Preliminary investigations on tactile perception of graphical patterns

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by
X. Wang

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触觉对图形感知的初步探讨

王　雪

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Abstract

In this report investigations on tactile perception of graphical patterns are presented. The tactile patterns used in the two experiments were generated on an Optacon vibrating array, with a modified system. The setup built for these experiments is described. The design of the experimental paradigms with the aim of solving a problem in the related literature is discussed. Preliminary results from the experiments show an agreement with the literature, even though the data were obtained from a different paradigm.

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Introduction

For those profoundly deaf persons who cannot benefit from conventional hearing aids, the tactile sense has become an alternative communication channel. One of the major difficulties in developing 'tactile hearing aids' is coping with the very low channel capacity of the tactile perception system when information is presented to the skin. In addition to the channel capacity problem, the tactile perception system has certain psychophysical characteristics which differ from other sensory modalities.

There have been psychophysical investigations on the ability and behavior of the tactile perception system [Craig and Evans, 1980, 1985, 1986, 1987]. In the investigation presented in this report, the *output* of the tactile perception system is characterized as the 'perception score', which refers to the percentage of correctly recognized stimuli. In this study We restrict the input to the tactile perception system, namely the tactile stimulus, to a binary code, i.e. the tactile patterns composed of the combinations of the 'on' and 'off' of the pins in the two-dimensional vibrator array of an Optacon (See section 1.1). With these restrictions, the investigation of the general psychophysical properties of the tactile sense can be reduced to the following four topics:

1. The relation between the actual shape of a set of patterns and the perception score of the information which is coded into this set of patterns (i.e. given a time signal to be transmitted, how to choose a set of tactile patterns to code the signal, so that the perception score of the information in this signal is maximum);
2. The relation between the perception score and the total time during which a pattern is presented on the array;
3. The difference in perception scores with two different ways of presenting the patterns, i.e. a dynamic mode in which the whole shape of the patterns is moving across the array, and the static mode in which all the pins comprising the patterns are turned on and off simultaneously;
4. The perception score for one pattern being interfered with by the other patterns presented earlier and later on the same array, i.e. the temporal masking effect (section 1.2).

The first topic, however, will not be dealt with in this report, while each tactile pattern used only refers to *graphical* ones, namely, the whole pattern is a fixed graphical shape displayed on the upper 16 rows of the Optacon array (Fig. 1), and the different parts of a pattern may not change independently (i.e. the information is only coded on the whole pattern as the smallest unit).

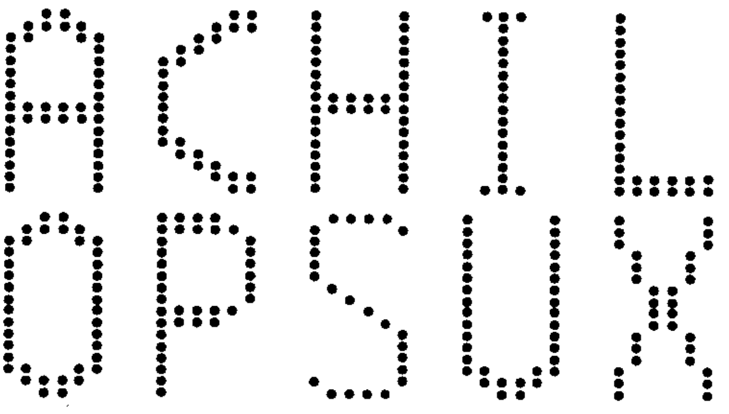

Figure 1: *Tactile patterns used in the experiments, shown as each of them displayed on the upper 16 rows of the Optacon array.*

The shapes of the tactile patterns are chosen as 10 of the upper-case alphabet letters (Fig. 1), and they will be used throughout all the experiments in this report. The reason for this choice is that these letters are familiar shapes for the subjects, so that the training procedure (section 1.5) for tactually recognizing them will be easier.

These four topics of the problems in investigating the tactile perception system can also be regarded as a *coding problem*, because they are all major problems that have to be considered when coding information to the skin. In other words, when coding consideration should be given to not only *what* tactile patterns have to be used to represent a particular sort of information, but also for *how long* each pattern should be displayed. It is intuitive that the longer a pattern is displayed on an vibrator array which is contacted to the skin, the better the perception score for this pattern will be. However, if the purpose is to perceive more patterns (thus more information) within a given period of time, the display time for one pattern should be kept short. Two experiments were carried out to obtain a quantitative expression of the shortest time needed to perceive a tactile pattern sufficiently well, and to obtain an insight into the behavior of the tactile perception system when the two different display modes are used, for various display times. They are presented in Section 2 and 3, respectively. In Section 1 the experimental setup for both experiments is described.

1 Experimental Setup and Paradigms: General Considerations

In order to measure an input-output relation of the human tactile perception system, where the input stimulus is a binary tactile pattern, and the output is the response whether a stimulus pattern is correctly recognized by the subject, a preparation of the experiment setup for both the input and output parts is needed. During the design and performance of these experiments, many necessary considerations have been incorporated in our particular setup and paradigms. The major aspects of these considerations are discussed in the following sub-sections.

1.1 Hardware

In all the experiments, the vibrator array of the Optacon (Model R1C, trademark of Telesensory Systems Inc.) was used. The original Optacon system is shown in Fig. 2. The vibrator array displays exactly the same pattern as the camera takes from the normally printed text. Therefore, when the user moves the camera over the text, the patterns on the vibrator array move at the same speed, across the array.

In the modified system (Fig. 3) the patterns used are pre-defined, and the data representing them are stored in the ROM of a DSP system. The DSP system [Matijssen, et al. 1989] was developed in our division for the Tactile Hearing Aids project. The central part of this system is the IC ADSP-2100 from Analogue Devices. It has a rather strong programming power to allow the sophisticated digital signal processing to be done in real time. For the purpose of the experiments of this report, however, there is no need for digital signal processing.

A program was written (in the assembly language of ADSP-2100) and stored in the ROMs, to set the time parameters so that the display mode and speed are defined, to display messages on the LED array and to display patterns of letters on both the vibrator array and the LED array. During the experiment, patterns to be displayed are chosen randomly from a 'dictionary'. Both the dictionary and the random numbers are also pre-stored in the same ROMs. These random numbers were only meant to confuse the subjects so that they were not able to predict the next pattern. The numbers were not really random, but were pseudo-random sequences, generated before programming and stored in both the ROMs of the DSP system and a personal computer which was used to store the responded patterns from the subjects and to calculate the perception scores (Fig. 4). In order to prevent the subjects from distinguishing patterns

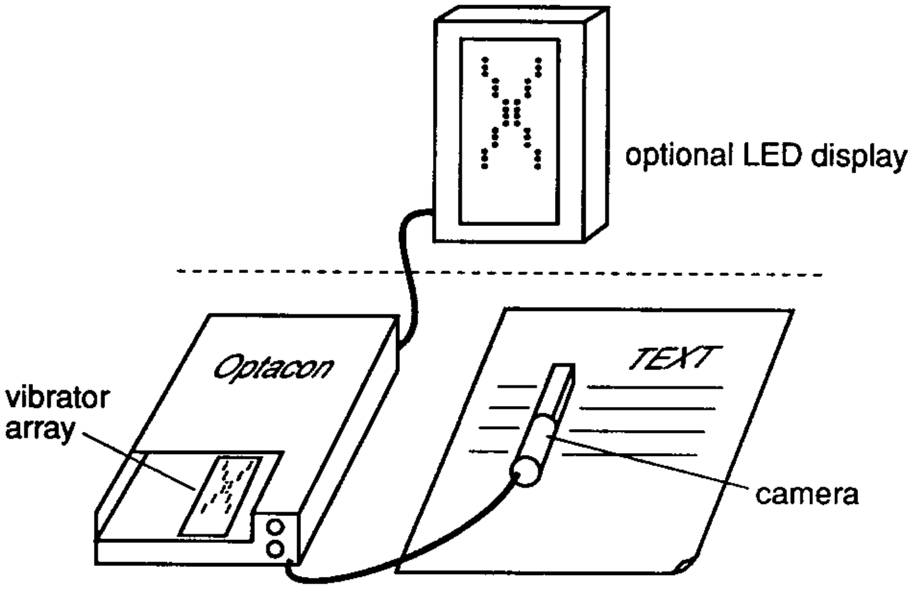

Figure 2: *The original Optacon system. The small camera is composed of an array of 6 times 24 CCD cells. It converts the optical (black-white) pattern of printed text into an electrical signal. The Optacon circuitry controls and drives the 6 times 24 small pins on its vibrator array, activated by piezo-electric ceramic bimorphs. The tactile pattern generated on the array is exactly similar to the text pattern, but with the size of the fingerpad (1.1 times 2.7 cm). An optional LED array displays the same pattern as in the vibrator array, with an enlarged size.*

by the possible different sounds made by the Optacon vibration, during the experiments all subjects wore earplugs and headphones through which white noise was presented.

The data transferred from the original Optacon controller to the vibrator array (Fig. 3) is in parallel for the 6 columns, but serial for the 24 rows (Fig. 5). In other words, during a complete cycle of 4.3 *msec.* at any given time only one pin in a column is activated. This is not changed in the modified Optacon system, because it will otherwise discard every part of the original Optacon except the array. Therefore, in order to prevent wrong displays such as in Fig. 6, in the modified Optacon system the procedure of writing data from the DSP system to the interface board should be synchronized. A synchronizing signal is given by the Optacon controller. This guarantees that the data for every full array is only written to the Optacon at the starting moment (point A in Fig. 5) for each cycle of time. Therefore, only after each 4.3 msec. can the data for a pattern be sent. This means that the tactile patterns on the Optacon array can only be updated at intervals of integer times of the cycle

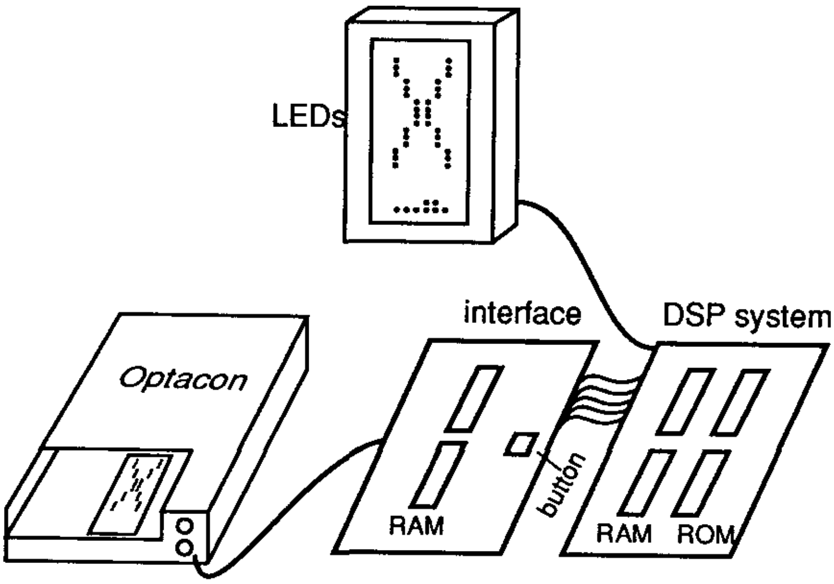

Figure 3: *The modified Optacon system. The data for the patterns and the program are stored in the ROM of the DSP system. The part of the patterns to be displayed is sent to the RAM of the interface and read by the Optacon control circuitry which drives the tactile vibrator array. The LED array displays the tactile patterns visually and, when there is no tactile pattern, the LED array is used to display messages concerning the settings of the timing parameters which determine the display mode, and other messages for the experimental procedures (section 1.4).*

interval, 4.3 *msec*, i.e. 8.6 *msec*, 13 *msec*, etc. (rounded values).

1.2 The Five-letter Paradigm

The fact that the perception of a tactile pattern is interfered with by the existence of other patterns which come earlier or later can be interpreted as a masking effect [Craig, 1985, Evans, et al. 1986, Craig, et al. 1987]. The pattern that is to be recognized by the subject is called a *target* pattern, while the other patterns that interfere with the target are called maskers. When a target is being masked by a masker which comes later, the masking is called *backward masking*[1], and when the masker comes earlier than the target, then the masking is called *forward masking*.

[1]These terms by themselves may cause confusion, because of the vagueness of what 'forward' and 'backward' refer to. It may help to state that when the masker comes later than the target, a process of masking produced by the masker and affecting the target goes 'backward' along the time axis. A similar concept holds for forward masking.

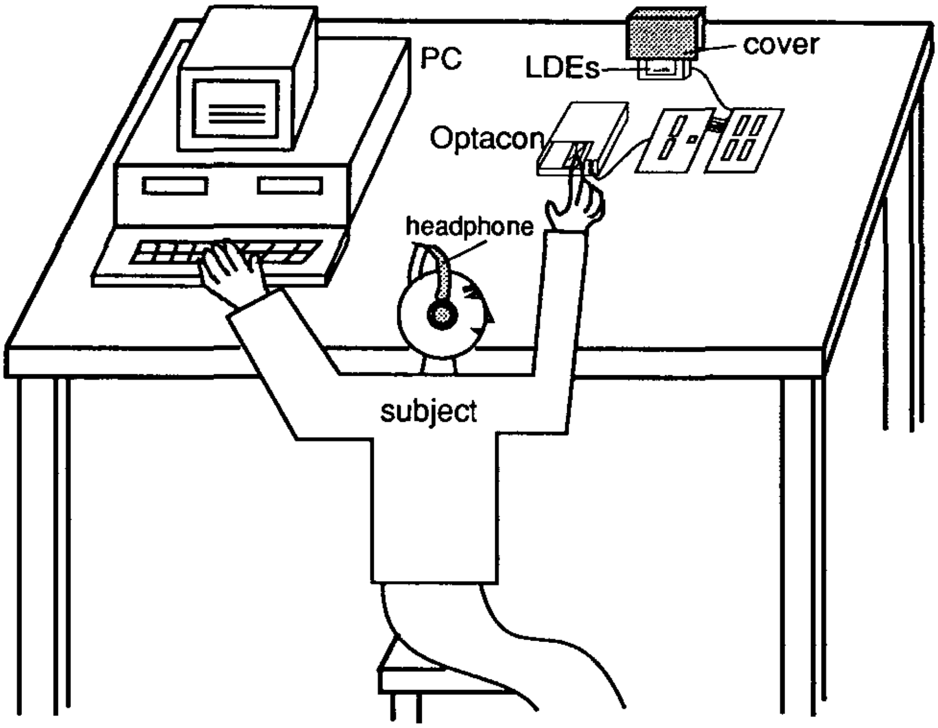

Figure 4: *The experimental setup*

Usually, the masking effect is measured in terms of the reduction in perception scores compared with that of the no-masking situation. In the experiment reported in the afore-mentioned literature, subjects were presented with only 2 or 3 patterns, with a temporal separation SOA[2], as a group of stimuli, and were required to recognize one of the three letters as the target. Such investigations gave a clear indication of the features of the masking phenomena.

However, arguments on the interpretation of the results may arise because the group of patterns was presented in isolation. This can be described in the following example. Craig [1985] presented the subjects with three-letter sequences as stimuli, and asked the subjects to recognize one of the three letters. The results show that the first letter was more difficult to recognize than the last one. The reported interpretation for this difference was that the first letter was subject to backward masking, and the last letter to forward masking, and the conclusion was that the backward masking is more severe than the forward masking. However, the difference in perception scores for the first and the last letters may also be due to the fact that, when the onset of the first letter arrives, the subject is not fully ready to concentrate on his fingerpad, while in recognizing the last letter, he/she is much better prepared

[2]SOA: Stimulus-Onset-Asynchrony, as seen in Fig. 7, i.e. the interval between the onset of the subsequent stimulus. It was proven [Craig, 1985] that SOA is a better 'dimension' (parameter) than ISI (Inter-Stimulus-Interval) (Fig. 8) in characterizing masking effects.

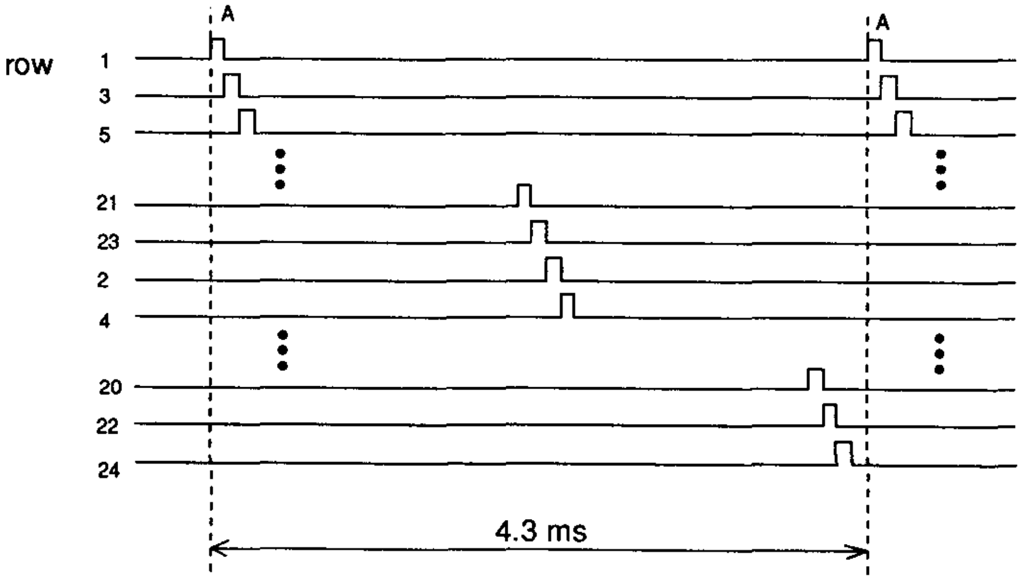

Figure 5: *Timing of driving signal on the 24 rows of any of the 6 columns*

after the presentation of the first two letters. In other words, a 'boundary effect' on this isolated 3-letter group introduces extra factors on the observed perception scores, therefore the interpretation may not be correct.

Although it is not our aim to distinguish the precise behavior of the forward and backward masking, it is necessary to eliminate the possible boundary effect and to remove the vagueness in the paradigms of the experiments. In other words, since the masking effect is objective, we should consider it more precisely in all situations where masking may occur, even though our aim is not to measure the masking effects themselves. More importantly, we try to relate the data obtained in this way to the real tactile communication process in which the patterns should come in a long sequence. Therefore we should consider the perception of patterns which are surrounded by other patterns, instead of the patterns at one edge of an isolated group. In order to observe the perception of a pattern (of a letter) when there is the backward, the forward, or both maskings, we need three letters in a sequence. In order not to put any of these three letters at a border of an isolated group, we need another two letters to be put one before and one after the three letters (Fig. 9). This five-letter sequence is to be used as an isolated group of patterns in one experimental trial (see section 1.4). However, only one of the three letters in the middle is to be recognized for each trial.

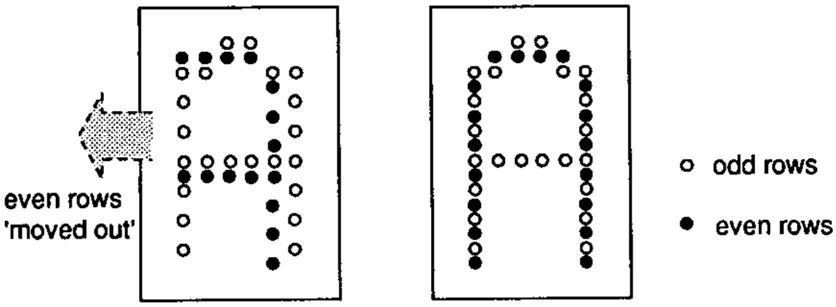

Figure 6: *The pattern on the right is a correctly displayed 'A'. The pattern on the left is a wrong display of 'A' owing to lack of synchronization. Only the even rows are moved one column to the left, because the data is updated just after the odd rows are displayed. Slower updating of the data may cause even more serious distortion than that shown above.*

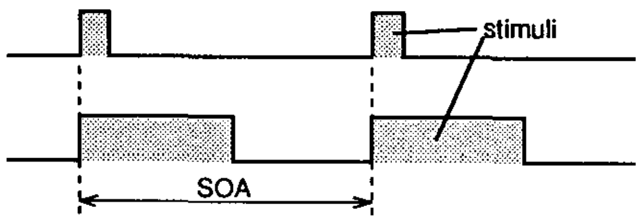

Figure 7: *Two sequences of stimuli with the same SOA (Stimulus-Onset-Asynchrony)*

1.3 Two Display Modes

The tactile patterns can be displayed on the array in two modes:

1. static mode; the complete shape of each of the five letters is turned 'on' on the array, it is sustained for a while (D, see Fig. 10[a]), then is turned 'off'. The next pattern is turned 'on' after a while. S (i.e. the SOA) is measured between the onset of the two patterns. During the whole display time of a pattern, the pattern is felt as 'static' on the array.
2. dynamic mode; the complete shapes of the patterns are moving from the right to the left side of the array (see Fig. 10[b]). The far-left column of a pattern is shown up first at the far-right column of the array, then stays for a while T, after which this column of the pattern 'moves' to the second-from-right column of the array, while the second-from-left column of the pattern moves into the far-right column of the array, etc. This

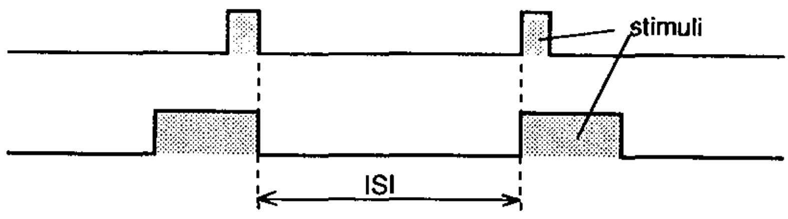

Figure 8: *Two sequences of stimuli with the same ISI (Inter-Stimulus-Interval)*

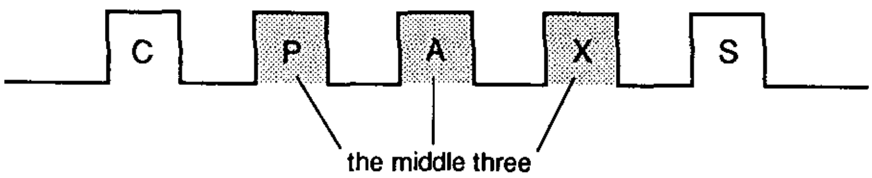

Figure 9: *An example of a 5-letter sequence as an experimental trial. One of the middle three letters: P, A or X is to be chosen as the 'target' letter.*

procedure continues until the whole pattern (six columns wide) covers the whole array, where the whole pattern can stay for a time interval D. Then the whole pattern starts to move away at the same speed (i.e. stays at each position for the same T), until it disappears from the far-left column of the array.

Both literature [Craig, 1980] and our own experiences showed that the subjects' perceptual behavior is different for the two modes of display. The general feeling of the subjects is that the movement of the patterns makes it easier to perceive the patterns. However, with very short display times, the subjects preferred to let the patterns stay, which led to a higher perception score. Furthermore, it was found that the subjects used two different ways to perceive static and dynamic patterns (as far as we know, the two ways are *different*, and it is not our aim to describe these ways), and it seemed that it takes time to 'switch' from one way to another. Therefore we argued that a combined display mode (Fig. 10 [b]) would not lead to a perception score superior to either the static mode (Fig. 10 [a]) or the dynamic mode (Fig. 10 [c]). Hence in the experiments presented in this report, we only used two 'pure' modes of display, which are depicted in Fig. 10 (a) as a pure static mode with T=0, and in Fig. 10 (c), as a pure dynamic mode, where D=T.

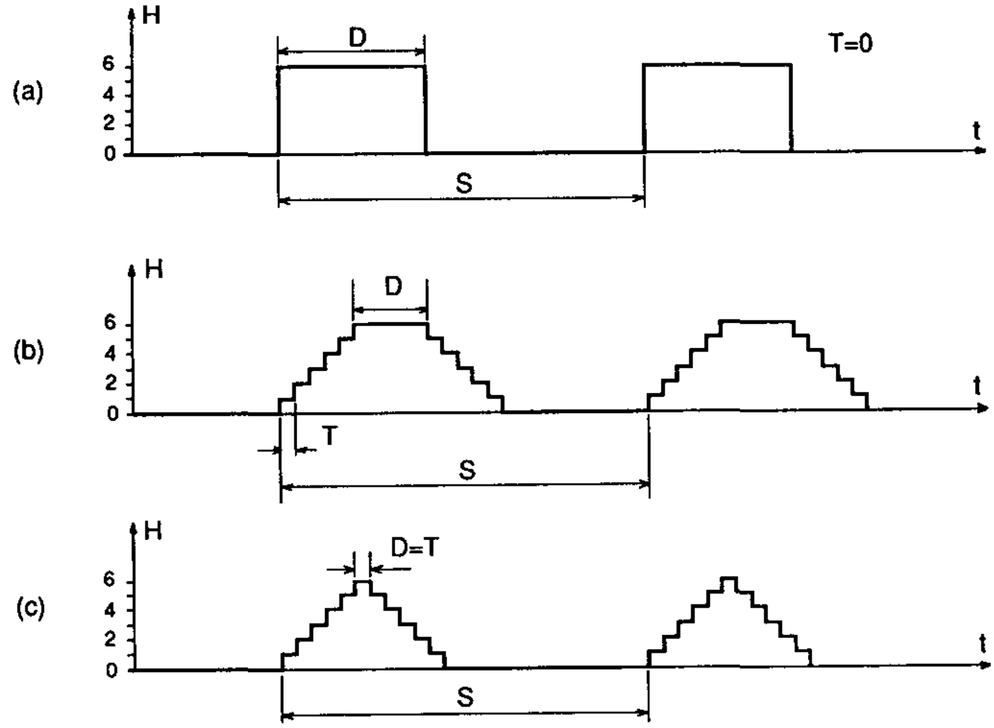

Figure 10: *Timing of sequence of letters: The height H of the curves denotes the number of the columns of a letter shown on the array.*

1.4 Testing Procedure and Stimulus Preparation

An overview of the experiment setup is schematically shown in Fig. 4 on page 6. The subject was sitting comfortably in front of a desk. Each subject chose one of his fingers during the training and used that one later on; usually it was the left or right index finger. His finger was placed naturally (i.e. without extra force) on the vibrator array of the Optacon in such a way that the most sensitive part of the fingerpad was on the position of the upper part of the array, on which the tactile pattern is displayed. The size of these patterns (only 16 instead of the whole 24 rows high) was chosen because this is the area of the sensitive part on the fingerpad of most of the subjects. According to the present interface circuitry, the vibrating intensity of the Optacon cannot be adjusted individually for each pin, but it can be adjusted as a whole with a knob. Each subject was allowed to adjust it until he felt the tactile vibrating pattern clearly and comfortably. (For stimuli with very short display times, the intensity approved was always at the maximum.) Each subject underwent training and testing procedures (section 1.5). During the testing procedure,

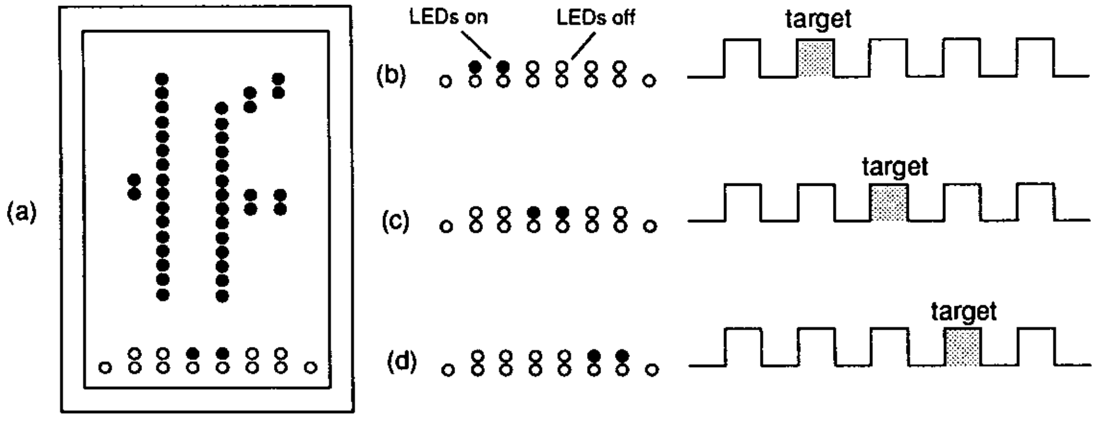

Figure 11: *(a) LED array. The lower part of the LED display indicates which letter must be recognized (the target): (b) the first one, (c) the middle one, or (d) the last one (in the middle of 5-letter sequence).*

the upper half of the LED display (Fig. 11) which showed the same pattern as the tactile one was covered.

The lower part of the LED display indicated whether the first, second, or third letter in the middle three of the five-letter sequence should be recognized, by turning on either the left, the middle, or the right LED cells (Fig. 11). Each experimental trial was a five-letter sequence. Before the trial started, the subject got his 'recognition target' by looking at the LED indication. Then he started a trial by pushing a button on the interface board, using his spare hand. The subject was instructed to concentrate only on the 'target letter', and try to remember it. After a trial, the Optacon system paused, waiting for the next trial to start, while the subject indicated on the PC the letter which he believed had been presented, by pressing a corresponding key on the keyboard. On the monitor of the PC, feedback was given as to whether the subject had given a correct response, or, if it was wrong, showing which letter it had actually been.

Three timing parameters T, D and S (Fig. 10) were used in the experiments. The combinations of the values of these parameters determined a testing *condition*, in which the patterns were presented in a particular mode (static or dynamic), and with a certain display time. Each of such conditions was tested in 180 trials, arranged in 6 blocks of 30 trials each. Each letter in each trial of the 5-letter sequence was chosen by a pseudo-random number, to prevent the subject from guessing or predicting the letters in the subsquent trials. Because the 10 letters used (Fig. 1) may not be equally difficult to recognize, a further constraint on the random numbers was made so that all the 10 possible letters occur with exactly the same chance, i.e. 18 times in the 180 trials for a condition. This guarantees that the perception score for the 180 trials is correct for all the 10 letters. This 'stimulus-balancing' procedure, however, was not applied to every block of 30 trials, because otherwise it will be too easy to guess. Only one of the middle three letters in each trial was chosen by this balanced random number, and the position of this letter in the trial was also determined by a balancing procedure so that each of the 10 letters appeared at any of the middle three positions exactly 6 times, in the total of 180 trials. The other 4 letters in a trial were filled in by using normal random numbers. In the total of 180 trials, the 'target' will appear at each of the three middle positions exactly 60 times. Blocks of different conditions were arranged in different experimental sessions.

Each session contained 6 to 7 blocks of different conditions, arranged in an unpredictable order. Among the blocks of each session, there was a 'check block' whose condition was the dynamic display mode with the longest display time. (This was the easiest condition for the subjects and led to the highest score.) This check block was used to check whether or not the personal condition of a subject was unfavorably affected by possible interrupts such as health, emotion, etc. When the perception score for this check block was lower than 90%, the data for this whole session were regarded as invalid and unusable. The blocks with the condition of these discarded sessions should be redone. Each such session took 20 to 35 minutes. Sessions were arranged at different days and time.

1.5 Subjects and Training

Since there exists a large individual difference in tactile perception among subjects [Craig, 1980], we first conducted a pre-training procedure on a group of 10 voluntary, normal-hearing subjects, to investigate their ability to recognize tactile patterns. Only 4 out of the 10 were selected to participate in the further training and testing procedure of the experiments. They were students and staff members of the Division of Medical Electrical Engineering of the Eindhoven University of Technology, the Netherlands.

Training was necessary for every subject to be able to recognize all the 10 letters used. When they put their fingers on the Optacon array for the first time, some subjects did not recognize any letter, while others recognized some letters vaguely. The training procedure started with a few easy letters such as 'C' and 'I', and more letters were added gradually as a subject learned. A training trial contained only one letter. During the training with a small group of easily confused letters (e.g. 'A' and 'H'), either the experimenter, or the subject himself, chose one letter for the next training trial (i.e. the subject knew in advance which letter was coming). When the training letter was presented on the Optacon array with the subject's finger on it, he was allowed to look at the visual display of the same letter on the upper half of the LED array, though in most cases the subjects preferred not to look at it.

After a few such training trials with a small group of letters, the subject's recognition of that group of letters was tested by the experimenter. When the score for these small groups of letters reached approximately 80%, training for other small confusing letter groups started or a larger, combined group of letters was used, until the score for the group of all 10 letters finally reached about 80%. At any stage of this training, the training procedure for the same group of letters was repeated when the score was too low. During the whole procedure of this training, the display time and mode were kept acceptable for the subjects and gradually became more difficult.

After completion of the training, the subjects were given instructions as to how the testing sessions should be carried out, and what they should do, and then they were given a demonstration of a few testing trials. Then the testing procedure started. Usually, during the first few testing sessions, the scores for the check blocks were less than 90% correct, hence, the data were not valid. For some subjects, it was necessary to go back to the training procedure. However, all subjects actually gained a qualified ability to recognize letters during the first few testing sessions, instead of during the training sessions (because the conditions in the training and the testing sessions may not be exactly the same). Only the data for these first testing sessions were not used. Each of the 4 subjects completed the total learning process within 2 to 6 hours.

2 Experiment One

In this experiment we investigated the relationship between the display time of patterns and perception scores with two display modes, i.e. the static and the dynamic modes.

All four subjects participated in this experiment. It consisted of 72 blocks plus a check block for each session, for each subject. The value of T, D and S were set so that there were 6 conditions for the dynamic mode and 6 conditions for the static mode. A comparison was made of the perception behavior for the two modes of displaying, on the basis of approximately equal display time. The display time for a static pattern was the time interval between the onset and offset of a pattern, namely D, while the display time for a dynamic pattern was defined as six times the interval of one moving step of the pattern, namely 6^*T. The argument for this basis of comparison can be found in Craig [1980]. The SOA was kept constant at 1 second in this experiment, so that the amount of masking was constant [Craig, 1985].

The perception scores for the 4 subjects are shown in Fig. 12 on page 18. The results were in agreement with the data of Craig [1980] where he used a 2-letter paradigm. By analyzing the data, the following comments can be made:

1. As the display time increases, the perception scores increase;
2. The rising slope (on the left part of the curves) is steeper for the dynamic mode than for the static mode;
3. At short display times, the static mode leads to higher scores than the dynamic mode;
4. The final (saturation) score is higher for the dynamic mode than for the static mode;
5. All four subjects showed similar behavior.

3 Experiment Two

In this experiment the experiment settings, procedures and conditions were the same as in experiment one, unless stated otherwise.

In this experiment we tried to investigate the influence of the temporal masking on the perception score. The display time of each pattern was kept constant, while the SOA (i.e. S) was varied. Also the two display modes were tested. Only two of the four subjects from experiment one participated in this experiment (because the other two were not available at that moment).

During pre-testing for this experiment, we found that when S becomes very short, the reduction of the perception score may not solely be due to the masking, but also to the difficulty in obtaining the correct pattern from the five patterns. Because the sequence of the five patterns comes so fast, the subjects often feel very uncertain whether they recognized the correct pattern (the 'target' pattern). For example, with a sequence of the letters 'C-P-X-A-S', and the target being the middle 'X', the subject might have actually recognized 'P' as the middle one, so the recognition was wrong. We call this a 'miscounting problem' because, in practice, the subjects *count* the patterns in some way while waiting for the target pattern, then try to recognize it.

In order not to exclude this potential miscounting problem, we re-designed the procedures of collecting data, so that the miscounting can be investigated quantitatively, i.e. the recording of not only how many recognitions are correct, but also the way in which the wrong responses are distributed. In order to do this, we had to generate the random numbers again to make sure that our explanation of the experiment data had a clear meaning.

The response to a given stimulus can be either 'correct' or 'wrong', as the response and the stimulus are identical or not, respectively. When one of the 10 letters is chosen as stimulus, the wrong response can be one of the other nine letters. When there is no miscounting, we assume that the distribution of the 'wrong responses' should be *uniform* among the nine letters (because there should be no reason for any biasing). When there is miscounting, however, the distribution of the wrong responses should be biased to some positions in the sequence of the five letters. For example, the subject may tend to recognize the letter that immediately precedes the 'target pattern', when he has difficulties in recognizing a letter in the sequence.

When generating the random numbers, we therefore introduced some more constraints. In addition to the fact that all the 'target' letters are balanced, all the 'non-target' letters are also balanced so that all the 10 letters will appear in each of the 5 positions exactly 18 times. Moreover, in each trial, the 5 letters are always made distinct (if this is not the case, e.g. two of the letters happen to be the same, a wrong recognition may be regarded as correct).

When collecting data, we recorded not only the confusion matrices, i.e. the accumulated numbers of the responses for each of the 10 letters with respect to each of the 10 stimuli, but also the relation between the response and all the 5 stimuli in a trial. For each condition, not only the percentage-correct scores, but also the distribution of the wrong responses is plotted (Fig. 13 and 14 on page 19 and 20, respectively).

The result shows that for both static and dynamic modes the perception score increases as the SOA increases. At about S=100 (steps of 4.3 *msec* each) (SOA=430 *msec.*), the score reaches a saturation. This is to say that temporal masking does not seriously exist at SOA of longer than half a second. However, the curves (Fig. 14 on page 20) show that when SOA becomes shorter than nearly the same value (430 *msec.*), the wrong response starts to distribute nonuniformly. This indicates that miscounting exists. In other words, the reduction of the perception score at short SOAs is not solely due to the temporal masking in this experimental setup (maybe the subject was too busy with counting). The amount of pure masking cannot be seen in these curves, and is hard to obtain with this five-letter paradigm.

4 Closing Remarks

From these experiments we obtained data which showed an ability of the tactile sense to process information transmitted by graphical tactile patterns, i.e. letters. The general ability of the tactile sense to recognize graphical patterns may be used to code information which stands for acoustic events occurring only one at a time, such as single alarm signals. Because the ability is poor at high presentation speed (namely, at short display times), it is recommended to present the events to the skin by graphical coding only if the events do not occur very frequently.

We obtained some experience in setting the experimental paradigms. Because the tactile perception system is a complicated psychophysical one, it is difficult to design experimental paradigms in order to obtain true data, or to interpret the data correctly. For example, we used a five-letter paradigm in order to eliminate a boundary effect when investigating masking effects in a sequence of patterns. However, when SOA was large, masking was negligible (Section 2); while when SOA became small so that the masking took effect, the five-letter paradigm introduced extra factors such as the difficulties of counting the letters for subjects. The analysis of the data shows that in solving one problem, we introduced another problem. Therefore, further work is needed for more carefully designed experimental investigations.

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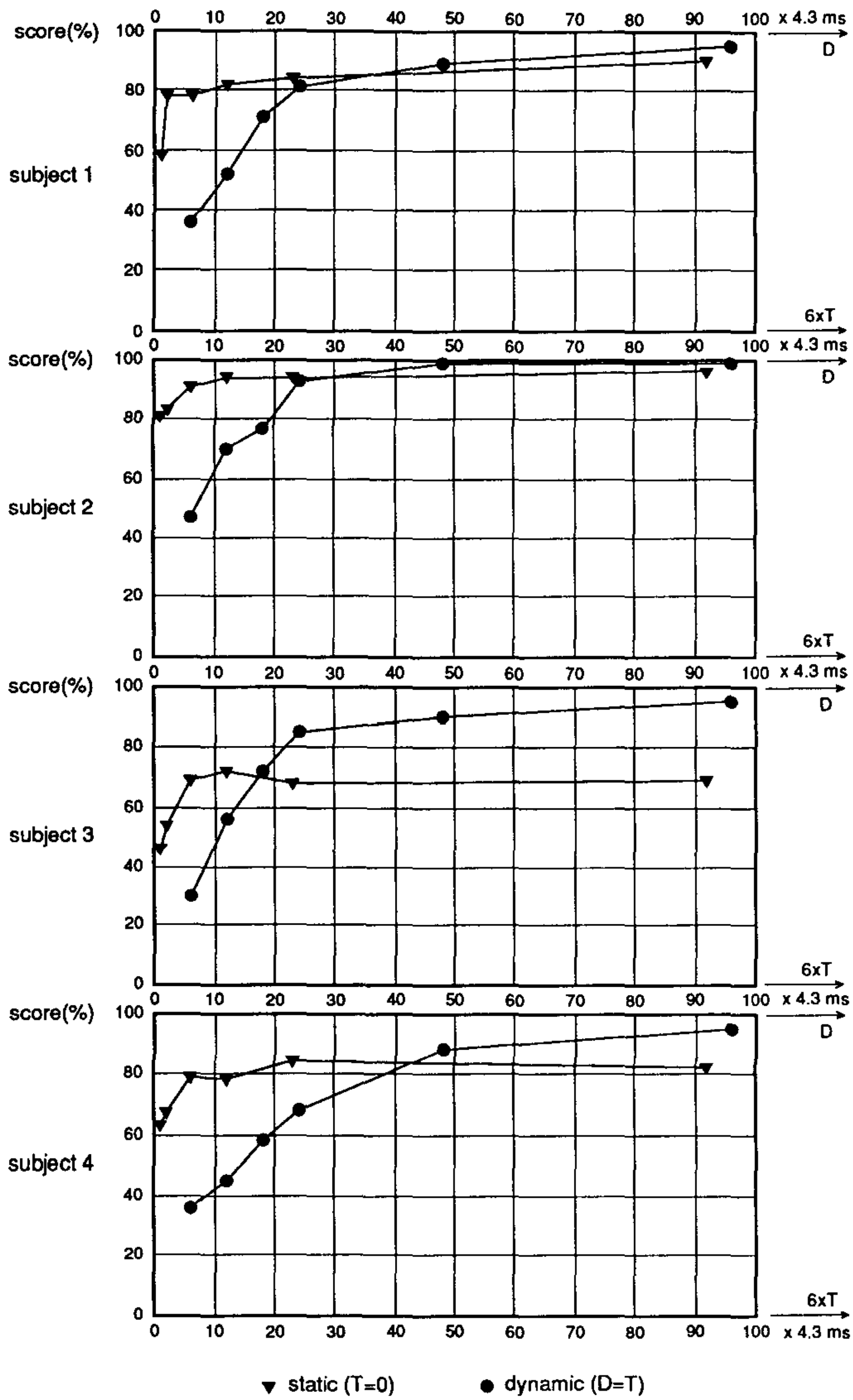

Figure 12: *Perception scores from 4 subjects in experiment one*

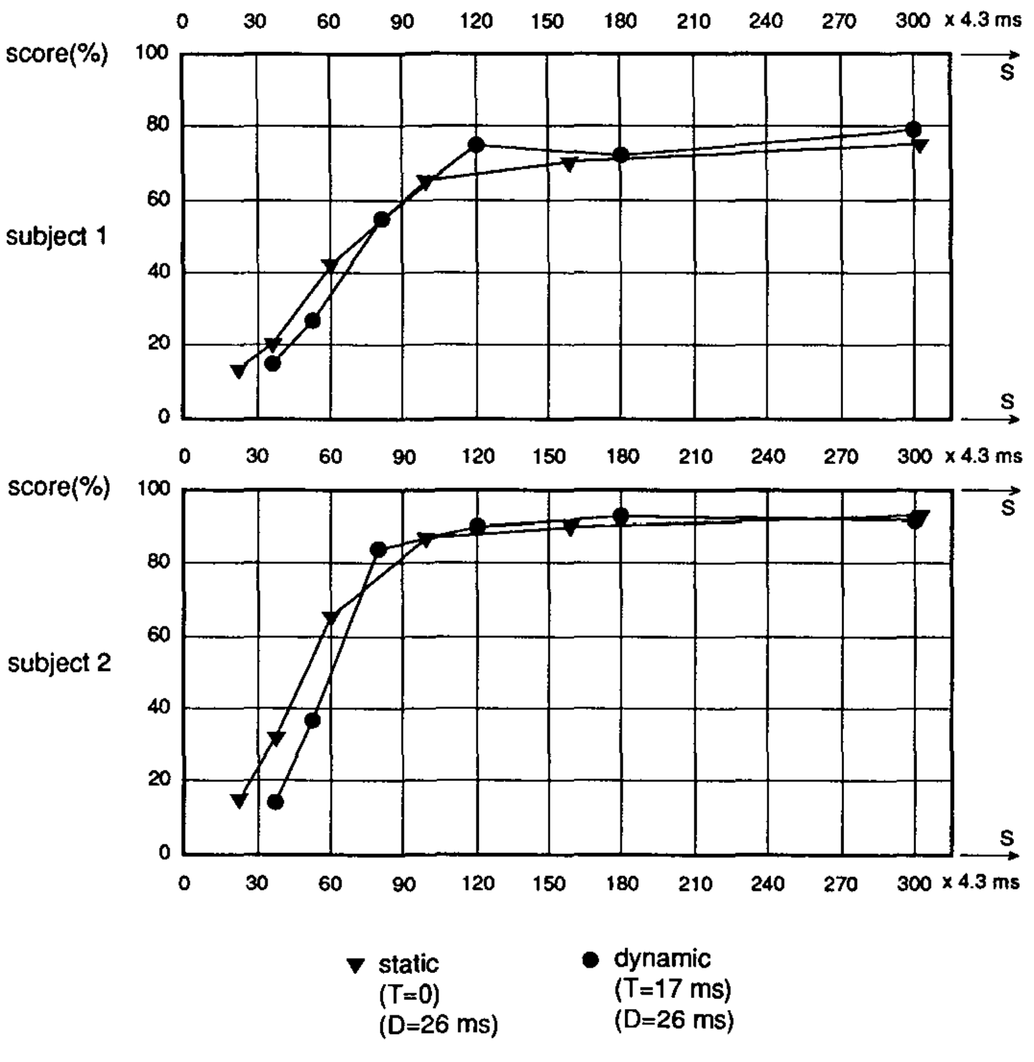

Figure 13: *Perception scores from 2 subjects in experiment two*

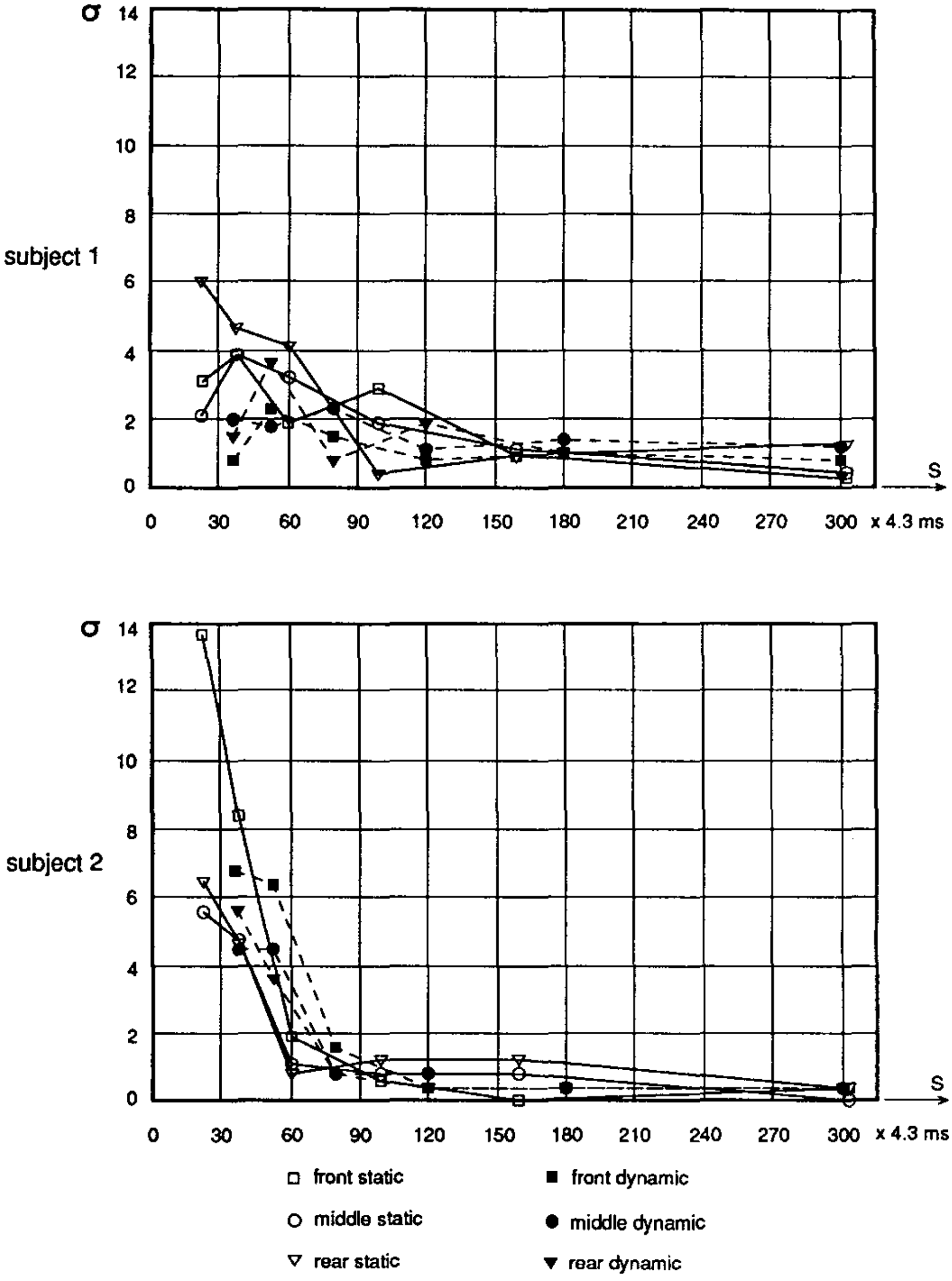

Figure 14: *Standard deviation σ of the wrong responses as a measure of miscounting, from two subjects. Curves are obtained from both the static and dynamic modes. 'Front' refers to the situation when the first letter in the middle-three is chosen as target, while the response is wrong, and happens to be the letters immediately surrounding it. 'Middle' and 'rear' refer to the second and the third letters, respectively.*

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