Multi-Modal Menus And Traffic Interaction. Timing As A Crucial Factor For User Driven Mode Decisions.

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Abstract

Varieties of multi-modal menu outputs were examined in a real driving situation with respect to efficient system interaction and aspects of safety. An electronic manual served as an exemplary application. The speech output was combined with four different display-versions concerning the timing of the output. The test was based on a *within-subject-design*. Every subject performed one control condition ride and three rides with system interaction. The test revealed that if presenting the spoken and visual output simultaneously the subjects mainly used the display for menu selection. In consequence, the attention towards the traffic declined, which had a negative impact on the driving behavior. Presenting the visual output after the spoken output had ended, lead to much less influences on the driving behavior. However, the system interaction was as effective. Menu selection proved only problematic in the first system interaction ride. The process of acquiring strategies for spoken system interaction and its coordination with the traffic situation was rather straining.

1. Introduction

The traffic situation has become more and more complex over the years. To relieve the drivers of that strain cars are increasingly equipped with assisting systems such as bordcomputers or navigation systems with integrated traffic information. At the same time the number of luxury features such as climate control or audio systems with extensive functions has been growing. As a consequence, the variety of systems leads to extensive control elements and their handling might become confusing. At present the automobile concerns pursue two concepts to simplify the controlling within the car. One is a central interface, that enables the driver to handle various systems. An example is BMW's *iDrive*. The other concept is based on speech control diminishing the visual distraction form traffic observation and the motoric distraction from steering. DaimlerChrysler's *Linguatronic*, for instance, was the first system that made possible oral dialing and oral addressbook management. Although the concepts of a central interface and of speech control are more advantageous than the conventional controlling, in cases of extensive information they prove suboptimal. One crucial problem within this field is the menu output.

2. Background

Selecting menu items from a display distracts the driver's attention away from the traffic observation. The longer the menus are, the more the driver's attention is drawn to the display which increases the danger of accidents (Lachenmayr 1987; Wierwille & Tijerina 1995). Oral interaction, on the other hand, leads to a great amount of mental strain. Selecting an item means memorizing the options, but the short-term memory is rather restricted. Concerning verbal information the mental capacities are limited to 5 ± 2 items (Miller 1956, Simon 1974). Memorizing longer menus requires a high concentration and in combination with the traffic interaction this might lead to mental overload (Pashler & Johnston 1998). Furthermore, the possibilities of automatic speech recognition are technically limited which - especially is cases of continuous speech recognition – demand that the exact phrasing of the menu items is memorized. But people rather memorize semantic concepts than literal wordings (Anderson 1985). This often causes problems of speech recognition and thus a delayed system interaction. User tests of the SIMBA-project[1] revealed this problem, too. Subjects testing a prototypic electronic manual that was based on speech-only interaction frequently rephrased the selected menu items. Due to this phenomenon 11,5 % of all menu selection turns were incorrect (Salmen et al. 1999).

A multi-modal menu output could provide a possible solution. By combining speech and text one can make use of the advantages of the single modes and diminish their disadvantages. With respect to safety spoken interaction should provide the primary mode. Both listening and speaking do not produce any interference with visual perception or with motoric reactions (Färber 1987; Becker et al. 1995; Bengler 1995; Franz et al. 1992) which, in principle, makes speech superior in this context. However, if due to the amount of information any problems with menu selection or memorizing occur, an additional visual output can relieve the mental strain. At the same time the visual output on the display supports the data input, as the driver can read the exact phrases on the display. Since referring to the display output means visual distraction drivers have to be aware that they should only make use of it when it is absolutely necessary and only in situations when traffic is at ease. Hence, the system design needs to support this desired user behavior.

[1] The SIMBA-project (**S**imulation des **i**ntelligenten **m**aschinellen **B**eif**a**hrers = simulation of the intelligent automatic co-driver) was carried out at the University of Regensburg in cooperation with DaimlerChrysler from 1996 to 1999.

Assumingly the timing of the visual output is a crucial factor. If the menu is displayed after the spoken output has ended it will probably support the main interaction mode of speech. A simultaneous output might again lead to a visual distraction from traffic observation. Since the textual menu selection is more familiar it might also distract from the spoken output itself and be preferred over the speech mode. If the textual output is only presented after the spoken menu, the question is: What information appears on the display in the meantime? Not displaying any information should be avoided as it might leave the user in doubt if the system is running properly (Herczeg 1994). A symbol or logo on the display might show that the visual component is working. A textual feedback of the recognized input, however, might be more supportive.

speech output	***logo***	***feedback***	***paging***	***scrolling***
feedback of recognized input "There are *x* items:"	car-logo (default symbol)	*textual feedback* "	*black screen* "	*textual feedback* "
menu items 1 - n "What item do you want?"	" "	" "	menu (page mode)	menu (scroll mode)
open recognition	menu	menu	menu	menu

Table 1: System states of speech and visual output

3. Experiment

3.1. System-Design

An electronic manual served as exemplary application. The menu constituted a categorized grouping of systems and their several functions in a hierarchical order. Retrieving information about single functions of the various systems corresponds to the concept of a central interface. The only difference is that selecting a function does not change a system state but gives back a description. Furthermore the findings from the SIMBA user tests provided an essential basis for the speech component of the multi-modal application (Salmen et al. 1999).

The application was implemented on a standard-PC under Windows NT with VBA and fastened in the trunk of the test vehicle. Pulling a lever behind the steering wheel activated the speech recognizer or stopped the output. After the spoken output had ended pushing the lever up or down paged the visual menu up or down if it consisted of more than one page[2]. The display was fixed above the center console. It was a 7" TFT-display with a resolution of 640 x 480.

Due to the experimental aim the information retrieval was only permitted over menu selection. There was a maximum of 3 sequencing menus. The length of the single menus was between 3 and 14 items. The speech output was of a constant schema: 1) feedback about the recognized input, 2) length of the menu, 3) menu items, and 4) request for selection. Four different display versions were tested as a supplement. With two versions the visual output was presented after the spoken output. One version displayed the car-logo during the spoken output (*logo*), that was used as default symbol in various states such as the initial state or the terminal state of giving the functional descriptions. The other one displayed the textual feedback of the recognized input (*feedback*). With the other two versions the visual menu was presented simultaneously to the spoken menu. One version was displayed in page mode (*paging*) the other one in scroll mode (*scrolling*) with highlighting the current menu item, which was shown in the second position on the display. Right before the output of the menu items the display in the *paging*-version remained black and in the *scrolling*-version the textual feedback of the recognized input was displayed. After the spoken output the menus were displayed again. The consecutive menus for all versions were in page-mode.

3.2. Set-up

The test was based on a *within-subject-design* that reduces the influencing parameters according to individual differences (Bortz 1993). 12 experienced drivers took 4 rides each in a real driving situation within 2 weeks. The first ride without system interaction served as control condition (R1). For reasons of limited resources every subject tested 3 of the 4 variants in the following rides (R2-R4). To level the effects of learning the sequence of the variants was permutated with regards to a standardized order. The test course was of 15 km length and lead through the inner city, residential areas, shopping areas and a beltway. The course consisted of different levels of difficulty according to Fastenmeier (1995) to achieve a representative set of driving situations (cf. Dahmen-Zimmer et al. 1999). The subjects had to perform 8 tasks per ride retrieving typical instructional information. The task performance was bound to sections of difficult levels to provoke situations of testing the limits. The system variants were scrutinized with respect to efficiency of system interaction, subjective strain and safe driving. The data was ascertained by questionnaires, the evaluation of the driving behavior by an assisting driving instructor, and a subsequent analysis of the system interaction based on video recordings.

[2] Due to the limited space within cars there is usually only room for small displays and because reading performance decreases with increasing amount of information (Kozma 1991) the length of a menu per page was limited to a maximum of 7 lines.

4. Results

It was hypothesized that 1) an additional display output reduces the mental strain caused by the need of memorizing the menu items and thus leads to an efficient system interaction and a stable driving behavior; and 2) a consecutive menu output supports the primary mode of speech best, because it does not, in contrast to a simultaneous one, draw the drivers' attention away from the traffic or the speech output.

Since each subject tested only 3 of the 4 versions that resulted in differing test series the statistical analysis was based on paired samples T tests (Bortz 1993).

4.1. Speech Interaction

The subjects valued the system versions via bipolar analog scales. They marked a position on a horizontal line giving two polar statements, for example *good – bad*. The markings were measured in steps of millimeters where the minimum was 0 and the maximum was 38.

The mean valuations via the analog scale with regards to coping with the speech output were: *logo* (L) 28.3, *feedback* (F) 32.2, *paging* (P) 32.4, and *scrolling* (S) 30.3. All differences proved not significant. It was striking, though, that the worst valuations with a mean of 19.3 were given at the first ride (R2) with the version *logo*. The valuations of ride 3 and ride 4 showed no more differences between the versions: *logo*: 32.8, *feedback* 32.1, *paging* 32.2, and *scrolling* 31.3.

	mean difference	standard-deviation	sig. (2-tailed)
L - F	-3.00	11.42	.548
L - P	-2.33	5.57	.352
L - S	-1.33	11.64	.790
F - P	-1.50	4.42	.443
F - S	.50	4.09	.776
P - S	2.67	3.39	.112

Table 2: Coping with speech output

The mean givings at what menu length subjects had problems with memorizing were: *logo* 9.2, *feedback* 8.4, *paging* 8.7, and *scrolling* 9.4. All differences proved not significant, though the mean givings of version *feedback* were constantly the littlest.

	mean difference	standard-deviation	sig. (2-tailed)
L - F	1.67	2.58	.175
L - P	.50	2.35	.624
L - S	-.33	.82	.363
F - P	-1.50	2.81	.248
F - S	-2.00	3.16	.182
P - S	.33	.82	.363

Table 3: Maximal length of menus

Menu selection was made via the number of the menu item in 69.4 % of all cases and in 30.6 % by repeating the menu item. Out of a total of 396 repetitions of the menu items only 2 were phrased incorrectly. Both of them were slips of the tongue. This is equivalent to a rate of 0.5 % incorrect inputs. Comparing the results to those of the SIMBA-project reveals the obvious support of the additional visual output. Menu selection with speech-only interaction had a rate of 11.5 % incorrect inputs.

4.2. Visual Interaction

The mean valuations of the supportiveness of the display versions via the analog scale were: *logo* 27.9, *feedback* 27.9, *paging* 34.0, and *scrolling* 34.7. Though the simultaneous visual menu output was graded higher the differences between the versions proved only a marginal significance between *feedback* and *scrolling* (Table 4).

The subjects estimated their visual attention towards the display during the speech output via the analog scale: *logo* 15.6, *feedback* 18.5, *paging* 29.6, and *scrolling* 30.7. Differences proved only significant between *logo* and the simultaneous versions (Table 5).

	mean difference	standard-deviation	sig. (2-tailed)
L - F	.17	4.58	.932
L - P	-7.83	10.17	.118
L - S	-5.33	6.80	.113
F - P	-5.50	9.29	.207
F - S	-5.67	6.50	.086
P - S	-.83	2.40	.434

Table 4: Supportiveness of display versions

	mean difference	standard-deviation	sig. (2-tailed)
L - F	-5.83	8.06	.136
L - P	-18.50	6.66	.001
L - S	-15.50	11.08	.019
F - P	-9.67	12.55	.118
F - S	-11.67	15.92	.133
P - S	-2.17	6.11	.425

Table 5: Estimated visual attention during speech output

The subjects estimated their visual attention towards the display after speech output via the analog scale: *logo* 20.7, *feedback* 27.7, *paging* 29.9, and *scrolling* 25.9. Differences proved only marginal significant between *logo* and *paging*.

	mean difference	standard-deviation	sig. (2-tailed)
L - F	-4.83	12.19	.376
L - P	-9.17	9.99	.074
L - S	-4.50	14.01	.467
F - P	.00	3.35	1.000

F - S	4.00	11.06	.416
P - S	-1.17	6.24	.666

Table 6: Estimated visual attention after speech output

The evaluation of the display versions was made via the video recordings. The means of actual display looks during speech output were per ride: *logo* 26.2, *feedback* 39.9, *paging* 102.7, and *scrolling* 99.7. The differences between the consecutive and the simultaneous versions proved all significant. The difference between the consecutive versions was marginally significant. Between the simultaneous versions was no difference.

	mean difference	standard-deviation	sig. (2-tailed)
L - F	-20.17	20.31	.059
L - P	-77.83	35.52	.003
L - S	-76.17	26.79	.001
F - P	-78.83	27.78	.001
F - S	-63.00	30.96	.004
P - S	3.00	29.87	.815

Table 7: Actual display looks during speech output

Since task performances varied and the subjects partly used differing paths searching the information, the looks per given menu item during speech output were counted as well: *logo* 0.2, *feedback* 0.3, *paging* 0.8, and *scrolling* 0.9. Again, all differences between the consecutive and the simultaneous versions proved significant. The difference between the consecutive versions was marginally significant, and between the simultaneous versions was no difference.

	mean difference	standard-deviation	sig. (2-tailed)
L - F	-.1354	.1534	.083
L - P	-.6324	.1260	.000
L - S	-.7961	.4153	.005
F - P	-.5566	.2473	.003
F - S	-.6987	.2952	.002
P - S	-.0220	.2923	.861

Table 8: Display looks per menu item during speech output

The means of actual display looks after speech output were per ride: *logo* 29.0, *feedback* 41.4, *paging* 27.8, and *scrolling* 23.1. Only the difference between *feedback* and *scrolling* proved significant.

	mean difference	standard-deviation	sig. (2-tailed)
L - F	-16.83	28.96	.214
L - P	-2.17	16.61	.762
L - S	6.17	29.29	.628
F - P	10.33	20.64	.275
F - S	20.50	16.88	.031
P - S	-3.67	23.56	.719

Table 9: Actual display looks after speech output

Between the mean display looks per menu item after speech output were no differences: *logo* 0.3, all other versions 0.4.

	mean difference	standard-deviation	sig. (2-tailed)
L - F	-.1119	.2579	.337
L - P	-.1292	.2153	.202
L - S	-0.9406	.4553	.634
F - P	-.0080	.2430	.939
F - S	.1764	.2785	.181
P - S	-.0810	.4157	.653

Table 10: Display looks per menu item after speech output

If the subjects could not select an item immediately after the speech output they repeated the menus mainly via the display. Only 5 times the menus were repeated via speech output what occurred over all rides and with any system version. The mean repetitions via display were: *logo* 2.3, *feedback* 4.2, *paging* 3.0, and *scrolling* 3.1. Only the difference between *feedback* and *scrolling* proved marginally significant.

	mean difference	standard-deviation	sig. (2-tailed)
L - F	-2.50	4.51	.232
L - P	-.33	3.93	.844
L - S	-1.17	4.36	.541
F - P	.50	3.62	.749
F - S	2.83	3.13	.077
P - S	-2.00	5.93	.447

Table 11: Menu repetition via display

4.3. Strain & Traffic Interaction

4.3.1. Subjective Strain

Immediately after the test rides the subjects answered a questionnaire asking them to judge the strain caused by both the system interaction and the traffic interaction. With all versions the mean ratings of how demanding the situation was increased compared to the control condition. This can be put down to the task performance itself since the increases were all about the same. With the version *logo* the differences of *time pressure, stress,* and *coping with the situation* were only marginally significant. The rather high decrease of coping with the situation is based on the first ride with system interaction. The mean difference of ride 3 and ride 4 has reduced to 2.0 (p = .467). All other versions showed significant differences to the control condition. With the version *feedback* these were the criteria *stress*, *coping with the situation,* and *concentration*. With the version *paging* concerning *time pressure, stress,* and *coping with the situation*. With the version *scrolling* the criteria *time pressure, stress,* and *concentration*.

	C	L	F	P	S
demanding	5,8	+7.0 p=.032	+6.6 p=.016	+7.3 p=.032	+7.1 p=.032
time pressure	2,3	+5.3 p=.060	+2.6 p=.135	+6.8 p=.031	+4.2 p=.015
stress	5,2	+3.8 p=.089	+7.2 p=.006	+9.0 p=.021	+7.6 p=.025
coping with	31,0	-8.7 p=.075	-6.3 p=.042	-5.6 p=.034	-5.2 p=.125
concentration	30,3	-1.4 p=.587	-4.7 p=.036	-2.6 p=.255	-7.0 p=.048

Table 12: Subjective strain

4.3.2. Driving Behavior

Control looks and speedometer looks were analyzed via the video recordings. As control looks were defined looks into the mirrors, and looks to the side and the rear when turning off or changing lanes. As speedometer looks were defined looks to the dashboard as these mainly concern speed control (cf. Dahmen-Zimmer et al. 1999). Differences of control looks to the control condition ride proved significant with the versions *feedback* and *paging*. With the version *scrolling* the reduction was only marginally significant. Differences of speedometer looks again proved significant with the versions *feedback* and *paging*. With the versions *logo* and *scrolling* the reduction was marginally significant.

	C	L	F	P	S
control looks	139	-15.0 p=.108	-24.7 p=.048	-24.4 p=.000	-20.6 p=.086
speedometer looks	112	-36.3 p=.082	-30.9 p=.001	-41.1 p=.016	-49.1 p=.058

Table 13: Control looks and speedometer looks

On every ride the assisting driving instructor was taking down traffic violations. The criteria were *indicating*, *distance* and *lane tracking*, complying with the *right of way* and *traffic lights*, observing *pedestrians* and *bicyclists*, *speed*, *passing*, and *compensations*. The offences were rated from 1 (minor obstruction) to 6 (necessary interference by driving instructor[3]). The single incidents were summarized in a danger index (D-index) per ride.

The means of D-indices showed no significant difference to the control condition. Splitting up the index in situational offences (D-situation)[4] and speed violations (D-speed) showed no significant differences because of offences within a concrete situation but because of speed. A marginally significant increase of speed violations was noticed with the version *feedback*. Those constituted of speeding and slow driving being obstructive. A significant increase was to notice with the version *scrolling* what was mainly and also significantly based on speeding. Compensations due to the system interaction could be observed with all versions. Only the with version *feedback* the occurrence proved only marginally significant.

	C	L	F	P	S
D-total	19.3	+2.6 p=.279	+2.4 p=.397	+2.7 p=.417	+2.8 p=.127
D-sit.	9.2	-0.6 p=.833	-0.2 p=.910	+1.2 p=.550	+0.2 p=.904
D-speed	10.1	+2.3 p=.133	+2.7 p=.071	+1.4 p=.425	+2.6 p=.023
D-fast	9.5	+1.0 p=.298	+0.8 p=.519	-1.1 p=.128	+2.1 p=.036
D-slow	0.6	+1.2 p=.202	+1.8 p=.222	+2.7 p=.130	+0.4 p=.225
compensation	0	+1.8 p=.021	+1.6 p=.077	+2.7 p=.013	+1.4 p=.016

Table 14: Index of danger

[3] The test vehicle had a second set of pedals to ensure safety.
[4] Situational offences included all criteria besides *speed* and *compensations*.

Additionally, the driving instructor judged the entire rides on a scale from 1 (very distinct) to 5 (little distinct). With respect to safety there were no significant differences to the control condition ride. Traffic control, however, diminished with version *paging* significantly and with version *scrolling* marginal significantly. Slowing down in acceleration proved significant with versions *logo* and *paging* and marginally significant with version *feedback*.

	C	L	F	P	S
safety	2.3	-0.2 p=.447	-0.1 p=.594	-0.2 p=.447	0 1.000
control	2.1	-0.3 p=.195	-0.2 p=.447	-0.4 p=.035	-0.3 p=.081
acceleration	2.8	-0.8 p=.001	-0.8 p=.088	-0.7 p=.022	-0.4 p=.169

Table 15: Judgement of driving behavior

5. Discussion

An effect of learning with respect to coping with speech interaction occurred only with version *logo*. Here also the strain of the first system interaction ride was increased. This leads to the conclusion that alone with this version the subjects used speech as primary mode of interaction. Displaying the textual feedback of the recognized input (*feedback*) turned out being distracting from listening to the spoken menu. The subjects also estimated their display looks during speech output fairly higher than with version *logo*. In consequence, there was a tendency of repeating the menus via the display more often than with version *logo*, and in all rides the strain increased significantly compared to the control ride.

If the menus were displayed simultaneously the subjects selected the menu items almost exclusively via the display. This lead to increased strain and to negative influences on the driving behavior. With the version *paging* subjects generally drove slower and their control over the traffic situation was reduced. With the version *scrolling* subjects drove faster and their control over the traffic situation was marginal significantly reduced. The difference between these two versions is to put down on the different displaying modes of menus longer than one page. The page mode required an additional timing controlling the change of the displayed subsets of menu items. With the scroll mode, however, this was not necessary, but reading of forthcoming menu items was possible. Since slowing down, what happened with the version *paging*, is an indicator for compensation while subjects rather speeded with the version *scrolling*, it can be assumed that with the version *scrolling* subjects were not fully aware of the potential of danger due to the system interaction.

The hypothesis that a consecutive menu output supports the primary mode of speech best was only partly verified. Alone with the version *logo* the subjects' attention was not drawn away from traffic observation or speech output.

Compared to speech only interaction the multi-modal output reduced the mental strain. Phrasing the input correctly did not cause any problems, and the supportiveness of the display was rated high with all versions. But the mental strain caused by coordinating system and traffic interaction and the impact on the driving behavior varied between the versions. Thus, the hypothesis that an additional display output reduces not only the mental strain caused by the need of memorizing the menu items but also leads to an efficient system interaction and a stable driving behavior was only verified with version *logo*.

6. Conclusion

A multi-modal menu output with a primary mode of speech proved probate with respect to system interaction as well as safe traffic interaction. The additionally displayed menu reduced the mental strain and the problems of memorizing that occurred with speech only interaction. The subjects had no problems phrasing the input and repeating the menu was scarcely necessary. Thus, the visual distraction was only minor. Moreover, repeating the menu makes it possible to read selectively, which reduces the visual distraction even more. The subjective strain and the driving behavior did not differ essentially from the rides without system interaction. Menu selection proved only problematic in the first system interaction ride. The process of acquiring strategies for spoken system interaction and its coordination with the traffic situation was rather straining. However, the driving remained stable.

7. References

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