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Review article

Emotions and respiratory patterns: review and critical analysis

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Abstract

The literature on emotions and respiration is reviewed. After the early years of experimental psychology, attention to their relationship has been sparse, presumably due to difficulties in adequate measurement of respiration. The available data suggest nevertheless that respiration patterns reflect the general dimensions of emotional response that are linked to response requirements of the emotional situations. It is suggested that the major dimensions are those of calm-excitement, relaxation-tenseness, and active versus passive coping. Research on the emotion-respiration relationships has been largely restricted to the correlates of respiration rate, amplitude, and volume. Finer distinctions than those indicated may well be possible if a wider range of parameters, such as the form of the respiratory cycle, is included in the investigation.

Key words: Emotions; Respiratory patterns; Critical analysis

1. Introduction

Emotions are linked to respiration. Panting in fear, rage and sexual excitement, yawning during boredom, and sighing in melancholy, relief or distress are common occurrences. Everyday speech contains numerous expressions which associate breathing with emotional states ("breathtaking", "a sharp intake of breath", "to be breathless with surprise", "to catch one's breath", "to breathe again freely"), and terms like "sighing", "gasping", "snorting" and "sobbing" all have direct emotional connotations. In the era of the silent movies, actors typically employed excessive breathing as a technique to express emotional states. Thus, evidence for links between emotion and respiration may lead to the plausible supposition that different emotions are associated with different respiratory patterns. That indeed has been a predominant hypothesis in earlier days of research in the psychophysiology of emotions (Feleky, 1914; Rehwoldt, 1911), and it has recently been advocated again (Santibañez and Bloch, 1986; Bloch et al., 1991). The aim of the present paper is to review the literature on this subject, and to evaluate the current status of this hypothesis.

Contemporary research on the relation between emotions and respiration is sparse. The respiratory response system has never aroused the same degree of interest as, for instance, cardiovascular variables and skin conductance. Characteristically, Greenfield and Sternbach's Hand-

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book of Psychophysiology (1972), that for so long has been somewhat of a standard text, does not contain a chapter on respiration. The main reasons for the infrequent inclusion of respiratory measures in psychophysiological studies appear to be primarily based on practical and methodological considerations (Wientjes, 1992, 1993). Traditional respiratory measurement techniques are often either too intrusive, too complicated, or too imprecise to provide adequate assessment of respiratory responses. Another reason for the apparent lack of enthusiasm about respiratory measures might be that the respiratory response is not a unitary phenomenon, but varies in a complex manner along a number of time and volume dimensions (Stein and Luparello, 1967). Thus, measurement of respiratory responses requires techniques that provide sufficient precision with regard to the assessment of respiratory time and volume parameters, as well as relatively easy applicability and unobtrusiveness. As we will see, such techniques have only recently become available.

Links between emotions and respiration have been established in several distinctive research areas. First, there is evidence that emotions in general may influence respiration, and it might be that different emotional states give rise to different breathing patterns. Second, breathing patterns have been shown to differentiate between diagnostic groups such as neurotics, psychotics and normals (e.g., Clausen, 1951; Coppen and Mezey, 1960; Damas-Mora et al., 1976, 1982; Skarbek, 1970), and have served as a diagnostic tool for assessing such groups. Third, some investigations have suggested that modifying and regulating one's respiration may help to reduce subjective distress (e.g., Clark et al., 1985; Grossman et al., 1985; Holmes, McCaul and Solomon; 1978). Fourth, other studies have shown that respiration is related to personality or constitutional type, or general emotional orientations (Morgan, 1983; Shershaw et al., 1973; Shershaw et al., 1976; Wientjes, 1993).

Although we will briefly mention a number of other studies, this review focuses primarily upon studies that deal with the first kind of relationship, that is, with effects of (induced) emotions upon breathing patterns in normal individuals. To achieve this purpose we will initially consider the nature of emotion-respiration relationships within the context of a number of emotional models. Since many important questions seem to be awaiting adequate measurement methodologies the next section of the paper is devoted to the discussion of respiratory parameters that have been used in the analysis of breathing patterns, and the recording techniques that have been employed in the measurement of respiration. We will then discuss the evidence regarding effects of the induction of (negative and positive) emotional states, and of cognitive factors, upon respiratory parameters. Cognitive factors will be discussed in so far as they may vary along with particular emotional conditions, and may be held responsible for differences found between such conditions. Next, the available evidence regarding the differentiation of emotional states will be reviewed. Finally we will try to draw some conclusions, in which we will come back to the other models that were discussed. We have also included some of the older literature in this review. Although conducted with primitive techniques, and lacking adequate statistical treatment of the data, these findings themselves are often interesting enough, and have generated suggestive hypotheses.

2. The nature of emotion-respiration relationships

With regard to the relationship between emotions and physiological parameters, three different types of models can be distinguished. The specificity model hypothesizes that different emotions are characterized by different physiological response patterns. These patterns differentiate one type of emotion from another. This hypothesis, obviously in line with the James-Lange theory of emotion (e.g., James, 1884), has recently found new supporters, who reported positive evidence regarding autonomic response patterns differentiating the six "basic" emotions of joy, sadness, fear, anger, surprise, and disgust (Levenson, Ekman and Friesen, 1990).

The *dimensional model* assumes that physiological parameters or patterns correspond to general dimensions of emotional feeling or emotional response that cut across emotion boundaries. Relevant dimensions of feeling are pleasant-unpleasant, active-passive, and calm-excited, the dimensions proposed by Wundt (1902) and (at least the first two) supported by more recent dimensional analyses of mood (e.g., Russell, 1980; Watson and Tellegen, 1985).

The third model, response requirement model, is not incompatible with the dimensional one. In this model, physiological parameters or patterns are thought to correspond to particular response requirements of the given emotional situation. Response requirements underlie the functional categories of flight and fight (Cannon, 1929), and more recently proposed functional dimensions like intake-rejection (Lacey and Lacey, 1970) and passive versus active coping (Obrist, 1981). A related formulation is that physiological patterns might correspond to appraisal patterns, or the patterns of stimulus evaluation checks performed on the eliciting situation (Frijda, 1986; Scherer, 1986). Appraisal patterns and response requirements are closely related notions, since the former are seen as the individual's perceptual basis for assessing the latter. The appraisal version of this model has been applied to generate hypotheses about the psychological correlates of voice intonation patterns (Scherer, 1986), an area obviously related to that of respiration. In both versions, physiological response patterns again are thought to correspond to emotion dimensions that cut across the boundaries of emotion categories. Active coping, or the appraisal of anticipated effort, for instance, might be common to certain forms of anger and certain forms of fear.

It will not be easy to distinguish between the three types of models. Physiological response patterns may be correlated with particular emotion classes without corresponding to these emotions as such. One reason is that, while different emotions are found to be consistently linked to particular locations in the space formed by two or three of the dimensions indicated (Russell, 1980; Watson and Tellegen, 1985; Woodworth and Schlosberg, 1955), these locations do not exhaust the description or definition of these emotions (Frijda, 1986). In actual practice, specific instances of particular emotions may be distributed widely over the space, even if typical instances, or the majority, occupy a point or restricted region. For instance, typical anger involves more strenuous effort or higher activation than typical sadness or joy; yet, there exist instances of passive anger (e.g., "anger in", Spielberger et al., 1985), of frenzied sorrow, and of vigorous joy. Correlations between physiological patterns and emotions, therefore, do not constitute decisive evidence that these patterns in a strict sense "belong" to these emotions. They may be due to the particular sampling of instances of the emotions concerned.

Similar difficulties arise in distinguishing between a dimensional and a response requirement model. Theoretically, it makes a difference whether a particular pattern of physiological response is thought to reflect, say, pleasant feeling, or readiness to accept stimulation; the first points to an expressive correlation, the second to a functional one, the relation of which to physiological parameters is more readily understood. However, one may expect that the two types of dimension are correlated; in fact, explanations of physiological response patterns in terms of general response dimensions like arousal, activation, and inhibition (Pribram, 1981) fall midway between the two models. Only to the extent that the dimensions of feeling diverge empirically from the response requirement or appraisal dimensions (pleasant-unpleasant from, say, intake-rejection), can these classes of models be empirically separated. The available evidence on emotions-respiration relationships will be reviewed primarily along the lines of the specificity model.

3. Respiratory parameters

Respiratory parameters can be categorized in: (1) volume and timing parameters, (2) measures regarding the morphology of the breathing curve, and (3) measures reflecting gas exchange (see Wientjes, 1992).

3.1. Volume and timing parameters

The respiratory cycle consists of an inspiration phase, followed by an expiration phase. There sometimes is a pause between termination of the inspiration phase and onset of expiration, and often between termination of expiration phase and onset of the next inspiration. The parameters most commonly used to describe breathing patterns are depth and rate of breathing. The volume of air that is inspired or expired during one cycle of respiration is called tidal volume (Vt). Respiration rate (RR) refers to the number of respiratory cycles per minute. The duration of each respiratory cycle (Ttot), can be broken down into inspiration time (Ti), and expiration time (Te). Sometimes, the pauses after inspiration (Pi) and expiration (Pe) are also included in the analyses. Traditional analysis of respiration only involves Vt and RR. However, the limitation of this type of analysis is that it does not provide insight in the mechanisms which determine Vt and RR. For example, a change in Vt can be accomplished by a change in the mean inspiratory flow rate (Vt/Ti), by a change in Ti, or both. Similarly, RR can be altered by changes in Ti or Te, or both.

The breathing pattern appears to be regulated by at least two interacting mechanisms: a central inspiratory drive mechanism which is cyclically switched on and off by a "timing" mechanism in the respiratory centre of the brainstem (Bradley, 1981; Gautier, 1980; Milic-Emili and Grunstein, 1976; Milic-Emili, Grassino and Whitelaw, 1981; von Euler, 1977). An enhanced inspiratory drive primarily augments the mean inspiratory flow rate (Vt/Ti) with only secondary effects on timing (Milic-Emili et al., 1981). The contribution of drive and timing mechanisms upon ventilation may be assessed by the following expression (Gautier, 1980; Milic-Emili and Grunstein, 1976; Milic-Emili et al., 1981):

$$\mathrm{Vmin} = \mathrm{RR} \times \mathrm{Vt} = \frac{\mathrm{Vt}}{\mathrm{Ti}} \times \frac{\mathrm{Ti}}{\mathrm{Ttot}}$$

where minute ventilation volume (Vmin) refers to the total ventilation during a 1-min period, mean inspiratory flow rate (Vt/Ti) is considered to be an index of the intensity of the central inspiratory drive mechanism, and Ti/Ttot reflects the periodicity of the timing mechanism (Gautier, 1980; Milic-Emili and Grunstein, 1976; Milic-Emili et al., 1981). This latter measure is often referred to as "inspiratory duty cycle" (a term that is used in electrical engineering to denote the fraction of a periodic cycle that is energetically active). In older research, this parameter is referred to as "I-fraction" (Woodworth and Schlosberg, 1955). Some of the older literature has also employed the inspiration/expiration ratio (I/E ratio; Stoerring, 1906).

3.2. Quantitative parameters

Gautier (1980) argues that mean inspiratory flow rate (Vt/Ti) may only be regarded as a valid measure of the drive component of the ventilatory output, when the inspiratory volume-time profile (Vt/Ti) is linear. When the Vt/Ti relationship is curvilinear, the use of a "shape factor" should be considered. In this case Vt/Ti is no longer a "pure" index of inspiratory drive because it is time dependent. The same applies to mean expiratory flow rate (Vt/Te). A curvilinear expiratory volume-time profile indicates that the Vt/Te relationship does not reflect the actual rate of emptying of the lungs. For instance, the exhalation phase might include an expiratory pause. Qualitative respiratory measures reflecting the morphology of the respiratory curves have indeed been employed in a few investigations. Clausen (1951), for instance, examined the smoothness and the shape of the respiratory curve, and the angle of transition between inspiration and expiration. More recently, harmonic analysis techniques for quantifying the shape of the respiratory cycle have been described by Bachy et al. (1986) and Benchetrit et al. (1989). Quantitative analysis of breathing have also included the abdominal-thoracic ratio (the ratio of the amplitudes of thoracic and abdominal excursions). Less attention has been devoted to sighing and yawning, respiratory responses that are both characterized by a long and deep inhalation. Parameters reflecting the time course of respiratory activity, such as regularity, duration of changes, systematic changes over time, have only been included in very few studies (e.g., Santibañez and Bloch, 1986). Some researchers have assessed irregularity of rate and depth of breathing (e.g., Alechsieff, 1907; Hormbrey et al., 1986; Lehmann, 1914).

3.3. Gas exchange parameters

Under normal circumstances, ventilation is mainly regulated by arterial carbon dioxide (CO_2) tension. The arterial CO_2 tension represents the degree to which ventilation is in accordance with metabolic processes. Excessive ventilation (i.e., hyperventilation) causes more CO_2 to be eliminated from the body than is currently produced by metabolic processes, and results in a drop in arterial and alveolar pCO_2 below the normal range (i.e., 36–45 mm Hg; Bass and Gardner, 1985; Grossman and Wientjes, 1989). For safety reasons, arterial blood samples are usually not collected in psychophysiological investigations. Instead, the arterial CO_2 pressure is estimated by measuring the percentage or partial pressure of CO_2 at the end of a normal expiration (end-tidal pCO_2, Gardner et al., 1986). Measurement of end-tidal pCO_2 is an important research tool to assess whether ventilation is in balance with metabolical demands. Other gas exchange parameters include O_2 consumption (VO_2) and CO_2 production (VCO_2). On the basis of these measures, energy expenditure may be estimated. Although this may be quite useful in certain respiratory psychophysiological studies, very little (if any) use has, to our knowledge, been made of these measures in the context of emotion research. Therefore, they will not be discussed or referrred to in this review.

4. Recording techniques

Recordings of tidal volume and respiratory rate can be obtained with a spirometer or flowmeter (pneumotachograph). These recording devices directly measure the volume of inspired and expired air. This type of measurement is obtrusive since it typically employs equipment that adds dead space and resistance to breathing (e.g. mouth piece, facemask, tubes with valves). Vt and RR can be greatly altered under the influence of these devices (Askanazi et al., 1980; Gilbert et al., 1972). A switch from nasal to oral breathing seems also an important determinant of the change in volume and time components of the breathing pattern with a mouth piece and nose clip (Perez and Tobin, 1985). In addition, Perez and Tobin showed that alteration in breathing pattern with a mouth piece and nose clip was associated with a significant reduction in end tidal CO_2, which persisted for at least 90 min. Furthermore, intrusive respiratory equipment may heighten the subjects awareness of his own respiration, which is known to alter the pattern of breathing (Western and Patrick, 1987). Recently however, techniques have become available that enable non-invasive assessment of both time and volume components of respiration (Chadha et al., 1982; Cohn et al., 1982; Morel et al., 1983; Sackner et al., 1980; Wientjes, 1992). These techniques employ measurement of the separate motions of rib cage and abdomen, either via inductive plethysmography (Watson, 1980) or via bellows pneumographs (Morel et al., 1983). An essential element of these techniques is the calibration procedure that is used to estimate the volume to motion coefficient (VMC) for the rib cage and abdomen signals (Gribbin, 1983). Different calibration techniques have been described (Chadha et al., 1982; Gribbin, 1983; Morel et al., 1983) that employ a calibration session during which the subject either is breathing with a fixed and known volume, or during which Vt is simultaneously measured by means of a pneumotachograph or a spirometer. The rib cage and abdominal VMC's are estimated by means of multiple regression. Unfortunately, attempts to calibrate respiratory measurement devices are almost nonexistent in most of the older psychophysiological literature on respiration. Consequently, accurate measurement of respiratory volume is uncommon in this literature. In most cases, only inferential statements can be made about volume changes during emotional stimulation. In these instances, we will refer to "depth" of breathing instead of Vt.

The most commonly used gas exchange measure in psychophysiological studies is the pCO_2 in end-tidal air. CO_2 measures are generally obtained by a infrared gas analyzer. By means of a heated sample tube attached to an open face mask or to one of the nostrils, the CO_2 content of the expired air is sampled and analyzed.

5. Effects of negative emotions

5.1. Respiration rate and depth of breathing

A number of studies have found increases in respiratory activity during the induction of negative emotional states. Rehwoldt (1911) asked three subjects to imagine emotions of their own choosing. On the basis of self-reports, the emotional states were classified as either positive or negative affect, and as calm, excited, or tense affect. Excited negative affects (anger, fear, indignation) resulted in increased RR and, in almost all instances, increased depth. Depth sometimes increased to three times the baseline value (as measured in millimetres pen deflection). Tense affects, whether negative (impatience, suspense) or positive (hope) were associated with a higher RR, but variable (sometimes decreased) depth. One problem with this study is that the self-reports which led to the affect classifications may have been influenced by the respiratory responses. Lehmann (1914) did not replicate the effects of imagery of both unpleasant and pleasant affect upon RR, but found that depth of breathing increased during these conditions. Imagery instructions of fear, anger, wonder, and pain led to strong depth and RR increases in a study by Feleky (1914), that will be discussed in more detail below.

Somewhat more recent research corroborates that RR and/or depth increase occur during negative affect states. Ax (1953) induced fear and anger in subjects by creating an atmosphere of alarm and confusion due to a "dangerous" malfunction of the recording equipment, and one of irritation and anger by an incompetent and arrogant polygraph-operator. Subjects whose emotional response was not strong enough (as judged on the basis of interview and observation), were excluded from the analyses. RR increased in both fear and anger, but the increase was greatest during anger. Schachter (1957) replicated the study, adding pain as induced by the cold pressor test. Fear and anger again yielded strong RR increases, but the RR response during pain was small. Fenz and Jones (1972) succeeded in inducing a real life fear situation of an intensity not readily replicable in the laboratory. For both novice and experienced parachutists RR measures were taken during a jump sequence; from the moment they arrived at the airport, to the final preparations for the jump: the ride up to the aircraft, reaching exit point, and after landing. Novice jumpers showed a continuous increase in RR during the prejump sequence, from approximately 17–25 cycles per minute. In experienced jumpers, on the other hand, a similar increase in RR was noted early in the jump sequence (up till 24 cpm), followed by a gradual decrease towards the moment of the jump. Increases in RR during fear or anxiety have also been noted by Zuckerman et al. (1968), and several others.

An alternative method to induce intense emotions is hypnosis. Dudley (1964) induced depression, anxiety, anger, and pain (headache), as well as exercise and relaxation by hypnotic suggestion. Suggestions of anger, anxiety and exercise were followed by an increase in RR, Vmin and oxygen uptake, and a decrease in end-expiratory pCO_2. Agreeing with Schachter's (1957) finding, pain only caused an increase in respiratory activity and hyperventilation when the headache induction evoked overt anger or anxiety. Hypnosis was also used by Freeman et al. (1986) with patients who were considered to suffer from hyperventilation syndrome (HVS), and controls. Negative emotional arousal was induced by imagery meaningful to each individual subject (phobic objects, bereavement experiences, imagined events, etc.). During emotional arousal, controls and HVS patients showed a slight increase in RR, as compared to the baseline condition, and a larger increase in RR as compared to hypnotically induced calm and relaxation. Respiratory volume was not assessed in this study. However, because the HVS patients responded with a larger fall in end-tidal pCO_2 than the controls (which reflects hyperventilation), it can be argued that the increase in respiratory volume must have been greater among the patients than among the controls.

An increase in RR (and depth of breathing) combined with a decrease in pCO_2 appears to be a common response pattern to certain types of stress. A study by Suess et al. (1980) further illustrates this. This study, in which RR and end-tidal pCO_2 were measured, assessed the effects of threat of electric shock via an intriguing experimental protocol. The subjects performed a highly ambiguous perceptual judgement task, and were told that they would receive an electric shock after making ten judgement errors. During the task, the experimenter falsely informed the subjects about the errors that were made, until the "fatal" tenth error was about to occur. In fact, the task was terminated after nine errors, and no shocks were given. RR increased, and end-tidal CO_2 dropped to hyperventilatory levels both during an anticipatory pre-task period and during the task. As was the case in the study by Freeman et al. (1986), Suess et al. (1980) assessed no volume measures; close inspection of the data, however, strongly suggests that volume must also have increased substantially during the pre-task and task periods. Several other studies (Landis, 1926; Schnore, 1959; Skaggs, 1930; Suter, 1912; Svebak, 1982; Willer, 1975) also found an increase in RR and depth, or an increase in Vmin (Finesinger and Mazick, 1940), in response to threat of electric shock or other painful stimuli.

Increases in RR and depth of breathing have, however, by no means been found in all negative emotional conditions. For example, absence of RR effects during stressful films has been reported by Goldstein et al. (1965); Adamson et al. (1972); Koegler and Kline (1965) and by Cohen et al. (1975). Similarly, Rimm and Litvak (1969), who instructed subjects to silently read sentences that had negative affective content, found no RR effects. RR decreases have furthermore been reported during imagery-induced wonder and pain (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 a study by Nakamura (1984) subjects had to judge music, RR correlated negatively with ratings of that music as "melancholical" or "dismal". Why RR is often not affected by stress films might be due to the fact that not only the intended emotion (anxiety) is elicited but other emotions as well, which in turn might have an opposite effect on RR. For instance, several films also induced depression and sadness which have been associated with a decrease in RR (Rehwoldt, 1911). A more parsimonious explanation is that film and imagery induced affect as well is often not intense enough to provoke changes in RR. The cold pressor data indicate that increased RR is not a necessary consequence of painful stimulation, although Vt is in most cases significantly enhanced (see e.g. Allen et al., 1986; Allen and Crowell, 1989). As noted before, an increase in respiratory activity might only occur when the pain stimuli evokes overt anger and anxiety. On the other hand, a decrease in RR in response to painful stimuli might point to a voluntarily induced slowing of RR in order to cope with the stress situation. Indeed, several studies have shown that under certain stress conditions slow breathing can reduce subjective indices of anxiety (see e.g. Grossman, 1983), although cold pressor pain perception may not be affected (Lane, 1980).

In many of the studies mentioned, changes in RR and depth of breathing appeared to go hand in hand. However, this is certainly not always the case. An increase in RR in combination with shallower breathing was observed by Alechsieff (1907) under "tenseness", by Rehwoldt (1911) during "tense affects", by Suter (1912) during anxious anticipation of electric shock, and by Lehmann (1914) in subjects reporting unpleasant affect that they sought to resist. Taken together, these findings emphasize that negative affects are not invariably tied to RR, depth, or volume increases, and that RR and depth are not always coupled. The variation in, and discrepancy between, RR and depth changes, may in part be due to a lack of adequate standardization of recording techniques and data treatment. Equally likely, however, they at least in part reflect precisely what Rehwoldt (1911), working within the framework of Wundt's (1902) three-dimensional model of affect, held them to reflect: differences between excited and calm, and between tense and relaxed emotional states. Within the domain of negative affect, RR and depth appear to respond to degree of excitement and degree of tenseness of the individual, and to each of these differently.

Several distinct respiratory response patterns thus emerge from the data. For example, excited affects, produced by the stress situation itself, may be primarily associated with rapid deep breathing, and tense, anticipatory affects with rapid shallow breathing. We will try to further specify these patterns after discussing the changes found in positive emotional states and during mental effort and attention.

5.2. I/E ratios and respiratory pauses

Older studies of respiration have included inspiration-expiration balance (I/E ratio) among their parameters. Feleky (1914) found longer inspiration than expiration durations (I/E ratios > 1) in most of her subjects when they imagined negative emotions, except hatred. Inspiration dominance was moderate, though, except in "wonder" (which may be assumed to include surprise) and fear. Similar observations were made by Rehwoldt (1911) in negative affects, both excited and calm ones, but only in thoracic recordings. I/E ratios tended to be larger in what he classified as excited than in calm negative affects. Low I/E ratios during feelings of tenseness were found by Drozynski (1911). Increases of I/E ratio from about 0.70 to about unity were found, however, among subjects that were lying during a fake court trial. This increase did not occur when the subjects made similar efforts that could not be understood as hiding the truth (Benussi, 1914). The precise meaning of the findings on I/E ratios is unclear, since the investigators did for instance not separate respiratory pauses from inspiration and expiration proper. That separate analysis of respiratory pauses is a potential useful endeavour has been shown by Cohen et al. (1975), who applied advanced component analysis of the breathing cycle. They found that stress films had no effect on RR, but that expiration times were longer and pauses shorter than during presentation of a neutral film; these findings were observed in the thoracic but not in the abdominal channel. A reduction in post expiratory pause duration in response to negative film clips (Boiten and Gerritsen, in preparation) and mental arithmetic (Boiten, 1993a) appears to reflect moderate stress levels. The former investigation revealed some strong negative correlation ratings between negative "film" affect (fear, tension and involvement) and the duration of expiratory pauses. On the other hand, very intense negative affect (horror) induced in some subjects extremely long expiratory pauses, which lasted up to 15 s, before commencing the next inspiration.

5.3. Thoracic and abdominal breathing

Discrepancies between thoracic and abdominal breathing have been discussed since the early days of research into associations between respiration and emotion (Bell, 1806). This pioneer reported that "excited negative affect" resulted in larger increases in thoracic than in abdominal records; I/E ratio tended to increase thoracically, and decreased abdominally under those conditions, as compared to "neutral" control conditions. The same, to somewhat lesser extent, applied to "calm negative affects" (almost all of these under imagined emotional conditions). Landis (1926) induced severe emotional upset by cumulative aversive manipulations. Subjects had to undergo periods without food (44–47 h) and without sleep (36–38 h). Late in the afternoon of the second day subjects were given severe electrical stimulation, until they felt that they could not endure the pain any longer. This resulted, among other things, in enhanced thoracic respiration, whereas abdominal breathing decreased. Similar effects were observed by Faulkner (1941) who reported that strong emotions can alter the range of abdominal-diaphragmatic movements. Predominantly thoracic breathing was found by Ancoli and Kamiya (1979) and Ancoli et al. (1980) in subjects viewing an unpleasant film, whereas a pleasant film resulted in dominant abdominal breathing. In a study by Svebak (1982), increase of thoracic movements occurred in subjects performing a task during threat of electrical stimulation, without a change in abdominal movements. For a long time, dominance of thoracic breathing has been viewed as an important feature of the hyperventilation syndrome (Garssen, 1986; Lum, 1976); however, this claim has never been substantiated by well-controlled research. All in all, the available information seems to suggest that enhancement of thoracic relative to abdominal respiration occurs during either unpleasant or tense affect, or during both.

5.4. Irregularity of breathing

Pronounced irregularity was found in patients suffering from anxiety disorders, particularly when angry (Stevenson and Ripley, 1952; see below). Similarly, hyperventilation syndrome patients, who often are anxious, fearful, tense and confused (see Grossman and Wientjes, 1989) have been reported to have greater irregularity of respiratory parameters than controls (Hormbrey et al., 1986). Irregularity of RR was also reported by Alechsieff (1907) and Lehmann (1914) under states of what they called excitement. Lastly, Mador and Tobin (1991) found that noxious stimulation produced by shining a bright light into the subject's eyes increased the variability (coefficient of variation) of Vt, Ti and Te.

5.5. Phasic respiratory activity

More or less pronounced phasic interruptions of breathing generally occur upon presentation of unexpected or novel stimuli. A catch of breath or arrested breathing is regarded as the respiratory component of the orienting reflex (Barry, 1982). Barry showed that respiratory pauses (phasic suspensions of breathing), were good indicators of stimulus novelty but not of stimulus intensity or significance. Other researchers described the respiratory component of the OR either as a decrease in RR and increase in amplitude or as an initial pause followed by reduction in RR and amplitude (see Porges and Raskin, 1969). Unexpected intense or aversive stimulation generally appears to produce an inspiratory switch in respiration, which seems to reflect the respiratory component of the startle response. Blatz (1925) placed unsuspecting blindfolded subjects in a chair which suddenly tilted backwards. Immediately after falling, RR went down and inspiration was lengthened. If the fall of the chair occurred during an inspiration, that inspiration was prolonged, and when it occurred during expiration the expiration movement stopped abruptly and gave way to inspiration. More recently, Harver and Kotses (1987) observed similar respiratory activity in subjects who received white noise at intensities of either 80 or 110 dB during either inspiration or expiration. When stimulation occurred during inspiration, the inspiratory movement was accelerated thereby decreasing the duration of stimulated period. When stimulation occurred during expiration, a phasic inspiratory movement evolved, and by doing so lengthened the duration of the stimulated period. Analysis of subsequent respiratory cycles revealed a transient increase in rate and tidal volume. Also our own research (Boiten and Gerritsen, in preparation) corroborates phasic inspiratory shifts in breathing in response to startle. The startle stimulus consisted of a particular scene of a stress film: an unanticipated attack of a mad dog. The respiratory response again depended on whether the "startle" stimulus occurred during an inspiration or an expiration. During the inhalation phase the "startle" induced an abrupt acceleration and deepening of inspiration. Occurred the "startle" during expiration than that expiration was stopped abruptly and was immediately followed by a short and fast inspiration, thereby significantly prolonging the expiratory phase duration and hence the total cycle duration. Also individual differences in the appraisal of the stress film appears to influence the reportage and elicitation of a startle response. Subjects who experienced significantly more negative affect (emotional responders) showed a strong tendency ($p < 0.07$) to report more often a startle response (11 out of 12 subjects) than the non-emotional responders (14 out of 25 subjects). They also showed a (non significant) prolongation of the expiratory phase (635 ms) of the respiratory cycle which was affected by the startle stimulus, relative to the expiratory "startle" phase of the non-emotional responders.

Thus, it appears that the occurrence and magnitude of the respiratory startle response is moderately affected by the level of negative affect a person may experience in response to film stimuli. These results seem in line with recent research suggesting that the vigor of the startle response varies systematically with the person's emotional state (Lang, Bradley and Cuthbert, 1990). Lastly, sudden cooling of large and sensitive body areas (e.g. chest and abdomen) has also been shown to induce a abrupt transient inspiratory shift (gasp) in breathing (Keating and Nadel, 1965; Mekjavic et al., 1987), followed by an immediately increase in RR and depth of breathing, and a fall in end-tidal pCO_2 (Cooper et al., 1976). An initial gasp accompanying startle has furthermore been reported by Hogan (1970).

Thus, unexpected aversive stimulation produces two phasic respiratory responses. A short-latency respiratory startle response, followed by a delayed phasic increase in depth and rate of breathing. In addition, the inspiratory gasp has a short onset latency which is in line with the fast rise time of other indices of the startle response, such as heart rate acceleration and cephalic vasodilatation (Turpin, 1986). Turpin also argued that the delayed, or long latency increases in physiological activity reflect fight and flight responding.

6. Effects of positive emotions

6.1. Respiration rate and depth of breathing

Psychophysiologists have paid almost no attention to the effects of pleasant stimulation or positive emotions upon respiration. The studies that do exist, however, are generally consistent with our earlier suggestion that changes in RR and depth are more strongly associated with Wundt's (1902) excitement/calm and tense/relaxed dimensions, than with pleasantness as such. In many studies of positive affect, RR and depth decreases were found. In Rehwoldt's (1911) study, decreases in RR and depth occurred during positive affects induced by imagery. Respiration was slow and deep in the excited positive affects, and slow and shallow in the calm ones. The latter findings correspond well with the findings of later, better controlled studies. RR decreases were found, for instance, in relaxation (Skaggs, 1930; Dudley, 1964), and daydreaming (Corwin and Barry, 1940). In Nakamura's (1984) study of respiratory reactions in subjects listening to music, RR was lower as ratings of calmness were higher. A number of other studies have observed no effects of pleasant stimulation upon RR. Finesinger and Mazick (1940) reported only very small changes during pleasant stimulation. In a review article on physiological measures of sexual arousal Zuckerman (1971) discussed several studies dealing with respiration and sexual arousal. He concluded that gentle sexual arousal, in most studies induced by visual stimuli, had only marginal effects on RR: "Apparently, respiratory measures will not be useful in assessing sexual arousal to visual (sexual) stimuli" (Zuckerman, 1971, p. 309).

On the other hand, some studies have described an increase in RR during positive affect. In some instances, "calm pleasant affects" were in Rehwoldt (1911) study associated with increased RR and decreased depth (fast and shallow breathing), instead of the slow and shallow breathing that was generally found. Ruckmick (1936) found the same fast and shallow pattern among subjects watching simple pleasant stimuli, such as slides of faces with emotional expressions. Lehmann (1914) generally observed both RR and depth increases in (imagery provoked) pleasant affects. Nakamura (1984) found that music ratings of "cheerful", "gay" and "powerful" correlated positively with RR. Strong increases in RR have been reported to occur during coitus by Masters and Johnson (1966) and by Bartlett (1956). Masters and Johnson (1966) reported that hyperventilation developing during the late plateau and the orgasmic phases of the sexual response cycle is a normal occurrence. RRs of 40 c/min have been recorded repeatedly during orgasm (both sexes). Bartlett (1956) reported marked peaks at orgasm with RRs of 20–70/min.

Most findings in this modest collection fit in the patterns that we mentioned earlier: an increase of RR and volume during excitement, and a decrease in volume, combined with an increase in RR, during pleasant attentive states. The major deviation from those patterns is formed by the excited affects in Rehwoldt's old study, during which a pattern of slow and deep breathing was found. This suggests an "activated" (rather than "aroused") respiratory response type, that is, a response type corresponding to tonic readiness to act rather than to sudden, reactive, response mobilization (see Pribram, 1981).

6.2. Thoracic and abdominal breathing

Under positive emotional conditions, thoracic/abdominal ratio has been observed to shift in the direction of stronger abdominal than thoracic breathing amplitude. Faulkner (1914) reported that when subjects were asked to imagine pleasant situations, the amplitude of the abdominal movement increased. Ancoli and Kamiya (1979) and Ancoli et al. (1980) found dominant abdominal breathing in subjects viewing pleasant films. In the calm positive affects in Rehwoldt's (1911) study, abdominal breathing was also dominant. Abdominal dominance is not found under all more or less pleasant conditions. Rehwoldt's (1911) excited positive affects yielded, on the whole, equal abdominal and thoracic amplitude. Timmons et al. (1972) studied abdominal-thoracic movements in subjects who were instructed to relax and try to go to sleep. Abdominal-dominant breathing was associated with relaxed wakefulness, equal to drowsiness, and thoracic-dominant breathing with sleep onset.

Care in the analysis of thoracic/abdominal balance is needed in light of sex differences that have been reported. According to Clausen (1951), women are relatively stronger thoracic breathers, whereas men appear to be predominantly abdominal breathers. These dominance differences have consequences for the leeway remaining for emotional response changes. Svebak (1975) found that in women duration and frequency of laughter in response to funny films are strongly correlated with abdominal (and not with thoracic) amplitude, both during the laughter and the silent periods of the entertainment. Zero correlations with abdominal amplitude, and non significant correlations with thoracic amplitude, were found in men.

6.3. I/E ratios and respiratory pauses

Rather variable I/E ratios have been reported in positive affects. Calm positive affect, in Rehwoldt's (1911) study, tended to yield longer expirations than inspirations (I/E ratios < 1). Excited positive affects showed ratios > 1 for thoracic, and < 1 for abdominal breathing. Feleky (1914) reported inconsistent results for imagining pleasant situations. I/E ratios in laughter, of course, were very low (average of 0.52 in Feleky's 6 subjects).

The duration of expiratory pauses seems a stable characteristic of rest or relaxation, diminishing whenever breathing is stimulated (Newson Davis and Stagg, 1975). This is in agreement with strong positive correlation ratings between subjective ratings of relaxation and the duration of expiratory pauses (Boiten and Gerritsen, in preparation).

7. Mental effort and stress

Several researchers have made attempts to assess the effects of stressful mental load tasks upon respiration. Extensively studied mental load tasks are mental arithmetic and reaction time tasks, performed under stressor conditions such as task difficulty (Svebak, 1982; Carroll, Turner and Hellawell, 1986), thread of electric shock (Allen et al., 1986; Sherwood et al., 1986) and making money rewards contingent on task performance (Turner and Carroll, 1985; Allen and Crowell, 1989). Some of the earlier researchers (Alechsieff, 1907; Suter, 1912; Skaggs, 1930) showed that mental arithmetic produced shallow breathing, with RR either not changing or increasing marginally. Decrease in depth and variability of the breathing pattern was also observed during concentrated sensory attention, presumably serving to suppress distracting and irregular breathing movements, which might otherwise interfere with task performance (see also Suter, 1912; Woodworth, 1938; Kagan and Rosman, 1964). Recent research generally supports these early findings. For instance, Caroll et al. (1986) engaged subjects in mental arithmetic and Raven's matrices. Each task was presented with three levels of difficulty: easy, hard and impossible. In addition, subjects were told that appropriate responses would be financially rewarded, whereas erroneous responses would lead to a reduction of the monetary rewards. Analysis revealed that an increase in task difficulty covaried with a significant increase in RR, a non-significant decrease in Vt and a significant increase in average ratings on an arousal scale (calm/at ease vs excited/aroused), indicating that for both tasks the hard and impossible condition were perceived as more arousing than the easy condition. That enhanced arousal levels increase RR has also been reported by Schnore (1959), who induced moderate arousal levels in his subjects by visual pursuit tracking, and high arousal by threatening them with strong electric shock if they failed to improve the best score that they had previously obtained. An increase in RR was found during the high arousal, as compared to the low arousal condition. Several other studies have produced evidence that a range of stressful laboratory tasks elicit an increase in RR, and a slight decrease in Vt (Allen, Sherwood and Obrist, 1986; Carroll et al. 1987; Langer et al, 1985; Sims et al., 1988; Svebak, 1982; Turner and Carroll, 1985; Turner, Carroll and Courtney, 1983; Wientjes, 1993; Boiten, 1993b). Since increases in RR are on the whole more pronounced then decreases in Vt, Vmin often is augmented.

Wientjes (1993) measured additional respiratory parameters during stressful mental load tasks, via inductive plethysmography, and performed a computer based component analysis on the calibrated respiratory signal. There were three reaction time task conditions in the study, that were equally difficult, but that differed in the degree to which they were effort-demanding and stressful. In all three conditions, duration of the time components of the breathing cycle (Ti, Te, pause times, and Ttot) decreased (and hence RR increased), as compared to the pre-task resting condition. Between conditions, however, there were no differences in the duration of the time components, and, consequently, in RR. Compared to pre-task resting levels, Vt decreased during the least stressful condition, but the decrease in Vt became less pronounced as the task demands increased, and reached, during the most stressful condition, a level that was nearly equal to the initial resting value. Both the "timing" and the "drive" mechanisms of respiratory control (Gautier, 1980; Milic-Emili and Grunstein, 1976; Milic-Emili et al., 1981) turned out to be affected by the stress level: Vt/Ti increased from rest to task, and increased further as the level of stress increased. Ti/Ttot only increased in the most stressful task condition. Thus, in the Wientjes (1993) study, the respiratory pattern during stressful mental task performance was characterized by relatively fast, shallow breathing, with a high mean inspiratory flow rate. As stress levels increased, the breathing pattern became less shallow, and mean inspiratory flow rate was even further augmented, but there was no change in the rate of breathing.

The respiratory changes during mental effort thus seem to resemble the pattern that was observed during "tense affects", during anxious anticipation of an aversive stimulus, and among patients with anxiety states (see below): rapid shallow breathing. This similarity can be explained in several ways. Both the performance of mental tasks and states of tension and anxiety may well involve sustained attention; also, both involve voluntary or inhibitory response control. Another similarity is that most mental tasks, like states of tension and anxiety, include a "stress" component (such as task difficulty, time limits, and positive or negative rewards).

8. Specific respiratory responses: sighing and yawning

8.1. Sighing

A sigh is a single breath characterized by a relatively long duration, deep in- and expiration, and a particular sound. In a sigh, a large volume of air is inhaled. However, the air passages are not widened during inspiration and remain tightened in the expiration phase. The discordance between the volume of air that is displaced and the calibre of the airways suggests that the sigh does not serve a need for increased oxygenation but is the expression of an emotional state (Bendixen et al., 1962; Harrer, 1969). Sighing has been observed in nervous, fatigued, bored and excited persons (Cabot and Adams, 1942). Finesinger (1939) reported that the induction of unpleasant ideas is associated with an increase in sighing. Sighing has also been related to anxiety (Stevenson and Ripley, 1952; Tucker, 1963). Tobin et al. (1983) reported that patients with chronic anxiety states exhibited sighs at a rate of 4–25 over a 15 min monitoring period. In young normal subjects the frequency of sighing was 0–1 sigh per 15 min. Clausen (1951) reviewed some studies on respiration in neurotics, from which he concluded that sighing is the symptom most generally observed in these subjects. These studies imply that sighing mostly occurs during unpleasant states, except perhaps for sighs of relief. Garssen (1986) hypothesized that the function of sighing might be the relief of feelings of tightness around the chest, and that this could explain why anxiety states are often associated with sighs. However, Garssen's attempts to confirm this hypothesis failed. The psychological function of sighing remains therefore unclear.

8.2. Yawning

There is remarkably little physiological or psychological literature available on the subject of yawning. Yawning is characterized by a prolonged inspiration with wide open mouth, followed by shorter expiration and is often associated with shivering and stretching movements of the muscles of the trunk and extremities. One of the most remarkable aspects of yawning is its contagiousness; something which has also been observed among animals. Like in sighing, the deep inspiration would suggest that yawning may serve to increase the body's oxygen uptake. However, a yawn is always followed by a period of apnoea, so nothing is gained as far as oxygen metabolism is concerned (Lehman, 1979). According to Mayer (1921), cited by Lehman (1979), yawning is a muscular and vascular reflex, the physiological function of which might be to improve circulation and to stretch the musculature. As to its psychological aspects, it has been proposed that yawning is an expression of an unpleasant state, namely boredom (Provine and Hamernink, 1986). However, yawning is certainly not only tied to unpleasant affect: its occurrence may also be associated with pleasant, comfortable feelings. Lehman (1979) argues that yawning is a signal that a person is making an effort to maintain contact with the outside world. Others have argued, from an evolutionary point of view, that yawning is part of a silent "sign language", and may serve to express the friendly or non-hostile intentions of an animal. Experimental evidence is as far as we know not available.

9. Differentiating between emotions

As far as we know, only two studies have systematically explored differences in respiration between specific emotions in normal subjects. Feleky (1914) induced what she considered to be the six primary emotions (pleasure, pain, anger, wonder, fear and disgust) by asking subjects to relive a past emotional experience. Measures of respiration were I/E ratio, depth of breathing, and the "amount of respiratory work": i.e. depth divided by breath cycle duration. RR can be derived from the variables "work" and depth. Table 1 reproduces her average data. We performed four one-way variance analyses (one for

Table 1
Emotion patterns according to Feleky (derived from Table 2, Feleky, 1914)

Emotion	I/E		Work		Depth		Rate	
disgust	1.1	0	5.9	0	15.3	0	23.4	+
pleasure	1.1	0	9.5	+	27.3	+	20.4	+
anger	1.5	+	13.3	+ +	31.8	+ +	25.2	+ +
pain	1.5	+	8.0	+	29.7	+	16.2	0
wonder	2.5	+ +	9.5	+	38.6	+ +	9.6	0
fear	2.6	+ +	14.6	+ +	33.2	+ +	26.4	+ +
normal	0.8	0	4.7	0	13.9	0	20.4	+

See text for explanation of the respiratory parameters. Zeros and plus signs indicate three crude classes of response magnitudes within each response variable.

each parameter) on the individual data from the six emotions and "normal", and four others from the six emotions only. All but one were significant at $p < 0.0001$ (the only exception was at $p = 0.0016$), indicating that the emotions differed on all four respiration parameters. Furthermore, if the averages are divided into three crude classes of response magnitude, all seven patterns turn out to be distinctly different, as can be seen in Table 1. Of course, these data should be interpreted with great caution. Subjects attached to a pneumograph asked to relive emotions can hardly be said to have been naive. They may have been producing stereotyped response patterns, as these also appear from subjective report studies (Rimé et al., 1990). Still, we have reported the data in some detail because they show the differentiation potential in respiratory patterning. Moreover, subsequent research has neither replicated nor rejected these findings.

More recently, Santibañez and Bloch (1986) observed specific respiratory (in addition to postural and facial) response patterns during emotional recall and revival in awake and hypnotized subjects, that were associated with particular emotions. The emotions were: joy-laughter, sadness-crying, anger, fear, erotic arousal, and tenderness. Time and volume components, and morphology of the breathing cycle were compared between baseline and emotion states. With the exception of tenderness, all emotions evoked a fairly irregular respiratory pattern. Characteristic for fear and anxiety were shallow breathing or cessation of breathing, and an irregular RR. Anger was associated with an increase in RR without changes in depth, but only at the onset and at the end of the emotion induction. In the intermediate period, RR did not further increase, but depth increased to three times base value, in a waxing and waning pattern. Erotic arousal (induced by making the movements of sexual response) was characterized by an initial decrease in RR, followed by an increase in RR and depth. Sadness was also associated with a very characteristic response pattern. RR remained stable but depth distinctly increased, as compared to the baseline period. Also, high-frequency oscillations were superimposed on the inspiratory curve. The pattern for joy was much the same as that of sadness, except that the high-frequency oscillations primarily occurred during the expiratory phase. High-frequency movements during laughter appear to correspond to the "ha-ha" responses (Svebak, 1975). Tenderness was associated with a decrease in RR below the baseline value, and an increase in depth, yielding a pattern of slow and deep breathing. Again, the results are only indicative, and suffer from some of the same shortcomings as those of Feleky. No quantitative analyses were performed. Yet, the study merits attention, if only because it is one of the few studies that have assessed the time course of respiratory responses. In a follow-up study (Bloch et al., 1991) young actors were instructed to voluntarily reproduce these six emotion-specific respiratory patterns, together with the corresponding facial and postural configurations. A qualitative analysis of the recordings showed that as the emotional reproduction went along, both breathing and facial expressions evolved from an initial "robot-like" phase to a more natural stage in which spontaneous vocalizations and gestures appeared. According to Bloch et al. this suggested that the production of specific emotional configurations initiated the corresponding emotional experience, although subjects were not questioned to confirm this. Respiratory analyses were conducted during the emotional reproduction phase which followed the initial "robot like phase". The results showed that the derived breathing patterns were significant different for the six emotional configurations. Relative to a neutral condition, the tenderness configuration was characterized by a slight increase in expiratory pause duration, erotic arousal showed a significant decreae in expiratory pause duration, whereas anger breathing was characterized by strong increases in rate and depth of breathing. Both the joy-laughter and sadness-crying configurations showed significant increases in depth of breathing while rate decreased, also high-frequency oscillations were superimposed on the breathing curve. Lastly, the fear configuration was characterized by substantial increases in depth of breathing, inspiratory shifts in end-expiratory lung volume, and a total absence of expiratory pauses. Bloch et al.'s (1991) claim, that the production of emotion-specific respiratory-facial-postural configurations can initiate emotional experience, is intriguing and obviously has important implications for the hypothesis that emotional states are associated with specific physiological responses. Unfortunately, the experimental support is not as strong as suggested. For instance, there is as yet not much evidence that the voluntarily reproduced breathing movements correspond to emotion-specific breathing patterns. Also, data on emotional self-report is lacking and the number of derived breathing curves is often too small to allow for sound analyses. In addition, the reported respiratory differences might be due to the differences in effort in producing the various configurations; for instance, a fearful expression is more difficult to produce than a happy expression and consequently has a greater impact on breathing (Boiten, submitted).

In Ax's (1953) study, respiration rate increases were greater for fear than for anger. Depth increased as compared to the control condition, but there was no difference between anger and fear. In Schachter's (1957) replication, fear and anger produced the strongest increase in RR, while pain induction led to only a slight RR increase. The patterns during imagined anger and fear were similar to those found by Ax (1953) during real emotion induction.

Emotions with a specific respiratory feature appears to be startle and surprise, which are characterized either by an inspiratory shift in breathing (startle) or a brief suspension of breathing (surprise). The phenomenon of respiratory suspension fits nicely into the interpretation of surprise as in part being an inhibitory response patterns (orienting response; Sokolov, 1963; movement arrest and jaw muscle relaxation; Dumas, 1948).

10. Studies among clinical populations

In most studies that were performed in clinical settings, the respiratory pattern was used to differentiate patients from normal subjects (Alexander and Saul, 1940; Burns, 1971; Christy, 1935; Coppen and Mezey, 1960; Finesinger, 1943; Stevenson and Ripley, 1952). Though our main interest is in breathing patterns recorded among normal subjects, we will discuss the most important clinical studies concerning anxiety neuroses and depression. It is in these studies that investigators claim that there is e.g. "hardly an emotion which has not its obvious respiratory manifestation" (Christy, 1935) or "respiratory patterns vary closely with the emotional state" (Stevenson and Ripley, 1952).

There is considerable speculation about the role of respiratory influences in the aetiology of psychosomatic disorders such as the hyperventilation syndrome (HVS), panic disorder (PD) and agoraphobia. A common factor in the clinical features of these disorders is the combined experience of anxiety and somatic symptoms. On the other hand, their clinical manifestations are somewhat dissimilar: patients suffering from PD and agoraphobia typically present with attacks that are characterized by a sudden onset of symptoms and by abrupt, uncontrollable panic, whereas abruptness of attacks is not considered to be a necessary feature for the diagnosis of HVS. Although there is some variation in the aetiological models that have been proposed by different authors, several investigators have hypothesized that the symptom attacks that typify these disorders are triggered by a distinct sequence of events. In this regard, it is commonly assumed that anxiety-induced hyperventilation produces somatic symptoms which are, in turn, cognitively misinterpreted in a catastrophic manner and thereby cause an increase in anxiety. This leads to a vicious spiral, in which further increases in anxiety result in further respiratory increases and in more intense symptoms (e.g. Clark et al., 1988; Ley, 1985). Although there is evidence that excessive ventilation and hypocapnia may indeed, to a minor degree, be involved in the formation of somatic symptoms (Wientjes, 1993), empirical support for hyperventilation models of HVS, PD and agoraphobia has by no means been unequivocal (e.g. Buikhuysen and Garssen, 1990; Grossman and Wientjes, 1989; Hornsveld et al., 1990). As an alternative, it has been proposed that the symptom attacks may be due to enhanced tendencies of anxious and distressed individuals to focus their attention upon bodily sensations, and to appraise these in a negative manner (Watson and Pennebaker, 1989). Notwithstanding these theoretical considerations, there is ample evidence that clinical anxiety disorders may be associated with aberrant respiration.

Respiratory complaints that are often associated with anxiety disorders are breathlessness and dyspnoea (difficult or laborious breathing). Patients typically complain of "air hunger" (a subjectively experienced inability to get enough air in the lungs), and a persistent feeling of pressure or heaviness on the sternum. Breathlessness and dyspnoea appear to be tied to hyperventilation and sighing (Burns, 1971; Grossman and Wientjes, 1989). Christy (1935) found that the respiratory pattern of patients with anxiety disorders who complained of breathlessness was characterized by a tendency towards rapid and shallow breathing, and by irregularities of depth of respiration. Finesinger (1943) and Tobin et al. (1983) also reported sighing and irregular breathing during chronic anxiety (episodes of rapid shallow breathing alternating with episodes of slow, deep breathing and transient inspiratory shifts in end-expiratory lung volume). Shallow breathing, and chronic inspiratory shifts in breathing caused by the incapacity to complete a full expiration, were also observed by Reich (1949) in tensed and anxious patients. Hormbrey et al. (1986) found HVS patients (who typically are tense and anxious and suffer from various psychosomatic complaints) to breathe more irregular than controls. Similar findings are reported in two studies cited by Bass and Gardner (1985). Jones and Scarisbrick (1941) and Friedman (1945) found that patients with anxiety disorders had a higher RR, a smaller Vt and shorter breath-holding times than controls. Thus, rapid and shallow breathing, sighing and irregular breathing patterns seem important features of respiration in patients suffering from anxiety disorders (see also Baker, 1934; Malmo and Shagass, 1949; Finesinger, 1943). Depressed affect, sadness and misery appears to be associated with the opposite respiratory pattern. During these emotions, a decrease in respiratory activity has been observed (Averill, 1969).

Clinical depression, on the other hand, appears to be associated with increased RR, with decreased levels of pCO_2, and with diminished CO_2 sensitivity (Damas-Mora et al., 1976; Damas-Mora et al., 1982; Shershaw et al., 1973; Shershaw et al., 1976). At present, it is unclear whether the respiratory characteristics of clinical depression are associated with the depressed affects as such, or rather with the anxiety component that is often observed among clinically depressed patients (Watson et al., 1988; American Psychiatric Association, 1980).

Stevenson and Ripley (1952) evaluated respiratory patterns of patients with asthma and anxiety states during relaxation and during episodes of emotional disturbance, such as anger, anxiety, guilt and depression. Since these authors investigated a broader range of emotions than is common in the literature, we will review their study in some detail. Emotions were induced by having the patients think and talk about various emotional experiences relevant to their life and illness. The patients' emotional statements were related to the observations of the physician with regard to voice intonation, facial expression, movements of the hands or body, and other indices of emotional change. Respiratory patterns were examined with respect to RR, depth, I/E ratio and irregularities. Increases in RR and depth of breathing were found chiefly during acute anxiety, and sometimes during anger and resentment. Decreases in respiratory function where found when the patients felt tense and on guard with feelings of anxiety or anger and when feeling sad or rejected. Irregularity of breathing was not primarily associated with acute anxiety, but rather with anger.

Stevenson and Ripley interpreted their findings in terms of adaptation of the respiratory system to the type of stress. They argued that the nature of the subject's stress response determined whether a decrease or increase in respiratory function would occur. Thus, they took an increase in RR and depth to reflect physical adaptation to stress (preparation for fight or flight), and suggested that a decrease in respiratory function was associated with a tense expectation in preparation for action. Stevenson and

Ripley's experimental design is an appealing approach to the problem of examining emotion specific respiratory patterns. An interview context allows for a more precise evaluation of the subjects' prevailing emotional state, which in turn can be synchronized with respiratory function. In this way one can control for feelings of hostility and tension evoked by experimenter or experimental setting. An experimental interview context might also allow for control over additional emotional behaviour. For instance, anxious patients are often also depressed, and most depressed patients exhibit an elevated degree of anxiety (Zuckerman et al., 1968). Without interview data, it might prove difficult to separate anxiety and depression as distinct affects (see Watson, Clark and Carey, 1988). This "mixing" of emotional behaviour might explain why breathlessness has also been observed in depression (Burns, 1971). It should however be noted that the relationship between emotions and respiration might have been confounded by the metabolic requirements of the patient's conversation. It is known, for instance, that the act of speaking itself is sufficient to cause elevations in heart rate and blood pressure (Lynch et al., 1980). Also, analysis of the respiratory signal during speech in terms of volume and time components is notoriously difficult because of the irregular expiratory movement of air through the glottis that is typical of voice intonation (Wientjes, 1993).

Most of the preceding studies seem to agree that the respiratory pattern associated with anxiety consists of irregular rapid, shallow breathing with many sighs. The combined decrease in depth, and increase in rate of breathing that appears to be typically observed among patients with anxiety disorders again fits in well with the pattern that is found during tense affects and during the performance of mentally demanding tasks.

11. Discussion

As is apparent from the previous sections, the literature on emotion-respiration relationships is fraught with methodological shortcomings. Many studies (especially the older ones) have included very small numbers of subjects, have employed deficient experimental control procedures, inadequate measurement techniques, or (at best) primitive statistical treatment of the data. Although the more recent literature generally has a higher level of methodological sophistication, there are only few studies available that may be regarded as methodologically sound. In this light, it is difficult to draw specific and detailed conclusions concerning the influence of emotions upon respiration. This does not imply that the available literature is insignificant or irrelevant. To the contrary, this literature has produced many suggestive results, that show an appreciable amount of consistency across studies. Consequently, several strands of evidence may be discerned, that run across different studies. On this basis, we will try to draw some tentative general conclusions that may be of value for future research. More specifically, with respect to the most widely employed respiratory variables, RR and depth, several distinctive patterns of response can be distinguished. These appear to correspond in a more or less orderly fashion to general dimensions of emotional and affective reactions that cut across the usual emotion boundaries, and even across the distinction between pleasant and unpleasant emotional states.

11.1. Fast and deep breathing

An increase in RR combined with an increase in depth of breathing seems to be associated with states of excitement. This is the generalization offered by early researchers like Lehmann (1914) and Rehwoldt (1911), and by Woodworth (1938; Woodworth and Schlosberg, 1955). More recent research supports this hypothesis. By "excitement" we mean the state that generates undirected, aimless behaviour, under conditions in which directed action is blocked or restrained. Feelings of excitement can be understood as the felt urge towards such undirected action (Frijda, 1986; Frijda et al., 1989). Excitement, in this sense, often is an aspect of states of fear, anger, and joy; but is not invariably so, because it can exist without any of these, as diffuse excitement. We prefer the term "excitement" to that of "arousal", because the concept of arousal has many meanings and implications of generality that do not necessarily apply to excited emotions (and that, in fact, render the concept useless in discussing emotional states; see Neiss, 1988, 1990; Venables, 1984). Moreover, excitement, as we defined it, is linked to an enhanced readiness for action. Thereby, a meaningful connection can be made with the primary function of enhanced respiratory activity. Such activity is usually interpreted as a preparation for flight or fight (Darwin, 1872; Cannon, 1929; Stevenson and Ripley, 1952; Suess et al., 1980). Dudley et al. (1964, 1969) indeed argue that changes in ventilation are primarily related to action or non-action orientations. On the one hand, action-oriented respiratory hyperfunction may be linked to emotions like anger and anxiety. On the other, it may reflect a readiness for active appetitive behaviour in excited positive emotions, or for physical exercise. This latter suggestion is supported by the observation that RR and depth increase have not only been shown to occur during actual physical exercise (Kay et al., 1975a, 1975b), but also during hypnotic suggestions of such exercise (Morgan, 1985).

11.2. Fast and shallow breathing

Rapid shallow breathing is certainly one of the most extensively documented breathing patterns. As is suggested by the Wientjes (1993) study, mean inspiratory flow rate tends to be high in this pattern, which signifies that inspiratory drive is high. When contrasted to the pattern of fast, deep breathing, this pattern appears to blend readiness for action with some degree of inhibitory control. As we have mentioned earlier, fast and shallow breathing is found during effortfull and stressful mental task performance (Allen et al., 1986; Carroll, Turner and Hellawell, 1986; Carroll et al., 1987; Langer et al., 1985; Sims et al., 1988; Svebak, 1982; Turner and Carroll, 1985; Turner et al., 1983; Wientjes, 1993; Boiten, 1993b), in "tense affects" (Alechsieff, 1907; Lehmann, 1914; Rehwoldt, 1911), when a subject is resisting unpleasant affect (Lehmann, 1914), during sustained attention (Kagan and Rosman, 1964), and during tense or anxious anticipation or expectation (Skaggs, 1930; Stevenson and Ripley, 1952; Suter, 1912). Behaviourally, fast and shallow breathing appears therefore to be associated with (tense) anticipation, involving alertness and often attention, or with consummatory behaviour characterized by some degree of control over effortfull action tendencies. In this sense, the pattern seems typical for attempts to tune in to behavioural demands that may necessitate a restrained, precise, and goal-directed (as opposed to massive) type of physical action. Emotionally, this pattern may apparently be tied to a range of affects varying from concentration, resolution and determination, through tension, to anxiety and fear, and maybe ultimately, panic. As we have suggested before, this range of emotional responding seems to correspond to a continuum of respiratory patterns that extends from rapid shallow breathing to rapid deep breathing. In this respect, the study by Wientjes (1993) is illustrative. He has shown that an increase in mental task stress produced a shift from shallow fast breathing to deep fast breathing (whereby RR remained high, and changed very little). Hence, it seems that variations in depth during rapid breathing correspond with different points on a inhibition-excitation continuum (which may be more or less equivalent to a continuum extending from behavioural control to loss of control). In other words, the relatively shallow breathing pattern that is usually found during states of concentrated attention, can apparently be modified by influences related to loss of control or increase in emotional excitement.

11.3. Slow and deep breathing

A pattern of relatively slow and deep respiration is most often encountered in relaxed resting states (Wientjes, 1993; Boiten, 1993b). The pattern tends to become slower and deeper during slow-wave sleep (Snyder and Scott, 1972; Douglas et al., 1982), and during relaxation (Grossman, 1983). Other links between this pattern of breathing and behavioural, or emotional responses have been reported in some of the older studies. It was observed during excited positive affect (Rehwoldt, 1914) and "when the subject abandoned him- or herself to negative affect" (Lehmann, 1914). These data are insufficient to draw solid conclusions concerning the behavioural and emotional correlates of this type of breathing. They do, however, suggest that the pattern might occur both during relaxation as well as during unrestrained emotional readiness to act.

11.4. Slow and shallow breathing

A decrease in RR and depth has been associated with emotions like passive grief and calm happiness, in which physical exertion is abandoned (Averill, 1969). This finding is supported by a number of studies. Decrease in RR and depth of breathing is found in depression, during calm pleasurable experiences and during states of relaxation (Rehwoldt, 1911; Nakamura, 1984). On the other hand, clinical chronic depression has been found to be related with an increase in RR and decreased levels of pCO_2 (Damas-Mora et al., 1976, 1982). However, as we noted before, this apparent paradox might be due to the anxiety component that is associated with clinical depression. Thus, slow and shallow breathing and decreased respiratory drive appears to be primarily indicative of states that are characterized by withdrawal from the environment and by passiveness, and might be encountered during depressed and unhappy, as well as happy, but unexcited moods.

11.5. Normoventilation and hyperventilation

Breathing patterns may not only be characterized in terms of variations in rate and depth, but also, on another level of description, by the degree to which ventilation is in accordance with metabolic requirements, i.e. with CO_2 production. In this regard, there is an important difference between normoventilatory and hyperventilatory responses. Normoventilatory responses (which are identified by stable end-tidal pCO_2 levels that remain within the normal range) seem to be characteristic for behavioural conditions that may either involve withdrawal from the environment, relaxation, or active coping (Allen et al., 1986; Langer et al., 1986b; Wientjes, 1993). Hyperventilation, on the other hand (which is characterized by a drop in pCO_2 below the normal range), appears to be the typical respiratory response during psychological challenges where very few, if any, active coping possibilities exist, such as states of threat, aversive stimulation or pain (Allen et al., 1986; Dudley et al., 1964; Freeman et al., 1986; Suess et al., 1980). Thus, hyperventilation appears to signify an unsuccessful outcome of the coping process. This type of coping is often called "passive coping" because the individual has no other choice than to try to accommodate to the stressor, or to try to reduce its impact as much as possible (Obrist, 1981). Passive coping may often involve strong (but inhibited) action-oriented tendencies, and may be accompanied by anxiety, fear, anger or panic. It has often been suggested that the hyperventilatory response may functionally be interpreted in terms of preparation for fight or flight (Suess et al., 1980; Dudley, 1964). This type of response by itself seems indeed to be physiologically functional if fight or flight would ensue (by way of anticipating enhanced O_2 consumption and CO_2 production). However, when physical action is blocked or suspended, the anticipated increase in O_2 consumption and CO_2 production does not materialize. As a consequence, the ventilatory response is in excess of metabolic needs and may be therefore be regarded as non-functional

11.6. Thoracic-abdominal balance

The psychological correlate of thoracic-abdominal balance might either be hedonic tone (variations along a pleasantness-unpleasantness dimension), or inhibitory control. Thoracic dominance appears primarily to correspond to unpleasant affect, tenseness or anxiety, and abdominal dominance to pleasant emotional states or relaxation (Ancoli and Kamiya, 1979; Ancoli, Kamiya and Ekman, 1980; Lum, 1976; Svebak, 1975).

11.7. Irregularity of breathing

A number of studies has shown that breathing may become irregular under conditions of emotional upset, excitement, and task involvement (e.g., Hormbrey et al., 1986; Santibañez and Bloch, 1986; Stevenson and Ripley, 1952; Tobin et al., 1988; Boiten, 1993b). Marked breath-to-breath variations in Vt, RR and Vt/Ti are quite common during normal breathing (Bradley, 1977; Milic-Emili et al., 1981; Tobin et al., 1988). It appears that variation in respiratory parameters is not an entirely random process since oscillatory patterns in the breath to breath variability of respiration have been observed in healthy subjects at rest (Lenfant, 1967). Oscillatory or cyclical changes in respiratory parameters have been related to respiratory feedback mechanisms such as peripheral and central chemoreflex activity (van den Aardweg, 1992). However, very little is known about the mechanisms that augment the occurrence of respiratory irregularities during emotional behaviour. It might be speculated that enhanced breathing irregularities ensue when neural influences upon respiratory control processes are highly incompatible, as may be the case during emotional and behavioural states that involve conflicting, or incongruous components.

11.8. Emotion differentiation

We reviewed the weak evidence, mostly dating from the beginning of this century, that emotions can be distinguished and identified by specific patterns of respiratory parameters. However, the only solid case of a specific emotion-respiration connection that we encountered is that of the breathing suspension in startle or surprise. The notion that specific patterns of respiratory (and other physiological) variables might be characteristic for different emotions is, of course, attractive and plausible, and consonant with the James-Lange theory of emotion. However, the scant evidence allows no firm conclusion that the notion is a valid or invalid one. Studies comparing the psychophysiological response patterns of emotions are plagued by conceptual and empirical difficulties that may be hard to overcome and that, surely, have not been overcome in the studies reviewed. The major obstacles that are commonly encountered when investigating emotion-respiration relationships are due to problems with regard to intensity scaling and dimensional interpretation. The intensity scaling problem refers to the fact that observed differences between emotional conditions may only reflect differences in intensity. Emotions characteristically differ in average intensities and in intensity ranges (Frijda et al., 1992). Typical fear, for example, tends to be more intense than typical anger (Scherer et al., 1986).

The problem with regard to dimensional interpretation resolves around the fact that responses to particular emotional conditions may solely reflect variations in the location of the resulting emotional states on dimensions like negative or positive affect, excitement, tenseness, motor preparation, or readiness for active coping. As we indicated earlier, these locations may not characterize particular emotions as such, but only the accidental exemplars of fear, anger, etc. that were included in the particular study. Indeed, considering the broad spectrum of emotional stimuli utilized in, for instance, the studies involving anxiety, it is not surprising that the results are often inconsistent. Anxiety has been evoked by threatening subjects with electric stimulation, by administering electric stimulation, by hypnotic suggestion, films, and among clinical conditions. The types and manifestations of evoked anxiety may well be different in many relevant aspects. An illustration is provided by Dudley et al. (1964). The induction of intense pressure headache produced respiratory hyperfunction only when it elicited overt, action oriented anger or anxiety. To truly establish relationships between particular emotions and respiratory (or more generally, physiological) patterns, one needs an experimental design that controls for the effects of specific stimulus situations and specific response requirements. As it was phrased by Averill (1969, p. 411): "A superior approach to the problem of differential physiological patterning during emotion would be to use an experimental design in which each emotion is compared with itself under different stimulus conditions, as well as with other emotions".

12. Conclusions

Although the literature that was reviewed obviously suffers from a number of important limitations, the available evidence on emotion-respiration relationships contains several elements of general interest. One of the most important conclusions that can be drawn, is that certain patterns of respiratory responses appear to be correlated with dimensions that define general aspects of emotions.

As a first approximation, we noted marked differences between patterns suggestive of respiratory hypo- and hyperfunction that appear to be tied to specific instances of passive/depressed, and active/excited affect states (whereby relaxed emotional states seem to correspond to respiratory responses that may be located in the middle region of the continuum). In a different formulation, this range of affect states extends from "passive withdrawal from the environment" to "active engagement".

Within the realm of respiratory hyperfunction (which is typified by a high mean inspiratory flow rate), we have furthermore found that there may be a continuum of respiratory responses extending from rapid shallow breathing to rapid deep breathing. Emotionally, this continuum appears to represent a range of affects that extends from inhibition, controlled activation and tenseness on the one extreme, to excitement, unstrained activation and overt panic on the other. Inhibition and activation, of course, are important facets of behavioural energetics, existing next to attentional or sympathetic arousal, and independent of it (Pribram, 1981). The respiratory dimension may be of general interest, in that diagnostic measures of inhibition or tenseness, and of unrestrained activation, are not otherwise readily available.

Lastly, there appears to be still another important dimension of respiration, distinguishing between breathing that is metabolically appropriate (normoventilation), and breathing that is in excess of metabolic demands (hyperventilation). The former type of respiration appears generally tied to adaptive or active coping behaviour, and the latter to be typical for passive or unsuccessful coping. Thus, taking all the available evidence together, the patterning of respiratory responses may hold potential as a diagnostic tool to distinguish a number of important dimensions of variation of emotional response.

With regard to the two-dimensional models of emotion, those of Russell (1980) and of Watson and Tellegen (1985), the evidence from respiration favors the former rather than the latter. Respiratory changes correspond to hedonic tone and level of activation, rather than to positive affect and to negative affect. This conclusion is of interest, because also on other grounds it can be argued that, while Watson and Tellegen's rotation of the bidimensional plot appears to reflect the ecology of emotional states, Russel's (1980) rotation better reflects basic emotional processes (Frijda, 1993).

Although, as we noted above, the specificity model of respiration-emotion relationships cannot be rejected, the available evidence is more readily compatible with a dimensional or response requirement view. The evidence is most easily interpreted in terms of functional response modes ("excitement", "active coping" etc.); strong similarities exist between the respiratory patterns in cognitively oriented tasks and tasks designed to elicited specific emotions, as well as between those in widely diverging emotions. Against the dimensional model, in the way we defined it earlier, and to the extent that it is different from a response requirement model, one may hold the fact that no pattern of respiratory response, so far, has distinguished between pleasant and unpleasant states.

The emotion aspects found to be reflected in respiration are fairly crude. Further differentiation, either between emotions or between aspects of behavior energetics, probably requires inclusion of additional respiratory parameters to those usually measured, and application of sophisticated analysis techniques. As we have seen, traditional respiratory analysis techniques are limited to assessment of changes in RR, depth, and Vt. The main disadvantage of these techniques is that they do not provide insight in the mechanisms which determine Vt and RR (Milic-Emili et al., 1981). Therefore, analysis of respiratory parameters should proceed along the lines that were proposed by Milic-Emili and his co-workers (1976, 1981), and that we have described in the section on respiratory parameters. Moreover, rate, depth and volume may not be sufficient nor subtle enough to detect emotion-relevant differences. Additional phasic components of the breathing cycle such as saccadic respiratory movements, hypopnoea, apnoea, inspiratory and expiratory pauses, the inspiration-expiration angle, and sighing might have to be included in the analyses. The effects of inhibitory processes could probably be evaluated by morphological parameters such as angularity of the respiratory curve (Clausen, 1951; Gautier, 1980), and disturbances of control processes by irregularities in breathing. With the aid of modern computer procedures and techniques, reliable component analyses of the breathing cycle can be undertaken (see Cohen et al., 1975; Wientjes et al., 1988; Boiten, 1993a,b). Investigating these additional parameters is both desirable and feasible.

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