C2 Experimentation

Empirical Comparison of Five Input Devices for Anti-Air Warfare Operators

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Abstract

Operators appointed in the warfare area Anti Air Warfare (AAW) on battleships have to identify and classify airborne objects using sensor data presented on workstation displays. They feed results into the system so that an adequate evaluation of the situation can be conducted and response can be initiated if necessary. Stress and time load are very high as the decision basis is often limited and wrong decisions may have severe consequences. Aside from computer assistance, adequate input devices could also support operators by allowing faster responses. Therefore, in an experiment a conventional computer mouse, two different trackballs as well as touch and speech input were compared in respect to response time, correctness, and subjective workload in a simplified AAW task. Furthermore popup menus and conventional buttons at the screen's upper edge were compared. The results demonstrate that in general touch input and mouse show the fastest response times whereas speech input and the trackballs constitute the other extreme. As well, popup menus were inferior to the buttons in response times. Workload was mostly consistent with these results, except for speech input, which was rated low in workload.

1 Introduction

An important task within Naval Anti Air Warfare consists in the identification and classification of airborne objects based on sensor data presented on the workstation display. In the identification process the operator decides if an airborne object is friendly, neutral or hostile. During classification the operator makes conclusions regarding the kind of airborne objects (bomber, fighter, helicopter etc.) which are on the display. The operator enters the results of his decisions concerning identification and classification into the system so that an adequate response can be initiated (e.g. engagement). The task has to be done under great time pressure and without failures as severe consequences have to be expected for the ship or the airborne object when the decisions are wrong. As input information is very often based on incomplete data the complexity of the decision increases.

One important approach to adapt the operator interface to the human capabilities and limitations consists in assisting the operator through a knowledge based decision support system (MOOSHAGE ET AL., 2003) which may reduce workload and improve performance. On the other hand an improvement could also focus on the input devices of the system. Appropriate input devices could reduce interaction times and errors and also time load of the operator. Aside from the conventional trackballs commonly used with this task also computer mice and touch and speech input are potential input devices for the system.

The question of speech input as a promising alternative for interaction in future man-machine-systems was investigated in a series of experiments with partially contradicting results. Speech recognition systems were tested with air traffic control (BIERWAGEN & VIELHAUER, 2000) and military flight control (GUBANKA & SANDL, 2000). The results show that for each application considerable efforts have to be invested to reach acceptable recognition rates which could satisfy user acceptance and safety demands. Problems arise especially when also technical terms in a foreign language are used and/or high noise levels are present. Nevertheless the problems can be solved. Another difficulty with speech input is that there are some factors which modify speech and might aggravate speech recognition. In this respect the influence of stress on military speech recognition systems was reviewed by VLOEBERGHS ET AL. (2001). The authors come to the conclusion that in many military operations factors like fear, pain, sleep deprivation, high workload etc. can influence speech in respect to amplitude, frequency and other variables so that an acceptable speech recognition with existing systems is not possible. KO (2000) comes to similar conclusions when realizing that speech processing for tactical applications of the Navy is not yet satisfying. Application of speech input in the cockpit was critically evaluated by HUDGINS ET AL. (1998) coming to similar results. This is also supported by a survey of ANDERSON (1998) with flight control tasks. In contrast, the work of GUBANKA & SANDL comes to contradicting findings.

The work of KO also gives information on touch input systems showing that touch input displays allow input times which are at least as short or even shorter than those of other input devices. Only some guidelines have to be followed: the method should be used with buttons and without windows. Furthermore, the buttons should be located at appropriate positions of the display so that far-ranging movements can be avoided in order to prevent fatigue.

As the literature is based predominantly on single tests of the different input devices the present investigation focused on a comparative evaluation of a selection of potential candidates of input devices for AAW operators. In addition, mental workload was neglected in all experiments, but effort spent to carry out the task seemed to be another important evaluation criterion besides performance. Therefore, workload was to be included in the present investigation, too.

2 Method

2.1 Sample

18 male subjects (Ss) from the Research Institute for Communication, Information Processing, and Ergonomics aged between 30 and 55 years attended to the experiment. Before the experiment, all subjects were tested with the Ishihara Test for Color Blindness (ISHIHARA, 1968).

2.2 Experimental setup

Ss had to select, identify and classify the airborne objects displayed on different positions on the synthetical radar screen (Plan Position Indicator = PPI) using the different input devices.

With selection Ss activated the symbol of the airborne object after its appearance. After selection Ss decided within the scope of identification if the airborne object was friendly or hostile and pressed the appropriate button. In the scope of classification Ss decided whether the airborne object was a fighter or a helicopter.

The monitor with integrated touch screen used for the PPI (NEC, 20,1” LCD TFT, 1280x1024 Pixel) on which the radar picture was displayed, showed the own ship and the environment in a bird's-eye view, the position of the own ship being in the center. One airborne object at a time (fighter or helicopter) appeared around the own ship in one of eight possible positions by chance and had to be processed as fast as possible. The result had to be entered into the system using the selected input device. After that the next object appeared (totaling 32 objects per trial). The task was simplified in order to reduce training time for the naive subjects. The identity of the objects had to be derived from the course, symbolized by the direction of the vector attached to the icon of the airborne object. A vector pointing to the own ship indicated a hostile object, a vector pointing in the opposite direction indicated a friendly object. Speed of the airborne object gave information for classification. A short vector indicated low speed typical for a helicopter, a long vector indicated high speed typical for a fighter aircraft.

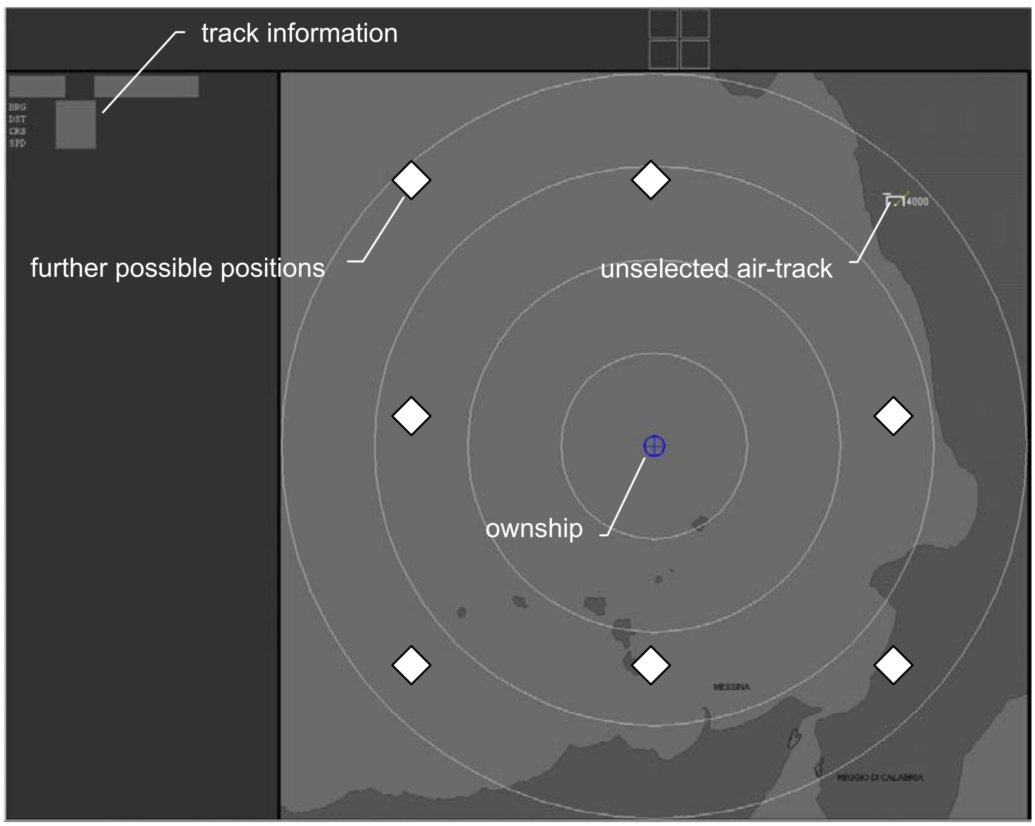

Figure 1: Plan Position Indicator (PPI)

2.3 Independent variables

There were two independent variables in the experiment: *Input devices* and *positions of buttons for data input* on the display. Five different input devices were used:

- Conventional computer mouse (Microsoft, IntelliMouse),
- Trackball (Cursor Controls Inc., P-75 Trackball),
- Logitech-Trackball (Logitech, TrackMan®Wheel),
- Touch input (Elo TouchSystems, IntelliTouch),
- Speech input (Philips Semiconductors GmbH, VoCon).

First the Ss had to activate the symbol for the airborne object in order to select the air-track for further processing. Afterwards the results of objects' identification and classification had to be fed into the system by pressing the appropriate buttons which contained the tactical symbols for the identities "friendly" and "hostile" as well as for the categories "fighter" and "helicopter" respectively.

These buttons were placed

- Either at the upper edge of the monitor
- Or within a popup menu which was located next to the symbol for the airborne object.

These different positions of the data-input buttons formed the second independent variable *position of the buttons.*

The conventional computer mouse served as a standard for input devices from the civil area. Usually such mice are not used on ships since roll and pitch movements of the ship may displace the mouse and the cursor. The trackball served as a standard for typical nowadays naval environments as a very similar one is used in the German Navy. Whereas the trackball was moved with the palm, the Logitech-Trackball was moved with the thumb. All these input devices had two buttons. The left one was used for selection, identification and classification. The right button was used in order to open the popup menu.

As the usability of all three manually operated input devices depends on the gain factor, which can be adjusted in the system control panel of the system software (in this case MS Windows NT 4.0), this variable was tested before with three different levels (2, 4, 7). Extreme levels (1, 8) were neglected as they selectively favored either precision or speed of the cursor control. Level 4 showed the best results with the four Ss used in this pre-test.

With the touch input device fingertips could be used in order to select both the symbol for the airborne object on the PPI and the buttons for identification and classification. The popup menu was activated by tipping twice at the object's symbol.

The speech recognition system VoCon is independent from the speaker and thus did not have to be trained for any particular user. With speech recognition Ss had to select the symbol for the airborne object by means of the touch input device. Selecting objects by saying their track number has been tried preliminary as well, but turned out to be virtually impracticable. Identification and classification was done by saying the words "friendly" or "hostile" and "fighter" or "helo" respectively.

2.4 Dependent variables

The dependent variables were task performance times for selection, identification, and classification of airborne objects as well as the total completion time (all calculated as arithmetic mean for each variable over all 32 events in one trial). Furthermore numbers of correct responses per trial were registered. Subjective workload was measured with the Two-Level Sequential-Judgement Scale (Figure 2) with ten levels (PITRELLA & KÄPPLER, 1988). The rating scale measures subjective task difficulty which is expressed by scores increasing parallel to workload from 0 to 100.

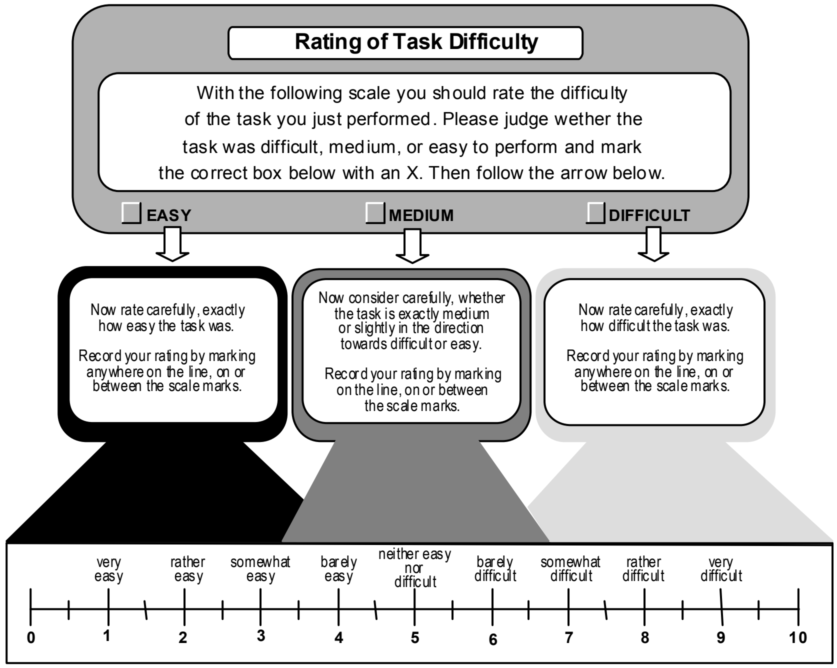

Figure 2: Two-Level Sequential-Judgement Scale (PITRELLA & KÄPPLER, 1988)

2.5 Procedure

Overall there were 9 experimental conditions which were presented in an incomplete counterbalancing design (UNDERWOOD, 1966): Four input devices with two button positions on the display (popup and upper display limit) and speech input. In each of the nine runs all experimental conditions were presented two times across all 18 Ss. In each trial there were 32 combinations of airborne objects which were presented randomly: 8 positions of airborne objects on the display, 2 identifications (friendly/hostile) and 2 classifications (helicopter/fighter). Ss had up to 10s for selection, identification, and classification of an object. After processing of the object or after exceeding the time limit the next object appeared. All Ss made two training runs with each experimental condition in advance of the run used for statistical analysis.

For statistical data analysis of all variables three ANOVA (analysis of variance) designs were used. The first factor "input device" with the treatments "mouse", "touch input", "Logitech" and "trackball" and the second factor "button position" containing the treatments "popup menu" and "buttons at the upper display edge" were compared in a 4x2 ANOVA with repeated measures in both factors (ANOVA I).

Speech Input was compared with the other input devices separately in two single factor repeated measure ANOVAs for the buttons at the display edge (ANOVA II) and for the popup menu (ANOVA III) with five levels in each factor. All ANOVAs and the following comparisons of means were computed by means of SPSS V11.0. The results are described in detail in PFENDLER ET AL. (2002).

3 Results

3.1 Selection times

Figure 3 shows the influence of the five input devices and the button positions on average selection times.

Selection times for the popup menu are significantly higher than for the buttons at the upper display limit (ANOVA I: $F_{1/17}$=4.962, $^{*}p$=0.040, o^2=0.007). However the strength of the position effect which is expressed by means of o^2 (EIMER, 1978) is quite small. Since the selection procedure is the same with both positions this effect is considered to be random. Variations of the selection times are primarily caused by the different types of input devices ($F_{3/51}$=102.22, $^{**}p$=0.000, o^2=0.779).

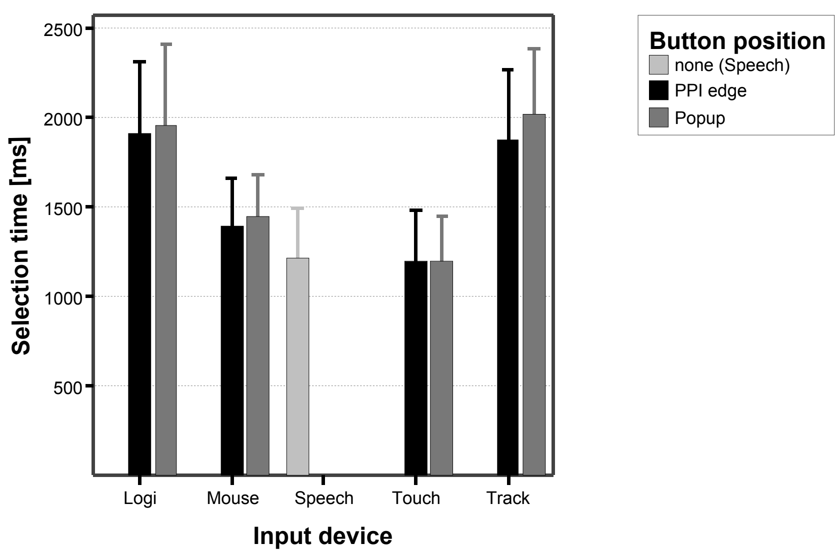

Figure 3: Average selection times with regard to input device and button position

Pairwise comparison of the means (df=1/68; Table 1) demonstrates that the significantly shortest selection times are reached with touch input followed by the mouse, whereas both trackballs – which do not differ significantly - need the significantly longest times.

		Mouse	Touch	Logi	Track
Mouse	1420,32		226,19 *	-509,62 *	-513,80 *
Touch	1194,13			-735,81 *	-739,99 *
Logi	1929,94				-4,18
Track	1934,12				

Table 1: Comparison of means between selection times [ms] of input devices (: p<0.05)*

As expected differences between touch input and speech input are very small since the touch input device is used for selection with speech input (Table 2). For this reason speech input shows similar differences to the other input devices like the touch input.

	buttons at PPI edge		popup menu	
		Speech		Speech
Mouse	1393,55	181,96 *	1447,09	235,50 *
Touch	1194,55	-17,04	1193,71	-17,88
Logi	1905,05	693,46 *	1954,82	743,23 *
Track	1868,81	657,22 *	2018,22	806,63 *
Speech	1211,59		1211,59	

Table 2: Comparison of means between identification times [ms] of input devices separated by button position (∗: $p<0.05$)

3.2 Identification times

Average identification times in dependence from input devices and position of buttons are depicted in Figure 4.

The position of buttons does not have a significant effect on identification times (ANOVA I: $F_{1/17}=4.296$, $p>0.05$) in contrast to input devices (ANOVA I: $F_{3/51}=122.042$, $^{**}p=0.000$, $o^2=0.774$).

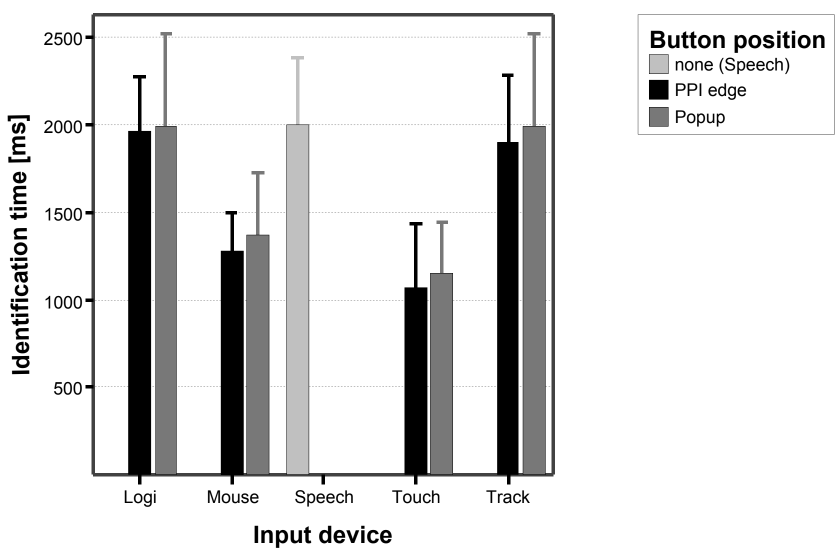

Figure 4: Average identification times with regard to input device and button position

Except for Logitech and the trackball all input devices show significant differences between means (df=1/68; Table 3). The significantly shortest identification times are reached by touch input followed by the mouse and the trackballs.

		Mouse	Touch	Logi	Track
Mouse	1325,44		214,08 *	-651,46 *	-623,53 *
Touch	1111,36			-865,54 *	-837,61 *
Logi	1976,90				27,93
Track	1948,97				

Table 3: Comparison of means between identification times [ms] of input devices (∗: p<0.05)

According to the analysis of the effects of the input device regarding the speech input ANOVA II and III show significant effects on identification times (ANOVA II: $F_{4/68}$=82.784, **p=0.000, o^2=0.818; ANOVA III: $F_{4/68}$=43.584, **p=0.000, o^2=0.700). Mean identification times of speech input are similar to those of the trackballs with buttons at the upper display edge and especially with the popup menu (Table 4). The more detailed pairwise comparisons of means (df=1/85) show that identification with speech input takes significantly more time than with touch input and mouse.

	buttons at PPI edge		popup menu	
		Speech		Speech
Mouse	1277,13	-720,39 *	1373,75	-623,77 *
Touch	1069,36	-928,16 *	1153,36	-844,16 *
Logi	1962,67	-34,85	1991,13	-6,39
Track	1904,06	-93,46	1993,86	-3,66
Speech	1997,52		1997,52	

Table 4: Comparison of means between identification times [ms] of input devices separated by button position (∗: p<0.05)

3.3 Classification times

Average classification times in dependence from input devices and position of buttons are depicted in Figure 5.

There are significant differences between the means primarily caused by the different types of input devices (ANOVA I: $F_{3/51}$=75.539, **p=0.000, o^2=0.708) and to a less extent by different positions of buttons on the display (ANOVA I: $F_{1/17}$=15.708, **p=0.001, o^2=0.026).

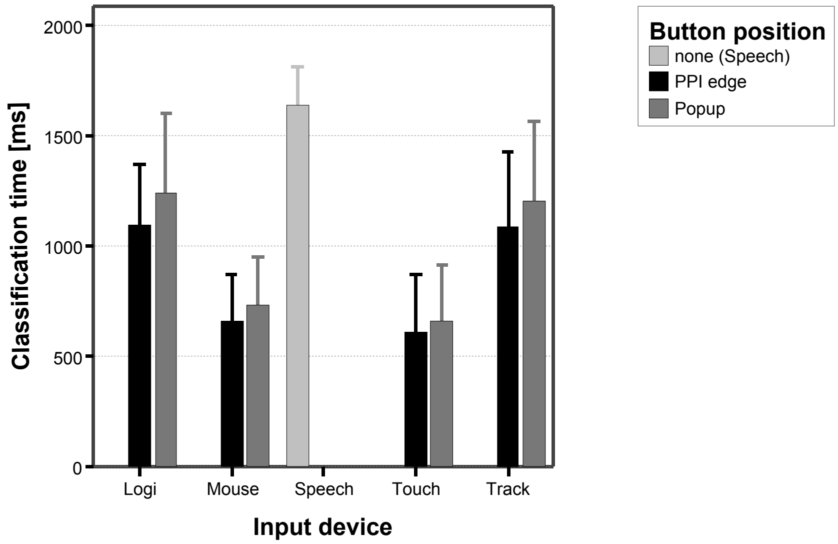

Figure 5: Average classification times with regard to input device and button position

Apart from the differences between touch input and mouse as well as between Logitech and the trackball, deviations between input devices are significant (df=1/68; Table 5). The shortest times for classification are observed with touch input and mouse, the longest times with the trackball and Logitech.

		Mouse	Touch	Logi	Track
Mouse	697,13		66,57	-469,02 *	-446,51 *
Touch	630,56			-535,59 *	-513,08 *
Logi	1166,15				22,51
Track	1143,64				

Table 5: Comparison of means between classification times [ms] of input devices (∗: $p<0.05$)

By comparing speech input with the other input devices when using popup menus or buttons at the upper display edge (ANOVA II: $F_{4/68}$=111.075, $^{**}p=0.000$, $o^2=0.858$; ANOVA III: $F_{4/68}$=84.480, $^{**}p=0.000$, $o^2=0.821$; subsequent pairwise comparisons of means with df=1/85) it can be shown that speech input causes significantly longer classification times than all other input devices (Table 6). Touch input needs approximately 30% of classification time of speech input.

	buttons at PPI edge		popup menu	
		Speech		Speech
Mouse	661,94	-975,91 *	732,32	-905,53 *
Touch	605,09	-1032,76 *	655,98	-981,87 *
Logi	1095,25	-542,60 *	1237,04	-400,81 *
Track	1087,37	-550,48 *	1199,90	-437,95 *
Speech	1637,85		1637,85	

Table 6: Comparison of means between classification times [ms] of input devices separated by button position (∗: $p<0.05$)

3.4 Total completion time

Time to perform the total task (selection, identification, and classification) is depicted in Figure 6. There are significant differences between means caused by variations of the input devices (ANOVA I: $F_{3/51}$=149.29, $^{**}p=0.004$, $o^2=0.835$) and to a minor extent by the positions of the buttons on the display (ANOVA I: $F_{1/17}$=11.141, $^{**}p=0.004$, $o^2=0.010$).

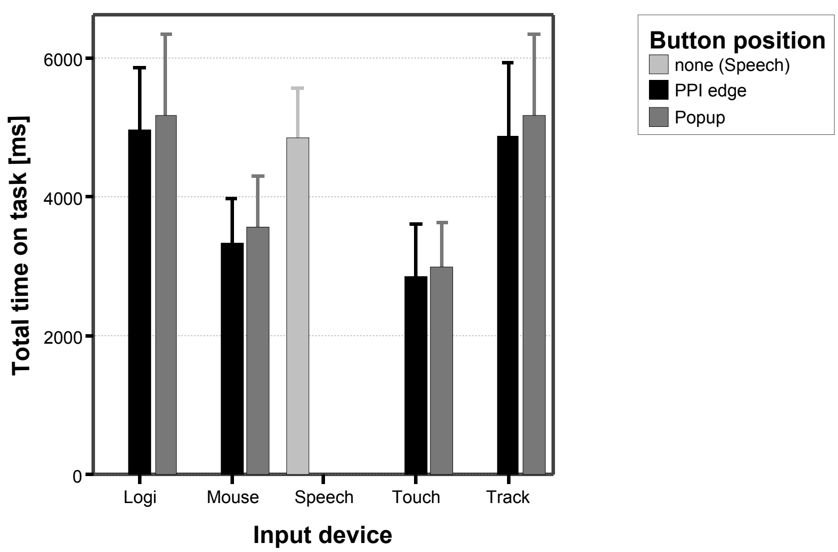

Figure 6: Average total completion times with regard to input device and button position

In contrast to the comparison between the trackball and Logitech all other differences between input devices are significant (pairwise comparisons of means with df=1/68; Table 7). With touch input the significantly shortest response times can be observed followed by the mouse and both trackballs.

		Mouse	Touch	Logi	Track
Mouse	3441,77		521,90 *	-1619,43 *	-1575,46 *
Touch	2919,87			-2141,33 *	-2097,36 *
Logi	5061,20				43,97
Track	5017,23				

Table 7: Comparison of means between total task times [ms] of input devices (∗: p<0.05)

Further analyses (ANOVA II: $F_{4/68}$=95.308, **p=0.000, o^2=0.838; ANOVA III: $F_{4/68}$=71.280, **p=0.000, o^2=0.794; and the following pairwise comparisons of means with df=1/85) show that speech input does not differ significantly from both trackballs with both positions of the buttons on the display (Table 8). Total time on task is significantly longer with speech input than with mouse and touch input, independent from the position of input buttons.

	buttons at PPI edge		popup menu	
		Speech		Speech
Mouse	3332,62	-1504,43 *	3550,93	-1286,12 *
Touch	2859,95	-1977,10 *	2979,79	-1857,26 *
Logi	4962,71	125,66	5159,69	322,64
Track	4860,24	23,19	5174,82	337,77
Speech	4837,05		4837,05	

Table 8: Comparison of means of total task times [ms] of input devices separated by button position (∗: p<0.05)

3.5 Number of correct responses per trial

The number of correct responses with regard to identification and classification is depicted in Figure 7. There are no significant differences in number of correct responses between input devices (ANOVA I: $F_{3/51}$=3.069, p>0.05) and between positions of buttons on the display (ANOVA I: $F_{1/17}$=2.508, p>0.05). Also speech input does not differ significantly from the other input devices in respect to number of correct responses (ANOVA II: $F_{4/68}$=0.659, p>0.05; ANOVA III: $F_{4/68}$=1.542, p>0.05).

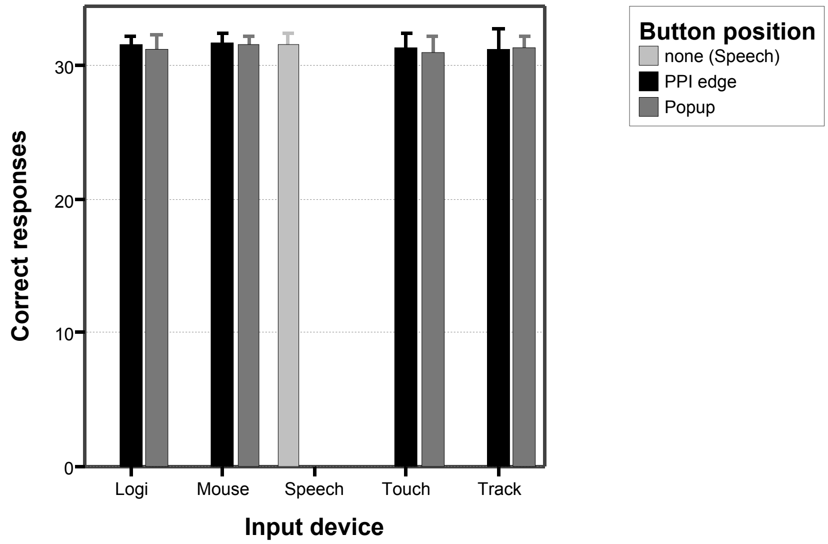

Figure 7: Number of correct responses with regard to input device and button position

3.6 Task difficulty

Results of subjective task difficulty in respect to input devices and positions of buttons on the display are depicted in Figure 8. Mouse, speech input, and touch input are rated from “rather easy” to “somewhat easy” whereas the trackball and Logitech are rated from “barely easy” to “neither easy nor difficult”. In respect to subjective task difficulty there are no significant differences between positions of buttons on the display (ANOVA I: $F_{1/17}=0.017$, $p>0.05$) but between input devices (ANOVA I: $F_{3/51}=20.035$, $^{**}p=0.000$, $o^2=0.379$).

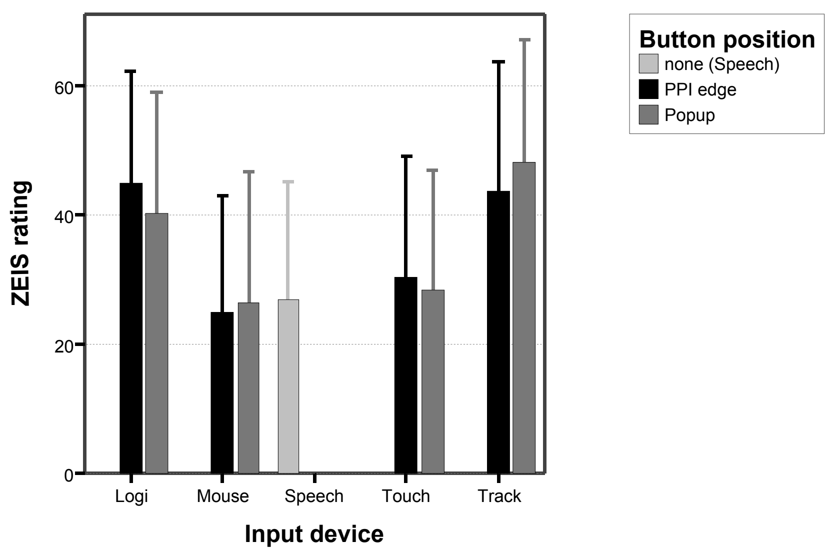

Figure 8: Average subjective task difficulty with regard to input device and button position

There are no significant differences between mouse and touch input as well as between Logitech and the trackball (pairwise comparisons of means with df=1/68; Table 9). All other comparisons are significant. Mouse and touch input cause significantly lower subjective ratings than the trackballs.

		Mouse	Touch	Logi	Track
Mouse	25,61		-3,67	-16,81 *	-20,28 *
Touch	29,28			-13,14 *	-16,61 *
Logi	42,42				-3,47
Track	45,89				

Table 9: Comparison of means between subjective task difficulty of input devices (: p<0.05)*

Further analyses (ANOVA II: $F_{4;68}=12.019$, $^{**}p=0.000$, $o^2=0.376$; ANOVA III ($F_{4;68}=11.805$, $^{**}p=0.000$, $o^2=0.372$; subsequent pairwise comparisons of means, df=1/85) show that speech input does not differ significantly from mouse and touch input in subjective task difficulty when looking separately at buttons on the upper display edge and at the popup menu (Table 10). However task difficulty is rated significantly lower when using speech input than with the usage of both trackballs with the buttons at the display edge, respectively the conventional trackball with the popup menu.

	buttons at PPI edge		popup menu	
		Speech		Speech
Mouse	24,89	-2,05	26,33	-0,61
Touch	30,22	3,28	28,33	1,39
Logi	44,78	17,84 *	40,06	13,12
Track	43,67	16,73 *	48,11	21,17 *
Speech	26,94		26,94	

Table 10: Comparison of means between subjective task difficulty of input devices separated by button position (: p<0.05)*

4 Discussion

The experiment demonstrates that the variation of input devices had a significant effect on the times needed for selection, identification, and classification of airborne objects which were displayed on the synthetical radar screen.

Most results were consistent concerning the three subtasks and the total task. The shortest response times were reached with touch input. Significantly longer response times were found with the computer mouse (exception: classification times). The longest response times were observed with the trackball and Logitech. Both of them did not differ significantly in any AAW subtask. The long response times are remarkable as similar trackballs are used for the same task in the German Navy. Computer mice are not used up to now, because it is assumed that they can be displaced easily in rough sea. However, it is possible to develop advanced computer mice which can be fixed magnetically so that these restrictions are not valid anymore.

The differences between the trackball and Logitech on the one hand and speech input on the other are partly significant. Speech input is only faster in the first subtask (selection) which is done by touch input. Approximately the same time as with the trackballs is needed for identification, and significantly more time is used for classification. These results show that the trackballs and speech input do not enhance operator performance with respect to response times and therefore cannot be recommended for AAW operators' tasks.

Aside from input devices popup menus and conventional buttons at the screen's upper edge were compared. The hypothesis of shorter response times with popup menus due to the shorter cursor movement distances could not be confirmed. The additional use of the right mouse button to open the popup menu is overcompensating the time gained by the shorter cursor movement distances resulting in longer response times with the popup menu compared to the buttons at the upper display edge. In addition, there are more response alternatives which could also increase response times. Another reason for this result can be hypothesized to be the changing position of the popup menu due to varying air-track positions. The operator has to adjust continuously to the changing positions, whereas with the fixed buttons the target to be reached is always at the same place. Furthermore, another disadvantage of popup menus has to be considered: In the present experiment there were only four response buttons. In reality there are far more alternatives. As a consequence, the area for the corresponding buttons for the popup menu could cover important information on the PPI. These reasons contradict to the use of popup menus for AAW tasks.

The number of correct responses does not yield any additional information to this and other aspects of the experiment as no significant differences could be found. In contrast, subjective task difficulty provides some more information. All scores show a relatively low subjective task difficulty meaning that the task was relatively easy to perform. Furthermore, there are no significant differences between positions of buttons on the display in respect of task difficulty. Regarding task difficulty there is nothing to be said against using buttons at the display edge instead of popup menus.

As for the influence of the input devices on task difficulty, the differences are not so clear cut as with response times. The main contrast to performance is that speech input is rated the lowest in task difficulty but shows one of the highest total task times. Obviously speech input is the most natural way of communication. However, speech input needs a rather clear pronunciation and speaking takes more time than simple operations with other input devices. In addition, the word processor affords a certain amount of processing time which cannot be shortened. All these aspects explain why total time on task with speech input is nearly 100% higher than with the touch input device. Therefore speech input cannot be recommended for such types of selection tasks. It could only be recommended when more than one task has to be performed at the same time and speech can be used as a parallel input channel.

Apart from speech input the results from subjective task difficulty parallel performance obtained with the other input devices. Mouse and touch input are rated approximately the same and show a low task difficulty level. In comparison, the trackball and Logitech are rated significantly higher contradicting to the use of these input devices for AAW tasks.

Therefore the conclusion can be drawn that touch input and a computer mouse can be recommended for AAW tasks as they show the shortest performance times and the lowest task difficulties. There is only the restriction that the computer mouse should have a device to prevent inadvertent movement. In addition, both methods have another advantage in respect to the trackballs: Comparable to pointing, inherent in touch input, most people today are accustomed to the usage of computer mice so that there is no additional training necessary.

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