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Int. J. Human-Computer Studies 58 (2003) 21–37
International Journal of Human-Computer Studies
www.elsevier.com/locate/ijhcs

Using large tables on small display devices

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Received 2 January 2002; accepted 13 September 2002
Paper accepted for publication by Associate Editor, A. Dillon

Abstract

The next evolutionary step in wireless Internet information management is to provide support for tasks, which may be collaborative and may include multiple target devices, from desktop to handheld. This means that the information architecture supports the processes of the task, recognizes group interaction, and lets users migrate seamlessly among internet-compatible devices without losing the thread of the session. If users are free to migrate amongst devices during the course of a session then intelligent transformation of data is required to exploit the screen size and input characteristics of the target appliance with minimal loss of task effectiveness.

In this paper we first review general characteristics related to the performance of users on small screens and then examine the navigation of full tables on small screens for users in multi-device scenarios. We examine the methodologies available for access to full tables in environments where the full table cannot be viewed in its entirety. In particular, we examine the situation where users are collaborating across platform and referring to the same table of data. We ask three basic questions: Does screen size affect the performance of table lookup tasks? Does a search function improve performance of table lookup based tasks on reduced screen sizes? Does including context information improve the performance of table lookup based tasks on reduced screen sizes? The answers to these questions are important as individual and intuitive responses are used by the designers of small screen interfaces for use with large tables of data. We report on the results of a user study that examines factors that may affect the use of large tables on small display devices. The use of large tables on small devices in their native state becomes important in at least two circumstances. First, when collaboration involves two or more users sharing a view of data when the individual screen sizes are different. Second, when the exact table structure replication may be critical as a user moves quickly from a larger to a smaller screen or back again mid-task. Performance is

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1071-5819/03/$ - see front matter
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measured by both effectiveness, correctness of result, and efficiency, effort to reach a result.

Keywords: Tabular data; Small screen; User performance

1. Introduction

The growth in interest in mobile devices is substantial (Clark, 1999). As wireless technology provides a more substantial backbone for mobile mail, ftp, and Internet access, users can expect an integration of mobile and fixed access for applications. Many applications, such as business, personal finances, medicine, sales, and education, are ideal scenarios for the use of different devices, both wired and wireless. Users need the flexibility of collaborating with mixed devices and individuals need the flexibility to migrate between devices in the course of a session.

Data access on the web is moving quickly past concerns with reliability and speed to concerns of usefulness and timeliness of information. The next evolutionary step in Internet information management is to provide support for tasks, which may be collaborative and may include multiple target devices, from desktop to handheld. This means that the information architecture supports the processes of the task, recognizes group interaction, and lets users migrate seamlessly among internet-compatible devices without losing the thread of the session or reducing task effectiveness.

From the user's perspective, even though a range of devices may be available, there needs to be continuity of task focus. Our approach is that the task is supported by data and the view of this data is tailored to the device rather than the task tailored to the device. This means that the task is supported in a consistent manner independent of the actual device and that the user can move (reasonably) seamlessly from one device to another in connection with that task. This transparency of device means that the software is required to track the task parameters from device to device, be knowledgeable about the device characteristics, and interpret the portal characteristics within the context of each device.

By independence of device we mean that the user is free to migrate between devices within the same session. The device and communication particulars of a given session determine the amount and type of data displayed and operations available at any given point in time.

In this work we are concerned with tasks that may range over a variety of access appliances, from desktop to wireless, in asynchronous and/or synchronous use. An earlier example, a physician's portal (Watters and Shepherd, 1999) was defined for managing information related to patient rounds, where individuals may join in the session from a desktop at the nursing station or office or from a wireless device while on rounds or in transit. All users share in the management of the data but individual access may vary dramatically based on personal preferences and the actual device in use.

The goal is to make the information apparent and the network, device and carrier transparent as far as the user is concerned. This means that users can use a variety of devices during any given session and the system will manage the continuity and transformations of data between laptop and handheld or even phone for the user. This notion of seamlessness and continuity is important in task situations where users may shift suddenly from one device to another or team members may join mid-task using a different device but where the information context and format must be *replicated* and made available in its entirety.

In particular, in this paper we report on a user study that examines three factors that may affect the display of large tables on small display devices. First, we ask "Does screen size affect the performance on tasks involving table lookup, where the table is larger than the screen?" Second, we ask "Does search function improve performance on tasks involving table lookup, where the table is larger than the display?" The use of large tables on small devices in their native state becomes important in at least two circumstances. First, when collaboration requires two or more users to work with a shared view of data when the individual screen sizes are different. Second, consistent table structure may be critical when a user moves quickly from a larger to a smaller screen or back again mid-task.

2. Device use characteristics

The simplistic approach of just presenting the same data on each device does not take into account what is known about the performance characteristics of users using data on small devices. First, studies show that screen size does have an effect on performance. A recent study by Jones et al. (1999) examined the effect of screen size on the overall metric of task performance and they found that the smaller screen size impeded both focused and less directed search task performance using web-based Reuters text data. Several factors have been identified. First, line width has been shown to effect performance more than number of lines. Duchnicky and Kolers (1983) showed that width was more important than height for comprehension of text on a screen. Reseil and Shneiderman (1987), show that smaller screen sizes result in slower reading time of programming text.

Second, studies indicate that navigational issues related to the reduced screen display area have an affect on performance as well. Accessing data on a smaller display often involves additional scrolling, which has a mixed review on user task performance. Dillon et al. (1999) showed that smaller screens result in many more page forwards and backwards interactions when subjects were asked to read and summarize text presented in a small window. Kamba et al. (1996) showed that semi-transparent navigational widgets improved performance on news reading on personal data assistant (PDA) size screens. Shneiderman (1987), however, tested completion times of tasks involving selecting hypertext links and found that the number of lines of text given (i.e. 18 or 34) did not significantly affect the time to complete the tasks.

Third, the organization of menus has an effect on performance. Han and Kwahk (1994) showed that searching through menus on single line displays is much slower than on conventional displays. It is interesting to note that this reduction in menu-based access does not affect hierarchical menus as much (Swierenga, 1990). In the Jones et al. (1999) study, they found that on smaller screens users followed shorter paths and used search facilities much more (double the rate) than users on larger screens. Not too surprisingly, small screen users used scroll right and scroll down extensively in order to read the data when browsing and searching text.

In theory, the same *content* would be available to the user no matter which device is currently in use. At a more practical level, knowing the screen and bandwidth constraints of the current device can be used intelligently, along with personal or task preferences to present appropriate data. For example, on a smaller device, in general,

- Lines of text should be short.
- Concise/abbreviated and verbose versions are generated for use as needed.
- The hierarchy of menu options or data choices is shown to reflect the aggregate view.
- Thumbnail sketches may replace full images as default with full images by request.
- Contextual information is included in each screen.
- Data in tables is filtered at source.

The challenge is to recognize these limitations and intelligently compensate by tailoring data presentation and/or navigation functionality to minimize negative performance effects resulting from trying to display more data than the screen can accommodate. There are several approaches to this problem; dump-and-scroll, tailor-made, chunking, and zooming. Dump-and-scroll is the simplest method; data is sent to the browser for display with horizontal and vertical scroll bars. On a large screen all of the data might fit while on a smaller device the user may have to scroll left, right, up, and down to view the data. The tailor-made solution is familiar to users of PDAs. The content of certain websites is tailor-made for viewing on the smaller screens, typically small volume data such as stock quotes, or calendar information. This may be done in several ways: using style or display guidelines, creating special web pages, or using specific description languages for use with certain devices, such as WML defined by WAP (Wap Forum, 2001) or the CHTML by the World Wide Web Consortium (2001). The chunking approach uses transformational rules to break up the data, based on data type (list, paragraph, table), so that the resultant display fits the target device. This approach builds on the notion of an appliance-neutral markup language, such as XML (Watters and Comeau, 2000) or UIML (Abrams et al., 1999). Such a schema separates the content from the device. In a similar manner, Gaedke et al. (1998) propose an object-oriented schema for the specification of adapted content and Abu-Hakim et al. (1996) propose cooperative agents for transformation of messages in a network of heterogeneous clients. An advantage of the chunking approach is that it permits access to a wide variety of heterogeneous devices from a common data source from which specific views are generated as needed.

The zoom techniques are more sophisticated methods that allow the visualizing of areas of large data sets by the use of focus areas. These focus areas may be standalone or may be presented within a metaphorical context. Most zoom functions allow the user to designate an area of interest and the entire screen is redrawn with a finer grained resolution of the designated zoom area. More sophisticated zoom functions, such as Table Lens, provide both focus (or zoom) and context (Rao and Card, 1994). The context is typically a metaphorical display of the entire data set using as much data reduction as needed to represent the data within the boundaries of the display device. This context is typically used as the view background. Within this coarse grained representation of the data set, a focusing component (zoom lens) is manipulated by the user to define where a fine grained resolution of a smaller area will be generated. These smaller zoom areas are generally located on the screen in a position related to where they fit in the entire data set, which stays as the background context. Systems such as Table Lens (Rao and Card, 1994) have been developed for data exploration and pattern finding in large data sets including tabular data. The ability of the user to designate focus areas within the larger context for large tables has an intuitive appeal for browsing and data exploration tasks in small displays as well as in the larger displays of these systems.

In the current research we are, however, concerned with data *lookup* in large tables rather than exploration or browsing activities. We are concerned with tabular data that cannot be distorted or chunked either because of collaboration or task constraints. At this time we are concentrating our interest on the delivery of data using simple web pages rather than supporting sophisticated applications at the client. The task-specific concern is effectiveness of lookup tasks involving large tables on small screens. For this task simple focus + content display models are likely to play a dominant role. This research addresses the basic question related to data lookups on small screens, "what do I give up data display space for?" Further research will follow up the question of fat vs. thin clients.

Tables are basic data structures in many areas, such as business, education, and medicine. There has been relatively little work done on the use of tables on small screens and so fewer guidelines for making decisions on the tradeoff of functionality and display real estate for large tables of data. Tables present at least two challenges for multi-device systems: presentation on small screens and collaboration across different sized screens. In the current work we consider viewing tables that must contain exactly the same data no matter what device is being used. This is important in those situations where a user may shift quickly from a device of one size to another, for example, from a handheld to a desktop. This is also important where more than one user is referring to data in a shared table with other users seeing the data on a different device.

3. User study on the effect of screen size for lookup tasks using large tables

A user study was performed to learn more about how to handle large tables in situations constrained both by a need to show the entire table and by a requirement to use only simple web pages. Performance is measured by both effectiveness, correctness of result, and efficiency, effort to reach a result. The first assumption we wanted to test was that performing tasks that require looking up data in large tables on small screens degrades user performance.

Hypothesis 1. Users will perform table lookups more effectively using larger screens.

Hypothesis 2. Users will perform table lookups more efficiently using larger screens.

Second, extrapolating from what has been found to help users on smaller screens when using lists and text we hypothesized that keeping a *context* of column headers and relative position within the table would increase the efficiency and effectiveness for the users in finding data in tables larger than the screen size.

Hypothesis 3. Users will perform table lookups more effectively on smaller screens when context information is presented.

Hypothesis 4. Users will perform table lookups more efficiently on smaller screens when context information is presented.

Third, extrapolating from earlier research we hypothesized that providing a search function would increase the efficiency and effectiveness for the users in finding data in tables larger than the screen size.

Hypothesis 5. Users will perform table lookups more effectively on smaller screens when a search function is available.

Hypothesis 6. Users will perform table lookups more efficiently on smaller screens when a search function is available.

Finally, we hypothesize that the benefits of the larger screen size, context, and search option will be more pronounced for a more complex table lookup task than for a simple task.

Hypothesis 7. The effects will be more pronounced for the complex task than for the simple task.

Recognizing that including contextual information and search capability necessarily removes a significant display area from the screen, the objective of the user study was to evaluate how effective each of these factors and their combination was to a user engaged in table lookup tasks. In other words, can we improve effectiveness of table lookups in large tables using these relatively simple devices and, if so, is any such improvement worth the screen space it takes away from data display?

To summarize the hypotheses. First, we test the assumption that users will perform table lookups more effectively and more efficiently using larger screens. Following that we examine whether including context information and/or the search function in the display will increase efficiency and effectiveness when using small screens for table lookup tasks. Finally, we examine whether the benefits of the larger screen size, context, and search option will be more pronounced for a more complex table lookup task than for a simple task.

To test these hypotheses we used two tasks, a simple one and a more complex one. The simple task required the user to perform a simple table lookup involving a row selection and cell selection. The more complex task required the user to perform the following sequence; row selection, cell selection, computation, remember or note, row selection, cell selection, and final computation.

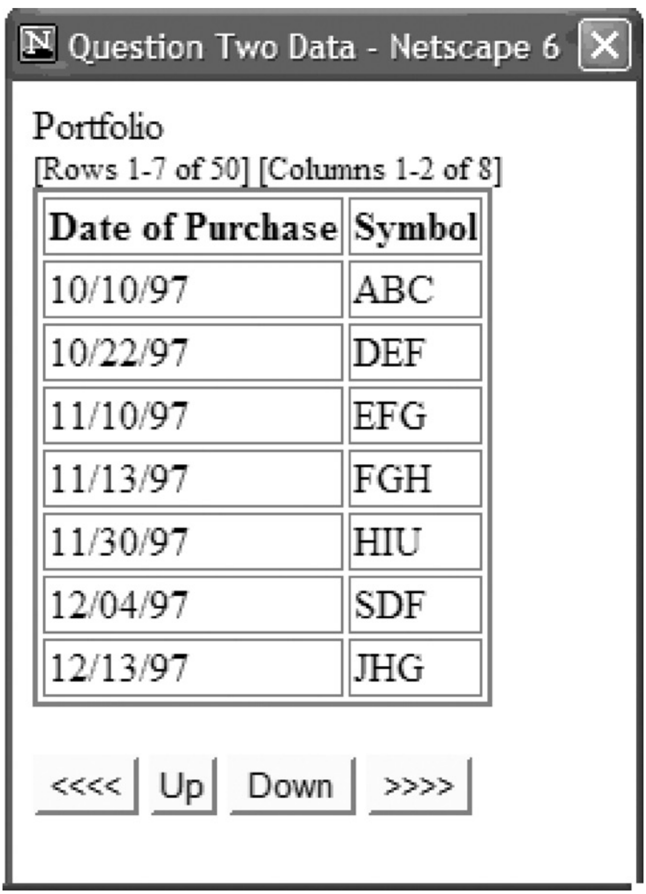

Fig. 1. Small display, PDA style.

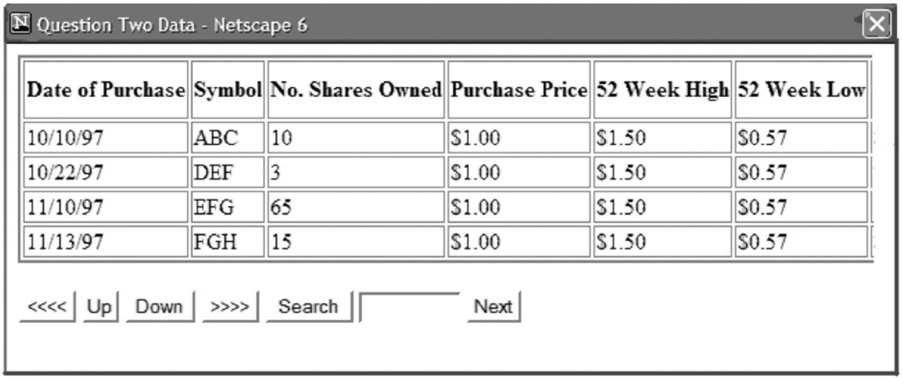

Fig. 2. Larger display, handheld style.

3.1. Methodology

The experiment examined three independent variables: use of search function, inclusion of context, and screen size. We chose two common small screen sizes, shown in Figs. 1 and 2. The first, Fig. 1, is the typical PDA device size, (3×5 in) and provides 2–3 columns of data depending on column width. The second, Fig. 2, is the typical handheld device size, 6×4 in, and provides 4–6 columns of data depending on column width. Based on screen area we refer to the 6×4 screen as the larger and the 3×5 as the smaller of the reduced screen sizes. This designation is supported in the study by the users who used a third more clicks to get their answers on the 3×5 screen.

For this study we used a $2 \times 2 \times 2$ factorial design, giving eight different experimental conditions. The dependent variables were *effectiveness* and *efficiency*. We measured effectiveness as getting the correct answer and we measured efficiency by counting actions (up, down, right, left, search). We did not put any time constraints on the users.

Participants were randomly assigned to one of the eight conditions and asked to complete both a simple and a more complex task. The data used in the tables was the same for all conditions and all users but different for Task One and for Task Two. The simple question, "What is Cathy's fax number?" involved simply locating information in the table. Each participant was then given the second table of data on the same screen size and asked to complete a more complex task, "How many shares of XYZ could you buy from the sale of ABC shares?" This query involved locating and using data from two cells in the table. The sequence includes an initial table lookup followed by a computation to determine how much money was available, notation or memorization of this amount, followed by a second table lookup and computation using this amount to determine the answer. Following the session, the participant was asked to fill out a short questionnaire.

3.2. Selection of participants

Eighty-four student participants from Business Administration and Computer Science completed the study. These students fit the target profile as people likely to use tabular data on devices with small screens, specifically, PDA, and handheld devices. Furthermore, these participants were also already familiar with working with digital versions of tables and so no training was needed.

Following the study we asked two separate classes, one from Business Administration and one from Computer Science, to complete the two tasks using a complete table shown on an overhead transparency. To measure the base rate of effectiveness when participants can see the entire table, we used the overhead rather than paper to remove the temptation of writing or marking the table to assist in completing the task.

3.3. User study

As discussed earlier, there is a direct trade off between the amount of data shown on the display and the features added. Each additional feature considerably reduces the amount of display space available for data. Having both context and search capability, as shown in Figs. 3 and 4, reduces the data display area by about 25% over having neither, i.e. full screen of table cells, shown in Fig. 2 or context only, shown in Fig. 1.

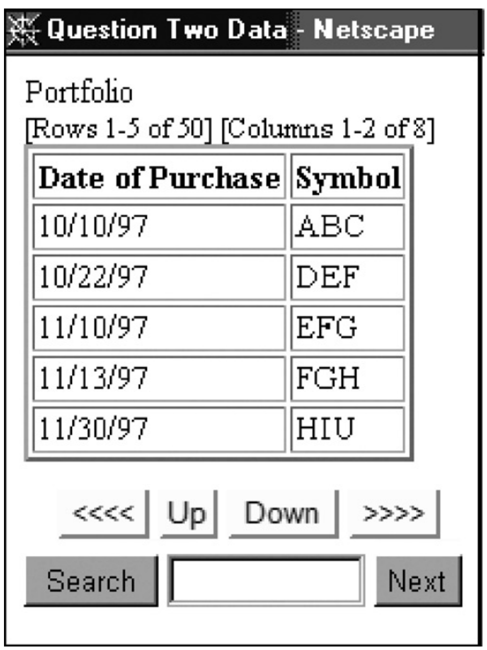

Fig. 3. Small display with context and search.

3.4. Study results

3.4.1. Preliminary measurements

To provide a benchmark for performance using the entire table, we asked two other classes, one business and one computer science ($N = 33$), to perform the same tasks using the complete table on an overhead transparency. We found that the students, who were given the complete table on a single transparency, exhibited no significant difference ($\chi^2 = 0.49$, df$=1$, $p = 0.51$) in success in completing the two tasks. They had the same success rate for the simple and for the complex tasks when viewing the complete table. In other words, when the students were able to see the entire table, they showed no significant difference in their ability to get the correct answer in either task. The percentage correct when the users could view the table in its entirety was 79% for the simple task and 83% for the complex task, not significantly different.

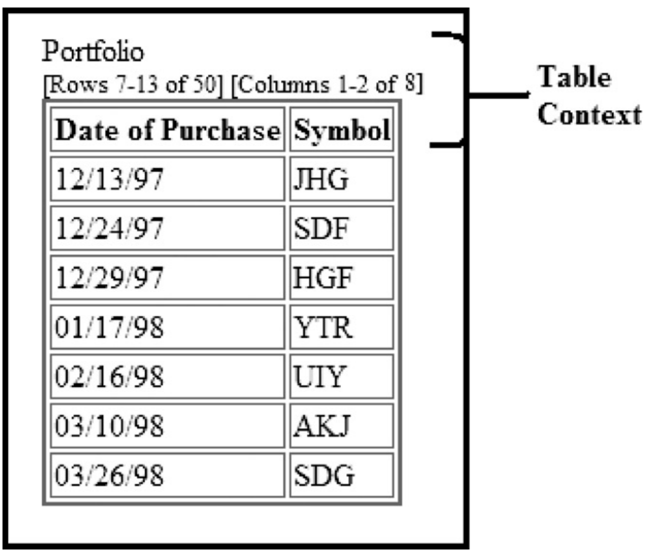

Fig. 4. Sample screen with context information.

Table 1
Overall effectiveness data by task

Screen size	Correct task one	Incorrect task one	Total task one	Correct task two	Incorrect task two	Total task two
6×4	39	2	41	25	16	41
3×5	38	5	43	25	18	43

Second we established that Task Two was actually more difficult than Task One for the users under the study conditions, i.e. using a screen smaller than the size of the table. From Table 1 we can see that Task Two was more difficult for the users on the smaller screens than Task One. The study participants using the small screens had access to only part of the table at any one time and we found, not surprisingly, that under every condition it was more difficult for the users to get the correct answer for the complex task than for the simple task. Only seven out of the 84 users got the answer wrong for the simple lookup task, while 34 out of 84 got the wrong answer for the complex lookup task. This difference is significant ($\chi^2 = 21.44$, df = 1, $p < 0.001$) and these results provide a quasi-manipulation check that Task Two was indeed more complex, or at least harder to get correct on the smaller screens, that was Task one.

Hypothesis 1. Users will perform table lookups more effectively using larger screens.

Effectiveness is the measure of how successful the participants were in getting the correct answer. Using the benchmark group results, we looked for significant differences in effectiveness for the specific tasks on any reduced size screen vs. viewing the entire table. We found that for Task One users got the correct answer significantly more often when viewing the entire table than when using any reduced screen size ($\chi^2 = 9.95$, df = 1, $p < 0.001$) and for Task Two users also got the correct answer significantly more often using the entire table than any reduced screen version ($\chi^2 = 34.28$, df = 1, $p < 0.001$).

In Task One, the simple task, screen size played a significant role in getting the correct answer. On the smaller screen (3×5) 5 out of the 43 participants got the wrong answer while on the larger screen (6×4) only 2 out of the 41 users got an incorrect answer. This difference is significant ($\chi^2 = 4.21$, df = 1, $p < 0.42$). Interestingly, this was not so for Task Two, where the difference between the two small screen sizes was not significant (18 out of 43 incorrect for the 6×4 screen and 16 out of 41 for the 3×5 screen $\chi^2 = 0.14$, df = 1, $p < 0.70$) on the ability of the users to complete the task correctly.

We interpret this to mean that as the task gets more complex even the larger incomplete table is too small for high effectiveness. That is, once the user needs to

Table 2
Effectiveness data for all conditions

Screen size	Context	Search	Task 1 correct	Task 1 incorrect	Task 2 correct	Task 2 incorrect
3×5	Yes	No	11	0	10	1
3×5	Yes	Yes	10	2	6	6
3×5	No	No	6	2	3	6
3×5	No	Yes	11	1	6	5
6×4	Yes	No	10	0	8	2
6×4	Yes	Yes	9	0	5	4
6×4	No	No	10	1	7	4
6×4	No	Yes	10	1	5	6

work with a partial table, his or her ability to perform the complex task correctly is affected. Furthermore, the ability of the users to get the correct answer for Task Two using either of the small screens was significantly worse ($\chi^2 = 34.28$, df = 1, $p < 0.001$) than for those users who presented the entire table on the overhead.

The effectiveness results for all eight conditions on both tasks are presented in Table 2.

To summarize, for effectiveness in getting the task correct, this study indicates that users perform better when they can see the whole table at once. If they must use a smaller table, then task complexity matters. For a simple task, the larger screen (4–6 columns of data) produced better results than the smaller screen (2–3 columns of data). Hypothesis 1 is confirmed for the simple task but not for the complex task.

Hypothesis 2. Users will perform table lookups more efficiently using larger screens.

We measured efficiency by the number of actions the user took to finish the task. This included; right, left, up, down, and, search actions. The means and standard deviations of the efficiency data for all eight conditions on both tasks are presented in Table 3.

Checking the overall data first, we used a multiple analysis of variance (MANOVA). We found that significance was reached for all of the main effects for efficiency. There were, however, no significant interactions between the conditions for efficiency.

An analysis of variance (ANOVA) test based on number of clicks on Task One indicates that screen size is significant ($F = 5.574$, df = 76, $\alpha = 0.021$). So we can say that the users were more efficient, i.e. used fewer clicks to complete the simple task using the larger of the two screens. The same ANOVA done for Task Two, however, failed to reach significance ($F = 1.241$, df = 76, $\alpha = 0.269$) and so the users were not more efficient on the larger screen than on the smaller screen in completing the more complex task.

As for Hypothesis 1, we interpret this to mean that as the task gets more complex even the larger incomplete table is too small for high efficiency. That is, once the user needs to work with a partial table, his or her ability to perform the complex task in a few clicks is affected.

Table 3
Efficiency data for all conditions

Condition	Screen size	Context	Search option	Mean task 1	Std task 1	Mean task 2	Std task 2
1	3×5	Yes	No	27	9	38	8
2	3×5	Yes	Yes	31	15	31	21
3	3×5	No	No	36	8	49	7
4	3×5	No	Yes	37	11	40	16
5	6×4	Yes	No	27	13	47	6
6	6×4	Yes	Yes	15	7	10	7
7	6×4	No	No	28	6	47	22
8	6×4	No	Yes	29	8	36	15

To summarize, for a simple task, users were more efficient when using the larger screen (4–6 columns of data) than the smaller screen (2–3 columns of data). Hypothesis 2 is confirmed for the simple task but not for the complex task.

Hypothesis 3. Users will perform table lookups more effectively on smaller screens when context information is presented.

By context information we mean, specifically, the following: title of table, current span of rows, current span of columns, and column headings. In the example shown in Fig. 3, the current view contains the first five rows (of 50) from the Portfolio table and the first two columns (of 8), Date of purchase and symbol. This data provides a context within the table for the data shown.

For Task One, the simple task, the inclusion of context did not improve effectiveness ($\chi^2 = 1.40$, df$=1$, $p<0.236$).

For Task Two, the more complex task, the inclusion of context had a significant positive impact on correctness of the answer ($\chi^2 = 0.695$, df$=1$, $p<0.015$). We interpret this to mean that as the task gets more complex, context helps the user get the right answer. This indicates that the screen space used for context was worthwhile in terms of task effectiveness for the more complex task.

To summarize, for a complex task, users were more effective when they had context information. There was no significant impact of context information for users on the simple task. Hypothesis 3 is confirmed for the complex task but not for the simple task.

Hypothesis 4. Users will perform table lookups more efficiently on smaller screens when context information is presented.

For the simple task, context yielded a significant improvement in efficiency ($F = 5.432$, df$=76$, $\alpha = 0.022$). For the complex task, context helped efficiency even more ($F = 8.200$, df$=76$, $\alpha = 0.005$).

We interpret this to mean that providing context information is well worth the screen space, if the goal is to help users be more efficient in either a simple or complex task. To summarize, Hypothesis 4 was confirmed for both the simple and the complex task.

Hypothesis 5. Users will perform table lookups more effectively on smaller screens when a search function is available.

For the simple task, the presence of a search function did not improve effectiveness ($\chi^2 = 0.236$, df$=1$, $p<0.891$). For the complex task, the search function had a significant effect ($\chi^2 = 4.78$, df$=1$, $p<0.03$). The most interesting thing about this finding for the complex task is that the results, while significant, were exactly opposite of what we expected. In other words, for the complex task the presence of a search function helped users get the WRONG answer! We believe this is because they trusted the search function to give the correct answer and did not check the answer.

In summary, Hypothesis 5 was not confirmed.

Hypothesis 6. Users will perform table lookups more efficiently on smaller screens when a search function is available.

For the simple task, the presence of a search function did not improve users' efficiency ($F = 0.142$, df$=76$ $\alpha = 0.707$). For the complex task, the presence of a search function did improve efficiency ($F = 14.948$, df$=76$ $\alpha < 0.001$). So a search function helped users' efficiency for the complex task only. But remember the effectiveness with the search function for the complex task significantly decreased effectiveness. In other words, combining the results of Hypotheses 5 and 6 for the complex task, we could conclude that on smaller screens a search function helps users get the wrong answer more quickly.

In summary, Hypothesis 6 was confirmed for the complex task but not the simple task.

Hypothesis 7. The effects will be more pronounced for the complex task than for the simple task.

Regarding effectiveness, both context information and search function had a significant influence for the complex task but not the simple task. The opposite was true for screen size. Thus we can conclude that the effect of context and search were more pronounced for the complex task. Since efficiency was measured on a ratio scale, we compared the relative variance accounted for by the main effects of screen size, context, and search on the simple task vs. the complex task. The result was significant for the complex task ($F = 14.44$, df$=1,80$, $p < 0.005$). Thus we can conclude that the effect of screen size, context and search were more pronounced for the complex task.

In summary, Hypothesis 7 was confirmed for all effects on efficiency and for two of the three effects on effectiveness.

3.4.2. Combined effects

Regarding effectiveness, only the interaction of context and search on the complex task reached significance ($\chi^2 = 7.943$, df$=1$, $p < 0.01$). All other interaction on the simple and the complex tasks were not significant. Since there were eight independent chi-squared tests used to look at all interactions on both task, we are somewhat reluctant to interpret the one significant result when there was no *a priori* hypothesis. We conclude that while screen size, context, and search have impacts on users' efficiency, for the most part, they do not interact to enhance nor cancel their respective impacts.

Regarding efficiency, using a MANOVA to check the overall data, given in Table 3, we found that there were no significant interactions between the main effects for efficiency.

An ANOVA on the simple task efficiency data found no significant interactions. Finally, an ANOVA on the complex task efficiency data also found no significant interactions. We can conclude that while screen size, context, and search have impacts on users efficiency, they do not interact to enhance nor cancel their respective impacts.

4. Summary of results and discussion

4.1. Summary of results

A summary of the hypotheses and test results are provided in Table 4.

4.2. Discussion

In this paper we present results from a user study looking at the effect of including search and context features in increasing the efficiency and effectiveness of using large tables for given tasks, one simple and one more complex, on two sizes of small screens. We found that providing consistent contextual information improved the performance of users and that context plus a search function improved the efficiency of people using large tables on small screens.

Table 4
Summary of hypotheses results

Hypothesis	Statement	Verified
H_1	Users will perform table lookups more effectively using larger screens.	Yes, for simple task No, for complex task
H_2	Users will perform table lookups more efficiently using larger screens.	Yes, for simple task No, for complex task
H_3	Users will perform table lookups more effectively on smaller screens when context information is presented.	No, for simple task Yes, for complex task
H_4	Users will perform table lookups more efficiently on smaller screens when context information is presented.	Yes, for both tasks
H_5	Users will perform table lookups more efficiently on smaller screens when a search function is available.	No, for simple task Yes, for complex task
H_6	Users will perform table lookups more effectively on smaller screens when a search function is available.	No, for simple task Yes, for complex task
H_7	The effects will be more pronounced for the complex task than for the simple task.	Yes, for effectiveness for context and search Yes, for efficiency for screen size, context, and search

For both the simple and complex tasks and both screen sizes using some of the limited screen space for context information improves efficiency *and* effectiveness. The search function, however, improved efficiency for the complex task but reduced effectiveness.

For the more complex task only the use of context improved the success of users in getting the correct answer. That is, for the complex task, further reductions in the size actually had no significant impact. They already had a hard time!

The results of this study are important for designers of systems using large tables on small screens. First, this study confirms the importance of including contextual information for the user on small screens. Second, the inclusion of the common search function, somewhat counter intuitively, had a negative impact on the correctness of answers in the complex task. From this result, we suggest that search functions, which take up significant real estate on small screens, be made optional so that the user can easily (single click) access the feature as needed. Third, that designers be careful to examine the impact of design decisions on effectiveness as well as efficiency of such decisions on a range of anticipated tasks. As with the search option, quickly arriving at an incorrect answer is often not a time saver overall.

5. Future work

We continue to work on several areas related to this work. First, we are now using these findings in the design of rules to drive real-time automatic transformation of data types for display on smaller devices. Second, we are beginning to examine how we can recognize domain or task conditions under which search would improve efficiency and/or effectiveness as this would allow us to design heuristics to toggle the search function on when most likely to be useful. Finally, comparisons in effectiveness and efficiency are needed for small devices to examine the applicability of the focus + context zoom display method mentioned earlier. The potential demand for sessions in which significant portions of data are viewed simultaneously on multiple device platforms, either sequentially or collaboratively, can only increase as wireless transmission rates continue to increase.

Acknowledgements

This research has been partially funded by a Canadian National Science and Engineering Research Council (NSERC) grant.

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