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BEHAVIOURAL AND ELECTROPHYSIOLOGICAL EVIDENCE FOR THE SPECIFIC PROCESSING OF TEMPORAL INFORMATION

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The attentional model of time estimation assumes that specific chronometric mechanisms are involved in the processing of temporal information. The two experiments reported here provide evidence in favour of this model. The first study, which uses the method of attentional sharing in a dual-task paradigm (discrimination of the intensity and the duration of a visual stimulus), shows that controlled attention can be applied to the processing of temporal information and that subjective duration shortens when the attention paid to time decreases. The second one, by comparing brain activities recorded during a temporal and a nontemporal tasks, suggests that certain prefrontal areas are involved in temporal processing.

INTRODUCTION

The experience of time has always intrigued human beings. In particular, the accuracy with which we perceive the duration of external events or time a number of our movements, essential as they are to our adaptation to the environment, has for long been an issue for research. Nonetheless, how humans perceive time remains, even nowadays, a much-debated question.

As far as brief durations are concerned, two main hypotheses emerge. Either time is constructed on the basis of the nontemporal cues available in the environment, or some sort of temporal cues exist and the information concerning duration is processed *per se*, in the same way as other types of information. Thus the key question is whether or not there is a specific processor (timer) whose aim is to process and encode temporal information.

Ornstein's "storage size" model (1969) rejects the idea of such mechanisms. It assumes that subjective duration is directly related to the amount or the complexity of the information stored in memory.

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For example, Ornstein presented geometrical forms to subjects who had to count the number of angles included. At the end of the experiment, they were required to compare the duration of presentation of each figure. The most complex figure induced the longest subjective duration. Ornstein's model has long been prominent. However, it seems reasonable to propose now (Block, 1992; Hicks, Miller & Kinsbourne, 1976; Macar & Jackson, 1992) that it essentially explains the data obtained under conditions of retrospective timing, that is when subjects are not forewarned prior to the relevant period that a duration judgement will be required. In contrast, when subjects know in advance that they will have to judge duration, that is under prospective conditions, time judgements seem to depend on the amount of attention allocated to time.

Thomas and Weaver (1975) have promoted this view. They proposed that the subjective estimation of short durations (in the 100 ms range) is based on the outputs of two processors: a timer and a stimulus processor. Both influence time judgements but their respective contribution is determined by the amount of attention that each one receives. Zakay (1989) applied this attentional model to longer durations and assumed that when the amount of nontemporal information in a given period increases, the attention shifts from the timer to the nontemporal processor and, hence, subjective duration is reduced. This reduction is explained as follows. The timer is thought to store pulses from various organic sources during the relevant period (Church, 1984). A decrease in attention would imply a reduction in the quantity of stored pulses, on which temporal judgements would be directly dependent.

Many experiments using dual-task paradigms have provided evidence in favour of the attentional model (Brown, Stubbs & West, 1992; Hicks, Miller, Gaes & Bierman, 1977; McClain, 1983; Zakay, 1989, 1992). Our studies are part of this framework. They aim to provide behavioral and electrophysiological evidence in favour of the existence of internal mechanisms specifically devoted to the processing of temporal information. The first experiment to be reported here investigates the role of attention in the processing of temporal information. It involves a dual-task paradigm in which subjects have to control the amount of attention they allocate to two concurrent tasks, one temporal and one nontemporal. The results indicate that controlled attention can be applied to time estimation and that subjective duration is reduced the more as attention is paid to nontemporal parameters. This is an argument in favour of specific processing of temporal information.

The second experiment is concerned with electrophysiological correlates of time estimation. The activity of prefrontal areas is compared when subjects perform either a task of reproduction of duration or a linguistic task. Different prefrontal areas seem to be activated under these two conditions.

EXPERIMENT 1

Materials and method

Sixteen subjects aged from 18 to 25 years took part in this experiment. They were seated in a dimly and soundproofed room. They faced a video screen on which a green light appeared with variable duration and intensity depending on trials. The subjects had to identify the duration (short or long) and/or the intensity (weak or strong) of this signal under different attentional conditions. Two response-keys were available, one for each judgement.

Instructions specifying how the subject's attention had to be shared between the two tasks were presented on the screen for 5 seconds prior to each trial. Five different instructions could appear from one trial to another: "maximum intensity-minimum duration", "maximum duration-minimum intensity", "half-half", "duration only" and "intensity only". In the first three of these conditions, subjects gave two judgements, one concerning the intensity and one concerning the duration, and tried to pay more or less attention to each task as required. The last two conditions were controls in which the subjects had only one task to perform and therefore gave only one response.

Each subject took part in 3 sessions of 400 trials in which different duration ranges were tested interindividually in counterbalanced order. The short and long durations were respectively 350 and 650 ms (1), 1250 and 1750 ms (2) and 2500 and 3500 ms (3). The intensities were 1,5 mcd (weak) and 2,25 mcd (strong) in all cases. Under the control conditions, constant median values were used: 1.875 mcd for the intensity under condition "duration only" and 500, 1500 or 3000 ms (depending on the session) for the duration under condition "intensity only".

Results

Two different variables were analyzed in both tasks: (1) the performance level was given by the d' index of sensitivity from the Signal

Detection Theory and (2) the probabilities of responding "short" in the duration task and "weak" in the intensity task were measured to detect the direction of the errors due to the attentional sharing. Only the main results concerning the d' index and the percentages of the response "short" are given here (for more details, see Macar, Grondin & Casini, submitted).

Table 1. *Mean Values of the d' Indices Under the Attention Sharing Conditions in the Three Duration Ranges (500, 1500 3000 ms) in the Intensity and in the Duration Tasks.*

Condition	Intensity			Duration		
	500	1500	3000	500	1500	3000
D	*	*	*	2.47	1.85	2.46
Di	1.42	1.64	1.73	2.46	1.79	1.99
hh	1.37	1.88	1.98	2.16	1.85	1.96
Id	1.43	1.83	1.95	1.75	1.63	1.85
I	1.29	1.74	1.85	*	*	*

Note. D, Di, hh, Id and I refer respectively to conditions "duration only", "maximum duration/minimum intensity", "half/half", "maximum intensity/minimum duration" and "intensity only". Interindividual data, 16 subjects. (Experiment 1)

* *d' index*: Table 1 gives the mean values of the d' index as a function of the attention sharing conditions in each task for the 500, 1500 and 3000 ms duration ranges. The d' index in the duration task generally diminishes with the amount of attention attributed to this task ($F(3,45)= 8.27$ $p < 0.001$). The effect of attention was not significant in the intensity task ($F(3,45)= 2.90$).

* *Percentages of "short" responses*: Figure 1 shows the evolution of the percentage of "short" responses as a function of the attention sharing conditions in each duration range. This percentage depends on the amount of attention devoted to the temporal task. The more attention is allocated to the intensity task, the higher is the probability of responding "short" ($F(3,45)= 6.85$, $p <0.001$). This result reveals that subjective duration shortens when attention is detracted from the temporal task.

Discussion

First, the evolution of the d' indices in the temporal task suggests that the amount of attention allocated to the temporal dimension of a

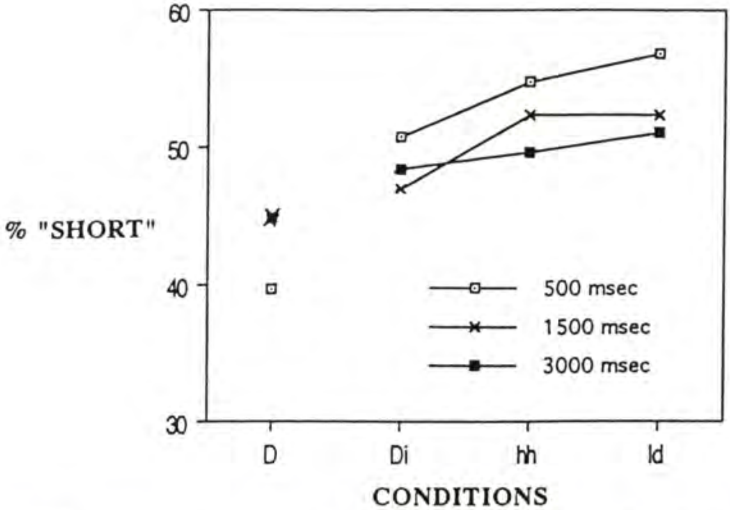

Figure 1. Percentages of responses "short" in the 500, 1500 and 3000 ms duration ranges as a function of attention sharing conditions in Experiment 1. Interindividual data, 16 subjects. On the abscissa, D, Di, hh, Id and I refer respectively to conditions "duration only", "maximum duration/ minimum intensity", "half/half", "maximum intensity/ minimum duration" and "intensity only".

stimulus can be controlled under prospective conditions. This strengthens the idea that controlled attention is involved during the processing of temporal parameters in certain tasks (Michon & Jackson, 1984) and that temporal information can be processed in itself. This provides also further evidence to assume that the "storage size" model proposed by Orstein (1969) is limited to results obtained under retrospective conditions. Secondly, the shortening in subjective duration obtained when the attention devoted to time decreases is consistent with the hypothesis of an internal timer which would use attentional resources to store pulses as a function of time. A certain quantity of pulses might be lost when attention is detracted from temporal parameters, whether the storage of pulses is momentarily interrupted or a certain number of pulses are erased from memory. In all cases subjective duration must shorten since it is assumed to be related to the quantity of recorded pulses. The exact nature of such pulses evidently remains enigmatic.

These results enable us to suggest that specific chronometric mechanisms could be involved in temporal judgements when durations in the

500 to 3000 ms range are concerned. On these grounds, is it possible to consider that certain cortical areas are prominently activated in relation with temporal processing? This issue is analyzed in Experiment 2.

EXPERIMENT 2

This experiment aimed at comparing the activity of prefrontal areas of the brain when subjects performed either a temporal or a non-temporal task. Prefrontal sites were chosen because various data suggest that they are particularly concerned with temporal mechanisms (Hicks, 1992 for a review). Brain activity was recorded in response to visual stimuli that were physically equivalent but induced different types of information processing. A task of reproduction of durations was contrasted with a linguistic task of resolution of anagrams. The Source Derivation Method (Hjorth, 1975) was used to analyze the topography of the prominent prefrontal activities recorded during each task.

Material and method

Fourteen subjects aged from 17 to 25 years took part in this experiment. They were seated facing a video screen on which 4 letters appeared on each trial. The experimental session included three blocks of 80 trials. Each block corresponded to a different task.

Each trial comprised the same basic sequence of events. A trial began when the subject pressed a push-button. After a 500 ms delay, a warning stimulus (S1) appeared on the screen during 800 ms. S1 consisted of 4 Xs that were then replaced by 4 other letters (S2). These letters were presented for 3 or 4 seconds depending on trials and were different in each block. In the first block (control condition) S2 formed the word RIEN (= "nothing") and subjects had nothing to do except watch the letters. In the second block, the four letters were different in each trial (example: AEGR). Subjects had to rearrange them to form a word (example: RAGE): this was called the "anagram" task. The third block involved a task of reproduction of duration. S2 was the letters AAAA. These appeared on the screen for 3 or 4 seconds and then were replaced by the letters BBBB (S3). Subjects had to press a button to stop the trial when they judged that BBBB had remained on the screen as long as AAAA. This task included two phases: the first (during S2) corresponded to the coding of the duration and the second (during S3) to its reproduction. Subjects performed the temporal and the linguistic tasks in counterbalanced order. The control condition was always presented first so as to lower the probability that subjects paid attention to the duration of the stimulus RIEN.

Cortical activity was recorded from 104 ms prior to the end of the warning stimulus till the disappearance of all letters in the control and anagram tasks. In the temporal task, the analysis was prolonged until the subject's response. Sixteen electrodes were placed on the scalp over the frontal and prefrontal areas symmetrically on the two hemispheres. Laplacian derivations were computed at 9 of these electrodes (the "nodal" ones) to measure the local electric field. This calculation was based on determined electrode patterns: each nodal electrode was surrounded by three other electrodes arranged in the form of a triangle and equispaced by 3.5 cm. The Laplacian derivation is the sum of the differences between the potential recorded by the nodal electrode and by the three surrounding ones.

Results

Two main questions were asked: Are different prefrontal sites activated in temporal and nontemporal tasks, and are prefrontal activities different depending on the accuracy of the subject's response in the temporal task? The intensity of the local electric field recorded under the 9 nodal electrodes was computed in three different 400 ms periods: 600 to 1000 ms, 1600 to 2000 ms and 2600 to 3000 ms from the beginning of S2. Since no significant difference was found between S2 durations (3 or 4 sec), all trials were pooled together in the following analyses. For the sake of brevity solely the clearest results which concerned the last 400 ms period will be reported here.

* *Comparison between tasks:* Figure 2 represents the level of cortical activity recorded between 2600 and 3000 ms during S2 in the three tasks: control, anagram and duration. The results of the ANOVA revealed a significant effect of task type ($F(3,39)= 6.47$, $p < 0.01$) and a significant task * electrode interaction ($F(24,31)= 1.86$, $p <0.05$). This suggests that the level of activity recorded under each nodal electrode was different depending on the task. The peak of activity was localized differently under the three conditions. In the control task, the pattern of activity was low and did not focus on specific sites. The activity observed in this task was subtracted from

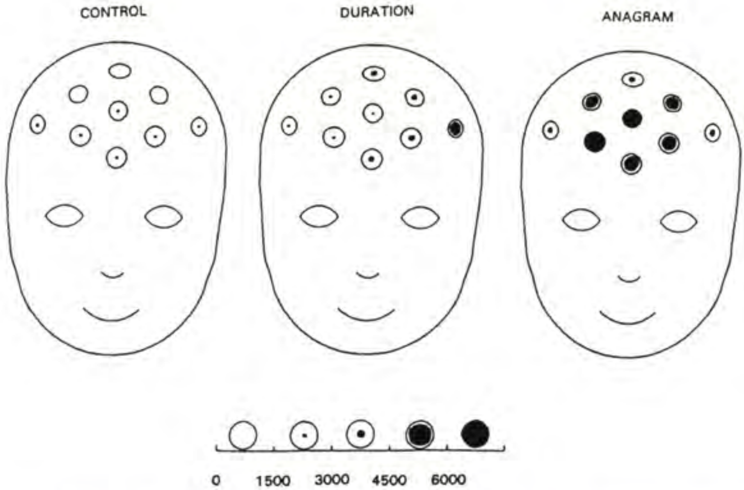

Figure 2. Level of activity (in arbitrary units) recorded between 2600 and 3000 ms during S2 in the control, duration and anagram tasks of Experiment 2. Interindividual data, 13 subjects.

the one recorded in the anagram and duration tasks so as to obtain, in each of the latter tasks, a level of activity specifically related to the particular type of information processing involved. Under the anagram condition, the peak of activity corresponded to the median electrodes, whereas in the duration task it focused on left sites. Similar patterns were obtained in the two phases of the duration task (S2 and S3), that is during both the coding and the reproduction of duration.

* *Accurate versus inaccurate responses:* the durations produced by the subjects were grouped into different bins 500 ms wide. Detailed comparisons were made between three categories of responses: "too short" (underestimation with a mean error of 1s), "too long" (overestimation with a mean error of 1s) and "accurate" (centered on the target durations, 3 or 4s). The accurate responses corresponded to a more focused activity on certain sites and to a lower general level of activity over the entire electrode configuration ($t = 4.5$, $p < 0.005$). The activity level was even more important when the errors were overestimations compared to underestimations ($t = 3.9$, $p < 0.005$). These differences in the activity level as a function of response accuracy were again observed in the two phases of the duration task, that is, during S2 and S3.

Discussion

The cortical maps obtained in this experiment revealed that the peak of activity in prefrontal areas was localized differently depending on the task. We shall concentrate here on the data yielded by the duration task. These suggest that certain brain sites are predominantly activated during the processing of temporal parameters of the task. Prominent activity was found under the most lateral electrodes that were placed over the left prefrontal cortex. This is consistent with neuropsychological studies which reveal that patients with lesions in similar brain sites present deficits on tasks involving temporal parameters (Lackner, 1982; Stuss & Benson, 1984). Obviously, since all electrodes were placed over prefrontal areas in the present study, one possibility cannot be excluded that more posterior regions are also active during temporal processing. It should also be considered that the particular brain areas which might be activated by temporal mechanisms are perhaps different as a function of other characteristics of the task, such as the modality of the stimuli involved. Further research is needed to clarify these issues and to test the generality of the present data.

Accurate responses on the temporal task were related to a lower level of activity than inaccurate ones. This was true in the two phases of the task, that is when duration was coded and when it was reproduced. This result suggests that the relative accuracy of the subject's response is determined whilst the target duration is presented rather than whilst it is reproduced. Accuracy would thus depend on the relative efficiency of coding, possibly mediated by attentional processes, rather than by memory factors.

With entirely different methods, similar differences in cortical activity as a function of the level of performance were observed by Elbert and collaborators (1991) in a duration reproduction task and by Gevins and collaborators (1987) in a nontemporal paradigm. These results may indicate that the way temporal and nontemporal information is coded is not intrinsically different. The increase in both intensity and spatial extension of cortical activity in the case of non accurate responses suggests that defective coding may be due to an increase in noise, decreasing the signal to noise ratio. In contrast, the focused activity corresponding to the accurate responses might indicate that the relevant information is "economically" processed and that only a small number of neuron networks are activated.

Conclusion

The important idea that emerges from these data is that temporal information is liable to be processed in itself rather than being derived from nontemporal information. Michon's postulate of "equivalence" (1972) is sustained: the temporal dimension of a stimulus should be considered as a source of information similar to its size, intensity or location. The first experiment reported here confirms a prediction of the attention model of time estimation and further reveals that the amount of attention allotted to temporal parameters can be under the subject's control. Similar effects were also obtained with auditory stimuli (Grondin & Macar, 1992): this suggests that the influence of the attentional factors in temporal judgements is independent of stimulus modality. The second experiment reinforces the idea of specific processing of temporal information on the basis of electrophysiological indices. The mechanisms involved seem to generate prominent activity on certain sites of the prefrontal cortex. The predominance of the left hemisphere which emerges from these data corroborates results yielded by the experiments concerned with the discrimination of temporal order in auditory modality, with durations shorter than 100 ms (Mills & Rollman, 1980; Leek & Brandt, 1983). In addition, neuropsychological data indicate that patients with left prefrontal lesions present deficits in tasks involving the discrimination of short durations (Lackner, 1982). One particular interest of the present electrophysiological study results is to extend these conclusions to duration ranges of several seconds.

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