

Handheld Applications Design: Merging Information Appliances Without Affecting Usability

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Abstract: We report experimental results regarding information handling and call handling tasks performed on integrated information appliance hybrids and separate devices used together. Three different interface conditions were used: The PowerCom prototype, an integrated application including calendar, address book, e-mail, etc. implemented on a Casio Cassiopeia E-105; the Nokia 9110 Communicator, an integrated mobile phone and PDA; and the standard bundle Windows CE, running on the same Casio device and complemented by a Nokia 6110 mobile phone. Out of seven tasks, effectiveness was significantly lower for an information modification and a complex call handling task when using PowerCom whereas it was the same for the other tasks. The findings indicate that the merging of certain information appliances can be done without losing usability. However, the navigational breadth must be considered carefully since it is assumed to be more critical than depth when high accuracy is important.

Keywords: PDA, mobile phone, breadth, depth, call handling, direct manipulation, usability evaluation

1 Introduction

To some extent, the functions of mobile phones and PDAs are merging. Advanced mobile phones, such as Smartphones and Communicators, are increasingly being given functionality for manipulating information and are therefore given capabilities usually found in PDAs. Correspondingly, PDAs are currently being enhanced with functionality from mobile phones in order to enable user to make and answer phone calls with the device.

In this paper, we report on a comparison between three design approaches of handling both information and communication on mobile devices: a PDA with telephone functions, an integrated mobile phone and PDA, and a regular PDA complemented by a mobile phone. We describe mobile phones and PDAs as information appliances in their respective use area. We introduce some concepts to classify interfaces, and explain the studied interfaces in those terms. An experiment to compare how generalized and specialized interfaces support call handling and information handling is then described, together with its results. This is followed by a discussion and a conclusion.

2 Background

Norman (1998) discusses how the presence of extensive functionality can limit a device's usability due to the complexity of its interface. His conclusion is that customized devices, information appliances, might be the solution to the present complexity of computers. However, finding a striking balance between ease of use and versatility is likely to prove an important issue in information appliance design. An interface designed to support a very small set of functions can be customized to these functions to a greater degree compared to a more general interface. In other cases, however, more flexible tools with more functionality are sometimes required, as the use of the device will be more varied.

Both mobile phones and PDAs can be seen as information appliances (Norman 1998) and have become popular devices that help everyday activities of people. Therefore, it is interesting to note the trend towards integrating their functionality, a move that may seem contradictory to the idea of information appliances.

PDAs have their origin in information centric devices such as desktop computers and as a result their interfaces are based in models such as the Graphical User Interface (GUI). In the case of the mobile phones, the original functionality is that of making phone calls and thus the interaction model is grounded in this activity. The hybrid devices that have been introduced can thus be seen as an experiment to both find what level of generality users can handle and how to design interfaces that support several types of activities. The functionality supported by these kinds of devices can be described as information handling and call handling:

2.1 Information Handling

Providing the user with an easy access to stored information is an almost ever-present problem when designing computer applications. In the case of PDAs, this problem is more pronounced, as the user often needs access to almost the same information as on a desktop computer despite having only a fraction of the space of an ordinary display available. Although many information visualization techniques have been applied to desktop computers, only a few have been used on devices with small screens (cf. Björk *et al.*, 2000; Taivalsaari, 1999).

The focus on information handling in this paper is that of information visualization; i.e. on presenting and visualizing information to support the retrieval of relevant information, rather than on supporting the entering and changing of information.

2.2 Call Handling

Call handling refers to the initiation, answering, and ending of phone calls, as well as handling more than one ongoing call at the same time. Current mobile phones support about 13 different call handling states (e.g. one active call; one held call; one active call and one waiting call; one active conference call, etc.) but are limited to two concurrent ongoing calls.

Exploring how to support call handling on a desktop computer, Grundel and Schneider-Hufschmidt (1999) created the Communication Circle application. From the empirical material gained for user evaluation, the authors stress the advantage of facilitating direct manipulation so that users initiate actions by manipulating the interface object that represent the calls, rather than having to select functions from menus and know their precise meaning.

3 Interface Description

Interfaces can be described by specifying their canonical vocabulary (Cooper 1995). This specification builds on basic actions such as tap, release, key press and drag as atomic elements. These elements

form primitives for the compounds, which are operations like double-tap, button click and drag & drop. The compounds are the bases for the idioms, actions such as deleting, creating and closing. The fewer atomic elements, the easier an interface is to learn, but it also becomes less expressive.

3.1 Breadth vs. Depth

The study of how breadth and depth of GUIs affect performance has its roots in the study of menus (Miller 1981). Breadth is defined as the number of choices per menu and Depth is defined as the number of menu levels. Performing an experiment where speed and accuracy was measured as breadth and depth varied (2^6 , 4^3 , 8^2 and 64^1 , where the base expresses breadth and the power expresses depth), Miller found that the 8^2 hierarchy was the best of the four and suggested that the depth should be minimized. Larson and Czerwinski (1998) confirmed the results for web page design, as did Goldstein *et al.* (1999) for the GUI of a Smartphone.

The canonical vocabulary together with the number of interactive objects of a user interface gives one quantitative metric of interface complexity. The number of interactive objects on the screen in combination with the canonical vocabulary is in this paper used to roughly decide the breadth. This can be expressed in a formula according to Equation 1, where n is the number of objects at a given level and m is the size of the canonical vocabulary at the same level. Depth is calculated as the minimum number of choices a user needs to do to accomplish a task.

$$\text{breadth} \approx \sum_{i=1}^n \text{objects} \cdot \sum_{j=1}^m \text{vocabulary}$$

Equation 1.

4 Interfaces

4.1 The PowerCom Prototype

PowerCom was designed to support users with relevant information during phone calls and meetings with other people. It uses an interface that can be classified as generalized as it integrates information and call handling functions in one application. Based upon the PowerView prototype (Björk *et al.* 1999), developed for information retrieval (of email, tasks, contacts, and meetings), PowerCom added support for information modification and call handling. The application was written in the programming language Waba and runs on all systems supporting Java. Pre-recorded sound clips were played to simulate phone calls as telephone functionality was not available on the device hosted PowerCom during the experiment reported in this paper.

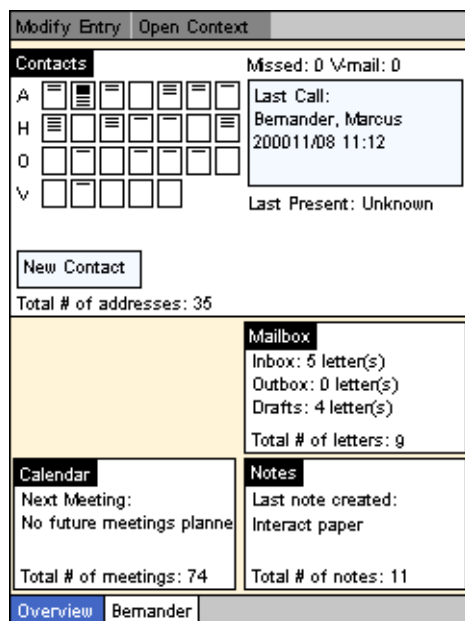


Figure 1: The PowerCom user interface. Figure 3 shows the Cassiopeia E-105.

Information Handling. The PowerCom prototype (Figure 1) uses the information visualization technique Flip Zooming (Björk 2000) for information presentation and navigation. In order to solve the problem of navigation between different types of information, PowerCom was designed to show several different information types simultaneously. To do this, information links were used to describe what information pieces were related to each other.

Information links are connections between two pieces of information, which can belong to different information domains, e.g. email and contact lists. Thus, the information links form a layer of relations between objects in the different data types on top of the storage of each data type.

Call Handling. The functionality associated with mobile phones is integrated within the Contact list in PowerCom. When a view showing individual contacts is displayed, all people with known telephone numbers (both stationary and mobile) are displayed as small icons. To call a person (and later on, end that call) the user directly clicks on the icon instead of navigating to a separate phone application. Due to the use of several activity foci (similar to having several windows related to different user activities) in combination with drag & drop, the telephone functionality of PowerCom supports call handling. By treating each phone call (to a single person or a group of people) as a separate activity, the user can move between single-person calls and conference calls by dragging phone icons to and from different activity foci.

Breadth vs. Depth. The integration of information and call handling and the use of multiple foci in PowerCom increased the number of objects presented on the screen. As PowerCom uses a canonical vocabulary of two (stylus single-click and drag & drop), this in combination with many objects gives a relatively wide breadth. The addition of information links allowed different types of information to be displayed together. This reduces effective depth since users who normally have to perform several consecutive tasks when using related information do not have to navigate between different applications of the GUI.

4.2 The Nokia 9110 Communicator

The Nokia 9110 Communicator (Figure 2) reveals a computer display and miniaturized QWERTY keyboard when opened. It can be used in two modes: as a regular mobile phone (closed mode), or as an integrated handheld computer and mobile phone (open mode). In the experiment only the open mode was used. The device does not have a touch sensitive screen and the navigation between the seven applications is done using the hard buttons above the keyboard. This interface can on one hand be classified as a general interface, since the interface supports many different tasks. However, the separation of applications allows the user to concentrate on one narrowly defined task at a time.

Information Handling. The interface is navigated using soft keys and the menu items and objects within applications are presented in simple lists and selected and opened by the user. The keyboard is mainly used to enter or edit information. Some navigational shortcuts are possible by entering the first letters in the object name on the keyboard.



Figure 2: The Nokia 9110 Communicator in open mode.

Call Handling. The separate telephone application is similar to that of other mobile phones, supporting all call handling functionality. However, the room metaphor is used to better visualize and separate different telephone calls.

Breadth vs. Depth. Selection and moving within an application is done using the four arrow keys (<, ^, v, >) and the four soft keys to the right of the screen. As

the call handling and information handling functionality is divided into two different applications and the canonical vocabulary is limited to one (key press), the breadth of the Nokia 9110 Communicator is narrower than that of PowerCom. Further, moving data entries between different windows or views is not supported.

4.3 Windows CE and Nokia 6110

Windows CE (Figure 3), the standard operating system on the Casio Cassiopeia E-105, is a handheld version of Windows 95/98/NT employed in the information handling situations. Nokia 6110 is a regular mobile phone appliance, which in the experiment was used together with handsfree equipment for the call handling tasks. The use of this additional equipment was motivated by the desire to enable users to simultaneously have access to information handling and call handling functionality in all the conditions of the experiment.



Figure 3: The Nokia 6110 and Windows CE running on the Casio Cassiopeia E-105.

Information Handling. Windows CE is based on the mostly metaphorical GUI of Windows 95/98/NT. Thus, it supports information handling by a number of dedicated applications similar to those on a desk-top computer.

Call Handling. The Nokia 6110 interface (Figure 3) is based on menus and submenus and have two dedicated buttons for simple call handling. The keypad is used to enter both digits and characters.

Breadth vs. Depth. The designers of Windows CE have tried to keep as many features as possible from the PC interface, which means a large number of objects on the screen. The stylus-based interaction in Windows CE uses three compounds: tap, double-tap and tap & hold, which increase the expressiveness but also the breadth at each level.

The Nokia 6110 is the reverse, and uses only key presses for input. The navigation is mainly carried out using the two up-down arrow keys (^, v) and the

two soft keys below the display. The objects on the display are few and if the keypad buttons are considered as one unit, the breadth of the Nokia 6110 is very narrow. Thus, substantial navigation in sub-menus is required, resulting in increased depth (up to 11 levels for the tasks used in this experiment).

5 The Experiment

The usability of information and call handling with the different interfaces was evaluated by benchmarking the PowerCom prototype (running on a Cassiopeia E-105), the Nokia 9110 Communicator, and the combination of Windows CE (running on a Cassiopeia E-105) and the Nokia 6110 against each other. The following four null hypotheses were set for the three interface conditions: no difference in effectiveness for any task, no difference in efficiency for any task, no difference in mental workload for any scale and no difference in subjective satisfaction for any statement. A more detailed description of the experiment can be found in (Nyberg 2000).

5.1 Experimental Design

A 3 x 7 factor (Interface (PowerCom, Nokia 9110 Communicator, Windows CE and Nokia 6110)) x Task (1-7)) within-subject repeated measurement design was used to minimize for individual differences among the subjects. To balance out learning effects and tiredness effects, the interface presentation order was according to all possible permutations, i.e. six, of three elements. The hypotheses were tested using a repeated measurement general liner model (GLM) in the SPSS 10.0 software. The significance level was set to 5% and the significance level of multiple pairwise comparisons was Bonferroni adjusted.

5.2 Independent Variables

Usability Laboratory. The experiment was conducted at the Usability & Interaction Laboratory at Ericsson Research in Kista, Sweden.

Subjects. 18 subjects, 13 men and five women (age 19-43 years, mean=29 years) participated in the study. They were all very familiar with computers (Windows) and mobile phones and ten of them owned or had owned a PDA. However, regarding the three interfaces used in the experiment, they were all novice users.

Interfaces. The three interface conditions described earlier were used.

Identical pre-recorded “messages” were used for the two Nokia devices and the PowerCom prototype to simulate the call handling situations. For the Nokia devices, a solution with voice mail answering

messages and sound clips playing on a laptop computer were adopted.

Tasks. Four frequently occurring information handling tasks (task 1-4), one frequently occurring (task 5) and two less frequently occurring (task 6 and 7) call handling tasks were defined. The tasks were identical for the three interface conditions, using the same data. Some complex tasks (1, 6 and 7) were divided into subtasks (a, b, c) to get a more detailed view of the subject's performance:

- 1a Find contact information
- 1b Change contact information
- 2 Find a note
- 3 Find a meeting as well as the participants
- 4 Find two emails about a vacation trip
- 5 Call a person
- 6a Answer waiting call/put active call on hold
- 6b Swap to held call
- 6c End active call/continue held call
- 7a Call a second person/put active call on hold
- 7b Create a conference call
- 7c Start a private call with a member of a conference call

If a subject did not accomplish a subtask, the following subtasks within that task were also regarded as failed. When using both Windows CE and the Nokia 6110, tasks 1-4 were performed using Windows CE and 5-7 using the mobile phone.

5.3 Dependent variables

Effectiveness. In this experiment, both information and call handling tasks were presented and they are very different considering fault tolerance. Therefore, the effectiveness was measured using a scoring system: 1.0 point for a successfully solved task, a 0.5 point reduction if the task was regarded as failed (this means a maximum of two fails per task were allowed) and a 0.25 point subtraction if a hint had to be given by the experimenter.

Efficiency. Efficiency was measured as completion time and number of keystrokes. The number of keystrokes was considered at a reasonable high level, a double-tap, several consecutive scrolling taps and entering information in a text area were all considered as one keystroke action.

Mental Workload. A multidimensional rating scale, the NASA-TLX (Hart & Staveland 1988) was administered after each interface condition. It reflects the perceived mental, physical and temporal demands as well as the performance, effort and frustration levels.

Subjective satisfaction. The subjects were asked to rate each interface according to 15 different statements that were chosen to represent central aspects and features of the interfaces. The design and statements in

this questionnaire, directly following the mental workload assessment, were taken from Shneiderman (1998, pp. 132-145).

5.4 Procedure

When arriving to the Usability Lab the test situation for both information and call handling was explained. In order to give the subjects a picture of call handling, the main features were discussed before repeating the following four steps for each condition:

Introduction to the interface(s). The main features and interaction properties were explained to the subject to assist the initial learning. This particularly applies to PowerCom, which has some novel idiomatic interface elements that needed priming. A previous study (Goldstein *et al.* 1999) showed that initial priming might be necessary when evaluating completely new interaction styles.

Familiarization. The subject was allowed five minutes of free browsing for each interface condition to try out the different interaction methods. The subjects were encouraged to adopt a trial-and-error approach. No manual was allowed at any point.

Performing the tasks. Each session with an interface was recorded on digital video for later analysis.

Assessments. After each interface session, the subject answered mental workload and subjective satisfaction forms.

Between each interface condition a break for about ten minutes was inserted. The total time for the experiment was about 150 minutes including breaks.

6 Results

6.1 Objective Measures

Effectiveness. The general outcome was that the subjects performed very well using the Nokia 9110 Communicator and Windows CE + Nokia 6110. Pairwise comparisons showed that the total PowerCom score was significantly lower than the other two interface conditions. With a maximum score of 12 the Nokia 9110 Communicator scored 11.53 points, Windows CE + Nokia 6110 scored 11.74 points whereas PowerCom scored 10.40 points ($F[2,34] = 10.757, p < 0.001$).

Comparing each subtask over the three interface conditions (Figure 4), no significant differences were found for the information retrieval tasks (1a, 2-4) or for the first call handling tasks (5 and 6). However, PowerCom scored significantly worse on task 1b (Change contact information), task 7b (Create a conference call) and task 7c (Start a private call with a conference member). It should be noted that 7b and 7c are correlated, as it is impossible to complete task 7c if one has failed to complete 7b.

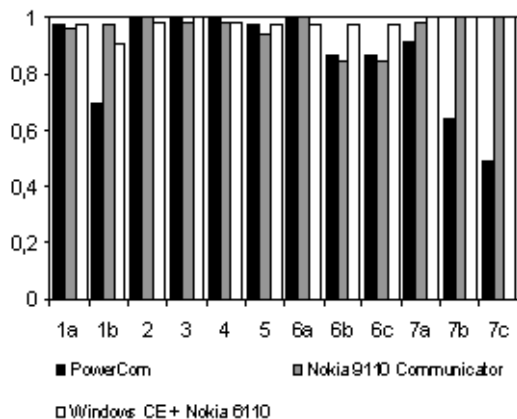


Figure 4: The average effectiveness score for the three interface conditions for the information handling (task 1-4) and the call handling (5-7) tasks.

Efficiency. The completion time for task 1, 5 and 7 was significant for the three interface conditions ($F[2,34] > 7.668$, $p < 0.003$). Pairwise comparisons showed that the completion time for task 1 (information handling) and task 7 (call handling) was significantly lower using the Nokia 9110 Communicator than for the other two interface conditions. Considering task 7, the Nokia 6110 completion time was also significantly lower than that of PowerCom. The completion time for PowerCom on task 5 (Call a person) was significantly lower than for the two other interfaces.

Number of keystrokes necessary to accomplish both task 1, 5 and 7 were significant ($F[2,34] > 8.500$, $p < 0.002$). Pairwise comparisons revealed that users needed significantly fewer keystrokes for the Nokia 9110 Communicator than the other two interface conditions on task 1 and 7. For task 7, Nokia 6110 also needed significantly fewer keystrokes than PowerCom. The situation was reversed regarding task 5 and PowerCom needed significantly fewer keystrokes compared to Nokia 6110.

6.2 Subjective Measures

The subjective measures showed very large differences disfavoring PowerCom. One reason for this could be that the subjects performed worst on the last task using PowerCom, while they performed best on the last task for the other two interface conditions.

Mental Workload. Significant differences existed for four out of six scales ($F[2,34] > 9.516$, $p < 0.002$). Pairwise comparisons showed that PowerCom was rated as significantly more demanding (higher ratings, low ratings indicates lower mental workload) than the Nokia 9110 Communicator on these four scales and as more demanding than Windows CE + Nokia 6110 on two of them.

Subjective satisfaction. These results were in line with the Mental Workload results. Significant differences were found for ten out of the 15 statements ($F[2,34] > 3.787$, $p < 0.034$). Pairwise comparisons revealed that the Nokia 9110 Communicator was rated significantly higher than PowerCom on nine of them and that Windows CE + Nokia 6110 was rated significantly higher on five statements. PowerCom was rated significantly higher than the Nokia 9110 Communicator on one statement: System speed and responses.

7 Discussion

7.1 The PowerCom interface

Since PowerCom is the only non-commercial system in the experiment as well as the most information centric one, some findings pertaining to it specifically are reported here. Although PowerCom employs many novel interface concepts, its performance was equal to the two other interfaces considering the information retrieval tasks. This is in line with the evaluation of a former prototype, PowerView (Jacobsson *et al.*, 2000). Call handling proved to be somewhat different, and the score for PowerCom was significantly lower for the last call handling task (task 7). Somewhat surprisingly, PowerCom was significantly better (regarding both completion time and number of keystrokes) for making a single phone call than the other two interfaces.

The drag & drop operation used in PowerCom for task 1b was very difficult to figure out for novice users. However, when given a hint most users managed to solve the task, which indicates that this operation would not be a problem for more seasoned users. Drag & drop caused more problems when handling conference calls. Although exposed to priming on how to use drag & drop (in task 1b), only one subject out of 18 used the shortest navigation path, without requesting a hint. The most common erroneous action was to drag one information view and drop it on another to merge the two information spaces into a joint space.

7.2 Information vs. Call Handling

The experiment indicates that different design criteria might apply for information and call and handling. For information handling, navigation depth ranged from 3 to 11 (Figure 5), but no finding indicates that depth is critical. However, the subjects' commented that not having too deep structures is preferable. Some of the difficulties with the tasks concerning information handling can be explained in terms of the many actions possible at each level in PowerCom and Windows CE compared to the Nokia 9110 Communicator.

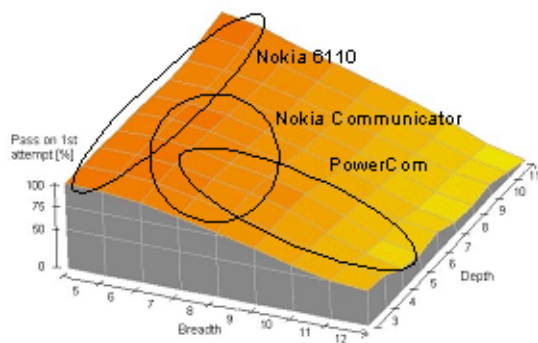


Figure 5: The percentage of the users that passed the call handling tasks (5-7) for each interface on the first attempt for different breadth/depth combinations.

However, it was for the call handling tasks that most problems related to breadth occurred. For PowerCom this affected the performance of task 7, which employed the widest average breadth (Figure 5). The Nokia 9110 Communicator keeps the breadth and depth more or less constant. The telephone function has its own application and the interaction buttons are the same. Nokia 6110, with its small canonical vocabulary and narrow menu breadth had a performance level close to 100 per cent although the navigation depth was large in some cases.

Although recorded telephone “messages” were used, users still adopted different behaviors between handling information and phone calls. Using a perspective of speed-accuracy trade-off (cf. Wickens 1992, pp. 318-322), the experiment identified a difference between the two classes of tasks: speed (completion time) was most important for information handling tasks, while accuracy (effectiveness) was more crucial for call handling.

When searching for information, users adopted a trial and error style that requires the possibility of quick exploration. This approach was not used in the call handling situation, where users valued accuracy as most important. One possible explanation is the involvement of other people in call handling situations; others can immediately notice your errors. Another explanation is that users’ previous experiences of phones suggest the importance of being correct from the start since recovering from an error might be difficult or time-consuming.

7.3 Generalized Devices vs. Information Appliances

General devices are often claimed to be more convenient, and thus superior, to information appliances for mobile users. Instead of carrying one device for each activity, one device can be used for all. However, as general devices are by nature more complex, they are assumed to be more difficult to use.

The small differences in usability between the Nokia 9110 Communicator and Windows CE + Nokia 6110 show that it is possible to design general interfaces without sacrificing usability. However, as the results in this experiment shows, breadth is an important factor when integrating several types of functionality in one interface. Viewing the distribution of breadth/depth of tasks for the different interfaces in Figure 5, and assuming that limiting the breadth is preferable to limiting the depth if it does not significantly affect efficiency (completion time and number of keystrokes) severely, it appears as the Nokia 9110 Communicator has the best compromise. This is surprising as it contradicts the perceived view that general, or multi-purpose, devices are more difficult to use than specialized devices.

One interpretation of the results is that the “activity” a mobile phone or a PDA is designed to support does not conform to actual activities that people perform. A device that merges functionality from both, even at the cost of increasing breath, may provide a better support for the activities of mobile users.

8 Conclusions

The experiment showed that users performed equally well on all three interfaces except for three subtasks. As some functionality in the different interfaces was not present in the others, the evaluation should not be seen as a benchmarking between the specific interfaces. The relatively small differences between the interfaces indicate that the different design approaches used may be feasible for most of the examined tasks. Given this, some of the differences between the types of tasks were identified using the canonical vocabularies of the interfaces:

- Information handling and call handling is different from a user perspective. A separate call handling application or visualization may be recommended when designing for novice users.
- Accuracy seems to be regarded as more important than speed when performing call handling tasks, especially when other people are involved. One way to address this is to prioritize depth over breadth when designing call handling interfaces.
- Drag & drop increases the expressiveness, but also the canonical vocabulary and the breadth of an interface. Reducing the number of objects in the interface is one way of limiting the breadth when implementing drag & drop.

Looking at the difference between information appliances and more generalized interfaces (Norman 1998), the results from the experiment point to some possible design guidelines:

- The usability of an information appliance or an interface with more general functionality is related to the breadth and depth of the user interface.
- It seems advantageous to maintain separation of functionality when merging information handling and call handling into a generalized interface that is to be used by novice users.

It should be stressed that the evaluation was conducted with novice users. Letting users train for a longer while (15 minutes or so) would make users familiar with the new interface concepts used in the PowerCom prototype (which also had the greatest integration of information and call handling functionality). It should also be noted that the PowerCom interface includes call handling functionality not supported by the other interfaces. As this functionality increases the breadth of the interface without increasing the number of solutions, it might negatively affect the results of that experiment.¹

9 Future Work

The experiment reported here must be followed by other experiments to validate the claims made. First, other types of tasks and other types of interfaces should be evaluated in similar experiments. Second, as the overall usability of the studied interfaces was high, a second evaluation with even more complex tasks or a higher resolution of success could be performed. In such an experiment, a dedicated call handling application on a PDA could constitute an additional comparison.

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1. This functionality is in addition to unused functionality that all interfaces support, such as creating new contacts and meeting, setting preferences etc.