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Designing personal attentive user interfaces in the mobile public safety domain

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Abstract

In the mobile computing environment, there is a need to adapt the information and service provision to the momentary attentive state of the user, operational requirements and usage context. This paper proposes to design personal attentive user interfaces (PAUI) for which the content and style of information presentation is based on models of relevant cognitive, task, context and user aspects. Using the police work environment as the application domain, relevant attributes of these aspects are identified based on literature and domain analyses. We present a user-centered design (UCD) method for the iterative development and validation of the proposed PAUI. Application of this approach provided requirements for (1) adaptation to users' attentive state, (2) notification, (3) information processing and task switching support and (4) user modeling. We aim at refining and validating the models and requirements through continuing empirical evaluation.

Keywords: Mobile computing; Attention; Context-aware computing; Personalization; User-centered design; Police

1. Introduction

The amount and diversity of information and services, which users can access via mobile devices, will continue to increase. In the mobile setting, both the interaction possibilities of

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devices and the momentary user needs for information or services continuously change over time and place. Using emerging computing appliances such as a personal digital assistant (PDA), digital information can now be accessed anywhere, anytime. For example, checking in for your flight can be done during the train ride to the airport, using a mobile phone.

A large amount of previous human–computer interaction (HCI) research has focused on mobile computing within the travel and tourist domain where information is accessible via portable or wearable devices (Abowd et al., 1997a; Cheverst, Mitchell, & Davies, 2002; Krug, Mountain, & Phann, 2003). A relatively new development is the emergence of location-based services, whereby the mobile device has access to geographical location information. Based on this information, users can, for example, access information relevant to tourist sights or locate friends or relatives (Anhalt et al., 2001). Location-based services fall within the broader domain of context-aware systems. These systems aim at a more fluid and relevant interaction by adapting their behavior to relevant context factors (Shafer, Brumitt, & Cadiz, 2001).

When users perform tasks in the mobile setting, a competition for the user's attention between the task and the environment occurs (Jameson, 2002). A user has to navigate through the environment while simultaneously attending to his device. As a result, actual usage of information or services in mobile computing is restricted by a number of constraints. Human *cognitive capacities* such as visual attention and information processing resources (e.g. working memory) are limited. Also, affective factors such as the emotional state of the user influence the interaction (Neerincx & Streefkerk, 2003). In addition, in contrast with "traditional" desktop computing, mobile computing is characterized by *limited interaction* possibilities using input and output means such as a stylus pen (pen-based input) and a small screen (York & Pendharkar, 2004). The *domain* in which the interaction takes place is important as well. A firefighter will have very different requirements for a mobile device and interaction than a tourist has (Jiang et al., 2004a). Finally, the *context* in which the interaction takes place is a constraint on interaction. Social and physical interactions with people and environmental factors such as noise or heat influence the interaction. It is therefore necessary to take these factors into account when designing for the mobile setting.

Observing the factors above, a pressing question is how to design personal attentive user interfaces (PAUI) that provide the right information, at the right time and in the right way for individual users (Fischer, 2001). We foresee an interface or system that has specific knowledge about the individual user, his context and his tasks. Then, using this information, the system has to be able to adapt its actions and interface. Adaptation to individual users and tasks is designated as *personalization*.

Our approach will be to identify and elaborate the cognitive, task, context and user aspects relevant for designing PAUI, using literature and domain analyses. Subsequently, with a user-centered design (UCD) technique we will show how these aspects can be modeled and used to guide the design process (Neerincx et al., 2006). In UCD, reasoning about prospected use of a system gives valuable insights on and validity to user requirements and collaboration styles. Using a scenario from the application domain, collaboration styles and user requirements are formulated, based on the relevant aspects.

Our primary application area is the domain of public safety and assistance; e.g. the police work environment. Recently, mobile information access has become available for police officers using PDA's (Ioimo & Aronson, 2004). The advantage of this development is somewhat lessened by the dynamic and complex situations in which police officers find themselves. In critical situations, such as rioting or plundering, cumbersome interaction with a device is not desirable. Imagine a police officer who has to attend to his PDA while a mob of angry protestors advances on him. For optimal task performance, it is necessary to guide the attention of the police officer to relevant information or objects (i.e. notification). In addition, when an officer has to execute two tasks at the same time, for example during crisis management, it is important that his attention is directed to the task with the highest priority.

We believe that police officers can benefit from attention support and notification from a system that has information about their task, duties and context both for the individual police officer and for a team. This is the design challenge we will address in this paper. The questions are thus: Which factors need to be taken into account to improve the deployment of attentional resources for mobile police officers? How can we model these factors in a user-centered design approach?

The outline of this paper is as follows. In Sections 2–4 respectively, we will show which cognitive, task and context aspects are necessary to specify the concept of PAUI outlined above. Previous relevant research within the areas of human–computer interaction, cognitive psychology and the police domain will be presented where relevant. Personalization issues will be discussed in Section 5. Then, based on the identified relevant cognitive, task and context aspects, we will propose a user-centered design method for the development of PAUI in Section 6. Finally, challenges for our PAUI are discussed and directions for further work conclude this paper.

2. Cognitive aspects

In Section 1, we stated that information needs and interaction possibilities with a device in a mobile context will continue to increase. One restriction to fulfilling these needs and using these possibilities are limited human cognitive resources. Attention and memory both play vital roles in information processing. Attention can be regarded as the selection process whereby conscious access to working memory is made possible (Wickens, 1987). Although there is lack of consensus on the exact nature of these limitations (see for example Allport, 1989), the limitations of cognition become clear for instance when people have to perform multiple tasks simultaneously (Horvitz, Kadie, Paek, & Hovel, 2003). Dual task situations illustrate the concept of divided attention, where attending to two or more tasks leads to decrements in performance. Limitations in working memory cause information to be lost due to overload, or information to be unattended due to distraction. Distraction can be regarded as failure of focused attention (Klapp, 1987). We will discuss the cognitive aspects of visual attention, task switching and situation awareness and how they are relevant for interaction in the mobile police context.

2.1. Visual attention

One of the goals of this paper is to identify support principles for attraction, guidance and maintenance of visual attention in a mobile work environment. Attention can be regarded as a cognitive selection process, depending heavily on the user goals and tasks (Wood, Cox, & Cheng, 2004). Attention can either be voluntarily directed towards or involuntary grabbed by objects, sounds or movement in the environment. Research from visual search shows that at the perceptual level, object features such as salience and color can catch attention. In addition, motion, sudden appearance and changes in luminance easily grab attention (Bartram, Ware, & Calvert, 2003). At the cognitive level, attention is directed to those elements that are consistent with the user's task, expectations or history. These will receive attention faster and easier (Pashler, Johnston, & Ruthruff, 2001).

Thus, the challenge is how to make sure the user is focusing the limited attentional resources on the right task and place in the mobile context. In order to make accurate estimates on user attention, we need a system that can sense, model and adapt to the attentive states of the user. Sensing attention as humans, we routinely assess and adapt to each others' cognitive limitations: we simplify our speech towards children; we wait a minute for a busy colleague to finish what he is doing before we talk to him. Such adaptation is now attempted in adaptive systems (Horvitz et al., 2003; Jameson, Schäfer, Weis, Berthold, & Weyrath, 1999).

Current research has begun to address the problem of limited attentional resources in human–computer interaction. Under the term of Attentive or Attentional Interfaces, interfaces are developed that can prioritize information presentation based on reasoning about information processing resources (i.e. attention). These interfaces model momentary attentive states of the user based on sensing techniques. Adaptations in system behavior are guided by sensing gaze direction, body posture, hand posture and speech (Vertegaal, 2002; Zhai, 2003). Attentional interfaces have also been developed for the mobile computing environment (Abowd, Mynatt, & Rodden, 2002; Horvitz et al., 2003; Jameson, 2002). These systems can sense gaze direction and estimate attention allocation based on this information. Limitations of current attentive interfaces are restrictions on modeling and learning about the attentive resources of the user. Also, they rely mainly on eye tracking data to estimate the user's focus and direction of attention. Ideally, information from multiple sensors and user history should be used to make predictions about attention. Thus, sensing and modeling momentary attentive states of the user is feasible, even in the mobile context. Based on a derived model of attention, the system can adapt modality, information presentation and interaction styles.

When the system senses the user is distracted, it can attract the user's attention in several ways, via different modalities. Attention can be caught visually by employing certain interface elements such as blinking icons. However, in some situations it is more effective to attract user attention via the auditory or tactile modalities, using sounds or vibrations. A simple example is the auditory signal when a SMS is received on a mobile phone. In this case visual attention was away from the display, and an auditory stimulus prompts the user to direct his attention back to the display. Relating to attention, the system should be able to dynamically adapt the output modality, based on the momentary attentive state of the user. Designing the right attention attractors in an interface is a challenge in itself (Bartram et al., 2003). For example, a system can sense the user is sitting down in a medium noise environment and decide to use an auditory warning. When the user is sitting in an office, this is more suited than when he is sitting in a theatre. Furthermore, the decision to attract attention should be based on task aspects and the context of the user, in order to be meaningful and relevant (McCrickard, Catrambone, Chewar, & Stasko, 2003). Once the user is notified, the system can provide dynamically adapted information presentation. Here, by using interface elements such as "partition dynamism" (Weld et al., 2004), attention can be guided to the relevant information.

The final step is to maintain attention. By using multiple interaction styles, limited visual attention can be relieved. In multimodal mobile systems, multiple input and output means are employed (van Esch-Bussemakers, Cremers, Neerincx, & van der Flier, 2003). Examples of input means are speech input and pen-based input. Output modalities other than screen output include synthesized speech or non-speech sounds and haptic/tactile feedback. A domain-related example comes from a recent user study in which a speech recognition system was implemented in a police cruiser (Kun, Miller, & Lenharth, 2004). By allowing the police officer to interact with his information system vocally, his visual attention could be directed towards his environment. Officers' comments showed that they found the speech interface most useful while driving and that they would like to have a portable device to take with them when they exit the car, so they can still profit from the functionality. Based on user's momentary attentive state, system interaction should be provided via an appropriate modality.

Above, we discussed the attraction, guidance and maintenance of attention by an adaptive system. Previous research focused on interface elements and auditory signals to notify the user. An attentive support system should sense and model the momentary attentive state using multiple sensors, and subsequently adapt information presentation, modality and interaction style based on this attention model. In order to provide a meaningful adaptation, we will need to know what the relevant task and context factors are. We will turn to those factors in Section 3.

2.2. Task switching

Unwanted task switching can be threat to effective and efficient task performance, but switching should be supported when necessary. In a dynamic mobile environment, multitasking situations can occur, where a user has to perform multiple tasks simultaneously. In these situations, the user pauses work on one task and commences work on another. Often, this switch is the result of an interruption. Interruptions can be caused by the environment (distraction), by the system (notification) or by the user (changing attentional focus). After finishing the other or secondary task, the user returns to the original task (see Fig. 1). An example is pausing reading a web page on a mobile device to answer an incoming phone call and subsequently returning to the reading task.

Task switching influences attention in two ways. First, the interruption of a task causes attention to be distracted away from that task. Depending on user goals, this is either an unwanted distraction from the primary task or an attraction to valued and necessary information (McCrickard et al., 2003). Unwanted interruption has negative consequences for task performance, causing disorientation on part of the user (Nagata, 2003). Second, research indicates that the process itself of switching between tasks places high demand on attention, thereby increasing cognitive workload. In addition, a switch between tasks is more disruptive than sequential finishing of tasks and thereby affects performance (Neerincx, van Doorne, & Ruijsendaal, 2000). How disruptive this switch is depends on the relatedness of the tasks, the duration of the work on the tasks and the cognitive workload experienced by the person working on the tasks (Wickens, 1987). Consider for example, a police officer engaged in checking a license plate on a car. Suddenly, a notification comes in about a theft of another car. He attends to this notification and receives a description of the stolen vehicle. Now he has to distinguish between the two sets of information. This would be much less cognitively demanding when the two sets (i.e. tasks) were less alike. It should be clear that in critical situations distraction from the primary task should be avoided when unnecessary, but that interruption of the primary task should be supported

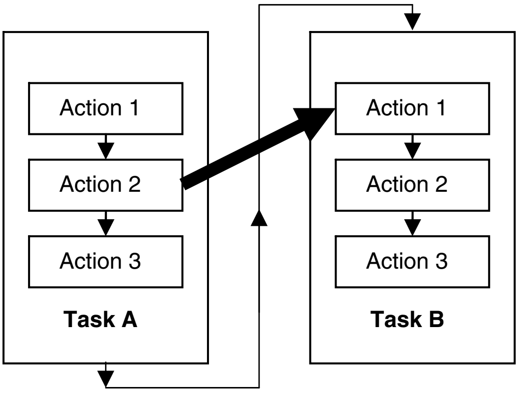

Fig. 1. Task switching. The thin arrows indicate sequential task execution, while the thick arrow indicates a task switch.

when necessary. To make this decision in a meaningful way, the system should have information on user goals and relevant task aspects.

Support for task switching has been designed, resulting in support systems for operators in emergency rooms (Neerincx, Grootjen, & Veltman, 2004). These systems used task aspects such as importance, time pressure and task interrelations. Based on these aspects they prompted the users when a task switch was necessary. Also, support for task switching has been designed for small mobile devices and users of mobile financial transaction services (Nagata, 2003). The system deployed certain interface elements, such as the Point of Return Indicator, which directed users' attention back to a specific point of a suspended task. A subsequent user study showed that these aids supported users effectively in continuing their work after an interruption (Nagata, 2003). In addition, interruptions had less impact when users expected an interruption to occur. Thus, creating anticipation of an interruption will facilitate task switching.

It should be clear that task interruption and switching influence attention. For the mobile police officer, support aids such as prioritization and visual aids in the interface can have a positive influence on performance in a multi-tasking mobile environment. Imagine an officer working with a mobile information system, carrying out a procedure. Suddenly, he receives an urgent notification which has a higher priority than the procedure. After attending this notification, he returns to the original task. In the interface, the procedure is shown just as he exited it, for example with a highlight around the next point.

In order for this aid to be employed meaningfully, the system needs to be aware of user goals and tasks. Further, it has to be able to check if officers are working on the task with the highest priority. By modeling this information, the interface and information presentation can be effectively adapted to support task switching.

2.3. Situation awareness

Situation awareness (SA) means you perceive and comprehend the situation around you. For a police officer, awareness of his environment is important for his functioning. For example, police officers scan their environment for criminal activity and take action when they notice it. Officers strive to obtain a complete overview of a situation and attempt to integrate all the relevant event, location and resource information. In a recent requirements analysis for mobile computing for police officers, prospected users indicated they would like to receive support in doing this (Baber, Haniff, Sharples, Boardman, & Price, 2001). In addition, they would like to be able to keep track of dynamic team information, such as the locations of colleagues and resources. This is difficult at the moment because of limited communication devices. In effect, they asked for support for situation awareness.

In our view, not merely the individual officer should be supported, but also a team of police officers as police work is often done in teams. So-called shared situation awareness is necessary for efficient cooperation and communication (Salas, Prince, Baker, & Shrestha, 1995). Dynamic adaptive systems can support teams, by allocating tasks to persons based on their functions, cognitive characteristics and momentary workload. This dynamic task allocation can ensure that tasks are performed by the right person at the right time (Neerincx et al., 2004).

In another sense, relevant to our current approach, SA in automated systems refers to the perception, comprehension and projection of system states (see Fig. 2) (Endsley, Bolte, & Jones, 2003). First, the user of a system has to perceive the state of the system: what is the system doing now? In what mode is the system? Normally, comprehension soon follows; based on what the user gave as input, the current system state should be comprehensible. Finally, again based on user actions, a prediction is made: if I do this, how will the system respond? Do I reach my goal with this response?

This process is fairly straightforward in a non-adaptive, desktop system. Contrasting, in mobile adaptive systems situation awareness is harder to maintain. Mobility means attention has to be divided between interaction with the system and with the environment. This diminishes perception and comprehension. In addition, adaptivity can cause inconsistencies in interaction, causing system states to be harder to predict (Alty, 2003).

SA is heavily dependent on the type of task the user has to perform and the level of routine a user has in executing the task. For routine tasks, situation awareness is less necessary for optimal task performance. Contrasting, in unfamiliar, highly critical tasks, such as crisis management, where multiple actions and interactions are required of the officer, SA is necessary yet harder to maintain. Support for maintaining situation awareness has been proposed in the form of a graphical overview of current tasks and their corresponding actions. In addition, current status of task, resources and persons is needed to maintain situation awareness (Neerincx, 2004).

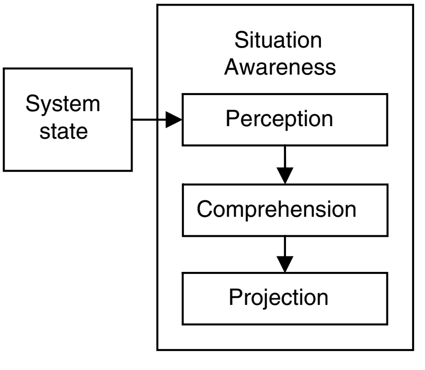

Fig. 2. Situation awareness (adapted from Endsley, 2000).

2.4. Conclusion

We have attempted to outline the role of attention in the mobile computing domain. When designing system support for attention, an accurate attention model is necessary, based on input from different sensors. This model subsequently guides system adaptations in information presentation, modality and interaction style. In our domain, task switching and situation awareness are two important processes that benefit from attention support. Thus, a context and task model should also incorporate task switching and SA aspects. Throughout this section, we have argued for system adaptation based on relevant task aspects, but not yet specified what elements of this "task" are important. Now we will turn to specifying the task aspects of our domain of application, the police work environment.

3. Task aspects for the mobile police officer

In our domain analysis of the mobile police officer, we used four user studies, a requirements analysis and an internal analysis. They are referred to where necessary. In addition, a workshop with Dutch police officers was held to give validation to the literature research. It is important to note that beside these sources a cognitive task analysis of the police officer in his work environment can be an invaluable source of information for design (Ioimo & Aronson, 2004; Neerincx, 2004). Example results of task analysis include knowledge on moments when a task can be interrupted or moments when this is absolutely not desirable. No such task analysis for police officers has been published yet.

The police officer's activities include three general tasks: emergency aid, law enforcement and criminal investigation. In emergency aid police officers have to respond to accidents and disasters, such as fires, floods or car crashes. This task is characterized by reactivity and urgency. Once the officer is notified of the accident, he proceeds to the accident scene as soon as possible. Here he has to execute certain protocols to manage and "solve" the accident. Contrasting, the task of criminal investigation is highly proactive. Before going out on the street, a police officer receives briefing on the assignments for that day. This information consists of descriptions of suspects, vehicles and relevant developments since the last briefing. Based on the assignment for the day, the mobile officer has to pay specific attention to events and objects in the street. Then, during debriefing, the officer reports acquired information and relevant developments.

Finally, in law enforcement, the officer is responsible for maintaining law and order in public spaces. Examples are police surveillance through shopping streets and at events such as football matches. The mobile officer has to be alert of criminal acts and has jurisdiction to intervene and apprehend suspects. Often, surveillance is done in teams of officers. For the moment, we are primarily concerned with the individual mobile police officer executing these three tasks. Recent requirements analyses for mobile computing for police officers identified four general requirements: access to accurate dynamic information, mobile information processing, prioritization and notification (Baber et al., 2001; Ioimo & Aronson, 2004).

3.1. Information

Timely access to accurate, dynamic information appears to be very important in the domain of law enforcement and criminal investigation. Easy and organized access to static information such as knowledge, procedures and forms is necessary (Mente, 2004). In addition, the officer needs task information such as his assignment, resource information such as database access, immediate information about incidents such as type and location (Baber et al., 2001). Previously, this kind of information was accessible only upon request via the operations room using a walkie-talkie. Assignments were presented orally combined with written notes during briefing and debriefing prior to work.

Recently, the police organization progressed towards direct mobile information access for the officer (Ioimo & Aronson, 2004; Stijnman, 2004; van Loon, 2004). Police officers could query databases and access digital briefing information using a PDA. User studies found that officers felt supported in their task execution and had easier access to information using these PDA's. This was above all beneficial for the mobile officer on foot and on bicycle. Officers indicated they felt information content was more accessible and easier to navigate through than before. However, users were dissatisfied with the implementation and interaction style. They had to create an opportune usage moment so they could devote their attention to interacting with the device. As a result, they could not maintain eye-contact with their environment. These results show that an optimal user-system interaction is necessary to benefit from potential advantages of mobile information access.

Police work is dependent on protocols and procedures that need to be followed. Officers want to be certain that they are working on the task with the highest priority and that they are not missing any information (Baber et al., 2001). To support these needs, proactive presentation and subsequent prioritization of procedures is necessary. In a mobile setting, a support system could (pro-actively) make procedures available using a PDA or another portable device. As was shown in other areas of research, a graphical display of the subsequent steps in a procedure and corresponding information can aid the user. This will greatly relieve the cumbersome task of remembering or searching for the right procedure (Abowd et al., 2002). An example is when an officer in the street needs to know whether a scooter is tampered with or not. When the system presents him with a list of points to check the scooter on, he will work more effectively.

Working with procedures also allows easy prioritization of tasks. In research on task switching, some support concepts for prioritization have been developed. These ensure efficient deployment of attentive resources (Neerincx et al., 2004). As it is, no support for prioritization has been implemented yet in mobile police work.

An important part of police work is to report information back to colleagues and the department. Usually, this is done during debriefing after work. The officer spends time processing information and writing reports. This process can be aided by enabling mobile information processing, whereby the police officer can send important information while mobile. For example, he can fill out forms on the spot or process information and send it to a database. After his shift, he has only to finalize the report. This will result in more up-to-date information at the department, as well as enable shared situation awareness in a team of police officers (Mente, 2004; Stijnman, 2004). A support system should take this functionality into account.

3.2. Notification

The police officers' attention should be guided to important events, information or objects in his environment. This is especially necessary in the domain of emergency aid. Early warning and notification on accidents and disasters are essential, because of the urgent nature of these incidents. In the domain of criminal investigation, notification can aid the police officer as well (Mente, 2004). An example is a system that automatically detects license plates on cars, compares them against a list of stolen vehicles and notifies the officer when a stolen vehicle is detected. In addition, video surveillance in public areas combined with intelligent picture processing can form the basis of an automated notification system that warns when riots or fights are imminent. This system is not yet in operation, but prototype development and testing show that it can be in the near future (Weitenberg, Jansen, van Leiden, Kerstholt, & Ferwerda, 2003). Using information from these systems, the police officer will be notified effectively.

3.3. Conclusion

From research with police officers, a need for accurate and timely information in their mobile work environment is evident in all primary tasks of law enforcement, emergency aid and criminal investigation. As it is, no attentive support for officers has been fully implemented yet. Attentive support should take into account the facts that the officer needs early warning and notification, access to and prioritization of procedures and the ability to process information while mobile. Special attention should go to the task the officer is trying to perform and the input/output options.

4. Context aspects

A police officer does not perform his tasks in isolation, but in rich interaction with the people and environment around him. Context aspects such as time, location, environment and social factors influence task execution in different ways. This section presents relevant context aspects of the mobile police officer.

There is no unequivocal definition of the concept of "context". It can be regarded as the complete surroundings of the user, including situation information, current user state, inferences on user behavior and long term properties of the user (such as knowledge, character, preferences in interaction style) that are relevant to the interaction between a user and a system (Jameson, 2001; Shafer et al., 2001).

As context influences the interaction, the assumption is that by making systems aware of their context, interaction can be made more relevant and useful (Lucas, 2001). Context-aware computing designates a research area in which devices, services or systems have access to context information. Context needs to be sensed and modeled to guide adaptations in system behavior. A simple example of context is user location. Imagine a dynamic travel information system on a mobile device equipped with global positioning system (GPS) receiver. This system has a context model containing the geographical coordinates of the device. The display will present the user's location and destination based on these coordinates; when the user moves, the systems adapts the display accordingly.

Three uses of context information are triggering automatic system behavior based on context (as in the example above), limiting the choice between possible actions and disambiguating users' goals and utterances (Shafer et al., 2001). To benefit from these potential uses of context-aware computing, the relevant context aspects should be modeled. Recent research has studied adaptive, context-aware systems in two mobile domains: crisis management (Jiang et al., 2004a; Vermeulen, 2004) and tourism (Cheverst et al., 2002; Jameson, 2002). We will review relevant examples and identify which context aspects are relevant for the mobile police officer.

4.1. Location and time

Two of the most widely used aspects of context are place and time. Location information can aid users in different ways. It can cause automatic system behavior at certain places, such as notification on important objects in the environment. Users' attention is directed to places of interest, once they are in proximity of such a place (Anhalt et al., 2001). Also, using location information, more relevant search results can be obtained. When a police officer searches for his nearest colleague, for example, the system provides him with results based on his own location (Anhalt et al., 2001; Baber et al., 2001). Police officers can be provided with location information on colleagues and incidents. Finally, by keeping track of locations of incidents, police officers can get an overview of where hot-spots of criminal activity are located. A location aware system could direct their attention when they are near such a spot (Mente, 2004).

Not only information access and notification benefit from context-awareness. Sensing location and using this to establish communication links can improve communication between team members. This so-called "ad-hoc network" enabled communication between aid workers in crisis situations (Abowd et al., 2002; Jiang et al., 2004a, Jiang, Hong, Takayama, & Landay, 2004b). All aid workers were equipped with a mobile communication device which was designed to make automatic connections to others, based on location and proximity. This resulted in a very robust communication network.

Sensing and recording when actions took place can be used for subsequent reporting and information access. In addition, time information can be used to make predictions on users preferences. When a user spends little time in one place, this can indicate a lack of interest. Finally, monitoring time can aid predictions on routine behaviors (Abowd et al., 2002; Kim et al., 2004).

4.2. Environmental factors

Environmental factors such as light, heat and noise influence the efficiency of attention allocation. Therefore, it makes sense to model these situational factors to guide adaptations in system behavior. For example, if the system is aware of the type of environment the user is in, such as a disaster area with a lot of noise and people running and shouting, the system behavior can be adapted to these circumstances. When lighting is insufficient, display luminance can be increased. When the user is in a noisy environment, notification can occur by alerting the touch senses (e.g. vibration) instead of via auditory modality. In addition, information exchange in such an environment could use graphical display of text instead of vocal communication (Cheverst et al., 2002).

Less trivial environmental factors include hazard warnings. Successful context-aware systems can detect high temperatures and hazardous gas development and notify users accordingly (Jiang et al., 2004b). In their task of emergency aid, police officers encounter such hazardous situations. By sensing relevant environmental factors, adaptive attention support for police officers will be made more meaningful and useful.

Social and physical interactions are an integral part of the police context and can also be regarded as part of the environment. A support system for mobile officers should not impede the user physically or socially during his work. For example, police officers already have many pieces of equipment to carry on their belts, such as handcuffs, pistol and note-taking equipment (Baber et al., 2001). Care should be given to the physical design of the system to allow him to react quickly, unhampered by physical constraints. The ability to maintain eye-contact with colleagues, other people and the environment was indicated as a necessity by police officers.

Possible solutions for these physical and social aspects come from recent technological developments. By integrating computers around the body and into clothes, designated by the term "wearable computing", the physical aspects of the human–system interaction can be addressed (Abowd, Dey, Orr, & Brotherton, 1997b). Displays can be positioned on the users forearm or mounted on glasses in the visual field of the user. Using this setup, it is easier to switch visual attention between the environment and the screen. In addition, this allows maintaining eye-contact with people and the environment.

Finally, a context-aware system should be aware of what means of transportation an officer currently uses, such as patrol cars, bicycles, horses, boats, etc. It is clear that an officer in a car will need different support than his colleague on horseback. In addition, when the system becomes aware of a change in transportation, it has to make sure the transition from for example car to mobile device occurs without interruption (Wahlster, 2003).

4.3. Conclusion

Summarizing the results from context-awareness research, the goal of using context information is to make interaction with a system more relevant, useful and robust. Using information on time, location and social and physical interactions and environmental factors such as light, noise, the mobile police officers can benefit from support such as notification to relevant objects, information access and ad-hoc communication networks. By making an attentive support system context-aware, support can be made more relevant.

Limitations of automatic adaptation based on context are that in order for adaptation to be meaningful, sensing context is not enough. The question why the user exhibits his behavior as he does, has to be answered (Abowd et al., 2002). This is an important step towards predicting user behavior. Without some way of prediction, automatic adaptation cannot reach its full potential (Isbell, Omojokun, & Pierce, 2004). Furthermore, there is no such thing as a prototypical user. Automatic system adaptation will work for one user, but can have negative consequences for the next. We will address user modeling and individual differences in the next section on personalization.

5. Personalization

We have investigated relevant cognitive, task and context aspects of mobile human–computer interaction for police officers. Up to now, we have discussed "the police officer" as a prototypical user with no characteristics, preferences or beliefs of his own. Research showed that individual differences in attention, working memory and spatial ability do exist (Derryberry & Reed, 2001; Vicente, Hayes, & Willeges, 1987) and are relevant for task performance. For example, research from neuropsychology shows anxious persons are particularly attentive to threatening information (Derryberry & Reed, 2001). Also, individual differences in control over attentive functioning are evident as some people are more readily distracted than others (Derryberry & Reed, 2001). Younger people generally have better spatial ability than elderly people. Individuals with higher working memory capacity exhibit greater attentional control (Conway & Kane, 2001). These findings show individual users have different needs for support. Personalization is aimed at providing this support.

5.1. User modeling

In Section 1, we presented personalization as the adaptation of system behavior to individual users, tasks and context, based on accurate user, context and task models (Jameson, 2001). There is no clear division between user and context model as elements from one influence the other and both should be taken into account (Jameson, 2001). In context-aware systems, modeling relevant user information is important. Examples include user history and preferences. User history can be monitored implicitly, by observing the user interacting with the system. Additionally, the user can state preferences explicitly. The system subsequently adapts the interaction, modality of output or information presentation, such as delivering a tactile rather than auditory notification in social situations.

To model the individual police officer, a user model can include elements such as notification preferences, duties, expertise, mode of transport and individual differences in attention. The duties or expertise of a police officer can be used to facilitate cooperation between team members. Anhalt and colleagues propose a system called "Matchmaker" that facilitates cooperation between novices and experts based on proximity and expertise (Anhalt et al., 2001). This kind of service could be used to aid police officers, for example in crises situations, to consult experts that are nearby in a disaster area. A user model containing information about expertise and availability could make this match effectively.

Because the user model itself can be adapted, personalization is a dynamic process. It can start with a generic user model which is further attuned to the individual user by modeling and sensing user behavior via relevant user profiling techniques (Neerincx et al., 2006). Examples of personalization in mobile computing come from the PALS project, where a personal assistant was developed which attuned the interaction based on user and context models. Within the PALS project, we aim to show that personalization is a powerful tool to ensure optimal user-system interaction and that it can be used to cope with a diversity of users and devices (Neerincx et al., 2006). For our current research effort, we expect personalization to optimize the interaction between the individual officer and an attentive support system.

5.2. Conclusion

Concluding from our discussion so far, there is a clear need for a system that attracts, guides and maintains individual police officers' attention in a mobile setting. By modeling the relevant cognitive, task, context and user aspects (summarized in Table 1), improvements in deployment of attention can be achieved. Personalization can further optimize this by attuning the interaction to individual characteristics and preferences.

The research described above made progress towards the development of PAUI and some results are directly applicable to our effort. In the next section of this paper, a user-centered design methodology will be presented to show its applicability in the design of PAUI. Using the concept of PAUI as stated in Section 1 and an actual usage scenario, we aim to define and specify collaboration styles and user requirements.

Table 1
The main conclusions on the relevant cognitive, task, context and user aspects described in the previous sections

Section 2. Cognitive aspects	
Attention	A model of momentary attentive state of the user guides adaptations in information presentation, modality and interaction style
Working memory	By using prioritization and limiting information presentation, working memory overload will be avoided
Task switching	Task switching should be supported by prioritization and interface elements
Situation awareness	Situation awareness should be supported by a graphical overview of tasks
Section 3. Task aspects	
Information access	Access to static and dynamic task-related information in a mobile environment
Prioritization	Prioritization of procedures relieves limited cognitive resources
Notification	Early warning and notification to relevant information or objects in the environment
Section 4. Context aspects	
Location Time Environment	The geographical location of the officer, the time of day and relevant elements from the environment such as heat, noise, light, momentary social interaction and mode of transport should be incorporated in a context model
Section 5. User aspects	
Preferences, duties, expertise and individual differences	A user model should contain the preferences, duties, expertise of individual officers. This model guides subsequent adaptations in information presentation, modality and interaction style

6. Designing for attention

Now that we have our relevant cognitive, task and context aspects for mobile attention support, we will present our approach to designing for attention in this section. There are a variety of different approaches to designing for human–computer interaction. We will use the usability engineering approach which incorporates scenario-based design (Carroll, 2000). The process is shown in Fig. 3 (Neerincx et al., 2006). In short, this is a user-centered design (UCD) process involving the iterative creation, assessment, refinement and validation of personalization features. These features are aimed to provide an added value for the end-user (cf. "the personalization feature space", Alpert, Karat, Karat, Brodie, & Vergo, 2003).

This process starts with the definition of a concept (see Fig. 3, left side), which is a general, broad description of the proposed system. Then, a scenario is drafted from the relevant usage context. Basically, scenarios describe users, their tasks and the context in which they carry out these tasks in a comprehensive style. Scenarios are not meant to give a complete and exhaustive picture; instead they focus on the general design rationale and intended use. From this scenario collaboration styles are defined which indicate how the system interacts with the user. For example, the system can either be passive or pro-active in information exchange with the user. Next, user requirements are derived. These requirements will be based on the relevant cognitive, task and context aspects. Finally, collaboration styles and user requirements form the basis of the features. As we progress from concept to features, the level of detail increases.

Assessment of the collaboration styles, user requirements and features is done by validating them to objective quality criteria, such as established HCI metrics (see Fig. 3, right side). Effectiveness, efficiency and satisfaction are established criteria for evaluating

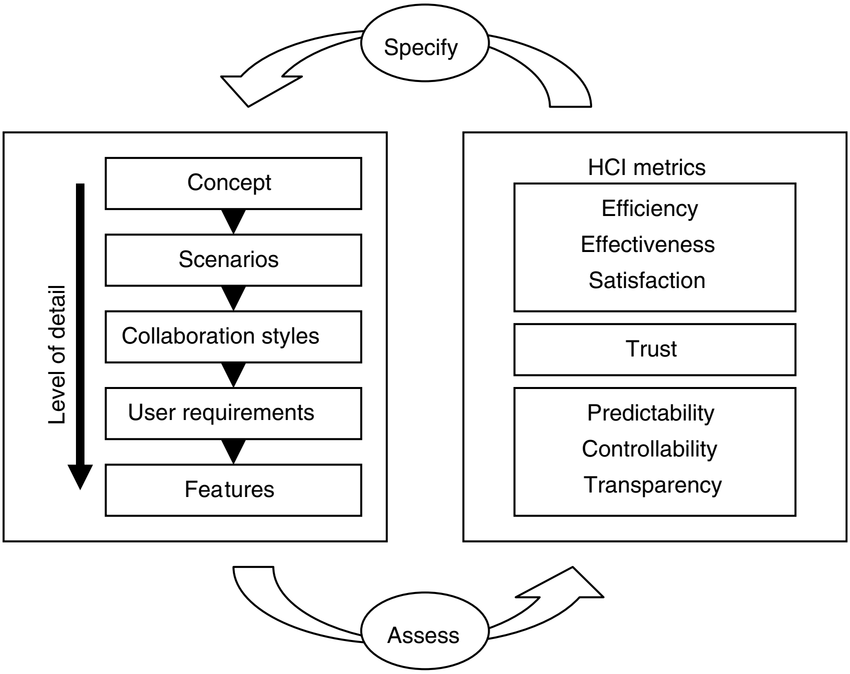

Fig. 3. The user-centered design (UCD) process.

human–computer interaction (ISO 9241-11, 1998). A relatively new but important aspect is trust, whether or not the user trusts the system (e.g. Parasuraman & Miller, 2004; Wang & Emurian, 2005). Trust has influence on user acceptance and user experience (Neerincx & Streefkerk, 2003). Specific criteria for usability of adaptive systems include aspects such as predictability (Cheverst et al., 2002), controllability and transparency (Nagata, 2003; Paymans & Lindenberg, 2004). Empirical evaluation should determine to what extent our design meets these user experience criteria.

It is important to note that this UCD approach is an iterative process, with a full cycle including the assessment of the proposed features on the HCI metrics, and the further specification of these features based on this assessment. This cycle will result in detailed description of the intended human–machine interaction and personalization features.

In the remainder of this paper, we will translate the relevant cognitive, task, context and user aspects from Table 1 into collaboration styles and user requirements for our envisioned PAUI, using a relevant scenario from the police work environment.

6.1. Concept

We began defining our concept of PAUI in Section 1. We envision an adaptive attention support system that has specific knowledge about user, context and task. Based on previous research, four aspects of our support system are important. Our system

1. Attracts the attention of the user to high priority events and objects ("notification").
2. Adapts to the attention of the user ("attentive").

3. Adapts to the individual user and context ("personalized and context aware").
4. Uses multimodal input and output means.

6.2. Scenario

During a recent workshop, Dutch police officers were asked to describe where they saw benefits of attentive support in their work environment and to illustrate these benefits in scenarios. Eighteen executive and management personnel of the Dutch Police organization participated voluntarily in this workshop. First, the participants received a presentation to introduce the concept of "Attentive Services" from one of the authors. Using relevant previous projects, attentive services were showed to be context and location aware and personalization was shown to be feasible. The second presentation by a coworker of the Dutch Police organization dealt with relevant developments and the prospected place of "Attentive Services" within this organization (Mente, 2004). Thereafter, participants took 2 h to generate three scenarios in three independent groups of six officers. Each group had a moderator, who instructed the participants to focus on benefits of attentive support, drawing on real-life work experiences. In addition, they were instructed not to focus on technical feasibility.

In every scenario, participants used examples from the domains of criminal investigation, emergency aid and law enforcement to illustrate expected benefits of attentive support. The benefits ranged from early warning and notification of accidents to dynamic task allocation between team members. At the end of the workshop, one scenario was elected by the participants as showing most benefits of attentive services. In Table 2, a part of this scenario is presented (simplified for illustrative purposes). From this scenario, crucial factors are identified. These factors, combined with the aspects

Table 2
Illustrative scenario from the mobile police domain

Attention guided police work
Police officer Bob receives a briefing before work. His team gets an assignment (Rq. U) to check out a disturbance report and is instructed to focus on pick pocketing and gang-activity. Bob straps his wrist display on and enters in his profile (Cs. D) that he wants to be informed of an important court case that is serving today (Rq. U). While cycling on patrol in the centre of Utrecht (Rq. U), his location aware system notices that Bob is near a hotspot of gang-activity. A colleague entered this information in the database yesterday. The system notifies Bob (Cs. P) that he is close to the hotspot and Bob decides to check six adolescents sitting nearby
While Bob interrogates the adolescents, a report comes in about a burglary. The system holds back the notification (Cs. I), because it senses that Bob cannot be disturbed (Rq. A) and the priority is low (Rq. T). The notification is kept to a minimum by only showing an icon on the display. When Bob is finished with the youths, the system gives a vibration to his wrist (Cs. P). Bob notices the icon, presented on a map (Rq. T). Hecycles to the indicated location while the system gives him auditory directions (Cs. P)
When Bob arrives, he asks (Cs. D) the system to provide him with the relevant procedure for handling a burglary case (Rq. I). The correct procedure is accessed by the system and the wrist display shows the actions Bob has to take (Rq. T). He is filling out the form on the burglary, the last action in the procedure, when suddenly he receives an urgent notification (Cs. P) about a team member in need of backup. He rushes to his colleague, abandoning the task (Rq. T). When he has verified all is well with the officer, his system notifies him (Cs. P) that there is still a form waiting to be filled out. When Bob is finished, he sends his information to the database (Rq. I) and returns to his patrol. His wrist display beeps and vibrates (Cs. I), drawing his attention to the screen (Rq. N, Rq. A). The court case was successful and the perpetrator was convicted

This scenario is a simplified and shortened version of the scenario from the workshop. The codes refer to collaboration styles (Cs.) and requirements (Rq.), which are described in Tables 3 and 4, respectively.

from the literature analysis from Table 1, are translated into user requirements for PAUI.

6.3. Collaboration styles

From the scenario, several collaboration styles are identified. These styles are illustrated in the scenario and presented in Table 3. First, Bob can directly ask the system to provide him with information, such as the relevant procedure in the burglary case. This collaboration is in effect the most analogous to traditional information requests. This is a "directed" (Cs. D) collaboration style in which the user is the pro-active part and the system more passive.

Second, the system can be more "pro-active" (Cs. P) in providing assistance and information such as notification based on location or duties. Bob is notified by the system that he is in the vicinity of a gang-activity zone, or he is automatically directed to the location of the burglary. Also, when Bob wants to pick up the procedure where he left off, the system aids him in this respect.

Finally, the third collaboration style that is currently part of the scenario is "independent" (Cs. I) whereby the system halts potentially distracting notifications until the user can be disturbed. In the scenario, a notification with less priority was halted until Bob was finished interrogating the adolescents. Here, the expected added value of our attentive support system becomes evident. The system has to be able to reason about the users' attentive state, and adapt its behavior independently.

6.4. User requirements

We will now translate the relevant cognitive, task, context and user aspects into user requirements. Based on our scenario and collaboration styles, an overview is presented in Table 4. The user requirements are illustrated in the scenario. In short, the system will need information on location, attentive state and preferences of the user. In addition, information on users' activities, duties and their priorities is necessary.

6.5. Features

From the workshop mentioned earlier, some useful features resulted which are directly applicable to our current effort. For instance, when police officers in the scenarios were

Table 3
Overview of the collaboration styles for PAUI

Collaboration style	Description
Directed (Cs. D)	The officer asks directly for information from the attention aware system (i.e. analogous to "traditional" information requests). For example, Bob can directly ask the system to provide him with information
Pro-active (Cs. P)	The system provides pro-active support such as notifications. For example, Bob is notified by the system that he is in the vicinity of a gang-activity zone
Independent (Cs. I)	The system undertakes independent action based on user, context or task aspects. For example, the system halts potentially distracting notifications until the officer can be disturbed

The codes used in the scenario are between parentheses.

Table 4
Overview of the relevant user requirements for PAUI

User requirement	Description
Adaptation to attention (Rq. A)	The attention aware system knows when the officer is available, when he is "interruptible". The interaction is adapted to fit the attentive state of the user and relevant context. E.g. in the scenario, the system halts non-necessary interruptions
Notification (Rq. N)	Notification on high-priority objects and events through multiple modalities based on relevant task and context aspects. E.g. Bob is notified to the court case based on his preferences
Task switching support (Rq. T)	Prioritization of tasks ensures officer is working on the most relevant task. When switching is necessary, system guides the user through a switch and back with interface adaptation and presentation of information. E.g. Bob can resume working on the procedure just where he left off
Information support (Rq. I)	The system supports the user with relevant task information such as procedures. Also, it acts as a communication device between team members and the central information database. E.g. the system presents Bob with the relevant procedure on the burglary case
User model (Rq. U)	The user and system can both change the user model which guides the adaptivity of the system. User model contains preferences, cognitive style, team duties, etc. E.g. Bob can tell the system to notify him when necessary

The codes used in the scenario are between parentheses.

confronted with a traffic accident involving a truck with chemicals, they would like to receive notification to maintain enough distance. They envisioned this notification to come from a wearable computing jacket which delivered a vibration to the chest. At the same time, they would receive an auditory message in their earpiece, telling them to maintain safe distance. Another feature of the envisioned system included the dynamic allocation of tasks when a team gets an assignment to handle a hostage situation involving an officer. This allocation was based on the location of nearby colleagues and expertise. Finally, another group of officers saw benefits in automatic license plate recognition. The (wearable) system will notify the officer once a stolen vehicle is detected.

6.6. Conclusion

In this section, we have translated our cognitive, task, context and user aspects into collaboration styles and user requirements using a user-centered design approach. This resulted in three collaboration styles (directed, pro-active and independent) and into five user requirements (adaptation to attention, notification, task switching support, information support and user model). Using a simplified scenario from a workshop with police officers, these styles and requirements were illustrated. This workshop is the first step towards validation of our development of PAUI for mobile police officers. These features will be further specified in subsequent workshops, following the iterative design approach proposed in this paper.

7. Discussion

In this paper, the concept of PAUI for the mobile public service domain was defined and specified. We envision an adaptive support system for individual mobile police officers, based on relevant cognitive, task, context and user aspects (see Table 1). Using a UCD approach, collaboration styles and user requirements are defined. We aim to continue working on this concept to reach generic techniques and guidelines for attentive support in the mobile setting.

However, the design of adaptive, context-aware support systems is not unequivocal. There are some challenges we need to overcome. First of all, the challenge in designing these systems lies in designing system behavior that is still meaningful for the user, given a current or future task (Shafer et al., 2001). As such, a trade-off exists between adaptivity and predictability, or consistency. As we said in Section 6, predictability of a system is a prerequisite for an optimal user experience (Nagata, 2003). Also, users will need and want to understand why certain adaptations were made, especially when these adaptations are not consistent over time, place and user. Empirical evaluation through user tests and field studies is needed to find a balance between these factors. Secondly, the success of our adaptive support system relies in part on accurate predictions about user goals and tasks. This has proven difficult yet feasible, due to recent developments in statistical modeling techniques (Horvitz et al., 2003; Isbell et al., 2004). For example, goal-oriented adaptation aims to use formal models to guide the prediction of user behavior. In addition, generalization on the basis of earlier user behavior (when in situation A, users' next move will be move X, based on earlier behavior) can serve as an "educated guess" (Weld et al., 2004).

In addition to personalization for the individual user based on a user model, we aim to provide support for a whole team of users. Here, a balance must be struck between shared situation awareness and personalization as every individual within a team has his own user model. How can, for example, information presentation be adapted, when a whole team has to cooperate? How do we support the diverse attentive states of multiple team members? These questions will have to be addressed in this research project.

Specific challenges for PAUI for mobile police officers include the acceptance of the proposed system and issues of privacy and security. User studies show acceptance rates of new technological developments such as mobile information access not to be very high. Also, in implementing such systems the organizational structure of the police organization has to be taken into account (Stijnman, 2004). In addition, police management is concerned with the security of information when it becomes accessible for the mobile officer. Where is the information stored: locally on a data-terminal, or in a central database? What if a terminal is stolen or lost? Furthermore, the privacy of the police officer can be violated when his support system gathers information about his behavior and preferences. Who has access to this information? These ethical issues cannot be ignored.

The underlying assumption of this paper is that the technology for such a system is available in the near future. We have not yet focused on technical feasibility of our proposed concept. Within our continuing research effort we will address the development of the system's architecture and sensing techniques.

8. Conclusions and further research

In the mobile public service domain increasingly more information becomes available due to connection to networks (mobile connectivity), increasing (multimedia) databases and environment sensing techniques. Task interruption and distraction of attention is a threat to efficient and effective interaction in such dynamic and information-rich environments. This paper uses an existing design approach to improve the deployment of attentional resources for mobile police officers.

Literature and domain analyses presented in this paper show that no attentive support for police officers has been fully implemented yet. It is also shown that this support is necessary and preferred by police officers. From these analyses we have deduced which cognitive, task and context aspects are important in the development of PAUI. Furthermore, we presented a UCD approach for the iterative design and evaluation of PAUI, consisting of defining concepts, scenarios, collaboration styles, user requirements and features. Finally, requirements analysis showed that an attentive support system should adapt to the attentive state of the user, notify the user to high-priority objects and events, support information processing and task switching, and contain a user model to guide adaptations for individual users (personalization). We identified several important attributes of these adaptation requirements and a set of PAUI features. In designing attentive support systems, care should be given to creating meaningful system behavior through accurate predictions on user goals and behavior.

Through empirical evaluation we will refine and prove the models, guidelines and requirements proposed in this paper. We plan user studies to validate our proposed concept of PAUI. In parallel, systems' architecture and sensing techniques research will be conducted. Our goal is to establish generic guidelines for the design of attentive support systems in the mobile domain, and to implement these guidelines in a working system. A pilot implementation for the Dutch police will start at the end of 2005 in the Netherlands.

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References

Abowd, G., Atkeson, C., Hong, J. I., Long, S., Kooper, R., & Pinkerton, M. (1997a). Cyberguide: A mobile context-aware tourist guide. *ACM Wireless Networks, 3*, 421–433.

Abowd, G., Dey, A., Orr, R., & Brotherton, J. (1997). Context-awareness in wearable and ubiquitous computing. In *Proceedings of the first international symposium on wearable computing* (pp. 179–180).

Abowd, G., Mynatt, E., & Rodden, T. (2002). The human experience. *Pervasive Computing, 1*, 48–57.

Allport, A. (1989). Visual attention. In M. I. Posner (Ed.), *Foundations of cognitive science* (pp. 631–682). Cambridge: MIT.

Alpert, S., Karat, J., Karat, C.-M., Brodie, C., & Vergo, J. (2003). User attitudes regarding a user-adaptive ecommerce web site. *User Modeling and User-Adapted Interaction, 13*, 373–397.

Alty, J. (2003). Cognitive workload and adaptive systems. In E. Hollnagel (Ed.), *Handbook of cognitive task design* (pp. 129–146). Mahwah: Lawrence Erlbaum Associates.

Anhalt, J., Smailagic, A., Siewiorek, D., Gemperle, F., Salber, D., Weber, S., et al. (2001). Toward context-aware computing: Experiences and lessons. *IEEE Intelligent Systems, 16*, 38–46.

Baber, C., Haniff, D., Sharples, M., Boardman, M., & Price, A. (2001). A requirements analysis of personal mobile computers for police officers. In D. Harris (Ed.), *Engineering psychology and cognitive ergonomics. Industrial ergonomics, HCI, and applied cognitive psychology* (Vol. Six, pp. 21–28). Aldershot: Ashgate.

Bartram, L., Ware, C., & Calvert, T. W. (2003). Moticons: Detection, distraction and task. *International Journal of Human–Computer Studies, 58*, 515–545.

Carroll, J. M. (2000). *Making use – scenario-based design of human–computer interactions*. Cambridge: MIT Press.

Cheverst, K., Mitchell, K., & Davies, N. (2002). Exploring context-aware information push. *Personal and Ubiquitous Computing, 6*, 276–281.

Conway, A., & Kane, M. (2001). Capacity, control and conflict: An individual differences perspective on attentional capture. In C. Folk & B. Gibson (Eds.), *Attraction, distraction, and action: Multiple perspectives on attentional capture* (pp. 349–372). Amsterdam: Elsevier.

Derryberry, D., & Reed, M. (2001). A multidisciplinary perspective on attentional control. In C. Folk & B. Gibson (Eds.), *Attraction, distraction, and action: Multiple perspectives on attentional capture* (pp. 325–347). Amsterdam: Elsevier.

Endsley, M. R. (2000). Theoretical underpinnings of situation awareness: A critical review. In M. R. Endsley & D. J. Garland (Eds.), *Situation awareness analysis and measurement* (pp. 3–32). Mahwah, NJ: LEA.

Endsley, M., Bolte, B., & Jones, D. (2003). *Designing for situation awareness: An approach to user-centered design*. New York: Taylor & Francis.

Fischer, G. (2001). User modeling in human–computer interaction. *User Modeling and User-Adapted Interaction, 11*, 65–86.

Horvitz, E., Kadie, C., Paek, T., & Hovel, D. (2003). Models of attention in computing and communication: From principles to application. *Communications of the ACM, 46*, 52–59.

Ioimo, R., & Aronson, J. (2004). Police field mobile computing: Applying the theory of task-technology fit. *Police Quarterly, 7*, 403–428.

Isbell, C. L., Omojokun, O., & Pierce, J. S. (2004). From devices to tasks: Automatic task prediction for personalized applicance control. *Personal and Ubiquitous Computing, 8*, 146–153.

ISO 9241-11 (1998). Ergonomic requirements for office work with visual display terminals (VDTs) – Part 11: Guidance on usability (Rep. No. 9241-11).

Jameson, A. (2001). Modeling both the context and the user. *Personal and Ubiquitous Computing, 5*, 29–33.

Jameson, A. (2002). Usability issues and methods for mobile multimodal systems. In *Proceedings of the ISCA tutorial and research workshop on multi-modal dialogue in mobile environments* (pp. summary of a keynote address). Kloster Irsee, Germany.

Jameson, A., Schäfer, R., Weis, T., Berthold, A., & Weyrath, T. (1999). Making systems sensitive to the user's time and working memory constraints. In M. T. Maybury (Ed.), *Proceedings of the fourth international conference on intelligent user interfaces* (pp. 79–86). New York: ACM.

Jiang, X., Chen, N. Y., Hong, J. I., Wang, K., Takayama, L., & Landay, J. A., (2004a). Siren: Context-aware computing for firefighting. In *Proceedings of Pervasive 2004*, Vienna, Austria.

Jiang, X., Hong, J. I., Takayama, L., & Landay, J. A. (2004b). Ubiquitous computing for firefighters: Field studies and prototypes of large displays for incident command. In *Proceedings of CHI 2004* (pp. 679–686). Vienna, Austria: ACM Press.

Kim, S. W., Park, S. H., Lee, J. B., Jin, Y. K., Park, H., Chung, A., et al. (2004). Sensible appliances: Applying context-awareness to applicance design. *Personal and Ubiquitous Computing, 8*, 184–191.

Klapp, S. T. (1987). Short-term memory limits in human performance. In P. A. Hancock (Ed.), *Human factors psychology* (pp. 1–28). North-Holland: Elsevier.

Krug, K., Mountain, D., & Phann, D. (2003). Webpark. Location-based services for mobile users in protected areas. *GeoInformatics, 6*, 26–29.

Kun, A., Miller, W., III, & Lenharth, W. (2004). Computers in police cruisers. *Pervasive Computing, 3*, 34–41.

Lucas, P. (2001). Mobile devices and mobile data – issues of identity and reference. *Human Computer Interaction, 16*, 323–336.

McCrickard, S., Catrambone, R., Chewar, C., & Stasko, J. (2003). Establishing tradeoffs that leverage attention for utility: Empirically evaluating information display in notification systems. *International Journal of Human–Computer Studies, 58*, 547–582.

Mente, R. (2004). Internal Analysis Notification Services CIP [Interne verkenning Attenderings services CIP], Unpublished report.

Nagata, S. (2003). Multitasking and interruptions during mobile web tasks. In *Proceedings of the human factors and ergonomics society 47th annual meeting* (pp. 1341–1346). St. Louis, MO: Mira Digital Publishing.

Neerincx, M. A. (2004). Cognitive task load analysis: Allocating tasks and designing support. In E. Hollnagel (Ed.), *Handbook of cognitive task design* (pp. 283–306). Mahwah: Erlbaum.

Neerincx, M. A., Grootjen, M., & Veltman, J. (2004). How to manage cognitive task load during supervision and damage control in an all-electric ship. *IASME Transactions, 1*, 253–258.

Neerincx, M. A., Herder, E., Lindenberg, J., van Dijk, E. M. A. G., Nagata, S. F., & Zwiers, J., et al. (2006). User-centered user modeling for ubiquitous service access. UMUAI special issue on User Modeling in Ubiquitous Computing, in press.

Neerincx, M. A., & Streefkerk, J. W. (2003). Interacting in desktop and mobile context: Emotion, trust and task performance. In E. Aarts, R. Collier, E. van Loenen, & B. de Ruyter (Eds.), *Ambient intelligence: EUSAI 2003 Lecture notes in computer science* (pp. 119–132). Berlin: Springer.

Neerincx, M. A., van Doorne, H., & Ruijsendaal, M. (2000). Attuning computer-supported work to human knowledge and processing capacities in ship control centres. In J. M. C. Schraagen, S. Chipman, & V. Shalin (Eds.), *Cognitive task analysis* (pp. 341–362). Mahwah: Erlbaum.

Parasuraman, R., & Miller, C. (2004). Trust and etiquette in high-criticality automated systems. *Communications of the ACM, 47*, 51–55.

Pashler, H., Johnston, J., & Ruthruff, E. (2001). Attention and performance. *Annual Review of Psychology, 52*, 629–651.

Paymans, T., & Lindenberg, J. (2004). Usability trade-offs for adaptive user interfaces: Ease of use and learnability. In *Proceedings of the IUI conference 2004* (pp. 301–303). New York: ACM Press.

Salas, E., Prince, C., Baker, D., & Shrestha, L. (1995). Situation awareness in team performance: Implications for measurement and training. *Human Factors: Special Issue on Situation Awareness, 1*, 123–136.

Shafer, S., Brumitt, B., & Cadiz, J. (2001). Interaction issues in context-aware interactive environments. *Human Computer Interaction, 16*, 363–378.

Stijnman, G. (2004). Evaluation Pilot Mobiel Blauw [Evaluatie Pilot Mobiel Blauw], Unpublished report.

van Esch-Bussemakers, M., Cremers, A., Neerincx, M. A., & van der Flier, A. (2003). Deriving the optimal modality combination for mobile search in multimedia databases. In IADIS international WWW/Internet 2003 conference.

van Loon, M. (2004). Digital briefing [Digitale Briefing]. *APB, 22*, 16–17.

Vermeulen, B. (2004). Freeband SPEARS Final Report: A scalable personal area services platform (Rep. No. Freeband/SPEARS/D1.13). Enschede: Telematica Instituut.

Vertegaal, R. (2002). Designing attentive interfaces. In *Proceedings of the symposium on eye tracking research and applications* (pp. 23–30). New York: ACM Press.

Vicente, K., Hayes, B., & Willeges, R. (1987). Assaying and isolating individual-differences in searching a hierarchical file system. *Human Factors, 29*, 349–359.

Wahlster, W. (2003). Smartkom: Symmetric multimodality in an adaptive and reusable dialogue shell. In Krahl, R., & Gunther, D. (Eds.), *Proceedings of the human computer interaction status conference* (pp. 47–62), Berlin.

Wang, Y., & Emurian, H. (2005). An overview of online trust: Concepts, elements, and implications. *Computers in Human Behavior, 21*, 105–125.

Weitenberg, N., Jansen, N., van Leiden, I., Kerstholt, J., & Ferwerda, H. (2003). Camera surveillance: the human factor [Cameratoezicht: de menselijke factor] (Rep. No. TM - 03 - C037). Soesterberg: TNO Human Factors.

Weld, D. S., Anderson, C. R., Domingos, P., Etzioni, O., Gajos, K., & Lau, T. A. et al. (2004). Automatically personalizing user interfaces. In *International joint conference on artificial intelligence (IJCAI) 2003* (pp. 1613–1619), Acapulco, Mexico.

Wickens, C. D. (1987). Attention. In P. A. Hancock (Ed.), *Human factors psychology* (pp. 29–80). North-Holland: Elsevier.

Wood, S., Cox, R., & Cheng, P. (2004). Attention design: seven issues to consider. In *Workshop, Designing for attention, 18th human computer interaction group annual conference*, Leeds, UK.

York, J., & Pendharkar, P. C. (2004). Human–computer interaction issues for mobile computing in a variable work context. *International Journal of Human–Computer Studies, 60*, 771–797.

Zhai, S. (2003). What's in the eyes for attentive input. *Communications of the ACM, 46*, 34–39.