Perceptual Deficit during a Mental Task

Abstract. *Subjects monitored for a visual signal while engaged in a demanding mental task. The probability of detecting the signal depends on the time of its presentation during the 8 seconds of the task. A similar time course is observed for failures to detect and for changes of pupil size. Momentary variations in the load that the task imposes on the subject are reflected in both indices. Detection failures are not explained by the pupillary changes.*

A driver who is engrossed in conversation is likely to miss a stop sign. Many similar observations suggest that intense involvement in thought may be detrimental to sensory and perceptual discriminations. Different patterns of autonomic activity characterize the two states of attending outward to the environment, or inward, as in problem solving (*1*).

Pupillary dilation is a sensitive indicator of the mental effort which is required by such activities as problem solving (*2*), imagery (*3*), rehearsal and retrieval from short-term memory (*4*), recall of familiar telephone numbers (*5*), and delayed discrimination between two tones (*6*). Changes of pupillary diameter in these tasks are relatively rapid: dilations of 5 to 8 percent of baseline diameter may occur within 1 second of the presentation of an appropriate stimulus (*5, 6*), and the constrictions are often equally fast (*4, 6*). We have interpreted changes of pupillary diameter as indications of second-to-second variations in the load that the mental activity imposes.

If intense mental activity hinders perception, perceptual efficiency should vary with the pupillary response. Our experiment tested this prediction. Seventeen student volunteers performed two tasks simultaneously: a digit transformation task and a detection task. The subject heard a string of four digits (for example, 8340), and responded with another (9451), adding 1 to each digit that he had heard. The string was presented by tape recorder at the rate of one digit per second, and the subject was to respond at the same rate, after a pause of 1 second. His response was paced by prerecorded tones. He was paid a bonus of 2¢ for every string correctly transformed, but only if the timing of his response was good.

At the same time the subject monitored a Bina-view display, placed approximately 40 cm from his eye, which flashed letters at a rate of five letters per second. The display was started 1 second before the first digit was presented by the tape recorder, and terminated 1 second after the subject finished responding to the digit task. The subject reported after each trial if the letter K had been among those presented. He was paid 1¢ if he correctly reported either the occurrence or the absence of a K in the trial. He was penalized 5¢ for reporting that a K had been shown when it had not. There was no penalty for failing to report that a K had been shown.

In 100 double-task trials the mental activity and the detection task were both performed. In 25 of these, no K was shown. When a K appeared, it was equally likely to be shown at any one of five times during the trial (although subjects did not become aware of this): on the first or third digit that the subject heard; during the pause; on the second or fourth digit that he spoke. In addition, there were 20 transformation-only trials before which the subject was informed that the letter K would not appear, and 20 detection-only trials on which the transformation task was made very simple—the subject heard 1111 and said 2222. The various conditions were represented in every one of five blocks, each consisting of 28 trials. The sequence of blocks was altered for different subjects, to prevent order effects.

Five subjects viewed the target through a 2.5-mm artificial pupil, with the left eye occluded. This was intended to prevent any direct effect of changes of pupil size on visual acuity. Photographs of the pupil were obtained for nine of the remaining subjects through a half-silvered mirror on Kodak high-speed infrared film. Exposures were made with a General Radio strobolume filtered for infrared. The tones which paced the subject also triggered the strobe, a procedure which ensures perfect synchrony between the pictures and the task (*6*).

An average pupillary response curve was computed for every subject in each experimental condition, counting only those trials on which the response had been fully correct (Fig. 1a). The responses are characterized by a steady dilation of the pupil through the listening phase of the task and the first part of the report. For each of the nine subjects, the dilation is smallest in the detection-only condition ($P < .01$), but there is no consistent difference between the curves for the two conditions of double-task and transformation only.

Illumination of the eye was low in

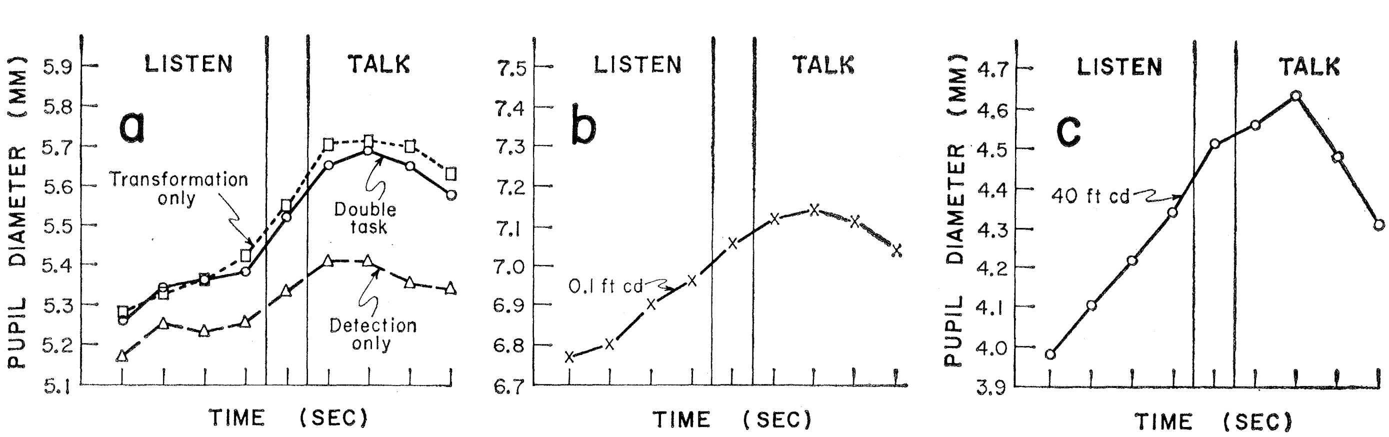

Fig. 1. Pupillary responses of subjects under various conditions. (a) Average pupillary responses for nine subjects under three task conditions: detection only, transformation only, and double task. (b and c) Effect of illumination averaged for five subjects. Pupillary responses to the transformation task after 30 seconds of adaptation to two selected levels of illumination at the eye. Illumination in (b) is 1.076 lux; in (c), 430.4 lux. Fixation distance: 42 cm. Curves similar to (b) are obtained at all lower levels of illumination.

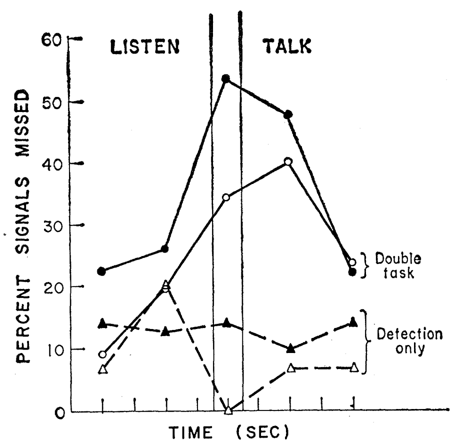

Fig. 2. Percent signals recognized as a function of time of occurrence during the trial. Filled symbols: average for 12 subjects viewing the target through natural pupil. Unfilled symbols: average for five subjects using a 2.5-mm artificial pupil.

this experiment, a factor which probably explains the sluggishness of pupillary constrictions in Fig. 1a. In Fig. 1, b and c are drawn from an auxiliary study of the pupillary response to the digit task, conducted at Harvard with five subjects. It is apparent that the rate of constriction during the final 2 seconds of the task depends on the level of illumination (t = 3.83, 4 df, $P < .05$). When illumination of the eye is high, the initial dilation probably consists of a transient inhibition of the pupillary constriction to light, as well as a response of the sympathetically controlled dilator muscles (*7*). As soon as the stimulus for the dilation is removed, the restoration of the response to light causes a rapid constriction. In an analogy to a measuring instrument, the pupil is spring-loaded by the light response when illumination is high, but the spring is weak or absent when illumination is low. The pupillary response in Fig. 1c is similar to one reported earlier for the same task (*4*). It probably provides a more sensitive measure of the time course of involvement in the digit task than does Fig. 1a.

The ability of the subject to detect the letter K varies with the time at which the letter is shown (Fig. 2). Only trials on which the transformation task was correctly performed are included in Fig. 2, but the omission of trials on which the transformation was wrong has no important effects. The curves for the double task are similar to the curves that describe the pupillary response to digit transformation, and in particular to the response obtained under moderately high illumination (Fig. 1c). The distribution of detection failures as a function of time of presentation is highly concordant for the different subjects ($W = 0.63$, $P < .01$ for the five subjects who viewed the target through an artificial pupil; $W = 0.31$, $P < .01$ for the other 12 subjects).

Subjects were much more successful in the detection task when the transformation task was not required. The 17 subjects missed the K on an average of 31.5 percent of double-task trials, and 11.5 percent of detection-only trials ($P < .01$). False positives were also more frequent in double-task trials, 11 percent against 3.5 percent in detection-only trials ($P < .01$). This pattern of results indicates a genuine loss of perceptual sensitivity in the double-task situation (*8*).

The interference between detection and transformation was mutual. Subjects were correct on the digit task in 81.9 percent of transformation-only trials. They made significantly more errors on the digits when they were also monitoring for the K (72.8 percent correct, t = 3.15, 16 df, $P < .01$). The failures of transformation in the double-task condition are apparently due to the activity of watching for the K, rather than to the event of detecting it: even when a K is not shown in the double-task condition, subjects make more transformation errors than they do in the transformation-only condition (t = 1.94, $P < .05$, one-tailed). The time of occurrence of the K has no effect whatever on transformation performance.

In summary, the activities of transforming digits and monitoring for a signal were antagonistic in this experiment. Detection performance suffered more from the competition than did the mental activity, but a change of the pay-off structure could probably alter this result. Certainly more important is the finding that the ability to detect signals varied continuously during the 8 seconds of the task, in parallel with an independent physiological indicator of processing load.

Since errors did not decrease monotonically in Fig. 2, it is unlikely that our subjects clearly recognized the target at the time of its presentation and then forgot all about it. It is also unlikely that changes of accommodation or pupil size can explain the perceptual deficit during the mental task: subjects who viewed the target through an artificial pupil showed the same pattern of interference as did the others. We therefore conclude that our subjects were to some degree functionally blind when they were engaged in thought. Their reported subjective impressions were in accord with this conclusion.

Although the effect which we observed does not seem to reduce in any simple way to a competition between sensory channels, the character of the perceptual deficit is quite possibly alike in both cases: that is, a marked subjective attenuation of the unattended message, a fragmentary analysis of the information that it conveys, and a severely reduced persistence of memory (*9*). These characteristics perhaps apply generally to various sensory channels during periods of active processing of information. An antagonism between thinking and perceiving may have important implications for our understanding of speech, which depends on both accurate reception of the message and much complex processing.

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