

Vibrotactile Signals

-using tactile stimuli to present information

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Tactile stimulation is a rarely utilized resource when presenting information. The present study was set up to investigate the use of six vibrotactile signals and to what degree, and how, they can get mixed up. The signals used in this study differed in temporal frequency, i.e. on/off-pulse. The experiment was conducted at the Swedish Defence Research Agency, FOI, in Linköping, using a combat vehicle simulator and a tactile vest. Even though the participants were quite good at detecting and identifying the signals and their performance increased rapidly, the result suggests that six signals designed in this way is too many, at least without extensive training. The most interesting result was a pattern found in the errors made by the participants; more than half of the errors made occurred when a signal was mistaken for the signal above it on the intensity scale. This pattern was named the HIMUTS-Effect, Higher Intensity Mix-up Using Tactile Stimuli.

Introduction

The use of tactile displays is a relatively new area of research which is interesting and relevant to explore since the use of tactile displays can help to present information, which in turn can support decision making. Though, very little is written about how the actual tactile signals should be designed, how many can be used and the accuracy of detection.

Purpose

The goal of the present study was to examine to what extent numerous tactile signals, varying in on/off-pulse (see an explanation of the term in section 3.3), can be correctly interpreted while driving a vehicle, in this case a simulated combat vehicle. The intention was also to find out how many signals that would be reasonable to use when designing tactile displays and how they should vary in on/off-pulse. Furthermore, the intention was to see if there are any signals that are less appropriate to combine than others, based on the on/off-pulse of the signals.

Theoretical background

The use of tactile displays has been receiving increasing attention lately and several studies the past few years have explored possible applications (e.g. van Erp, 2002; van Erp & van Veen, 2004). Studies vary from experiments in strictly controlled environments, to understand the biological aspects of tactile sensations on the skin, to field studies where tactile displays are put to use in realistic situations.

Different studies have shown that tactile displays have a positive effect on performance both in single and parallel tasks. For example tactile displays are used to indicate threat- and target positions, navigation, to alert attention and to enable quiet delivery of commands or instructions (Svensson et al., 2009).

According to the Multiple Resource Theory we have different resources for different mental tasks (Wickens, 2008). If

you use different resource pools the workload does not increase for the entire system. Therefore, presenting inputs by using different resources are beneficial. Perceptual and cognitive tasks use resources that differ from selection and execution of action. Tactile information uses other resources than visual and audible information. This allows the user to simultaneously receive and process more information both faster and with less risk of getting overloaded. Tactile information are more about selection and execution of action (Wickens, 2008) and less about perceptual and cognitive tasks since tactile stimuli is intuitive (van Erp, 2006). Tasks that use different resources do not interfere with each other according to the Multiple Resource Theory.

Method

The present experiment took place in a lab at the Swedish Defence Research Agency, FOI, in Linköping. 24 participants with driver's license drove a simulated Combat Vehicle 90 in a virtual environment resembling a military exercise area in Kvarn, Östergötland. The participants wore a tactile vest that generated different vibrotactile signals on four tactors in the directions 0°, 90°, 180° and 270°. The tactors had a vibration frequency of 120 Hz. To identify the signals a touch screen was placed at the driver's right side, where there was a set of buttons which represented the different signals.

Six different vibrotactile signals were designed and used. Since the tactors' vibration frequencies could not be changed, different on/off-pulses were used. The signals that were used are presented in Table 1.

Table 1 The signals in order of on/off-pulse intensity, where Commander's position is signal 1, Cross line is signal 2 and so forth (the names are translated from Swedish).

On/off-pulse intensity scale	
1. Commander's position:	on: 1000 ms off: 1000 ms <i>lowest intensity</i>
2. Cross line:	on: 500 ms off: 500 ms
3. Community:	on: 250 ms off: 250 ms
4. Near collision:	on: 125 ms off: 125 ms
5. Enemy:	on: 10 ms off: 10 ms
6. Fighter aircraft:	on: 100 ms off: 10 ms <i>highest intensity</i>

The experiment started with a learning session which was followed by three trials. After each trial the participants had a pause for about five minutes during which they answered a short questionnaire about the trial. When they had finished the last trial and its' questionnaire they received a final questionnaire about the overall experiment. Each trial consisted of one out of three different tests. There were three groups consisting of eight participants, and each group was divided into two subgroups consisting of four participants, see Table 2. Test 1-4 consisted of signals 1-4, Test 3-6 consisted of signals 3-6 and Test 1-6 consisted of signals 1-6. The order of the tests for each group can be seen in Table 2.

Table 2 Which trial and test that were presented to each group. The different groups were presented to the three tests in one of the six orders.

	Trial 1	Trial 2	Trial 3
Group 1a	Test 1-4	Test 3-6	Test 1-6
Group 1b	Test 3-6	Test 1-4	Test 1-6
Group 2a	Test 1-4	Test 1-6	Test 3-6
Group 2b	Test 3-6	Test 1-6	Test 1-4
Group 3a	Test 1-6	Test 1-4	Test 3-6
Group 3b	Test 1-6	Test 3-6	Test 1-4

The participants were told that while driving they would be presented with a number of signals and that their task was to react to the signals by pressing the corresponding button on the touch screen.

Data were collected from the participant's keystrokes on the touch screen. Each test data was saved to a separate file. Four questionnaires were also used to collect data, these dealt with the participants' subjective opinion of how they had performed in the test and how difficult the different signals were. All the questionnaires were written in Swedish.

Results

The results presented in this section is focused on how the signals was recognized and how the errors was distributed between the signals, which is where we found the most interesting result in this study.

The means of each participant's correct answers for each signal in every test were used to compute each signal's rate of identification, see Figure 1. This was done with a Repeated Measures ANOVA $F(5, 115) = 13.77, P < 0.001$, with a Greenhouse-Geisser correction. An LSD Post Hoc analysis showed significant differences of correct identification between some of the signals which can be seen in Table 3.

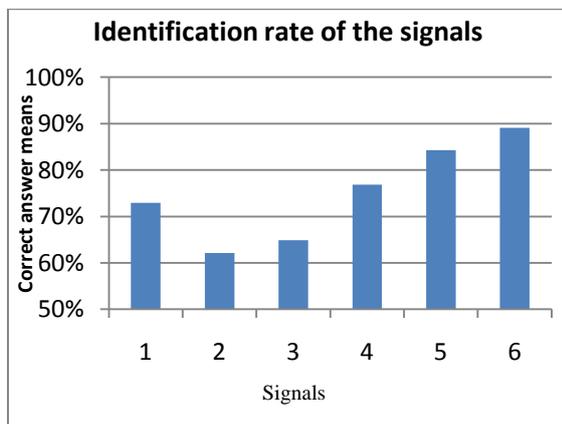


Figure 1 The participants' overall means of correct answers in percent for each signal.

Table 3 The participants' mean of correct answers on each signal in percentage and which signal they significantly differed from.

Sign.	% correct answers	Differed from (in identification)
1	73	2, 3, 6
2	62	1, 4, 5, 6
3	65	1, 4, 5, 6
4	77	2, 3, 5, 6
5	84	2, 3, 4
6	89	1, 2, 3, 4

Errors made by the participants are plotted out in Table 4. Since signals 3 and 4 occurred in all three tests, the data was normalized by randomly removing half of the participants' responses to signals 3 and 4 in Test 1-4 and Test 3-6. In addition, the first signal of every test was removed since the participants were presented with that signal one more time than the other signals. Since the same error distribution pattern was found prior to the normalization this did not alter the results.

The pattern in Table 4 shows that over half of the errors made occurred when a signal was mistaken for the signal right above it on the on/off-pulse intensity scale, see Table 1. However this did not occur the other way around to the same extent. For example, signal 2 was mistaken for signal 3 in 70% of the errors made for signal 2. Signal 3 was mistaken for signal 2 in 12% of the errors made for signal 3. This pattern is highlighted in red in Table 4. Numbers highlighted in yellow represent when a signal has been mistaken for the signal right below it in the on/off-pulse intensity scale. As can be seen the pattern emerges for all the signals' errors except for signal 6 which had no signal above it on the intensity scale, and signal 5. The columns "Higher" and "Lower" shows the total portion of errors made when mistaking a signal for the one right above, "Higher", and below, "Lower", in the on/off-pulse intensity scale. The column "-" shows when a signal has been missed by the participants. The numbers have been rounded off to the nearest integer.

Table 4 An error distribution table showing the wrong answers made by the participants.

		Answered signal									
		-	1	2	3	4	5	6	Total errors	Higher error	Lower error
Signal presented	1	10%	0%	12%	1%	0%	0%	0%	23%	52%	
	2	5%	3%	0%	23%	2%	1%	0%	34%	70%	8%
	3	1%	0%	2%	0%	10%	0%	0%	13%	77%	15%
	4	1%	0%	0%	3%	0%	5%	0%	9%	56%	33%
	5	1%	0%	0%	1%	4%	0%	7%	13%	54%	31%
	6	2%	0%	0%	0%	0%	6%	0%	8%		75%

Discussion

The participants were better at identifying the two signals with higher on/off-pulse intensity than the four signals in the lower part of the intensity scale. Signals 1-4 differed analogously, i.e. they all had a difference in milliseconds, relative to the signal below and above it, by a factor of two (signal 1 had no signal below it and signal 4 was followed by signal 5 with another difference, explained below). For example, signal 2 had an on/off-pulse of 500 ms and signal 1 had an on/off-pulse of 1000 ms, which is twice as long. Based on the results, differentiating a signal with the on/off-pulse of 50 ms from one with 125 ms, is easier than differentiating a signal with the on/off-pulse of 500 ms from one with 1000 ms. Even though the difference in on/off-pulse between signals in the first case is 75 ms and 500 ms in the second (which while reading might intuitively seem as the greater difference and hence should be easier to differentiate), the factor difference in the first case is 2.5 while being 2 in the second. This difference is intuitive when you feel it and it is important to not only focus on the difference in milliseconds alone, it is the difference relative to other signals that is important.

Signals 3 and 4 were presented in each of the three tests while signals 1, 2, 5 and 6

were presented in two of the tests. This could increase the participants' ability to correctly identify signals 3 and 4 since they had more practise with those two signals compared to the others. However, after reviewing the data we did not discover any obvious reason to believe this was the case, since the arbitrary learning curves of each signal did not seem to differ, note that no statistical test of significance has been made to ensure this.

As can be seen in Figure 5 and 9, the participants' overall perceived difficulty of identifying each signal correlates fairly well with their actual results on each signal, with the exception of signal 1. Signal 1 is rated as easier to identify than signals 2, 3, 4 and 5 even though it was correctly identified to a lower extent than signals 4 and 5. It is worth noting that the questions asked in this case were not aimed towards the participants' own perceived degree of how they actually succeeded in identifying the different signals. Also noticeable is that the participants' learning curve is matched with how difficult they felt the trials were, 50% of the participants felt that their first trial was the most difficult and it also had the lowest accuracy of answer rates. There are no differences in subjective rating of trials 2 and 3, both each being judged by 25% of the participants as the most difficult trial, and

there was no significant learning effect between them. 67% of the participants perceived Test 1-6 as being the most difficult. Looking at Figure 8 it is worth knowing that five out of the six participants who had Test 1-6 in trial 2 perceived that trial as the most difficult. Similarly, four out of the six participants who had Test 1-6 in trial 3 perceived that trial as the most difficult.

The higher the intensity of a signal's on/off-pulse the more correct answers that signal accumulates, with the exception of signal 1. This might be due to the fact that signal 1 only has one signal next to it on the on/off-pulse intensity scale, there is no signal below it on the scale. This should lower the probability of a mix-up compared to the probability of a mix-up for signals with a signal above and below them in the intensity scale.

The mix-up pattern shown in Table 4 was named the HIMUTS-Effect, Higher Intensity Mix-up Using Tactile Stimuli. The HIMUTS-effect suggests that, when lacking a clear reference point in an on/off-pulse intensity scale, signals tend to be identified as being more intense. In stressful situations this effect could increase since the response to signals should be rapid, leading to less time of identifying the signal correctly. This makes it important to design signals with a high intensity if the response to them needs to be rapid. Also, they need to differ intuitively.

Signal 4 being mistaken for signal 5 had a low mix-up rate. This may be due to how the tests were designed, since signal 4 could not be mistaken for signal 5 in one third of the tests, possibly leading to skewed data. In the same way, signal 3 could not be mistaken for signal 2 in one third of the tests. The effect is still apparent.

Every combination of one signal following another appeared once in Test 1-6 and twice in Tests 1-4 and 3-6. This design increases the credibility for the HIMUTS-effect since the possibility of one signal being presented before another and in some way affecting the identification of the following signal has been covered. Further on studies on the HIMUTS-effect should increase its' credibility further.

If two signals need to be next to each other in an on/off-pulse intensity scale, for example if there are only two signals, the one with the higher intensity should be the one that causes the least damage if being mistaken for the other signal. This is because of the HIMUTS-effect. With this being said, it is still important that the signals and their meaning are intuitive.

Conclusions

The most interesting result of this study is the so called HIMUTS-effect, named as such since we have not come across that effect in any literature. Over half of the wrong answers occur when a signal is mistaken for the signal directly above on the on/off-pulse intensity scale. The mix-up does not occur the other way around to the same extent.

The mix-up rate between signals 2 and 3 is high, leading to the conclusion that signals with a 500 ms on/off-pulse should not be combined with a signal with a 250 ms on/off-pulse. In other words, a relative difference between signals should be greater than a factor of two.

The signal that to the highest extent did not receive an answer either right or wrong was signal 1. The fact that 10% of the totals errors for the signal occurred when participants were unable to answer in time suggests that signals that require quick responses should be more intense, in regard to the on/off-pulse intensity scale. The time to identify a signal's vibration pattern increases as the on/off-pulse

intensity gets lower. A possible interpretation is that it becomes more difficult to separate signals from each other as the on/off-pulse intensity gets less intense.

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