Olfactory fatigue: what it is and how to avoid it in product testing

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Olfactory fatigue (like wearout or sensitivity loss) is a name for the common experience of losing sensitivity to odors after continued smelling. It occurs when we are exposed with each breath to a relatively unvarying source of odor. Our olfactory system is robust—but if it is faced with a continuous stream of constant odorant (perfume, flavor, or noxious environmental odor), we lose our sensitivity. We adapt to the stream of odor, and it seems weaker. In its most dramatic form, olfactory adaptation produces a total loss of odor perception.

Adaptation characterizes all senses to greater or lesser degrees. Each sense is susceptible to adaptation to a continuous stream of unvarying sensory inputs. As we emerge from a darkened movie theater to daylight, we find that the outside is too bright. It takes a few moments to re-adapt to the outside. In olfaction, fortunately, adaptation is a temporary phenomenon, soon dissipated by breathing nonodorized air.

Olfactory self adaptation

If we smell a substance, and shortly thereafter smell the same substance at a lower concentration, the odor sensation may either be absent (total adaptation) or considerably weakened. "Self adaptation" refers to this weakening of olfactory intensity.

Researchers interested in self adaptation have tried to assess its properties, and have asked the following questions.

- How long does it take a smell to entirely disappear?
- Does disappearance depend on the concentration of the odorant?
- How can the degree of adaptation be assessed without waiting for total disappearance of the odor?
- Should one test threshold or superthreshold levels after a specific time of adaptation?

Time for total disappearance

This is an easy measure to obtain experimentally. The panelist has to signal the experimenter that the odor has disappeared. Of course, disappearance as a criterion may vary from one person to another.

Perhaps the first systematic study which measured time of disappearance was reported almost a century ago. Aronsohn (1886) tested eight different substances, some simple (camphor) and some complex (eau de cologne). Times required for complete disappearance of odor sensation ranged from a minimum of 50 seconds to a maximum of 12 minutes. Eau de cologne required substantially less time in diluted form than did its constituents alone, in their more concentrated form. As a benchmark chemical, Aronsohn reported that camphor required approximately 5 minutes to disappear. Unfortunately, this study used impure substances, at different concentrations, with single levels of stimuli evaluated.

Later studies repeated this paradigm with minor modifications. Vaschide (1902) reported that the smell of ether disappeared after 85 seconds and the smell of ammonia after 10 minutes, while the smell of camphor lasted for 30 minutes or more. All were presented under continuous conditions. Similar experiments by Woodrow and Karpman (1917) showed that it took at least 60 seconds to eliminate the moderate to strong odors of propanol, camphor, and naphthalene. Mullins (1955) repeated Woodrow and Karpman's design, using three other substances (n butane, n butanol = odor of fusel oil, and pentadecanolide = musk smell). Each substance did eventually disappear, but there was no clear relation between odor strength and total time required for the sensation to disappear.

In 1935, Elsberg reported the results of a comprehensive series of studies using the blast olfactometer, a device which could push air of various volumes and odors into the nose. A short blast of odorant into the nose was followed by a 15 second wait. The blast was then repeated. This interrupted presentation led to diminution of perceived odor, and finally to its total disappearance, if done with the correct timing. With citral (lemon odor) about 10 blast injections of

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citral were needed, separated by 15 second waits. Twenty injections were required for the odor to disappear totally if the wait was increased to 20 seconds. When a wait of 25 seconds was imposed, the odor did not disappear even after 30 sequential injections. Coffee odor, run under the same conditions, disappeared only for the 15 second wait condition. As soon as an interval of 20 seconds elapsed between injections, coffee aroma no longer adapted.

Effect of concentration on disappearance time

The most important studies on disappearance time vs. concentration are the parametric studies reported by Woodrow and Karpman (1917) and, forty-one years later, by Stuiver (1958). All researchers used constant odor stimulation. Woodrow and Karpman used streams of odorized air (propanol, camphor, or naphthalene) at relative concentration levels of 1, 2, 3, 4, 5, or 6. With increasing odor concentration the smell took longer to disappear.

Stuiver first began detailed, parametric work on adaptation with a precision olfactometer. This olfactometer delivered a precisely measured stream of odorized air. There was a clear relation between the time required for an odor to disappear (T) and the odorant concentration (C) measured in units relative to the individual's threshold. The equation relating T and C is:

D Octanol (fatty, fruity odor) $T = 20(C-1)^{0.5}$

M Xylene (solvent odor) $T = 30(C-1)^{0.5}$

This square root rule means that doubling the relative concentration of odorant did not double the time needed to reach total adaptation. The time to reach total adaptation is proportional to the square root of concentration, so that doubling concentration requires only about an additional 40% time to achieve total disappearance of the smell.

The researcher should be aware of biases which occur when the panelists are asked to report the disappearance of an odor. Some individuals may adopt a more stringent criterion than others do of what it means to perceive no odor. Different criteria may yield different appearing rates of olfactory adaptation vs. concentration.

Rate of odor disappearance

The rate at which odor disappears during adaptation is another important question. Does the odor sensation disappear relatively rapidly, so that within a few seconds most has vanished, with just a residuum left to completely adapt out over the next few minutes? Or does the odor impression decline slowly and thus steadily diminish until it is no longer experienced?

To measure how quickly the olfactory sensation disappears, the researcher must have a scaling procedure which lets him "track" the change in perceived intensity. Psychophysical scaling is just such a method—the panelist in a scaling study can be likened to an instrument which registers changes in perceived strength.

Several studies have traced the course of olfactory adaptation by one or another scaling method. For example, Pryor, Steinmetz and Stone (1970) instructed subjects to rate the odor intensity of n propanol using a 10 point category rating scale. The propanol odor was presented continuously, and ratings were solicited after 5-second intervals. Adaptation can be easily illustrated by this simple scaling device, since the panelist provides a descending sequence of numbers which mirror the decrease in subjective odor strength. Adaptation was most rapid during the first 90 seconds, and then slowed down. The rate of adaptation, as scaled by this method, was shown to depend upon the concentration of the odorant. Steinmetz, Pryor, and Stone (1970) used a similar category rating procedure, this time with methyl isobutylketone. The adapting stimulus was presented at two levels, a lower one at 10× the panelist's threshold, and a higher one at 20× threshold. As might be expected, rate of adaptation was higher with the more intense stimulus.

A caveat about such approaches with fixed point category scaling has been raised by Schutz and Laymon (1959) who suggested that at the start of the experiment, the panelists may assign inappropriately higher ratings on the fixed point scale to weak odors in order to make sure that they do not 'run out of numbers' at the low end of the scale. This inordinately high initial rating biases the range of numbers used.

An ancillary question about adaptation rate is the nature of the curve relating time to rate of adaptation. Does odor intensity diminish linearly with time? If adaptation curves could be developed for different chemicals, then the practitioner of sensory analysis in fragrance evaluation would be able to adjust the evaluation time for each product fragrance to insure and optimize constant panelist sensitivity. If, in fact, olfactory adaptation proceeds systematically, then perceptions obtained 30 seconds after the start of an evaluation will differ from those obtained after the initial 5 seconds of inspection.

The late Gösta Ekman and his coworkers used modern psychophysical methods akin to magnitude estimation (Moskowitz, 1976) to assess how odor intensity changes over time. An early study by Ekman, Berglund, Berglund, and Lindvall (1967) examined the time course of olfactory adaptation to hydrogen sulfide. Subjects in that study matched finger span to odor intensity, and subsequently matched numbers (magnitude estimates) to finger span. This method allows subjects to keep their attention on the task, without needing to speak.

After the course of a 12 minute evaluation period, the perceived odor intensity declined quite rapidly, and then more gradually, until it finally approached an asymptote. The asymptote reflected a terminal or final, nonzero, perceived odor level. For all but the highest concentration, the asymptote was reached within 4-10 minutes. The relation of perceived intensity (I) and time (T) can be expressed by the equation:

$$R = a + b(c)^{-T} \quad (1)$$

An alternate expression is:

$$R = a + e^{-vT} \ (v = \text{rate constant}) \quad (2)$$

Here, as time (T) increases, $(c)^{-T}$ gets closer to 0, and the odor intensity approaches a (the asymptote).

Recovery from self adaptation

If the continuous stream of odorized air is interrupted, and replaced either by odorless air, or by air odorized with a different substance, then recovery is allowed to occur. Recovery means a return to sensitivity prior to adaptation. In addition to assessing the effects of adaptation, Aronsohn (1886) also evaluated the rate of recovery of the olfactory nerve by determining the time needed for total cessation of smell after an initial conditioning had occurred. The conditioning consisted of adaptation of the olfactory system to an odor until the odor sensation ceased, followed by a wait for a specified period, and finally the re-presentation of that odor and the determination of the time needed for total adaptation once again.

The comparison of times needed for total adaptation is a measure of relative recovery. If it took just as long to totally readapt the nose to the odorant in question, then Aronsohn assumed recovery to be 100%. If it took the subject a shorter time to readapt, then somehow sensitivity after previous adaptation had been diminished and remained diminished. The new adapting stimulus was sensed from a lower baseline of olfactory sensitivity. Under this rather rigorous regimen, Aronsohn found that even an interval of 3 minutes was not sufficiently long to fully recover from the prior adaptation effects of coumarin.

Virtually all the other studies cited above on the time course of odor adaptation also evaluated recovery. Elsberg's olfactometric blast method was used with coffee and citral, presented at fixed concentrations for periods of 30, 60, and 120 seconds. After cessation of the blast, Elsberg measured the time necessary for complete recovery of sensitivity. The subject was given an odor blast injection at odor threshold every 30 seconds. The measure of recovery was the time taken for sensitivity to be restored, so that the odorant corresponding to the subject's own threshold value could again be sensed.

With increasing adaptation time, there was an increase in olfactory fatigue, requiring longer waits to recover sensitivity.

Stuiver (1958) adapted his panelists to constant streams of odorized air for varying time periods, and then measured their thresholds by a similar procedure. After the adaptation sequence was completed, the panelists were presented with a stream of pure, odorless air. At intervals, they smelled a current of odorized air whose odorant concentration was below that level to which they had been adapted. The time following adaptation that was needed to perceive this subadapting level was a measure of olfactory recovery. Afterwards, the odorized air (the probe sample) was adjusted to a still lower level of concentration. This method allowed Stuiver to determine the time it took for the panelist's sensitivity to return to the original threshold. For the two test odorants, D octanol and M xylene, recovery was shown to be most rapid during the first few minutes, but then the rate of recovery slowed down. Full olfactory recovery, so that initial sensitivity prior to adaptation was reached, required up to 1440 seconds for M xylene.

Both these methods are attractive because they provide an objective measure of sensitivity, as well as an estimate of how long it takes to return the sense of smell to unadapted baseline sensitivity level. Nonetheless, since we are dealing with thresholds, which themselves are subject to a great deal of variability, there may be effects of adaptation that seem major, but in the real world of flavors and fragrances, would be relatively minor and unimportant. Most odors, after all, are evaluated at levels substantially above threshold.

More recent work on recovery from self adaptation has appeared from several sources. In each case, the researcher has used some method of sensory scaling to trace the perceived intensity of the odor. The study by Ekman, Berglund, Berglund, and Lindvall (1967) provides a typical example. They had adapted panelists to the malodor of hydrogen sulfide (requiring some 4-12 minutes of continuous presentation). After a two minute rest, the perceived intensity of hydrogen sulfide at the adapting level was shown to have returned to its preadapting strength.

Practical implications

Adaptation is affected by odor intensity or odorant concentration and time of exposure.

Users of odor evaluation panels must therefore keep these points in mind.

- Short fragrance evaluations are more effective than long ones in avoiding adaptation.
- Perceived odor intensity may change during an evaluation, even though the physical sample is unaffected. This may be accompanied by a change in odor quality, when really all that has happened is that adaptation has occurred.
- With a sufficiently well planned regimen of fragrance evaluation, the panelist will be able to smell more than just a few odorants especially if odorants are above their threshold levels.
- During the sequence of fragrance presentations, the researcher should take care not to present a very weak stimulus just after a strong stimulus. However, reverse presentation sequence is feasible.
- When odorants of different types or qualities are presented in succession, a different phenomenon, cross adaptation, occurs.

Cross adaptation

Numerous experiments have investigated the parameters of cross adaptation in olfaction. Some researchers have determined thresholds, adapting the subject to a suprathreshold level of one chemical (A), and testing sensitivity to a criterion chemical (B).

As Table I shows, cross adaptation is either minimal, nonexistent, or, if it does occur, neither systematic nor predictable. It is also not symmetric. The effect of one odorant on another is not reciprocal. Adaptation to odorant A and testing the threshold of odorant B show that the change in threshold for B after adaptation to A (as compared to the change in threshold after self adaptation) is not the same as obtained if A is tested after adaptation to B.

Cross adaptation, like self adaptation, varies with both concentration and time. Cheesman and Mayne (1953) and Cheesman and Townsend (1956) used the sniff bottle method. Panelists took sniffs of both the adapting and the test odors (in succession) from opened bottles which contained pure odorants in various liquid dilutions.

The threshold for the adapted odorant (B) grew as a function of the concentration of the adapting odorant (A). Furthermore, the relation was linear in log-log coordinates [meaning that threshold of adapted odor = k (threshold of adapting odor)^N]. N, the exponent, in all cases was less than 1.0, and was highest for self adaptation, and lower for cross adaptation. Since N is less than 1.0, this means that a 10-fold change in adapting odor produces less than a 10-fold change in threshold. Furthermore, since cross-adapting odors have lower values of N, a constant (100%) change in concentration of a cross-

Table I. Cross-Adaptation Studies -- Method, Results, Sources

Adapted Odorant	Adapting Odorant	Criterion	Results	Source
Plant Extracts	Plant Extracts	Thresholds	Little C.A.	Aronsohn, 1886
Camphor or Ether	Ether (at various times)	Threshold	Minor C.A. Large S.A.	Vaschide, 1902
Ammonia or Camphor	Ammonia	Threshold	Large S.A.	
Ether or Ammonia	Ether or Ammonia	Threshold	Large S.A.	
Coumarin + Vanilla	Vanilla	Smell quality	Coumarin smell emerged	Nagel, 1903
Phenol, Vanillin or Menthol	Guaiacol, Camphor or Benzaldehyde	Threshold	Little systematic C.A.	Backmann, 1917
Odors in Zwaardemaker's 'Aromatic Group'	Odors in the same Classification Group 'Aromatic'	Threshold	S.A. Strong C.A. Varies Adaptation is symmetric. Camphor unusually effective vs. citral and safrole	Ohma, 1922
Dioxan, Isopropanol, Cyclopentanone, Cyclopentanol	Same	Threshold	S.A. stronger than C.A.	Cheesman and Mayne, 1953; Cheesman and Townsend, 1956
Ethyl Mercaptan, Acetone, Isopropanol	Undiluted levels of 22 odorants	Threshold	Degree of C.A. higher with stronger odorant	Moncrieff, 1957
Propanol, Pentanol	Propanol, Pentanol	Magnitude Estimation of Intensity	S.A. stronger than C.A. Pentanol more effective on propanol	Cain and Engen, 1969

C.A. = cross adaptation, S.A. = self adaptation

adapting odor (A) produces less effect on threshold (of B) than the 100% change in concentration of a self-adapting odor (B'). Moncrieff (1957) investigated the adapting effect of one deep inhalation of an odor on thresholds for other odors and found similar results. The substances measured were acetone, ethyl mercaptan, and isopropanol. The odorous adapting stimuli were 22 undiluted simple odorants. The more intense the adapting stimulus, the greater its effect on threshold for the criterion chemical.

Many of the experiments summarized in Table I used different, incommensurate methods, and studied different criteria and adapting odorants. Hence, the results of one study cannot be translated to others.

Adaptation, cross adaptation and the psychophysical function

Odor intensity increases systematically with odorant concentration. Researchers have shown, via scaling experiments, that the best-fitting function to describe how numerical estimates of odor strength (a sensory measure, quantified by magnitude estimation; see Moskowitz, 1976) grow with concentration is a power function of the form

$$\text{Sensory Odor Intensity (S)} = \text{K (Concentration)}^{N} \qquad (3)$$

The exponent, N, relates percentage increases in concentration (C) to percentage increases in odor strength, S. The exponent, N, for odorants, is always lower than 1.0, meaning that odor intensity, subjectively perceived, grows more slowly than concentration, measured instrumentally.

Olfactory adaptation can modify the exponent, N, and intercept K of the psychophysical power function. If we present to the panelist an odorant of constant strength just before presenting the test odorant, and carefully follow this regimen, then we set the stage for adaptation to appear. Since panelists assign numbers to reflect perceived odor intensity, we can compare no adaptation vs. adaptation in several ways: (a) the effect of the adapting stimulus upon the numbers themselves; (b) the effect upon the exponent, N; or (c) the effect upon the intercept, K.

The most important parametric study was reported by Cain and Engen (1969). They studied the psychophysical function for two odorants, propanol and pentanol. Both odorants grow in odor intensity as power functions: $S = kC^N$. Prior presentation of a constant concentration of propanol increased the exponent for propanol. That is, the value of N became higher. Furthermore, the numerical values of the magnitude estimates for a fixed concentration of propanol decreased, showing that after adaptation the same odorant seemed weaker. Cross adaptation was also effective, but asymmetric. Pentanol affected propanol more than propanol affected pentanol. The parameter used as the criterion of adaptation effectiveness was the size of the slope, or exponent N, of the respective psychophysical functions.

By and large, Cain and Engen's findings parallel those in other sense modalities. The specific rule which emerges is that an adapting stimulus can affect other stimuli in the same modality, and the effect is apparent primarily on odorants of lower physical concentration.

Hedonic and long-term adaptation

Even though sensory adaptation to odors dissipates rather quickly, quite often there remains perceptual or hedonic adaptation. Panelists may report that an odorant or fragrance no longer smells as pleasant as another odorant, or no longer seems as strong.

The nature of this longer-term adaptation is not sensory adaptation, but rather a cognitive adaptive process. Cain (personal communication) has noted that substantial hedonic habituation may occur during the course of a single session, if the panelist is presented with the same odorant several times. Even though sensitivity is maintained, panelists report that noxious odors do not smell quite as noxious at the end of the session as they did at the beginning.

Long-term hedonic adaptation (habituation) was studied by Young in the 1920's. Unfortunately, little information was published thereafter. Young instructed four individuals to judge the hedonic tone of 8 odors on a 6 point liking/disliking scale. Each of the odors was presented a total of 15 times over the 5-week period. The judgments tended toward neutrality over time, but not dramatically, and Young was unable to show any general and conclusive findings. A similar study by Beebe-Center (1932) also failed to show any conclusive trends in hedonic habituation. This experiment required panelists to rank order 14 different olfactory substances, on subsequent two-week occasions. Ranking was accomplished by paired comparisons. After each experimental hour, the individual smelled a single stimulus 210 times. In half the cases there was an increase in liking, and in half the cases there was a decrease in liking as Table II shows.

Table II

Familiarization Stimuli	Pleasantness Ordering Rank before Familiarization	Rank after Familiarization	Change of Familiarization Stimuli
Oil of Sweet Orange	2.5	3.5	- 1.
Oil of Sweet Orange	3.5	3.	.5
Oil of Sweet Orange	2.5	5.	- 2.5
Extract Carnation	3.	2.	1.
Oil Cloves	6.	8.	- 2.
Extract Carnation	2.	5.	- 3.
Oil Cloves	6.	8.	0.
Oil Ylang	3.	2.	1.
Oil Bergamot	6.	6.	0.
Oil Ylang	4.	4.	0.
Oil Bergamot	2.	2.	0.
Oil Ylang	7.	7.	0.
Oil Bergamot	3.	2.	1.
Arithmetical average	3.88	4.26	.92

The commonly observed phenomenon that a fragrance or a flavor no longer seems as pleasing or as strong as it used to thus must be traced to another form of long-term habituation. Repeated stimulation with a variety of different fragrances sets up a background of experience, against which each new fragrance or flavor is evaluated. Modification of this background to include substantially stronger fragrances will result in a frame of reference comprising experience with stronger odors. If the fragrance in question maintains its strength unchanged, it will seem weaker against the new frame of heightened odor intensity. Relative odor intensities of two odorants probably would not change. Rather, the frame of reference acts to alter what we would call these odors in absolute or descriptive terms.

Helson (1964) has called this the Adaptation Level Theory of Perception. Adaptation level is the perceptual/cognitive counterpart of adaptation, but it is not sensory in nature. Rather, it is a result of the property of our system of processing and coding information, and the nature of how we classify sensory inputs on intensity.

Implications for fragrance testing

Product testing sequence can and should be optimized to avoid adaptation. Rest periods lasting from 2-5 minutes appear to be sufficient to insure recovery of sensitivity, at least to the supraliminal, or suprathreshold intensity levels. In this way, many dozens of fragrances might be evaluated without loss of sensory sensitivity (although boredom is a problem).

Panelists should not be exposed to a single fragrance continuously. Blotter or arm sniffing, or even taking a whiff from the top of a sniff bottle, should last, at most, 2 seconds. If further sampling is necessary, then the panelist ought to wait 15-20 seconds and test again. The 20 second wait can be accomplished effortlessly if the researcher takes the precaution of having the panelist sniff an odorless sample, blotter, or piece of cloth.

Motivation is necessary to prevent boredom, the psychological consequence of unmotivated panelists. In-house panels are particularly subject to this loss of motivation, since they have other jobs. Perhaps an external panel for consumer-oriented work would be a feasible compromise. The researcher could have the panelists participate for several hours (by paying them a nominal sum). Stringent controls may then be imposed on the test situation, and error due to adaptation avoided. Payment would alleviate boredom.

Effects such as product wearout may be indications of a change in the respondent or panelist adaptation level. Such changes are part of our experience, and they reflect the effect of previous experience with new products. Product wearout is not a sensory phenomenon, but an evaluative, cognitive one.

Up to 20+ fragrances can be evaluated in a session, provided that the respondents are motivated. Sufficient care must be taken to insure no loss of sensitivity. If skin evaluations are made, the same timing and motivation requirements apply.

Many of the "don'ts" in fragrance testing, such as "don't test more than 3 fragrances," may prove to be the results of experience with adaptation and pertain to nonoptimized testing situations. For an optimized testing situation, many more products can and should be tested. Adaptation then becomes more of a motivational phenomenon than inherent limitation on olfactory sensitivity.

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