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Candidate Physiological Measures of Annoyance from Airborne Chemicals

Brigitta Danuser

Institut für Hygiene und Arbeitsphysiologie, Swiss Federal Institute of Technology, CH-8092 Zurich, Switzerland

Correspondence to be sent to: Brigitta Danuser, Institut für Hygiene und Arbeitsphysiologie, Swiss Federal Institute of Technology, CH-8092 Zurich, Switzerland. e-mail: danuser@iha.bepr.ethz.ch

Abstract

Annoyance due to short-term exposure to airborne chemicals is a key factor in modern environmental research. Unpleasant odors or those that are believed harmful can annoy us. Since annoyance is modulated by the psychological and physiological states of the exposed persons, it is essential that we understand how these factors interact with environmental stimuli to yield a given level of this response. A potentially fruitful approach in this effort may be to treat annoyance as an emotion induced by the odor, and possibly irritation, resulting from chemical exposures. In this way, methods applied to assess induced emotions will likely be of value in elucidating annoyance. A rationale is presented for use of the startle reflex to elucidate the motor component of annoyance, which is manifest as a redirecting of attention towards the annoying odor (or irritant). Although evidence supporting the use of breathing changes to assess the vegetative component of annoyance is somewhat more scattered and indirect, this approach seems likely to be the most fruitful for future research. Experiments to enhance our understanding of annoyance using these two non-verbal end-points are outlined.

Introduction

The nose is our most important environmental sensor. Very low levels of environmental chemicals can be detected and categorized as pleasant, neutral or unpleasant. Especially unpleasant odors or those that are believed harmful can annoy us. Lindvall and Radford defined annoyance as ‘a feeling of displeasure associated with any agent or condition believed to affect adversely an individual or a group’ (Lindvall and Radford, 1973). This feeling is characterized by dissatisfaction, unpleasantness and some degree of psychological disturbance. In some cases it appears that we can simultaneously passively endure and actively attend to the offending stimulus.

Shusterman emphasized that environmental odor pollution problems generate a significant fraction of the publicly initiated complaints received by US air pollution control districts (Shusterman, 1992). As the concentration of an environmental chemical is progressively increased we typically expect the following end-points to be affected in decreasing order of sensitivity: odor detection, odor recognition, annoyance, acute irritation of the nose and/or eyes and toxic effects.

Clearly, annoyance can occur with exposure concentrations that cause no toxic effects and may not even elicit significant nasal or ocular irritation. We recently investigated acute sensory responses of non-smokers to environmental tobacco smoke (ETS). In a stepwise multiple linear regression model odor strength and arousal accounted well for the declines in acceptability of indoor air. No additional predictive power was achieved by incorporating into the model irritation of the nose, eyes or throat (Junker *et al*., 2001). This finding is in general agreement with Walker *et al*. and Cain *et al*., whose findings suggested that the mere detection of ETS odor was sufficient to create some dissatisfaction (Cain *et al*., 1987; Walker *et al*., 1997).

Individual differences in the degree to which a given exposure leads to annoyance may provide important clues as to underlying processes. Winneke *et al*. showed that subjects previously classified as being high or low responders to either traffic noise or industrial odors (in their everyday living environments) exhibited, respectively, elevated or reduced reactivity to two controlled laboratory chemical exposures (Winneke *et al*., 1996). A potentially fruitful approach to understanding how a given chemosensory stimulus leads to annoyance is to treat annoyance as an emotion induced by odor or irritation. In this way methods applied to assess induced emotions will likely be of value in elucidating annoyance.

Emotions are reaction patterns which manifest themselves in at least three components: verbal expressions, motor behavior and vegetative changes controlled by the autonomic nervous system (Hamm and Vaitl, 1993). Although adequate measurement of the verbal component of emotions is important (Mehrabian and Russel, 1974), our focus here is on the remaining two components and how they may be most effectively studied. A rationale is provided for employing the startle reflex to study the motor behavior aspects of emotions induced by environmental chemicals. Similarly, it is proposed that breathing patterns be used to measure vegetative changes. Since perceived irritation of the nose and/or eyes so often accompanies odor, the discussion will include some stimuli that elicit both odor and irritation.

Startle reflex as a measure of the motor aspects of annoyance

Since the startle reflex is not confounded by voluntary muscle activity, it is well suited to assess motor behaviour caused by a foreground stimulus. This response is most often elicited by a very brief acoustic or visual stimulus; it is assessed by electromyographically measuring the tension of the eye blink muscle (muscularis oculi). Startle reflex amplitude is affected by the extent to which the foreground stimulus can attract attention (Putnam, 1990) and by its emotional valence (Lang *et al*., 1990). Ehrlichman *et al*. and Miltner *et al*. investigated acoustic startle reflex modulation during short exposure to pleasant and unpleasant odors (Miltner *et al*., 1994; Ehrlichman *et al*., 1995). Unpleasant odors enhanced startle amplitude whereas pleasant odors had no effect. Later work (Ehrlichman *et al.,* 1997) provided some evidence that a decreased startle reflex resulted from pleasant odors. These observations with odor stimuli are generally consistent with other startle work that employed short visual stimuli of different emotional valence.

A much larger body of literature demonstrates the relation of startle reflex amplitude and/or latency with attention (Putnam, 1990). Anthony and Graham presented half their participants with visual stimuli that were *a priori* judged interesting or dull and half with interesting or dull acoustic stimuli (Anthony and Graham, 1985). Modality of the reflex-eliciting stimulus (visual versus acoustic) was varied within participants. The startle response during interesting foreground stimuli was larger than during dull foreground stimuli if foreground and reflex stimuli were from the same modality (e.g. both acoustic or both visual), but the reverse was the case if they were from different modalities. Schicatano and Blumenthal showed that distracting attention away from the startle stimulus by attending to a visual search task caused a reduction in startle response amplitude (Schicatano and Blumenthal, 1998).

These findings suggest the possibility of measuring, with the startle reflex, the redirecting of attention towards the foreground annoying odor or irritation. For example, it is predicted that ETS exposure should, in a dose-dependent manner, decrease the startle reflex amplitude when the degree of habituation is taken into account. In a laboratory setting the foreground annoying stimulus represents an emotional state rather than a short emotional ‘burst’, therefore the attentional effect on startle should be dominant.

Breathing patterns

In contrast to other physiological systems, breathing is under both autonomic and voluntary control. Although the former is dominant, its mean output can be overridden by behavioral factors; this is especially true when individuals are at rest. It is precisely the close coupling between lower and higher order control aspects that makes the respiratory system appealing to those interested in the convergence of physiological and psychological processes (Wientjes and Grossman 1998).

Apart from clinical diseases and physical needs (exercise), breathing can be altered by chemosensory or other stimuli, centrally acting drugs, mental load and emotions. Bass and Gardener and Boiten *et al*. have reviewed the rather strong effects of emotions on breathing parameters (Bass and Gardener, 1985; Boiten *et al*., 1994). Table 1 summarizes our current understanding of the changes in breathing pattern as a result of emotion or mental load.

Breathing responses to airborne chemicals

In comparison with the literature concerning startle as an indicator of the motor aspects of emotion, findings that bear on the possible use of breathing to assess vegetative aspects are more fragmented and oblique. In part this is attributable to the paucity of studies of sensory or annoyance effects that have also included breathing as an end-point. Warren *et al*. reported perceptual and breathing responses to ranges of concentrations of acetic acid, amyl acetate and phenethyl alcohol (Warren *et al*., 1994). The authors noted that tidal volume (amount of air inhaled per breath) appeared to have a reasonably close and inverse relationship to nasal irritation, although a decline in tidal volume appeared to require that some criterion level of nasal irritation had been exceeded. Phenethyl alcohol, which elicited odor magnitudes similar to those seen with *n*-amyl acetate and acetic acid, caused only very modest elevations in nasal irritation and had no significant effect on tidal volume. For each of the remaining two stimuli the lowest concentration that depressed tidal volume was near the minimum concentration required for detection by anosmics (Walker *et al.*, 1989).

Later work (Walker *et al*., 2001), in which normal and anosmic individuals were tested much more extensively with a range of propionic acid concentrations, showed that the tidal volume decline may occur with stimuli that are not detected by anosmics and elicit very low levels of nasal irritation in normals. Therefore, although nasal irritation sensitivity was greater in normals, declines in tidal volume predicted increases in nasal irritation in both groups. Duration of inhalation in normals declined only with stimuli readily detected by anosmics. Although not reported by Walker *et al*. (Walker *et al*., 2001), annoyance judgements were recorded in this study and exhibited a 0.94 correlation

Table 1 Summary of breathing patterns related to emotions and mental load [modified from Boiten (Boiten, 1994)]

Breathing pattern	Associated emotional and mental influences	References
Fast and deep breathing (RR ↑, Vt ↑)	linked to an enhanced readiness for action in a positive or negative sense	
	states of excitement	(Woodworth and Schlosberg, 1955)
	fear, anger and joy	(Ax, 1953)
	hypnotic or suggestions or imagined of exercise	(Morgan, 1985; Gallego *et al*., 1996)
Fast and shallow breathing (RR ↑, Vt ↓; mostly + Vi/Ti ↑)	readiness for action with some degree of inhibitory control, concentrated attention	
	variations in depth during rapid breathing correspond to different points on a inhibition–excitation continuum	(Wientjes, 1993; Boiten *et al*., 1994)
	stressful mental task performance	(Allen *et al.*, 1986; Carroll *et al.*, 1987; Sims *et al.*, 1988; Boiten, 1993; Wientjes *et al.*, 1993)
	tense effects	(Lehmann, 1914)
	tense or anxious anticipation or expectation	(Skaggs, 1930; Stevenson and Ripley, 1952)
Slow and deep breathing (RR ↓, Vt ↑)	relaxed resting states (slow-wave sleep, relaxation)	(Grossman, 1983; Boiten, 1993; Wientjes, 1993)
	excited positive effect	(Rehwoldt, 1911)
Slow and shallow breathing (RR ↓, Vt ↓ + Vi/Ti ↓)	passive grief, calm happiness	(Averill, 1969)
	states of relaxation	(Nakamura, 1984)
	withdrawal from the environment, passiveness	(Boiten *et al.*
Thoracic–abdominal balance (%Rc / %Ab)	Rc ↑: unpleasant effect, tenseness or anxiety	(Ancoli and Kamiya, 1979)
	Ab ↑: pleasant emotional states or relaxation	(Svebak, 1975; Ancoli *et al*., 1980)
Irregularity of breathing	conditions of emotional upset, excitement and task involvement	(Stevenson and Ripley, 1952; Santibanez and Bloch, 1986; Mador and Tobin, 1991)

Vt, tidal volume; RR, respiratory rate; Vi/Ti, inspiratory drive; % Rc, percent of ribcage breathing in Vt.

with nasal irritation in normals (J.C. Walker, personal communication).

An intriguing interpretation of the normal–anosmic differences in breathing reported by Walker *et al*. (Walker *et al*., 2001) may be constructed in terms of orientation. Orienting involves attention directed towards novel and significant stimuli. Orienting is characterized by a fast decrease in indices (e.g. heart rate, skin conductance) and a delayed or long latency increase in physiological activity (Turpin, 1986). Since the normal participants in the Walker *et al*. work showed a greater drop in tidal volume than in inhalation duration with increasing concentration, inhalation flow rate declined (Walker *et al*., 2001). This parameter, since it represents *intensity* of inhalation, may be taken as an index of central inspiratory drive. Given that odors have been shown to be important inducers of orientation (Winneke, 1992), the breathing observations of Walker *et al*. (Walker *et al*., 2001) might be understood as an orienting response to olfactory and or trigeminal stimulation. Brief suspension of breathing is described in connection with orientation (Barry, 1982). The reduction in inspiratory drive represents an inhibitory response pattern and fits neatly into the concept of orientation (Sokolov, 1963). Orienting responses are sensitive not only to the occurrence of a change, but also to the magnitude and significance of this change (Ben-Shakhar *et al*., 2000). This could account for the dose–response relation between nasal irritation and tidal volume reported by Walker *et al.* (Walker *et al*., 2001).

As indicated by the few studies cited above, a major obstacle to a thorough evaluation of breathing as an index of annoyance is the paucity of work that has included detailed measurements of this end-point. Just as very few studies of responses to very brief (a few seconds) stimuli may be consulted, little effort has been made to assess breathing in studies that incorporate much longer stimulus exposures. A recent exception to this pattern demonstrates the sensitivity of breathing changes and provides clues as to the interpretation of such changes. Walker *et al.* exposed non-smokers to a 13-fold range of ETS concentrations for 70 min periods (Walker *et al*., 1997). The lowest concentration elicited only very weak odor and eye irritation and no nasal irritation. Surprisingly, all ETS levels resulted in a similar 5–8% decrease in respiratory rate (RR), due largely to an increase in exhalation duration, but no change in minute ventilation.

It seems quite unlikely that these breathing changes were due to a direct effect of ETS on respiratory mechanics. This would likely have required an increase in the resistance that the exhaled air encounters (Clark and von Euler, 1977). Yet, even in the case of persons with hyperreactive airways inhaling ETS through the mouth, reliable airway constriction was seen in a subset of the experimental participants only when much higher concentrations were employed (Danuser *et al*., 1993). Rather, the decrease in RR and increase in tidal volume reported by Walker *et al*. (Walker *et al*., 1997) may signal that some criterion level of annoyance had been reached. Decreases in RR have been reported during imagery-induced discomfort (Feleky, 1914) after presentation of simple unpleasant sensory stimuli (Ruckmick, 1936) and in response to the cold pressor test (Craig, 1968; Allen and Crowell, 1989). In most painful or negative situations tidal volume is significantly enhanced. Boiten *et al.* stated that, within the domain of negative effect, RR and tidal volume appear to respond to degree of excitement and tenseness of the individual (Boiten *et al*., 1994). The fact that the slowing of RR was largely attributed to much larger increases in exhalation rather than inhalation duration may be an indication that in the Walker *et al*. work (Walker *et al*., 1997) ETS caused increased feelings of tenseness. This interpretation is consistent with the work of Drozynski (Drozynski, 1911).

A second possible interpretation of the breathing changes reported by Walker *et al.* (Walker *et al*., 1997) may be advanced. As Winneke *et al*. noted, it is often difficult to cope with environmental odors effectively since elimination of the offending chemicals or exiting the space is often not an option (Winneke *et al*., 1996). In these situations the only remaining coping strategy may be to alter the emotional response to the stimulus. Several studies have shown that under certain stressful conditions slow breathing can reduce subjective indices of anxiety (Grossman 1983; Boiten *et al*., 1994). Increases in tidal volume may in some cases reflect the increased effort needed to actively cope with a task or situational demands (Wientjes, 1993).

Based on this view, it is possible that some of the breathing changes reported by Walker *et al*. (Walker *et al*., 1997) could reflect a strategy for coping with annoyance from the odor of ETS. This should be investigated in more detail, including analyses of respiratory pauses, assessments of emotion with self-report measures (e.g. semantic differential) and, possibly, the stratification of subjects according to their coping style (Winneke *et al*., 1996).

In summary, breathing appears to be useful in the study of annoyance in at least three ways. First, annoyance derived from perceived irritation may be correlated with breathing changes. Second, there appear to be characteristic changes in breathing that may be used as indices of the emotional impact of environmental contaminants. Finally, some changes in breathing may serve as coping responses and thus serve as somewhat indirect measures of the stress caused by the annoying odor (or irritation) arising from various airborne chemicals.

Conclusions

Collectively, the evidence cited above provides a strong argument that startle and breathing measurements will be quite useful in understanding the processes that lead to an overall appraisal of a contaminated environment as annoying. Application of these tools, together with appropriate verbal reports as well as vegetative measures, should help us to investigate the components of the emotional effects induced by environmental chemical stimuli and may even elucidate some aspects of odor-related disorders.

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