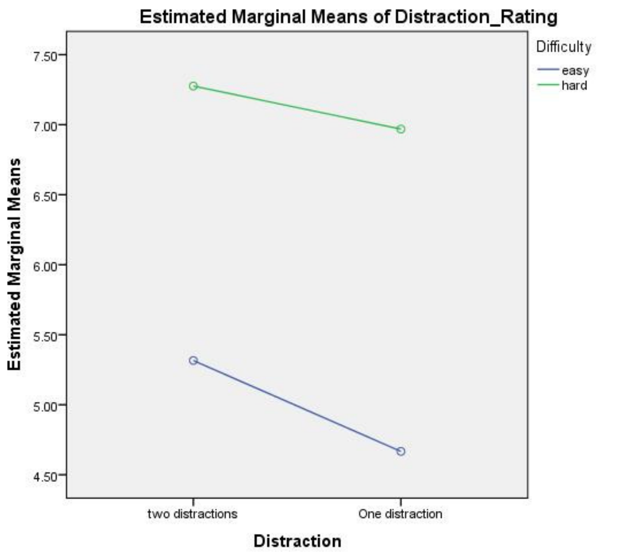

Figure 4. Cognitive load ratings of the primary distraction

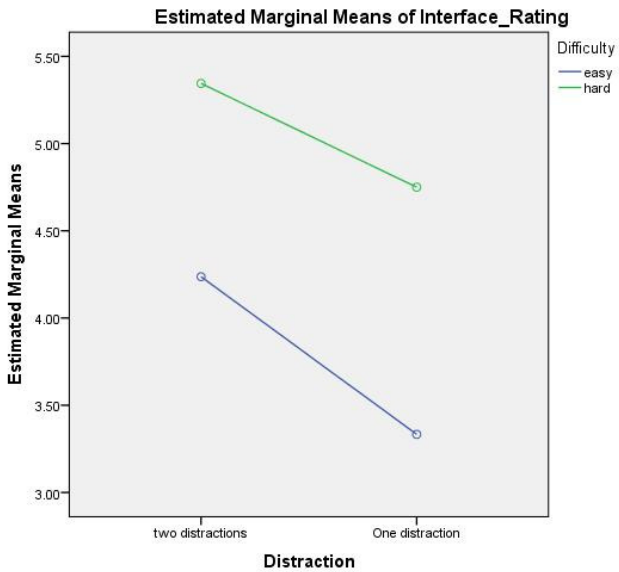

Figure 5. Cognitive load ratings of the interface / perceived Usability

What the below graphs demonstrate is that when the primary distraction became difficult so did the users perceived difficulty associated with the interface e.g. the usability became more difficult.

This phenomenon was not unexpected, as it was repeated in an earlier experiment [23]. It appears that participants felt that they needed more mental effort to deal with the interface when the difficulty of the primary distraction increased. At the same time there was no significant effect on the task performance or task rating of Cognitive Load associated with the performance, again noted in previous work [23].

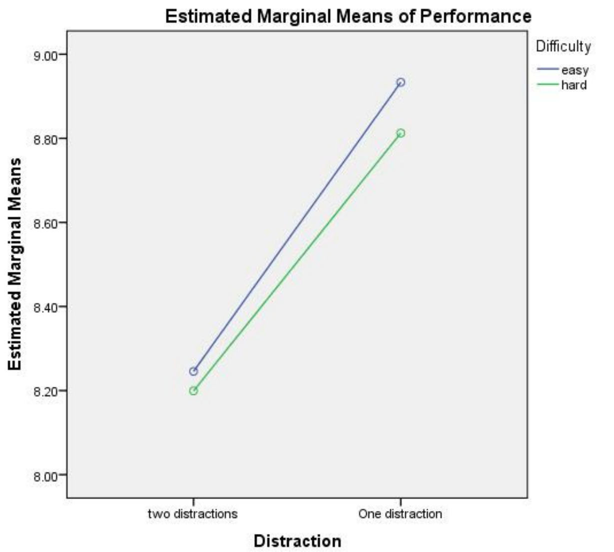

Figure 6. Performance of the primary task

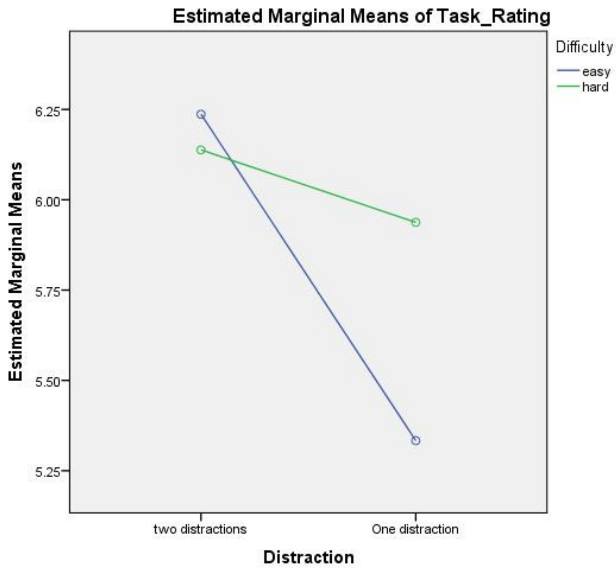

Figure 7. Cognitive Load ratings of the primary task

Varying the number of distractions

A significant difference was observed between participants who experienced the solitary primary distraction and the participants who experienced both distractions. The participants who experienced both distractions displayed a noticeable drop in performance in the primary task (figure 6).

However, the participants did not apparently '*feel*' this drop in performance e.g. they did not rate a difference in related Cognitive Load (figure 7). However it does appear that while a difference was noticed between the levels of difficulty of the primary distraction alone, when the second distraction was added no differences were observed. This suggests that, as planned, the second distraction did in fact push the participant towards the state of cognitive overload.

Interestingly, a difference in Cognitive Load for the interface was not noted in this scenario. This in itself is surprising as it suggests that with one distraction the interface is '*felt'* to be affected, but the performance is unaffected and with two distractions the performance is '*actually'* affected but the participants do not *'feel'* affected, and neither do they *'feel'* the interface has been affected.

CONCLUSION

As with the previous experiments, this study can conclude that a distraction affects the user perceived sense of usability of the interface (H2 is accepted). This study also can conclude that adding a second more severe distraction can indeed affect the performance of the primary task (H1 is accepted).

However, these conclusions may be superficial. If one considers the nature of the distraction it is apparent that they are both slightly different.

One of the distractions occurs simultaneously with the primary task. As such, mental resources are split between the primary task, the distraction and using the interface. When this distraction's demands for cognitive resources are increased the user sacrifices the cognitive resources allocated to using the interface and re-allocates them toward the distraction. This can be considered a 'subconscious ordering' of task priorities. The user wants to maintain performance in the primary task so '*other*' cognitive resources get allocated to dealing with the distraction.

The second type of distraction results in the abrupt '*pausing'* of the primary task. In this instance performance cannot be maintained so '*all'* cognitive resources can be applied to dealing with this secondary distraction e.g. in this case the interaction or interface usability is not sacrificed. Once the distraction has been dealt with the user then resumes the primary task.

These distractions can be seen to be balanced with the primary task and using the interface and this distinction is reflective of research investigating distractions and interruptions in relation to dual tasks where differing tasks are often interleaved [cf. 25].

Of course the performance of the primary task is affected as the distraction caused the primary task to halt. There is also the likely hood that the distraction has caused a lingering effect [24] which can affect performance unbeknownst to the user. In any case the user does not seem aware of this task performance degradation, as is apparent from the cognitive load rating for performance.

Essentially, from the user's perspective, the Cognitive Loads dedicated to handling the task before and after the distraction are similar. In exactly the same manner the Cognitive Load dedicated to interacting with the software / device etc. before and after the distraction is also similar. Unfortunately the performance related to the interaction (e.g. effectively usability) was not measured so it is uncertain how the distraction affected this.

This suggests that there are (at least) two different ways that distractions can affect mobile usability, and possibly two different categories of distraction related to Mobile Usability.

The first type is when the distraction is simultaneous with the primary task. If this distraction is not enough to degrade the performance then it will most likely affect the interaction/usability.

The second type is when the distraction affects the performance of the primary task. In this instance the performance is affected and not the interaction/usability.

Understanding these types of distractions is important for mobile usability as it helps HCI to better understand the Context of Use that these mobile devices are being used in.

Specifically, as explained in the introduction, this means more powerful devices allowing more cognitively complex applications being used in more cognitively complex environments can be better designed from a usability perspective. As mobile devices become more mainstream and ubiquitous understanding this Context of Use will become more important.

Furthermore, this study adds more merit to the argument for cognitive load aware systems as presented in [22]. With this series of experiments complete, future work should attempt to justify this research with a series of scenarios designed to test the ecological validity of this theory e.g. in real life do certain distractions affect performance and certain distractions affect usability. Finally, can a Cognitive Load aware system be realised and designed to deal with these distractions.

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