Mobile assisted living – concepts and evaluation to design user-centric pedestrian navigation aids

Michael Schellenbach
Max Planck Institute for Human Development
Lentzeallee 94, 14195 Berlin, Germany
schellenbach@mpib-berlin.mpg.de

Antonio Krüger
Institute for Geoinformatics
University of Muenster
Robert-Koch-Str. 26-28, 48149 Münster, Germany
antonio.krueger@uni-muenster.de

Martin Lövdén
Max Planck Institute for Human Development
Lentzeallee 94, 14195 Berlin, Germany
loevden@mpib-berlin.mpg.de

Ulman Lindenberger
Max Planck Institute for Human Development
Lentzeallee 94, 14195 Berlin, Germany
lindenberger@mpib-berlin.mpg.de

ABSTRACT
Mobile devices to assist persons in their everyday life need to take into account the context of use, including different types of input in order to react to changing cognitive as well as to haptic constraints. In this paper we discuss psychological concepts to evaluate the usability of assistive mobile devices. In our approach we use a laboratory evaluation framework to examine devices based on these concepts. Finally, we present a first experiment to show the association between cognitive ability and walking.

Author Keywords
Evaluation, navigation, mobile devices.

ACM Classification Keywords
H.5.2 [**User Interfaces**]: Ergonomics, Evaluation/ methodology.

INTRODUCTION
Many work settings in modern societies require mobility. A substantial portion of this mobility requires spatial navigations skills, and is pedestrian in kind. For instance, firm representatives need to visit their clients, security officers need to control buildings, and employees of postal and delivery services need to deliver mail and goods to companies and private households. The average age of employees working in these various sectors is steadily increasing, and mandatory retirement is postponed to later ages. The general goal of our approach is to explore and evaluate the potential of assistive technology for supporting aging employees in pedestrian spatial navigation. The specific goal is to design concepts for a device that effectively enhances pedestrian navigation performance among aging individuals. Cognitive resources such as executive control operations, working memory, and binding mechanisms evince age-associated decline, with pronounced negative consequences on spatial navigation skills. At the same time, sensory and sensorimotor aspects of behavior are increasingly in need of cognitive resources with advancing age. In combination, these two changes result in increasing demands on decreasing resources, thereby constituting the quandary of behavioral aging [12]. Paradoxically, the operation of assistive technology aimed at attenuating the consequences of this quandary also entails cognitive resource investments. Hence, the use of assistive technology is adaptive only if the costs required for its operation are lower than the payoffs associated with other changes in processing. We adopt criteria of successful development derived from lifespan psychology [1] to guide the design and evaluation of assistive technology in old age (cf. [9]). We predict that spatial navigation support, if tailored to the needs and capabilities of aging individuals, will result in two beneficial consequences: (a) it will increase spatial navigation (e.g., way-finding success) by providing task-relevant navigation prompts; (b) it will enhance walking stability by releasing cognitive resources formerly needed for postural control. Based on earlier work [12], we propose to test these predictions in a controlled and ecologically valid manner by means of virtual environments equipped with a walking interface. Technologically, we plan: (a) to critically evaluate available navigation aids on both objective and user-perceived criteria; and (b) to design concepts for a novel pedestrian navigation aid that effectively enhances older adults' spatial navigation and walking stability.

[S. 23 - 33]

THEORY-GUIDED DESIGN AND EVALUATION OF ASSISTIVE TECHNOLOGY

Recent years have witnessed increasing efforts at improving and expanding assistive technology for diverse segments of the aging population [3,5,6], but technological and psychological inquiries have rarely been merged into concerted efforts. Based on the selection, optimization, and compensation (SOC) model of successful development [13], Lindenberger and Lövdén [8] specified three criteria for the utility of assistive technology in relation to SOC mechanisms. First, assistive technology usually comes at a cognitive cost because its operation requires an investment of sensory/sensorimotor and cognitive resources. The use of assistive technology is adaptive only when requiring fewer resources than it releases and the marginal resource gain associated with selecting assistive technology thus is positive. This point is analogous to the definition of successful aging in terms of maximization of gains and minimization of losses [1]. To enhance the likelihood of marginal resource gains, design of assistive technology has to incorporate knowledge about negative adult age changes beyond the target activity, such as spatial navigation, and consider a broader set of domains, such as sensorimotor functioning.

Second, cognitive and sensorimotor functioning are variable within and across individuals [10]. Utilizing knowledge about the average aging individual provides just a starting point for the development of assistive technology. To be successful, assistive technology must fine-tune itself to the idiosyncrasies of the individual's behavior, to his or her specific competencies, habits, and preferences. This process of fine-tuning critically requires the evolution of an adaptive external cuing structure that matches the structure of the individual's action space. Specifically, the technology has to capture the regularities in a given individual's behavior, and needs to react or adapt to the user's fluctuations and long-term changes in competencies (cf. [2,6]).

Third, the effects of assistive technology are modulated by historical and ontogenetic context. Historically, prior lifespan exposure to the same or related technologies is likely to influence both the usage and the marginal gain of assistive technology in old age through positive or negative transfer. For example, relatively few of today's generation of 60-70 year old are likely to embrace the use of pedestrian navigation systems whereas the use of such systems may become a natural assistive technology in old age for today's 20-30 year olds. Also, within individuals, short-term and long-term benefits may not always be congruent. For example, the use of modern GPS-based spatial navigation aids may have positive short-term effects upon way-finding behavior. However, to the extent that the use of such aids reinforces route-learning strategies at the cost of strategies that achieve spatial integration, long-term and transfer effects may actually be negative.

Strategies for Assistive Technology in Old Age

In summary, two broad classes of change processes are occurring simultaneously in the course of later adulthood and old age. First, sensory and motor systems are deteriorating, with the important consequence that sensory and motor aspects of behavior are increasingly in need of cognitive resources. Second, cognitive resources such as executive control operations, working memory, and binding mechanisms also decline with advancing age. In combination, these two classes of changes result in increasing demands on decreasing resources, and constitute the quandary of behavioral aging [9]. A key purpose of assistive technology is to attenuate the adverse effects of this quandary on development in later adulthood. Progress towards this goal requires the integrated consideration of sensory, motor, and cognitive changes as well as close collaboration among psychologists, computer scientists, and engineers. Specifically, designers of assistive technology need to be aware of the reciprocal and increasingly tight interactions among motor, sensory, and cognitive aspects of behavior with advancing age.

Based on the three criteria for evaluating the effectiveness of assistive technology in mind, we propose *two complementary strategies* for the design of assistive technology. The first strategy is to free up cognitive resources by reducing the cognitive demands of sensory and/or sensorimotor aspects of performance. Past design recommendations have favored this approach, perhaps because it is more easily implemented (e.g., [5]). Typical examples include the reduction of background noise, or glare-free, high-contrast, and well-lit environments. The second strategy attempts to provide individuals with adaptive external cuing structures that directly alleviate the effects of reduced cognitive control, working memory, and binding capabilities on cognitive performance. To be effective, this strategy needs to incorporate knowledge about the structure of the task, the task environment, and the person into a device that supports goal-oriented action in an adaptive and flexible manner. E.g. in a situation where an older person walks through the city the navigation aid have to track his movement. While walking it supports the user with short and clear direction advices and when the person stands still it switches the mode and gives some additional information about the environment.

Older adults have difficulties in accessing and operating on details but show less or no decline when processing general or gist-like information, probably due to the problem to link the information to its correct context (e.g., [4]). In addition, executive processes that help to regulate and coordinate goal-directed action also function less reliably, and the ability to simultaneously process and retain events in working memory is reduced (e.g., [12]). In this situation, *a key purpose of assistive technology is to provide an adaptive cuing structure that orients the aging individual in time and space by providing prompts that connect*

properties in the environment to the action goals of the individual (cf. [8]). Cues are helpful when they prompt the appropriate action at the right point in time. Relevant research on memory functioning indicates that compatibility and distinctiveness contribute to cue efficiency. Thus, designers of assistive technology are asked to adapt the properties of assistive devices to aging individuals' needs and competencies (e.g., [5]).

LABORATORY EVALUATION FRAMEWORK

To afford the added focus on aids directly targeted at spatial navigation, the motion lab (see Figure 1) at the Max Planck Institute (MPI) in Berlin has been refined in several respects relative to the corresponding motion laboratory at Saarbruecken, which was used in the Lövdén et al. [11] experiment. The concept of the proposed test framework (see Figure 2) consists of:

1. the controller, the core of the experimental program,

2. the visualization engine,

3. the VICON motion capture system.

4. the walking interface,

5. the input interface, and

6. the navigation interface,

The controller

The controller (see Figure 2, frame 1) is the main program of the test framework written in Java. It is implemented for the experimental tasks and controls capturing data, mode of integrated navigational help and navigational task. It also holds a map representation of the scene to control and update the interaction and movement of the user. In the running process the controller repeatedly communicates with the visualization engine to update position and view in the visual scene. The implemented interfaces allow the communication with the physical devices integrated in the framework. Additionally the controller stored the captured decisions and walked routes of each user in a database. The synchronization to the gait parameters captured by the separate VICON system is enabled through a trigger process that allows sending start- and stop-commands to the camera system.

The visualization engine

The virtual environment is now back-projected by means of one or two projectors on a 270 x 200 cm power-wall in front of the treadmill. Usage of two projectors allows for 3D projection.
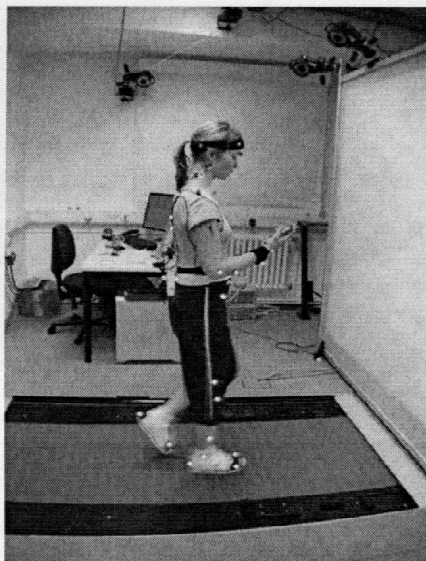
Figure 1: The virtual reality motion lab at the Max Planck Institute for Human Development, Berlin.

The visualization engine (see Figure 2, frame 2) runs on a different computer and communicates with the controller via a network connection. The systems exchange data concerning the changes of the user position and the line of vision. At the beginning of the task the controller loads the desired map and commands the graphical engine to show the corresponding environment on the wall. Afterwards the engine runs in a passive mode controlled through the core of the framework. This is realized as in multi-player game engines which also allow showing the perspective of another player. For recent experiments we are using VEs running on a modified quake engine[1] or other graphical engines[2]. As navigation scenes we are using indoor and outdoor scenarios to represent large buildings like museums or virtual cities or zoos/parks. For future work we are able to use different visualization engines, e.g. video based systems, or to switch to a CAVE environment. The new techniques only needs to adapt to the network interface of the experimental system that controls the movement of the visual flow or rather the virtual position and walking direction of the user in the VE.

The VICON motion capture system

The current configuration of the VICON motion capture system[3] consists of 12 infrared cameras that detect up to 41 reflective markers attached to the body of users. The

---

system is fully functional and allows for whole body motion capturing, advanced biomechanical modeling, and millisecond synchronization with a portable 8-channel EEG/EMG system. The biomechanical model provides a full interpretation of the user's movements, so that the common spatial temporal gait parameters, e.g. steplength, stepwidth, velocity, knee angles, cadence, can be analyzed. Furthermore, principle component analysis to characterize the gait in terms of variability, stability or flexibility can be performed.

During testing of navigational devices the motion capture system delivers information how strongly the interaction with the device interferes with walking. Additionally, we can capture numbers and time of user's stops while handling the aid. The camera system also allows to personalize the framework to the user's habits by

supporting the adaptive walking speed and capturing gestures for user interaction.

The walking interface

The walking area of the treadmill (200 x 70 cm) is integrated into the floor (see Figure 1). The treadmill is connected via a serial port to the experimental computer and offers a full functional protocol, e.g. to send and receive speed and acceleration changes. A drawback of the treadmill in the framework pictures the fact that the user is limited in physical turns. To catch this problem we implemented smooth visual turns to reduce the break between physical and visual feedback. The walking interface (see Figure 2, frame 4) is implemented with the treadmill protocol allowing the controller to synchronize the virtual movement with the speed of the treadmill. So far the participants have shown a good accommodation to the compromise.
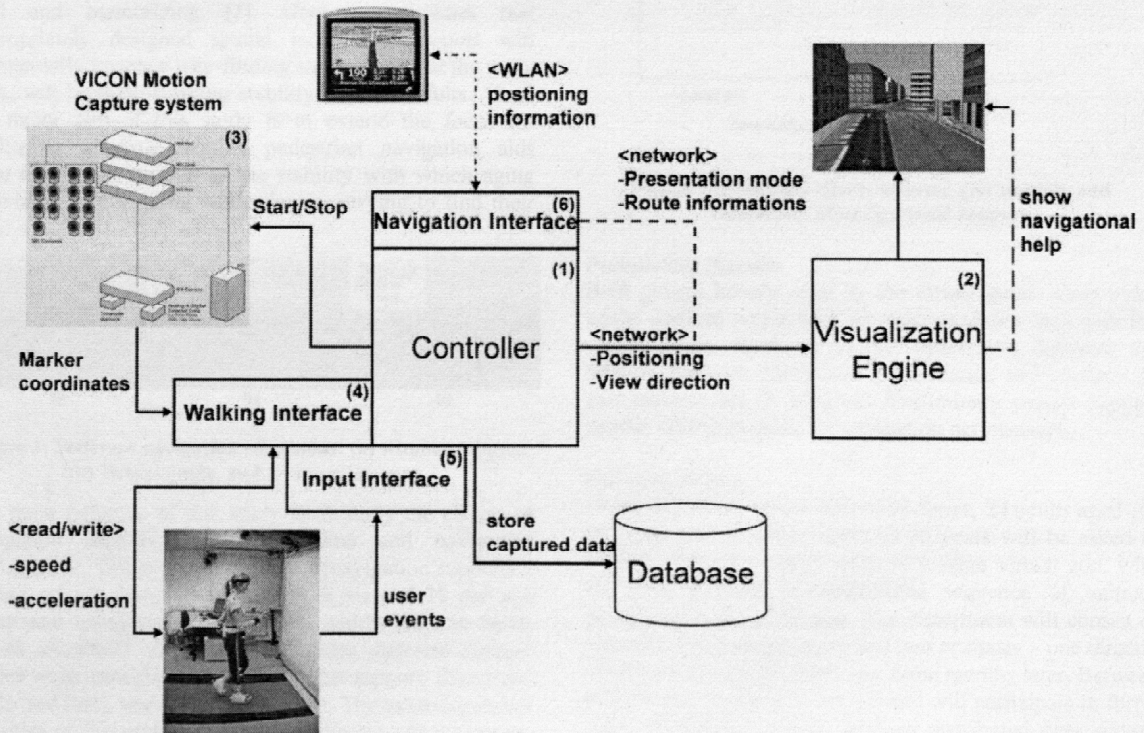

Figure 2: The architecture of the experimental paradigm

The input interface

The input interface (see Figure 2, frame 5) processes all kind of usual user inputs, namely key and mouse events. The user interacts with wireless handheld buttons, e.g. to induce a virtual turn in the scene. These buttons based on wireless computer mouse to simplify the interaction with the experimental system. But the input interface is also

open to read and analyze events from other input domains like the VICON real-time module or measurement cards.

The navigation interface

A core feature of the test framework is the integration of navigational aids (see Figure 2, frame 6). Assisting the user in his navigational task can be realized in two different features. For rapid prototyping of navigational help and

experiments abstracting from the physical design of assisting device the support is integrated in the virtual environments. In this case the experimental system sends the required information to the visualization engine. The engine can show an additional window with an overview map or integrate arrows or direction lines directly in the scene. The other possible feature loads a network process to communicate with a mobile device, e.g. a PDA, via wireless LAN. Therefore we wrote a simulation program running at the mobile device that builds up a network connection to the navigation interface of the experimental system and presents visual or oral navigational help via the PDA.

FIRST EXPERIMENT IN NET RESOURCE RELEASE

In the past, walking speed has been shown to be a sensitive marker of cognitive load induced changes in postural control while walking [9,14]. Additionally, earlier work has shown that walking support frees up cognitive resources that then can be invested into navigation-related processing [11] and memorizing [7]. Here, we predict that appropriately designed spatial navigation support will substantially improve way-finding success, and, at the same time, will increase walking stability in older adults. Thus, the major aim of this study is to extend the focus for evaluating resource-adaptive pedestrian navigation aids from navigation success to the stability with which aging individuals are walking while they are trying to find their way.
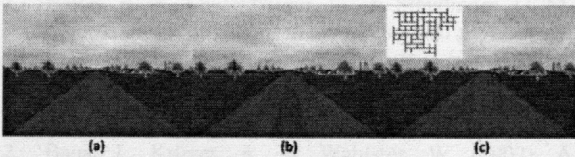
Figure 3: Different navigation conditions: (a) without support, (b) virtual guide, and (c) overview map.

The main rationale of this study is to study the effects of navigation support on gait patterns and navigation performance. The study followed a 3 (navigation support) x 2 (age group) design, with a sample size of 18 per age group and navigation support as a within-subjects factor (21-28 vs. 68-77 years of age). Three different support modes were used (see Figure 3): (a) no support, (b) virtual guide (red line), and (c) overview map. The main dependent variables of this study are walking stability and navigation performance. We predict that the navigation support will influence older adults' walking stability, whereas gait patterns of younger adults will remained unchanged. In contrast, navigation support is expected to affect the navigation performance of both younger and older adults. Specifically, we predict that navigation performance will be best with the virtual guide (see Figure 3) because the difference between the costs associated with processing the support information and the benefits of using this information is largest for this kind of support. We further

expect that walking stability for older adults will improve with the virtual, but will deteriorate with the overview map, as the latter kind of nominal navigation support is assumed to overtax the cognitive abilities of the majority of older adults (see Figure 4). As in our previous work (e.g., [11]), controlled virtual environments with landmarks will be used to test these predictions. In each of two sessions, participants were asked to navigate under all three navigation support conditions in a randomized order to control for daily fluctuations in performance and familiarization with the setting.
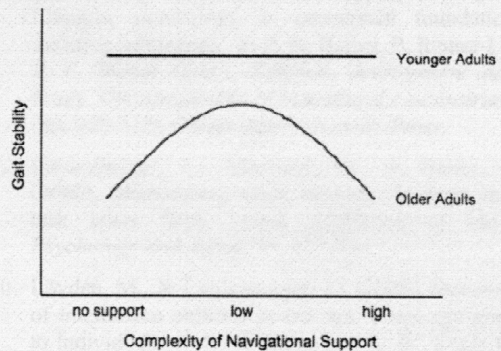
Figure 4: Predicted effects between gait stability and complexity of navigational support.

Preliminary Results

Both groups benefit most by the virtual guide. Only older adults perform worse with the map condition than with the virtual guide. Analyses of gait patterns to delineate the relation between navigation performance and changes in gait patterns are in progress. Preliminary results suggest similar effects as those for navigation performance.

FUTURE WORK

Using the VR paradigm described above, 24 adults aged 20-30 years and 24 adults aged 60-70 years will be asked to walking through several areas of a large virtual zoo, with the goal to find a randomized sequence of animals distributed all over the zoo. The experiment will consist of a pretest, the training phase and two posttests – one directly after training and the other one three months later. Between pre-test and post-test 1, individuals will participate in forty-eight 50-minute training sessions distributed over sixteen weeks, with three sessions per week separated by one or two days. During training, participants will sequentially explore different areas of the zoo to find all animals in a predefined order. At pre-test, post-test 1, and post-test 2, navigation performance in novel environments matched for contents and topography will be measured to assess navigational skill acquisition.

We will track the routes walked and the decisions made during the navigation session for each participant in each session. This data will enable us to examine individual

differences in navigational patterns and their relation to navigation performance and spatial orientation. Our analyses will address: (a) whether younger and older adults differ in navigational patterns (e.g., turns, use of already known routes, use of shortcuts, integration of distal landmarks); (b) which aspects of navigation behavior predict navigation success; (c) how navigational patterns change in the course of training; (d) how navigation behavior in novel environments differs from navigation behavior in thoroughly explored environments; From a technological point, answers to these questions will inform the design of navigation aids by providing algorithms that recognize a user's navigational pattern and provide individualized assistance.

CONCLUSION

In this paper, we described the technical features and the potential of the framework to evaluate pedestrian navigation devices in the benefit of navigation performance and effects of the user's motion. Results of our first experiment demonstrate that the effectiveness of different kinds of navigational assistance vary by context and individuals' sensorimotor and cognitive resources. Better knowledge about the interaction between walking stability and cognitive load in old age may serves to improve the adaptivity of mobile navigation systems to this type of users.

REFERENCES
1. Baltes, P. B., Lindenberger, U., & Staudinger, U. M. (2006). Life span theory in developmental psychology. In W. Damon & R. M. Lerner (Eds.), *Handbook of child psychology: Vol. 1. Theoretical models of human development* (pp. 569-664). New York: Wiley.

2. Baus, J., Krüger, A., & Wahlster, W. (2002). A resource-adaptive mobile navigation system. *Proceedings of IUI2002: International Conference on Intelligent User Interfaces 2002.* ACM Press.

3. Charness, N., & Schaie, K. W. (Eds.) (2003). *Impact of technology on successful aging.* New York: Springer.

4. Craik, F. I. M. (2006). Remembering items and their contexts: Effects of aging and divided attention. In H. D. Zimmer, A. Mecklinger, & U. Lindenberger (Eds.), *Binding in human memory: A neurocognitive perspective.* Oxford, UK: Oxford University Press.

5. Fisk, A. D., Rogers, W. A., Charness, N., Czaja, S. J., Sharit, J. (2004). *Designing for older adults. Principles and creative human factors approaches.* Boca Raton: CRC Press.

6. Kautz, H., Etzioni, O., Fox, D., & Weld, D. (2004). *Foundations of assisted cognition systems.* Technical Report CSE-02-AC-01. Department of Computer Science and Engineering, University of Washington, Seattle, USA.

7. Li, K. Z. H., Lindenberger, U., Freund, A. M., & Baltes, P. B. (2001). Walking while memorizing: Age-related differences in compensatory behavior. *Psychological Science,* 12. 230-237.

8. Lindenberger, U., & Lövdén, M. (2006). Co-constructing environmental support in old age: Lifespan psychology as conceptual foundation for assistive technology. In P. B. Baltes, P. Reuter-Lorenz, & F. Rösler (Eds.), *Lifespan development and the brain: The perspective of biocultural co-constructivism* (pp. 350-375). Cambridge University Press.

9. Lindenberger, U., Marsiske, M., & Baltes, P. B. (2000). Memorizing while walking: Increase in dual-task costs from young adulthood to old age. *Psychology and Aging,* 15, 417-436.

10. Lövdén, M., & Lindenberger, U. (2005). Development of intellectual abilities in old age: From age gradients to individuals. In O. Wilhelm and R. W. Engle (Eds.). *Understanding and measuring intelligence* (pp. 203-221). Thousand Oaks, CA: Sage.

11. Lövdén, M., Schellenbach, M., Grossmann-Hutter, B., Krüger, A., & Lindenberger, U. (2005). Environmental topography and postural control demands shape aging-associated decrements in spatial navigation performance. *Psychology and Aging,* 20, 683-694.

12. Mayr, U., Kliegl, R., & Krampe, R. T. (1996). Sequential and coordinative processing dynamics in figural transformations across the life span. *Cognition,* 59, 61-90.

13. Riediger, M., Li, S.-C., & Lindenberger, U. (2006). Selection, optimization, and compensation as developmental mechanisms of adaptive resource allocation: Review and preview. In J. E. Birren & K. W. Schaie (Eds.), *The handbooks of aging: Vol. 2. Handbook of the psychology of aging* (6th ed., pp. 289-313). Amsterdam: Elsevier.

14. Verrel, J., Lövdén, M., Schaefer, S., & Lindenberger, U. (2007). Variability in whole-body movement while walking as a function of working memory load in middle childhood, adulthood, and old age. *Manuscript in preparation, Max Planck Institute for Human Development, Berlin.*