

A user evaluation study of a multi-modal mobile navigation aid for pedestrians with respect to gender differences

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ABSTRACT

The results of an experiment carried out at the Institute of Psychology, University of Bonn with 60 participants are described in this study. The main target was to study the use of speech, graphical display, and its combination as system output modalities in a controlled experiment within a simulated environment on a computer. The purpose of the user study was to evaluate perceived easiness, effectiveness, subjective acceptability, comprehensibility, preciseness of instructions with respect to gender differences, and the required average interaction time concerning three different modalities in a tourist navigation scenario for pedestrians. It seems that a system output modality combining human perceptual channels is superior (for females and males) to a modality just based on one perceptual channel ('Audio only' or 'Map only' modality). This interpretation is strongly supported by the fact that participants were also willing to pay the highest amount of money for such a navigation service in the 'Combined' modality.

Introduction

In the field of Human-Computer Interaction it is important that the information presented by the system fits to the human understanding of the world. The Information has to respond to human knowledge about categories, concepts, objects and their mental representation. Therefore the designer of Human-Computer Interaction has to identify the mental information architecture of the users and map it in the system's architecture of information presentation (for an overview on designing the user interface see also Shneiderman, 1998). There has been a lot of psychological research in the study of human knowledge of isolated modalities (see Eysenck & Keane, 2002 and Goldstein, 1997) but research on the combined use of different output modes is still scarce.

Building these advanced new features and functionalities, like user positioning, may allow sophisticated applications for the benefits of the end-user but there is a lot of basic research necessary in several directions: both technical constraints (e.g., low data rates of mobile networks, bandwidth limitations for streaming audio or video, limited resources of mobile devices, the client device, i.e. screen size, character size, contrast and resolution) and user constraints (e.g., user preferences, users spatial cognitive abilities, age, physical capabilities, needs, et cetera). Users have also special demands because of the mobile environment. In other words, the success or failures of these types of applications depend strongly on many factors and it can only be fulfilled if such a system is designed in a user-centred way.

For situation adapted information presentation and interaction the development of a suitable situation and process model is vital determining the individual information needs on the basis of user, location, environment, activation and task features. There will be a shift from static to dynamic changing user interfaces adapted by the users' current needs or by an adaptive system taking into account user preferences, task characteristics and environmental variables. Beyond to known approaches of the location-aware computing where primarily the location of the user is been considered an exhaustive situation model identifying and using all relevant situational parameters for proactive information supply and user interaction will be of great use.

Users wish to be able to seamless access information and services regardless of the device they are using, even when the system or the environment changes dynamically (Paterno, 2002). This brings up many interesting questions such as: How to interact with the system? What are the constraints in navigation? How to specify the destination? How to specify the preferred modality? How to specify the level of detail? How to specify map overview? How does the system

automatically adapt to the situational context? How to specify diversity of user needs? How to avoid cognitive overload?

To meet all these requirements context awareness is needed. For the system adaptability as well as the systems adaptively from a user perspective (e.g., short keys for changing modalities, situational aware modality suggestions). Another interesting question is: Are there gender differences in evaluating a mobile navigation aid for pedestrians? Halpern (2000) mentioned that on the average females have better verbal abilities than males have. On the other hand males achieve higher scores in spatial tasks than females do (Halpern, 2000, Halpern, 1996; Voyer, Voyer, & Bryden, 1995). Visual-spatial abilities refer generally to discern the relationship between objects and shapes or to imagine what a figure would look like when it were rotated in space. This ability and its utilisation of spatial relationships is important for a map based navigation aid.

This study is a follow-up study of an internet experiment made by de Heer, Eisenhauer, & Siochos (2003) which was carried out at Fraunhofer FIT, Sankt Augustin, Germany in collaboration with the Telematica Instituut, Enschede, Netherlands. $N = 90$ participants aged between 19 and 53 years ($M = 29.74$, $SD = 6.92$) took part in the experiment. Participants saw a PDA mock-up showing the navigation aid. There were three routes, each route in a different modality (audio only, map only and audio + map). The whole navigation was based on the imagination of the participants of the routes navigating through the city of Calcutta, India. After each scenario participants were asked to rate their perceived easiness, efficiency and how much money they were willing to spend for such a service. At the end of the experiment a general questionnaire was presented and participants were asked for an overall rating of the three modalities (audio only, map only and audio + map). They found that a combined modality, combining audio and map instructions, was superior to a modality just based on one perceptual channel.

A user-centered approach in the design of a pedestrian navigation aid based on multi-modal interaction possibilities was explored in this study. The goal was to explore the benefits of multi-modal interactions. To assess user's attitudes of the interaction possibilities a PDA mock-up was constructed showing three different routes through the city of Troisdorf, Germany. The participants completed their tasks by following the routes, visualized by video sequences from a pedestrian's point of view. The three routes corresponded to three different modality combinations: 'Map only', 'Audio only' and 'Combined'. All three modalities had certain benefits and flaws. The 'Map only' modality provided a good overview but the requirement to look on the display may distract the attention of the user to pay attention to the traffic. The 'Audio only' modality had freed the user

from looking on the display but doesn't provide a general overview and turn-by-turn displays. The 'Combined' modality (combines Audio and Map) should complement the user's benefits. The main differences to the previous study (de Heer, Eisenhauer, & Siochos, 2003) were: The experiment was carried out as a controlled experiment session, the users were asked to also rate the comprehensibility and the preciseness of given instructions of the navigation aid. A measurement of the average interaction time the user required while interacting with the navigation aid was integrated, gender differences on ratings were examined and participants were confronted with their navigation movements on video sequences from a pedestrian's point of view instead of imagining the navigation. All this should raise the internal and external validity of this follow-up study reported here. This study should also contribute to a broader insight of user's preferences for multi-modal interaction. The Hypotheses of this experiment were: (a) Participants will rate the three modalities different. (b) There is a gender difference in the ratings of the three modalities. (c) The required average interaction time is different in the three modalities.

Method

Design

Participants were randomly assigned to one of nine conditions, see Table 1. There were three routes in each condition, involving the three modalities ('Map only', 'Audio only' and 'Combined') resulting in a 3 x 3 (three routes x three modalities) within design. Sequence effects were controlled through permutation of a random order (see Table 1). Participants though were running through three different routes each in a different modality.

Table 1:

Routes and modalities within each condition.

Condition	Route / Modality		
1	1 / Audio only	2 / Map only	3 / Combined
2	1 / Map only	2 / Combined	3 / Audio only
3	1 / Combined	2 / Audio only	3 / Map only
4	2 / Audio only	3 / Map only	1 / Combined
5	2 / Map only	3 / Combined	1 / Audio only
6	2 / Combined	3 / Audio only	1 / Map only
7	3 / Audio only	1 / Map only	2 / Combined
8	3 / Map only	1 / Combined	2 / Audio only
9	3 / Combined	1 / Audio only	2 / Map only

Participants

Participants were recruited at the University of Bonn, Institute of Psychology. The entire sample consisted of 60 participants aged between 19 and 54 years ($M = 24.88$, $SD = 6.57$), 30 males aged between 20 and 35 years ($M = 25.43$, $SD = 4.78$) and 30 females aged between 19 and 54 years ($M = 24.33$, $SD = 8.03$). Participants were of different majors. Psychology students received partial course credit; students of other majors were paid € 5.- (approx. 6\$) for their participation.

Material

The whole study was carried out on a localhost (Apache Server 2.0) on the following computer: AMD Athlon 900 Mhz, 512 MB RAM, 17" Belinea 107050 Monitor (1152x864@75Hz). All routes were filmed with a digital camera from a pedestrian's point of view. The whole experiment was designed in HTML. All questionnaires and time measurements were realised with PHP- Scripts. The used operating system was Microsoft Windows 2000 Professional SP3. The used Browser was Microsoft Internet Explorer 6. The PDA mock-ups were realised with Macromedia Flash mx.

Procedure

A number of pre-tests were conducted to evaluate the experimental set-up before the real experiment started. The study was carried out from December 2003 until February 2004 at the Institute of Psychology, University of Bonn. Participants had to follow the route (visualised by video sequences) from the point of departure until the final destination. They were allowed to do this in their own pace. Participants started the experiment by clicking on 'START' after they had read the instructions of the scenario. All users accomplish to follow the three routes by looking at the PDA mock-up and video sequences. After each video sequence the participant decided in which direction to go next. User's attitudes towards navigation were assessed immediately after each route and some general questions explicitly addressing the user evaluation of the three modalities were asked at the end of the experiment. A short demographic Questionnaire (age and gender) appeared after the participant had clicked 'NEXT' on the welcome screen. Then participants were getting the instruction for their first scenario. All scenarios took place in Troisdorf, Germany. In each scenario, a user pretended to walk on a certain route in the city of Troisdorf, Germany. After the participant had clicked on a 'start' button the first screen of a scenario appeared. Either an overview map ('Map only' and 'Combined' modality) at the right side (PDA mock-up) of the screen, see Figure 1, appeared showing his start position (arrow) and his final destination (the end of the line), or an icon

of a loudspeaker at the right side (PDA mock-up) of the screen, see Figure 2.

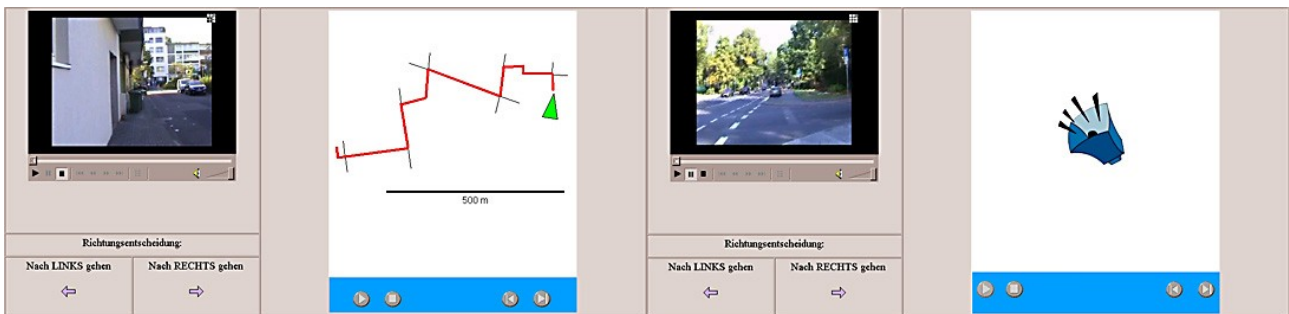


Figure 1:

Screen shot of an overview map in the 'Map only' and 'Combined' modality (right side of the screen).

Figure 2:

Screen shot of the 'Audio only' modality (right side of the screen).

The 'Map only' and 'Combined' modality showed a general overview map of the route, see Figure 1. The navigation was broken into small sectors. Each sector contained landmarks (pictures of remarkable objects / buildings). A click on a landmark enlarged the picture, see Figure 3. The landmarks were there to ease the navigation because they identified the point where to turn left or right. Below the map ('Map only' modality) a text description of the route was shown, see Figure 3. The 'Audio only' modality provided exact the same information in small audio files, see Figure 2. The 'Combined' modality combined the modalities 'Audio only' and 'Map only' and provided a map plus audio descriptions of the way, see Figure 4.

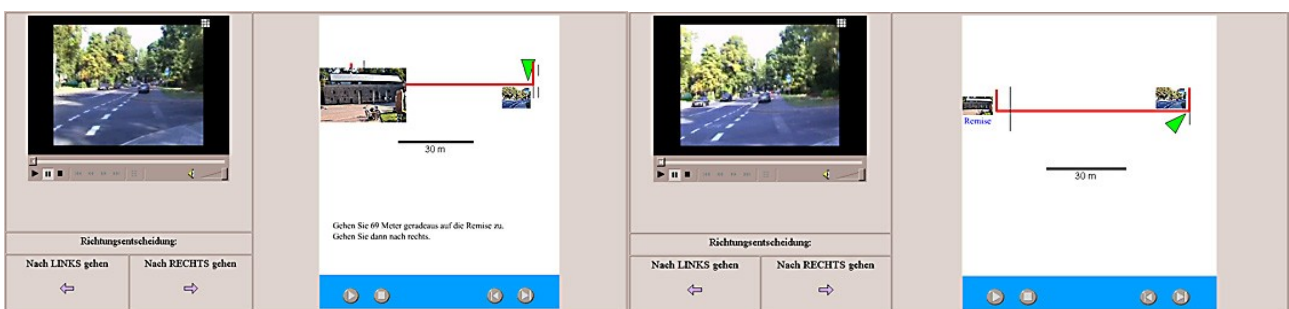


Figure 3:

Screen shot of an enlarged landmark in the 'Map only' modality (right side of the screen).

Figure 4:

Screen shot of the 'Combined' modality (right side of the screen).

The user's task were simple: First they had to listen ('Audio only' modality) to the instruction by pressing the 'play' button on the PDA mock-up or read the instructions and the map ('Map only'

modality) or listen to the instruction by pressing the 'play' button on the PDA mock-up and read the map ('Combined' modality). Participants were allowed to hear the audio instruction any time they needed, even while the video sequence were running. Then, second, participants had to click on the play button of the Windows media player on the upper left side of the screen to start the play back of the video sequence. After the video sequence had ended participants had to decide in which direction (left and right arrow at the left lower side of the screen) to go next (depended on the given instruction), see Figures 2, 3. After finishing a scenario a questionnaire appeared and participants were asked to rate (on a 5 point Likert scale) the easiness, the amount of money they would spend for such a service, the effectiveness, the comprehensibility and the preciseness of instruction of the navigation aid in that modality. After completing the questionnaire participants were presented with the next scenario in a different modality. When participants completed all scenarios they were asked to rate the general easiness and efficiency of each modality.

Results

All results are reported with two-tailed levels of significance.

Rating scales

All Chi square values and the degrees of freedom reported here refer to the complete design including all levels of dependent and independent measures. The chosen effect size for all Chi square tests was set to $\epsilon = .5$.

First we will take a look at the questions appeared immediately after participants finished each scenario. Participants were asked to evaluate perceived easiness, amount of money participants would spend for such a service, perceived effectiveness, comprehensibility and preciseness of instructions of each modality.

Perceived easiness: There was no significant difference at the chosen α -level $< .05$ between the three modalities, $\chi^2_{(4)} = 8.89, p = .064$.

Money: The highest amount of money (1 Euro or more) would be spent in the 'Combined' modality ('1 Euro or more' = 52.9 %), followed by 'Audio only' (32.4 %) and 'Map only' (14.7 %). At the same time the most participants would spent no money in the 'Audio only' modality ('0 Cent'

= 43.5 %), followed by 'Combined' ('0 Cent' = 30.4 %) and 'Map only' ('0 Cent' = 26.1 %). The 'Audio only' modality was rated by the most participants to be 25 Cent worth (42.9 %), in contrast to 'Map only' and 'Combined' (both '25 Cent' = 28.6 %). The 'Map only' modality was rated by the most participants to be 75 Cent worth (54.2 %), in contrast to 'Audio only' ('75 Cent' = 25 %) and 'Combined' ('75 Cent' = 20.8 %), see Table 2, $\chi^2_{(8)} = 17.28, p < .05$.

Table 2:

*Modality * Spent money Cross tabulation.*

		Spent money					Total	
		0 Cent	25 Cent	50 Cent	75 Cent	1 Euro or more		
MODALITY	Audio only	Count	10	18	15	6	11	60
		Expected Count	7,7	14,0	19,0	8,0	11,3	60,0
		% within Spent money	43,5%	42,9%	26,3%	25,0%	32,4%	33,3%
		Adjusted Residual	1,1	1,5	-1,4	-,9	-,1	
Map only	Count	6	12	24	13	5	60	
	Expected Count	7,7	14,0	19,0	8,0	11,3	60,0	
	% within Spent money	26,1%	28,6%	42,1%	54,2%	14,7%	33,3%	
	Adjusted Residual	-,8	-,7	1,7	2,3	-2,6		
Combined	Count	7	12	18	5	18	60	
	Expected Count	7,7	14,0	19,0	8,0	11,3	60,0	
	% within Spent money	30,4%	28,6%	31,6%	20,8%	52,9%	33,3%	
	Adjusted Residual	-,3	-,7	-,3	-1,4	2,7		
Total	Count	23	42	57	24	34	180	
	Expected Count	23,0	42,0	57,0	24,0	34,0	180,0	
	% within Spent money	100,0%	100,0%	100,0%	100,0%	100,0%	100,0%	

Perceived efficiency: A majority of participants rated the 'Combined' modality as very efficient ('Very Efficient' = 48.6 %) in contrast to 'Map only' ('Very Efficient' = 29.7 %) and 'Audio only' ('Very Efficient' = 21.6 %). The 'Map only' modality had its highest rates at 'Efficient' (39.8 %) in contrast to 'Audio only' and 'Combined' (both 'Efficient' = 30.1 %). The 'Audio only' modality was rated by a majority of 53.3 % of participants to be 'Moderate' in contrast to 'Map only' ('Moderate' = 16.7 %) and 'Combined' ('Moderate' = 30 %), $\chi^2_{(4)} = 12.40, p < .05$.

Comprehensibility of modality: There was no significant difference between the three modalities, $\chi^2_{(4)} = 11.54, p = .173$.

Preciseness of instruction: In the 'Audio only' modality 76.5 % of participants rated this modality as moderate in contrast to 'Map only' and 'Combined' (both 'Moderate' = 11.8 %). The 'Combined'

Modality was rated by 43.6 % to be 'Very precise' in contrast to 'Map only' ('Very precise' = 37.2 %) and 'Audio only' ('Very precise' = 19.2 %), $\chi^2_{(4)} = 22.42, p < .001$.

After completing the questionnaires relating to each modality, participants were asked to give an overall rating of perceived easiness and effectiveness of the three modalities. Easiness was rated 'Best' in the 'Combined' modality (50.0 %), followed by 'Map only' ('Best' = 38.3 %) and 'Audio only' ('Best' = 11.7 %). The 'Audio only' modality was rated to be 'Worst' by a majority of 72.5 %, followed by 'Map only' ('Worst' = 23.5 %) and 'Combined' ('Worst' = 3.9 %), $\chi^2_{(4)} = 55.53, p < .001$ (see Figure 5). The effectiveness reflected almost the same picture: In the modality 'Combined' were the highest rates for 'Best' (51.7 %) in contrast to 'Map only' ('Best' = 36.7 %) and 'Audio only' ('Best' = 11.7 %). On the other hand the 'Audio only' modality was rated by a majority of 74.5 % as 'Worst', followed by 'Map only' ('Worst' = 21.6 %) and 'Combined' ('Worst' = 3.9 %), $\chi^2_{(4)} = 60.17, p < .001$.

Gender differences in rating scales

Perceived easiness (Audio only): 35.0 % of male participants rated the 'Audio only' modality as 'Very easy', whereas 65.0 % of female participants rated the 'Audio only' modality as 'Very easy'. 84.6 % of male participants rated the 'Audio only' modality as 'Moderate' in contrast to female participants ('Moderate' = 15.4 %), $\chi^2_{(2)} = 8.36, p < .05$. There were also gender differences in the overall ratings of perceived easiness and effectiveness of the 'Map only' modality. 84.6 % of female participants rated this modality as 'Worst' in contrast to male participants ('Worst' = 15.4 %). 33.3 % of female participants rated this modality as 'Moderate', in contrast to male participants ('Moderate' = 66.7 %), $\chi^2_{(2)} = 8.94, p < .05$ (see Figure 6). There was almost the same picture for perceived effectiveness of the 'Map only' modality and gender differences. 91.7 % of female participants rated the 'Map only' modality as 'Worst', whereas a majority of 65.4 % of male participants rated this modality to be 'moderate', $\chi^2_{(2)} = 10.98, p < .01$.

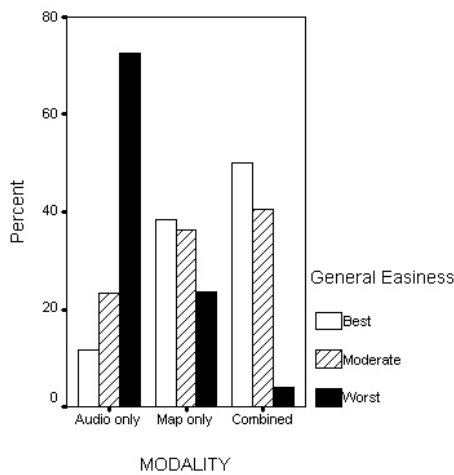


Figure 5:
*Distribution of ratings of Modality * General easiness.*

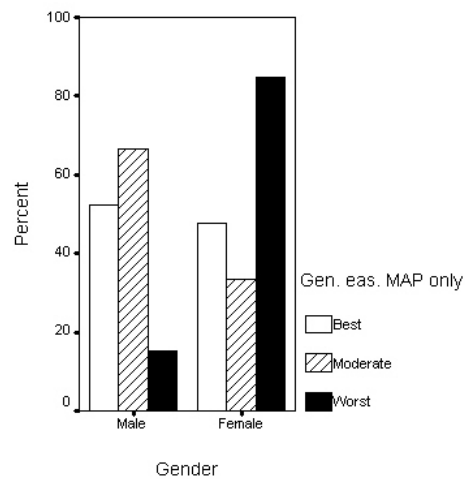


Figure 6:
*Distribution of ratings of Gender * General easiness of the 'Map only' modality.*

Average interaction time with navigation aid

The chosen effect size for the analysis of variance time calculation was set to $\epsilon = .35$. Participants required the shortest average interaction time (seconds) in the 'Audio only' modality ($M = 7.28, SD = 4.21$) and 'Combined' modality ($M = 9.42, SD = 5.18$). The longest average interaction time was required in the 'Map only' modality ($M = 15.60, SD = 7.44$) which differs significantly from the other two modalities, $F(2,171) = 36.73, p < .001$ (see Figure 7).

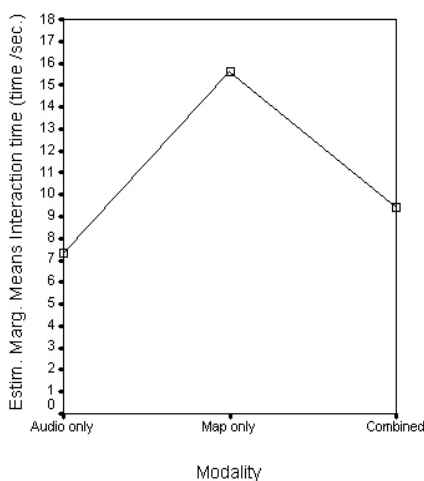


Figure 7:
Estimated marginal means (sec.) of required average interaction time of the three modalities.

Discussion

The initial question was how participants rated a multi-modal mobile navigation aid for pedestrians with respect to gender differences and the required average interaction time. Furthermore the question will be answered what implications the results have for further studies and the practical use in designing a user interface for a navigation aid for pedestrians in real life for tourist applications.

Rating scales (all participants)

The modalities were rated different concerning all rating scales except the easiness and comprehensibility rating scale. As seen in the study of de Heer, Eisenhauer, & Siochos (2003) the most preferred modality was the 'Audio + Map' modality and the least preferred modality was the 'Audio only' modality. These results were also found in this study. Dingus et al. (1997) found the same results for car drivers. A modality combining both perceptual channels (visual and audio perception) is superior and safer than to a modality just based on one perceptual channel (visual or audio) for in-vehicle navigation systems (TravTek). So it seems a 'Combined' modality meets the requirements for both car drivers and pedestrians. The result of the present study that a 'Combined' modality was perceived as the most favorable modality by all participants is also supported by the result that participants were willing to spent the highest amount of money (1,- € or more) in the 'Combined' modality. A comparable result was found in the study of de Heer, Eisenhauer, & Siochos (2003) in their study for a navigation aid for pedestrians. Again a sequence can be shown that Participants favored the 'Combined' modality over the 'Map only' modality which was perceived as more favorable than the 'Audio only' modality. It seems to be necessary at least to integrate a combined modality in a navigation aid for pedestrians. The easiness and comprehensibility of the navigation aid was not rated differently by participants. This result showed the well designed user interface of the navigation aid concerning usability (see also Shneiderman, 1998). Easiness and comprehensibility of the navigation aid was perceived almost the same regardless of the used modality.

There were interesting differences concerning the preciseness of instructions of the navigation aid. Although the sound files of the PDA mock-up in the 'Audio only' modality and 'Combined' modality were the same, participants perceived the given instructions concerning preciseness as different. Preciseness of instruction showed the same pattern, to prefer the 'Combined' modality. The 'Combined' modality was perceived as most precise, followed by the 'Map only' modality,

which was perceived as more precise than the 'Audio only' modality. Addressing of both perceptual channels was again perceived more superior than the addressing of one perceptual channel. This result was also found by Dingus et al. (1997) with car drivers. The mental load in a combined modality was lower than in a modality addressing one perceptual channel. This is of major importance with respect to the safety aspects of car driving.

Gender differences in rating scales

Since there are gender differences in cognitive abilities it was likely that the different modalities were perceived different by females and males, while different channels were addressed. Gender differences occurred in the modalities addressing one perceptual channel ('Audio only' and 'Map only'). The 'Audio only' modality was perceived by a majority of female participants to be 'Very easy', whereas the majority of male participants perceived the 'Audio only' modality as 'Moderate'. This result was expected, since females tend to outperform males in specific aspects of verbal abilities (Halpern, 2000), even in a navigation task.

The 'Map only' modality was perceived (general easiness and effectiveness) different by females and males. The majority of female participants rated this modality as 'Worst' and this result was again expected since males achieve higher scores in spatial tasks than females do (Halpern, 1996; Voyer, Voyer, & Bryden, 1995). Again it can be concluded a navigation aid with a combined modality meets the requirements for both males and females.

Required average interaction time of the three modalities

The results showed there was a difference in required average interaction time between the 'Map only' modality and the other two modalities ('Audio only' and 'Combined' modality). This result was unexpected, since participants rated the 'Audio only' modality to be the least favorable modality. There was a remarkable conflict between the ratings (subjective) in the 'Audio only' modality and the time measurement (objective) of required average interaction time in the 'Audio only' modality (required less average interaction time than the 'Map only' modality). Since participants required the longest average interaction time in the 'Map only' modality there could exist various explanations. The cognitive workload could be higher in the 'Map only' modality because first participants were confronted with a visual stimulus (the map on the PDA mock-up) which required sometimes the ability of mental rotation of the actual sectors' map that was shown. And second there was also a text description of the actual sector (how to move on). Another reason why the 'Map only' modality

required the longest average interaction time could also have occurred because participants needed to read the navigation instruction which took some time. But this can not explain that participants perceived the 'Map only' modality as more easier and more effective than the 'Audio only' modality which required the shortest average interaction time and was the most efficient modality but was not perceived by participants as the most effective modality.

One must as well consider that the effectiveness item in the questionnaires could be perceived by participants as another 'easiness item'. This could explain that perceived easiness was rated almost the same as perceived efficiency. Further studies have to pay more attention to this point and explain explicitly what efficiency really means in a navigation context.

Conclusions

If all points of the discussion were summed up one must conclude that the 'Combined' modality (combining both perceptual channels, visual and auditory channel) would be the best and most favorable modality for pedestrians regardless of the gender. So it is an important advice to engineers of navigation aids / systems to include a combined modality since males and females will profit from this modality.

On the other hand one have to be fully aware this study was based on a simulated environment where participants were confronted with a navigation aid for pedestrians and simulated scenarios. The video sequences helped to raise external validity, compared to the study of de Heer, Eisenhauer, & Siochos (2003) which was based on the imagination of participants navigating through Calcutta, India because they were all filmed from a pedestrian's point of view and participants were sawing their movements through the city of Troisdorf, Germany. But a real life situation is still different from a controlled safety experimental situation. Further studies have to be made with a specific focus on safety aspects.

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Background

This study is a follow-up study of a study made by de Heer, Eisenhauer, & Siochos (2003). It was made as a diploma thesis at the Institute of Psychology, University of Bonn.