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THE PERSISTENCE OF A VISUAL DOMINANCE EFFECT IN A TELEMANIPULATION TASK : A COMPARISON BETWEEN VISUAL AND ELECTROTACTILE FEEDBACK

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In the two experiments reported, we have examined the efficiency of an electrotactile stimulation for manipulation control. These studies were based on a psychological point of view and issued from the ergonomical purpose to feedback information to a severely handicapped operator, such as a quadriplegic, to control a telemanipulator. We have generalised the telemanipulation situation to non handicapped people operating with a hand controller and compared visual to electrotactile feedback. This sensory feedback informed operators on the sum forces exerted by the terminal device on the environment. An experimental material made of an orientable slider on a stem was developed which allowed to test the control of the three cartesian coordinates and the forces involved by the manipulator during a linear constraining movement task. Different cognitive activities were hypothesised in three situations : a first one where operators performed the task in a viewing situation, a second one where they were in a blind-folded situation but knew the spatial orientation of the stem and a third one where they had to operate blind-folded and guess the spatial orientation of the stem. Attention demand, type and quantity of information feedback were experimentaly modified so as to examine different effects such as visual dominance, alerting effect and treatment capacity. Main results showed that an electrotactile frequency modulation (1-50 Hz.) provided information which is treated as an on/off signal and is longer to access cognitive treatment and to develop operative image than visual information. Comparatively equivalent visual information is more sensible and makes decision movement faster, showing a permanent visual dominance effect even if the operator's attention is centered on the tactile modality.

In telemanipulation control evidence has been established that a force feedback system improves operator performance (Hill, 1976, Vertut and al. 1976). In the CEA - La Calhène MA 23 master-slave manipulator system the force feedback is delivred as a force reflecting the force vector on the slave handled by an operator. The Psychological interpretation for this improvement is quite simple if we assume that the force feedback presents an information increasing the operator's knowledge of the results of his control actions. Therefore movement correction and initiation can be improved by increasing such feedback to the operator. However if no force-reflecting master-slave manipulation is used, in what other may could the force information be presented ? This question is posed in particular when the master is replaced by a "syntaxer", a control transducer combining 6 degrees of freedom in a single handle.

As one possibility we studied the use of an electrotactile stimulation to return information to the operator and to test the efficiency of the electrotactile modality in teleoperator control. Several studies have been published on electrotactile stimulation, showing that a frequency modulation may be used (Shannon, 1976; Szeto, Prior and Lyman, 1977; Tachi, Tanie and Abe, 1978; Kato and al. 1970; Solomonow, Lyman and Freedy, 1977: Solomonow and Lyman, 1978). However, thus for it is not clear what cognitive processes are involved in presenting the information provided by different sensory modalities. One could argue that the electrical stimulation is transmitted to the cognitive center faster than visual or auditory stimulus. However, the attention required to code and stock information may depend on the modality through which this information accesses the cognitive treatment centers and whether parallel processing of information is possible when different modalities are stimulated simultaneously.

In Hill's studies (1974) no clear results have been obtained with a touch feedback system in telemanipulation tasks as compared to a visual feedback and he concluded that the learning effect was to strong to observe an effect on the type of display. The author recommended to alternate experimental variables in order to reduce the variance caused by learning.

Earlier Bliss and al. demonstrated that a tactile display augmented the human response time in comparison to the one for a visual display. However, their stimulation was mechanical and for electrical stimulation the results might be different.

In manual manipulation visual and kinesthetic information is used to control movements, information is delivered bimodaly and attention is divided between two sensory modalities. Some results have shown (Treisman and Davies, 1973) that dividing attention between two different modalities is more efficient than dividing attention between signals of the same modality. We hypothesized that in teleoperator control where vision is focused on controlling the task, force feedback on a visual display presents a situation where attention is divided on the same modality (vision). In comparison, force feedback to the operator through the tactile modality divides his attention between two different modalities and could be more efficient.

This result is explained (Richard, 1980) by assuming that the limitations of divided attention are in part caused by the conditions of the reception and storage of the sensory input.

Basically, two different models of information processing were discused. In the Broadbendt's model semantic information is treated after its selection and is limited in capacity or sequencially processed. In the Deutsch and Deutsch's model semantic analysis is processed before the selection of information which could be treated in parallel. Various intermediate models have been proposed since this two first one (See Richard, 1980 for this question). As a model we retained the hypothesis that a first kind of semantic analysis could be effectuated in a sensory memory register before transfer to the short-term-memory. Final treatment could be of a sequential nature, while surface features of the stimulus, such as physical characteristics and some semantic features, could be processed in parallel, especially in the case of perception through multiple sensory channels. If this is the case, decision and motor responses should be better in a bimodal situation than in a monomodal one.

Another argument concerns the electrical skin stimulation we used. Stevens (1938) noted that "the electrical stimulus has its principal effect directly on the sensory nerve fibers. That is, electrical stimulation bypasses the receptive structure". So if a first treatment of the information is effectuated in the receptive structure before its transfer to short-term-memory, electrical stimulation bypassing this first structure will directly access short-term-memory without a first treatment. The consequence will be a loss of information if this peripheral structure is able to initiate a first treatment of the information (see diagram 1).

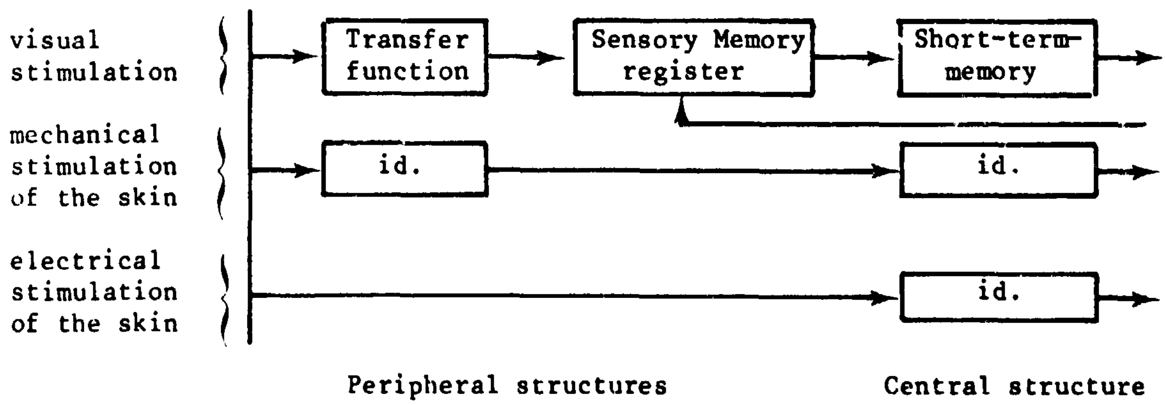

Diagram 1 : Hypothetical Peripheral Structure for visual stimulation, mechanical and electrical stimulation of the skin.

The transfer function could initiate a first treatment of the information. In the case of the visual stimulation information could be stored for a short time in a sensory memory register where information could be retrieved (Sperling, 1980).

In a previous experiment (Gaillard, 1981) testing the effect of an electrical feedback in a telemanipulation task, we did not find a significant effect on the execution time of the task. However, the number of errors with electrotactile feedback was greater than with an equivalent visual feedback. We concluded of that the gain in performance when dividing attention between two modalities could be null with electrical stimulation. Therefore, we have developped two experiments without direct vision of the task to study in more detail the role of the peripheral structure as a function of the modality of the feedback and their effects on motor control.

EXPERIMENT 1

METHOD

- Subjects : Two subjects were trained in telemanipulation control. They had been operators in previous experiments and work in the SPARTACUS Laboratory.

- Apparatus : The experimental system was composed of a manipulator type CEA - La Calhène MA 23 with six degrees of freedom plus gripper (Photo 1).

The manipulator was controlled by a "syntaxer" with six simultaneously controllable degrees of freedom. However only three of them were used for this experiment, controlling the three translations in the Cartesian coordinates. These three translations were operated with a velocity control by three micro-displacements of the handle. These micro-displacements required a certain amount of force to be exerted on the syntaxer (Photo 2).

Manipulator and syntaxer were connected through a SOLAR 16/65 computer, programmed to allow the operator to control the manipulator using a specific language linking the three degrees of freedom of the syntaxer to the three translations of the gripper in space. Initially, the system and its program were studied for a medical manipulator as a part of the SPARTACUS project as an aid to high-level quadriplegics (Guittet and al. 1979). Then the same concepts were used to control an industrial manipulator, but through another control transducer and an adapted control language.

Two types of sensory feedback were used to inform the operator about the forces exerted by the gripper on the axis. The first one was a visual display of 5 LED's with each diode successively representing a higher level of force. One diode lit meant the sum of the forces was low, but not negligible, and 5 diodes lit that the gripper was exerting a strong force. The sum of the forces was obtained from the summation of the currents of the torque motors approximately corresponding to the three cartesian coordinates.

The second display was an electrotactile stimulation situated on the operator's arm with the following characteristics :

- rectangular pulse train
- frequency modulation 1 → 50 Hz
- pulse duration 150 μs
- pulse intensity 5 mA.

These characteristics allowed the operator to distinguish 5 levels of frequency and was sufficiently confortable. (Kato and al. 1970, Szeto, Prior and Lyman, 1977). The frequencies varied proportionaly with the sum of the forces.

- Task. The task consisted of the displacement of a cursor along an orientable axis that could be rigidly fixed with three different inclinations and twelve horizontal orientations (Photo 3). The cursor was linked to the axis by a self-aligning bearing to avoid variation of sliding friction. The task required the operator to precisely control manipulator movements in the space and to guide the cursor held by the gripper into a direction strictly parallel with the orientation of the axis.

The operator was in a "blind folded" situation. If the gripper was not guided in parallel with the axis, an increasing effort was generated and the cursor could not be conducted to the limit switch at the end stop. The sliding distance remained the same all over the experiment. The execution time was measured automatically at each trial. When the cursor began to move a microswitch was released, starting a chronometer and when the cursor had moved about 40 cms on the axis, a record microswitch was activited stopping the chronometer.

Another way to finish a trial was by the triggering of an automatic safety stop when sum of the forces exerted a certain level. Then the syntaxer was automatically uncoupled to the manipulator and the trial was considered as a failure.

- Design and Procedure. Three conditions of sensory feedback were permuted on 30 trials, 10 trials were run with visual feedback, 10 with electrotactile feedback and 10 without force feedback. The experimental design was $S_3 \times M_3 \times T_{10}$ with S for subjects, M for sensory modality and T for trials. Of the 30 trials, 21 required the control of three degrees of freedom and 9 required only two degrees of freedom. The orientation of the axis was changed for each trial and there were never two identical orientations in the 30 trials. Before each trial the experimenter fixed the axis with a new orientation and positioned the gripper on the cursor at the starting position . The operator saw the orientation of the axis and memorized it. Then, he turned his back to the axis, grasped the syntaxer, and started the trial controlling the movement only using the sensory feedback (visual or electrotactile) in 20 trials out of 30 and without sensory feedback, only relying on his memory of orientation, in 10 trials out of 30. After each trial he was informed on his execution time of the task.

- Experimental predictions. Under electrotactile feedback condition we expected the information, bypassing the receptive structure, to be entered directly into short-term-memory (STM) where its treatment requires more time to be correctly interpreted than under the visual feedback condition where a first treatment is effectuated before its access to STM. Memory load in STM will be greater under the electrotactile condition than under the visual one and task time will be longer in the former case.

RESULTS

Task time for the 2 degrees of freedom trials were not significantly different $F(1,2) = 1{,}27$; $p > 10$ whereas they were different for the 3 degrees of freedom trials $F(1,6) = 8{,}68$; $p < .05$. No other factors, nor interaction were significantly different. Average times and number of failures were as listed in table 1.

	task time for 3 df	failure	task time for 2 df	failure
visual	13,06	2	12	0
electrotactile	17,13	0	19,93	1
no feedback	11,53	11	14,35	3

Table 1 - Task time in seconds and number of failures as a function of sensory feedback

DISCUSSION

As predicted the average time was longer with an electrotactile feedback, indicating that the task time is varying with the information treatment and memory capacities required and not with its transmission delay from peripheral to central structures. The number of failures as a function of sensory feedback showed that force feedback was of a great use to complete the task and even made it possible to execute it without feedback, only using the memorised spatial orientation of the axis. The information presented by electrotactile feedback was effectively treated and interpreted as indicated by a low number of failures and a longer task time. It suggested that electrotactile information was treated in STM and that the limit of the capacity of treatment and retention was not reached. The results also suggested that visual information could receive a first treatment in the peripheral structure before its access to STM, thereby facilitating this subsequent treatment. In this experiment feedback information had to be interpreted and compared with the information of the memorised orientation of the axis and physical analysis of the stimulus could be sufficient to perform this comparison in memory. Now a question was raised about a semantic interpretation of electrotactile information.

EXPERIMENT 2

METHOD

- Subjects, apparatus and task remained the same as in the first experiment except for the blindfold task that had to be completed without a prior knowledge of the orientation of the axis. The subjects had to estimate the orientation of the axis during manipulation. In one half of the trials an additional task had to be completed simultaneously during the manipulation task. In this additional task, or semantic task, the operator had to listen to a text and had to press a button when he identified a proper name in the text. Subjects, therefore, were in a condition of divided attention.

- Procedure. There were four different conditions, two with attention focused on motor control with visual or electrotactile force feedback, and two with attention divided between the semantic task and the motor control with visual or electrotactile feedback. There were 40 trials for each subject, 10 for each condition. Task time, number of failures and responses in the semantic task were recorded. In addition, we recorded in X, Y recorder the sum of the forces exerted by the gripper during each trial and we asked the subject his estimation of the orientation of the axis at the end of the trial.

- Experimental predictions. To complete the telemanipulation task the subject interpreted the feedback as a confirmation or rejection of an estimated orientation of the axis, and could build a cognitive representation of the axis in space. Assuming that the electrotactile stimulation bypassed the receptive structures, we predicted that in the focused attention condition task time and failure rate would be more important with an electrotactile feedback than with a visual display as in experiment 1. If we hypothesize that a first treatment of the semantic information is made before its input in STM , then the performance will not be dramatically affected in divided attention. However, if a first treatment of semantic information is only made in STM, performance should be affected by this additional task. In this case it means that semantic information bypasses the sensory register. Indeed, we hypothesized a conscious process to interprete the sensory feedback to build an operative image of the axis in space and that process should at least involve STM storage. In other words, if semantic information is selected before its access in STM, in a preconscious activity, interpretation of the stimulus feedback should be made. If semantic information is selected in a conscious working memory, interpretation and operative image formation should be difficult. In the latter case, task time and failure rate should increase and the number of motor response decrease.

RESULTS

Mean task time and number of failures were calculated for each sensory conditions and were the following : Table 2.

Sensory conditions		Visual		Electrotactile		Visual divided		Electrotactile divided	
Dependent variables		Task time	Failures	Task time	Failures	Task time	Failures	Task time	Failures
Operators	S_1	54,2	1	86,2	22	98,1	9	115,7	16
	S_2	70,1	2	93,5	4	87,5	4	93,5	8
	m	62,1	1,5	89,8	13	92,8	6,5	104,6	12

Table 2 - Mean task time in seconds and number of failures

For the additional semantic task the percentage of alarm was 95% with visual feedback in the motor task and 96 % with electrotactile feedback. The numbers of false alarms were, respectively, 19 or 20. Guessing of the orientation of the axis was calculated from the number of degrees of freedom correctly estimated by the operator after each trial. No significant differences were found between visual and electrotactile feedback (for the two operators χ^2 were, respectively, 0.75 and 0.79 $p > .10$). The proportions of degrees of freedom correctly estimated were 72 % for the first operator and 54 % for the second one. Ranking the execution times in the condition of focused attention indicates a significant difference between visual and electrotactile (Sign test $N = 20$, $x = 1$; $p < .01$). The difference was not significant in divided attention (sign test $N = 20$, $x = 9$; $p > .10$). The only factor approaching the level of .10 in the variance analyse was the sensory condition $F(3,27) = 2,26$. In return we found a large difference between the two sensory feedbacks for the number of motor responses $t(38) = 7,82$; $p < .001$. The rate of motor response was calculated by dividing the number of responses by the task time for each trial and is indicated in table 2.

Visual	Electrotactile	Visual divided	Electrotactile divided
0,68	0,38	0,66	0,31

Table 3 - Rate of motor response

DISCUSSION

As expected results corresponded with those obtained in the first experiment. With electrotactile feedback both task execution time and number of failures increased. The score obtained in the semantic task indicated a good semantic detection when attention was divided on two different sensory channels. But the effects on task time and number of failures correspond with a decrease of performance in the telemanipulation task. Guessing the spatial orientation of the axis was more difficult with an electrotactile feedback and with attention divided, but the formation of a conscious operative image of the axis in space was necessary to complete the task and this mental image obtained with both sensory feedbacks under all conditions, as suggested by the number of degrees of freedom guessed after each trial completed.

More interesting is the number of motor responses obtained under respectively, visual and electrotactile feedback. Dividing attention had no effect on either the number of motor responses or on motor decision. Task time was increased with electrotactile because the operator could not make motor decisions during part of the time. This result suggests that the interpretation of the electrotactile feedback is more difficult and not as sensitive as of an equivalent visual feedback, and supports the general assumption that an electrotactile stimulation bypasses the peripheral structure. If so, physical features of the stimulus are not treated in this first stage and have to be treated in a working memory where the stimulus is roughly interpreted. Results also indicated that the performance in motor control and formation of a compatible operative image the axis with a visual feedback is more affected by the additional semantic task. It could be hypothesized that the semantic information is processed in a working memory after a preliminary treatment of the physical features of the stimulus in a sensory memory register. This suggests that the semantic treatment is not effectuated in parallel, but sequentially and that it is limited in capacity. With the electrotactile feedback, where no motor decision could occur for relative long periods of time, semantic information can be processed and does not interfere with the motor control.

CONCLUSION

The two experiments reported here were not designed to generalize the results to the population. Generalizations have been made for the repetition of the tasks and do only suggest direction for further research in the field of general psychology. The aim of this research was to investigate the possibility to use an electrotactile stimulation in teleoperation and to observe the interpretation of such information as a feedback to the operators. It leads us to formulate cognitive hypothesis and to propose the following assumptions :

1. A visual feedback is more informative than an electrotactile one, suggested by the general visual dominance effect.

2. A complex electrotactile feedback :
   - slows down both the motor decision and motor response processes.
   - is processed as an all or nothing signal.
   - bypasses the receptive structure and accesses directly in a working memory where information is to be sequentially processed and where memory is limited in treatment capacity.

Finally, the electrotactile stimulation could be used more as an alerting signal than a complex information feedback. It does not seem to be well adapted to code semantic or mental image information. Visual or auditory information, however, does benefit from the transfer function in the peripheral structure where information could be treated before its access to a working memory. The visual dominance effect could be the result of the advantage of both a transfer function and a sensory memory register where information is pretreated and memorized for a short time. Dividing attention has an effect on the acquisition of the information but not on the subsequent decision processes, suggesting that in motor tasks the attention variable is primarily affecting early cognitive activities.

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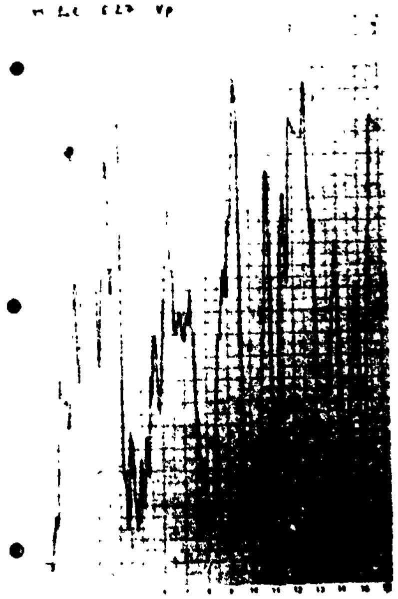
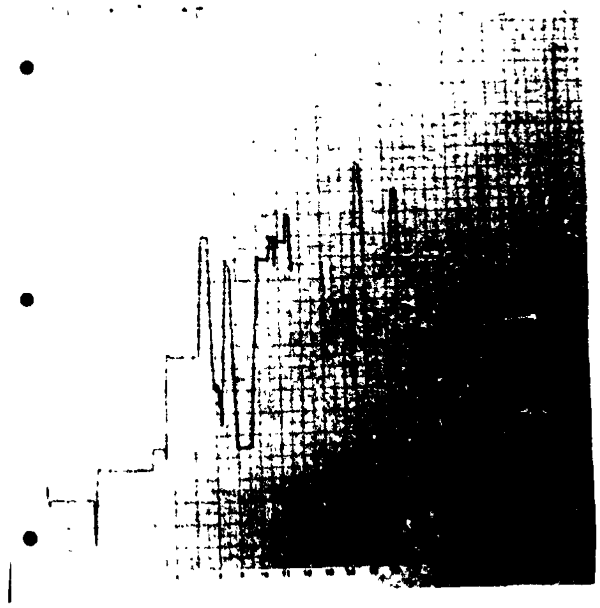


Recording of the summed forces with the visual feedback.



Recording of the summed forces with the electro-tactile feedback.

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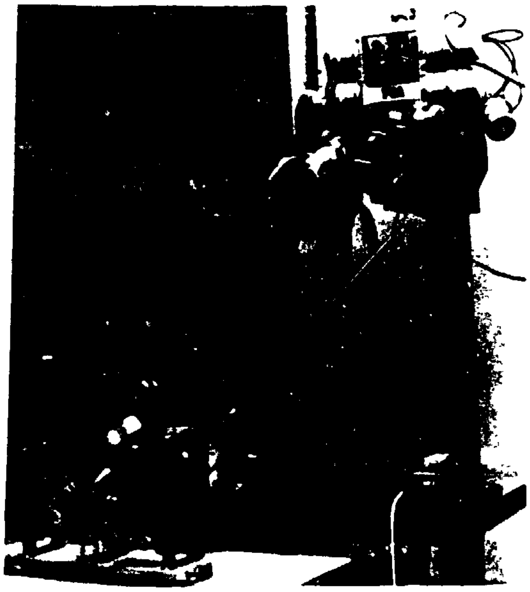

Photo 1

Photo 2

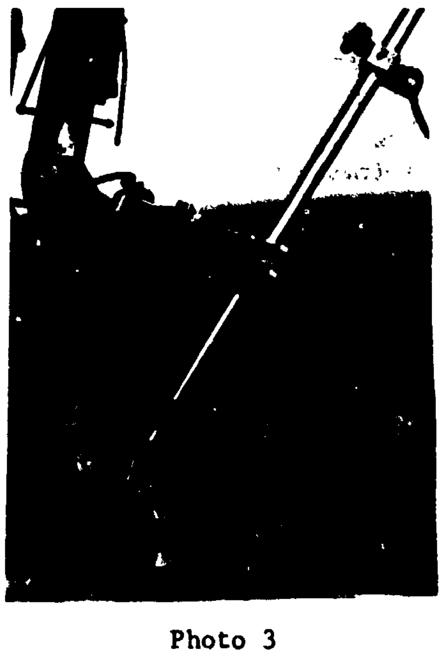

Photo 3

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