Olfactory adaptation and recovery in man as measured by two psychophysical techniques[1]

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Olfactory adaptation and recovery was investigated in man, using two psychophysical procedures: modified category scaling and threshold detection. Both procedures yielded similar qualitative information regarding loss and recovery of olfactory sensitivity as a function of time and concentration of adapting stimuli. However, quantitative differences were observed that could be partially attributed to artifacts inherent in each procedure. Often more than 50% adaptation (and recovery) occurred within the first 2 min with either test procedure. In all experiments the rate of adaptation and recovery was greater at the higher of two adapting concentrations (10 X and 20 X the detection threshold I_t). Recovery occurred more rapidly than adaptation. The usefulness of both techniques is discussed in terms of the overall problem of characterizing the olfactory adaptation and recovery process in man.

Olfactory adaptation is characterized by a marked reduction in sensitivity to an odor stimulus. The rate and degree of loss in sensitivity are dependent on the stimulus intensity and its duration. When the adapting stimulus is no longer perceived, a stimulus of higher intensity may still be detected. Removal of the adapting stimulus results in recovery to previous levels of sensitivity. Finally, adaptation to one odorant may lower the sensitivity to other odorants; viz, cross-adaptation (Cheesman & Mayne, 1953; Cheesman & Townsend, 1956; Moncrieff, 1957; Koster, 1969; Cain & Engen, 1969; Ekman et al, 1967).

During the course of a larger investigation of odor perception in man, we obtained preliminary measurements for the rates of adaptation and recovery to two odorants. Our initial psychophysical procedure was based on the modified category scale used by Stone (1966). Difficulties in maintaining a frame of reference with this procedure prompted us to use a threshold detection procedure similar to that described by Stuiver (1958). This report describes the results of a more systematic investigation of the adaptation and recovery process using these two psychophysical procedures.

METHODS

Subjects

The Ss tested were six volunteers (four males and two females) selected from the Institute staff on the basis of their olfactory sensitivity in preliminary screening tests. None of the Ss had any obvious or known olfactory defects, and each demonstrated an ability to respond reliably to the standard stimulus. The Ss were considered trained at the time of this study.

Apparatus

An olfactometer was used to present the stimuli. The original apparatus has been described elsewhere (Stone & Bosley, 1965). In brief, it is an air-dilution system that permits delivery of a known concentration of an odorant for a controlled duration. In these experiments the apparatus was modified to increase the efficiency of its operation (Stone et al, 1969). The modifications consisted of the addition of electronic timers and solenoid valves to facilitate ease of odor presentation and to select odor intensities and test intervals more rapidly and accurately. Communication between E and S during testing was by a visual system of light signals.

Concentrations of the stimuli delivered to S were calculated from vapor pressure, experimental temperature, and gas-flow rates, according to previously established procedures (Stone et al, 1962).

Test Odorant

The odorant used was methyl isobutyl ketone. Purity, checked by gas-chromatographic analysis, was > 99%.

Test Conditions

Each S completed one adaptation-recovery cycle during each experimental session. An average of two sessions were held on each test day, several times a week. Each S was tested using both psychophysical procedures. Six to eight sessions were completed for each S. The concentration of the adapting stimulus was 10 X or 20 X the absolute detection threshold for each S. The detection threshold (I_t) for each S was estimated using the tracking procedure described earlier (Steinmetz et al, 1969); S's threshold was verified prior to each test session.

Test Procedures

Category scaling. A modified category scale, with anchor points at the top and bottom, was used for estimation of relative perceived odor intensity of the adapting stimulus. At the beginning of each session, S was given a blank sample and instructed to assign this a value of 1, or "no odor." The adapting stimulus was then turned on (and remained on), and S was instructed to assign to this stimulus the maximum value of 10 on a category scale from 1 to 10. At intervals thereafter (every 15 or 20 sec), S was instructed to rate the intensity of the adapting stimulus, which was left on until he reported no odor or until his responses reached an asymptote, as judged by E. The adapting stimulus was then turned off and recovery was initiated. After a period of no stimulus (and at selected intervals thereafter), the adapting stimulus was presented for 5 sec, and S rated its intensity. This sequence continued until S assigned the maximum value to the test stimulus (indicating full recovery) or until it became apparent that S's responses had reached an asymptote. Thus, the procedure measures changes in perceived intensity of the suprathreshold adapting stimulus as a function of adaptation and recovery.

Threshold detection. The threshold-detection procedure monitors the change in absolute threshold as a function of adaptation and recovery. It requires S merely to indicate the presence of the test odor. A session began with S's exposure to the adapting stimulus for a predetermined interval. The adapting stimulus was switched off and S's threshold checked by presentation of a test stimulus equal to some multiple of his absolute detection threshold (I_t). Since two diffusion bulbs and their separate delivery systems were used, the switching from adapting to test stimuli was accomplished rapidly with no special adjustments necessary. If the test stimulus was detected, it was repeated after another exposure to the adapting stimulus. If it was

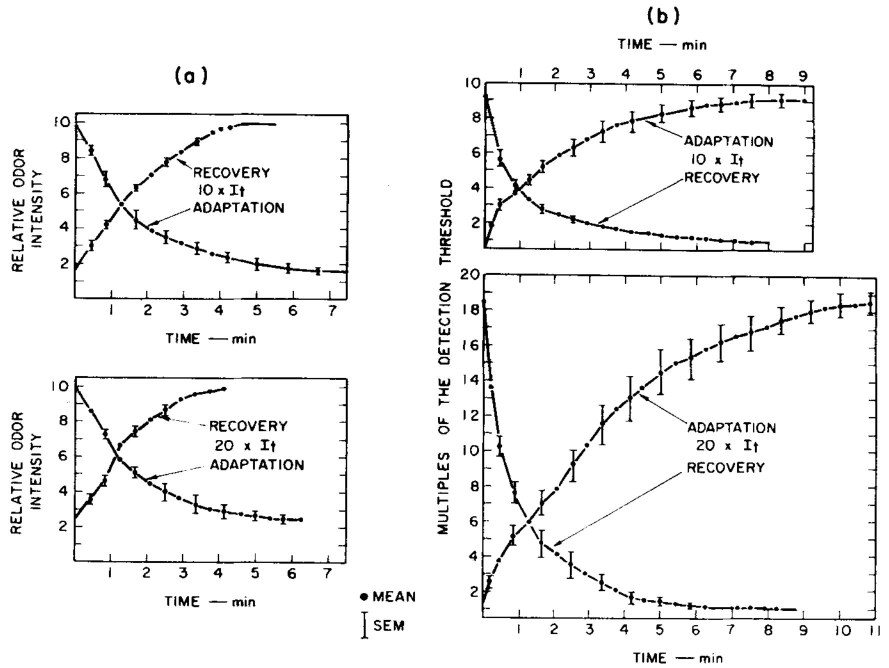

Fig. 1. Pooled rates of adaptation and recovery for the odorant methyl isobutyl ketone at two adapting concentrations (10 X and 20 X I_t), using the category scaling procedure (a) and the threshold detection procedure (b). Each entry is the mean of 8 to 10 responses from each of six Ss. Standard errors of means (SEM) not shown at curve asymptotes were too small to indicate.

not detected, a higher multiple of I_t was presented after the next adaptation period. The flowmeters were calibrated for most settings, and E needed only to refer to prepared tables to determine the concentrations to be presented at each test interval. This procedure continued at regular intervals until the test stimulus was equal in concentration to the adapting stimulus, or until a stable asymptote was reached.

The recovery procedure was similar to that for adaptation except that the intervals between test stimuli consisted of no odor. The threshold was checked after successive intervals with decreasing multiples of I_t until S's original absolute threshold was reached, i.e., recovery was complete.

As a control, an air blank was occasionally substituted for the test stimulus. Blanks were presented frequently during recovery where a blank sample would not impede the function in question. During adaptation, where blank samples would amount to brief recovery periods, they were presented infrequently.

The test interval consisted of a 2- to 3-sec period of no odor (to ensure against S's responding to possible carryover of odor from adaptation to test) followed by the test stimuli, which remained on until S responded or for 5 sec.

Six to eight sessions in which the concentrations of test stimuli were varied from session to session were sufficient to establish an average threshold value at each time interval during adaptation and recovery, thus generating curves representing S's change in olfactory sensitivity as a function of time.

Analysis

Intensity estimates from the category-scaling procedure were averaged for each S at each time point, and the mean values were plotted as a function of time. The data for all Ss were then pooled and mean values ± standard error of mean (SEM) were plotted.

Results obtained from the threshold-detection procedure were treated similarly, based on estimates of the I_t at each time point. A curve of ascending adaptation thresholds and descending recovery thresholds was plotted for each S, and data from all Ss were pooled to determine curves of mean values ± SEM.

RESULTS

Figure 1(a) shows the pooled results during adaptation and recovery to 10X and 20X I_t for methyl isobutyl ketone as measured by changes in perceived intensity using the category scaling method with a 10-point scale range. Ss performed reliably throughout testing, and the curves generated were regular and without excessive variability. At both concentrations, asymptote was reached in adaptation at a level where, on the average, some odor was still being perceived. Some Ss reported complete adaptation in all experiments, while others exhibited continued slight perception of the odor. Also, at both concentrations recovery took less time than adaptation and was complete for all Ss (in terms of their intensity ratings).

Figure 1(b) shows the change in I_t during adaptation and recovery measured by the threshold-detection method. The ordinate represents multiples of the absolute threshold. The recovery of olfactory sensitivity for this odorant is apparently more rapid than its loss by adaptation, especially at the outset of the two phases.

S's report is identical at the point of complete adaptation in each procedure (i.e., nondetection of the adapting stimulus). Therefore, it seemed reasonable to equate the data from both methods on the same ordinate in terms of percent of adaptation complete. As shown in Fig. 2, the shapes of the resulting curves are similar, but differences between methods in percent adaptation completed are frequently large, especially at the higher concentration.

In the threshold-detection method, the adapting stimulus was repeatedly interrupted for insertion of the threshold test stimuli. It is likely that some recovery occurred in the 2- to 3-sec interval between the offset of the adapting stimulus and the onset of the test stimulus and, therefore, the rate of adaptation is obviously slowed. An ad hoc "correction" for this interval was made, in an attempt to more reasonably compare the two curves. These data, presented in Fig. 3, yielded closer agreement between the two curves during adaptation to 10 X I_t for the two methods. However, considerable disparity remained in comparisons obtained at 20 X I_t. This, in turn, may be partly accounted for in terms of the "coarseness" of the discrete-category scale compared to the finer discrimination possible with the threshold method.

DISCUSSION

In a study of olfactory adaptation and recovery in man, the selection of a reliable and practical method of investigation is of great importance. The two methods used in the present study, while measuring different aspects of these phenomena, provided similar information on the progression of adaptation and recovery as a function of stimulus strength and time of

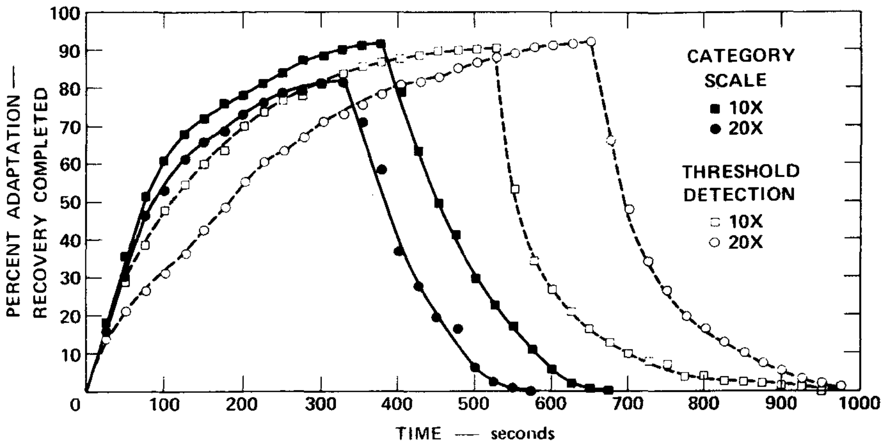

Fig. 2. Pooled results for the panel, depicting the percent adaptation and recovery per unit time at the two concentrations for both psychophysical methods.

exposure. With category scaling, Ss assign category ratings to changes in perceived odor strength of a continuous suprathreshold stimulus. With threshold detection, Ss indicate detection or nondetection of threshold test stimuli inserted periodically in the suprathreshold adapting stimulus. This is a discontinuous procedure in which the perceived threshold remains static.

Each of the two methods has its limitations. The category-scale method may tend to create a response set by Ss; i.e., they may learn to habitually report decreasing values in adaptation and increasing values in recovery. Also, the coarseness of the discrete scale detracts from the sensitivity of the method. This is especially true at points near asymptote, where perceived intensity changes are slight. Finally, although during adaptation Ss know the lower limit of the category scale corresponds to no odor, they are less certain of the upper anchor point of the scale during recovery. They must therefore develop an internal reference image of the original perceived intensity of the adapting stimulus in order to scale responses relative to the final perceived intensity when recovery is complete. The method is largely subjective and requires considerable concentration by well-trained Ss. Cross-modal scaling methods, such as the finger span match used by Ekman et al

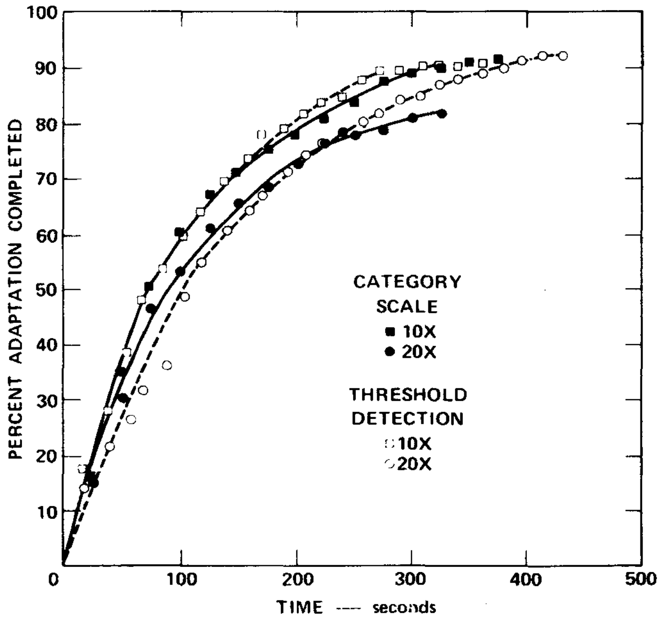

Fig. 3. Comparison of pooled rates of adaptation by the category scaling method and by the threshold detection method corrected for time.

(1967), provide S with a continuous scale and may facilitate the task of scaling small changes in perceived intensity. However, these are equally subjective and no less prone to problems related to response set or need for an internal frame of reference.

Threshold detection is a more objective technique, requiring only a yes/no response from S on the basis of whether the test stimulus is above or below his absolute threshold at various time points in adaptation and recovery. However, it also has disadvantages. The interruption of the adaptation stimulus for threshold test stimuli results in some degree of recovery. This is especially true when the threshold stimulus itself is of low intensity, or when a blank sample is presented as a control. Although we attempted to "correct" for this by considering exposure time rather than elapsed time as the salient factor in adaptation, there is no way of knowing exactly how much recovery takes place in these intervals. It is considered to be minimal, on the average.

When the threshold-detection method is corrected for time, the agreement in results enabled us to compare these data with those reported by Stuiver (1958). According to Stuiver, adaptation proceeded more rapidly than recovery and, further, the rates of adaptation were much faster at levels of 10 X and 20 X I_t. Our results revealed that recovery proceeded considerably more rapidly than adaptation. Although this difference may be due to the odorants or concentrations, we suspect other factors may be involved. Multi-S experiments, using several odorants (e.g., benzyl acetate, β-ionone, allyl isothiocyanate) and other psychophysical methods (Pryor[3]), yielded similar rapid recovery rates. Stuiver, on the other hand, used only one S and pooled duplicate runs for each concentration. More detail on the differences will be available upon repeating the tests with the same odorants.

Stuiver's data revealed a curvilinear function. Based on our results at 10 X and 20 X I_t, the adaptation process approximates a hyperbolic function. Our individual Ss all exhibited a similar pattern. Stuiver noted the function to be almost linear within this concentration range for his S, and curvilinear at much higher concentrations. Ekman et al (1967) reported results using a different psychophysical method, in which the function was described as curvilinear. Although the various results reported to date are not in complete agreement, they serve to emphasize some of the difficulties inherent in studying the olfactory adaptation and recovery process, especially by the two methods described herein. Our studies are being continued in an effort to understand the total process more fully.

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NOTES

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