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Assessing Attentional Control of Breathing by Reaction Time

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ABSTRACT

The reaction time (RT) to an auditory stimulus was measured in 27 subjects during spontaneous breathing and during controlled breathing, which consisted of maintaining a set inspiratory duration. During spontaneous breathing, reaction times were unrelated to the time the stimulus was delivered during the breathing cycle. During controlled breathing, reaction times were longer than during spontaneous breathing. Peak reaction times were observed at the transition from inspiration to expiration. After the end of controlled breathing, reaction times gradually became shorter until they reached their initial level. The findings are discussed in terms of varying allocation of attentional resources to breathing. It is argued that probe RT methodology provides a suitable means for investigating attentional control of breathing.

DESCRIPTORS: Probe reaction time, Breathing, Voluntary control.

Spontaneous breathing is adjusted by the bulbopontine respiratory centers as a function of metabolic needs. Nevertheless, breathing is not only influenced by these respiratory centers, but more generally by all the main descending systems (Hugelin, 1986; Plum & Leigh, 1981; Von Euler, 1983). One of the clearest illustrations of the multiplicity of these pathways is an individual's ability to alter his or her breathing pattern by shifting from spontaneous breathing to transient voluntary control. Moreover, even the slightest attentional control of breathing affects breathing (Western & Patrick, 1988) independently of metabolic drive. Little is known about the link between spontaneous and voluntarily controlled breathing, but there is a broad consensus that the descending influences from the cortex also act on the bulbopontine centers via corticobulbar pathways. Use of cortical stimulation technique (Gandevia & Rothwell, 1987) has indicated that there is a direct projection from the motor cortex to the diaphragm via monosynaptic or oligosynaptic pathways in humans. Moreover, Bassal and Bianchi (1981) have shown that cortical stimulation inhibits inspiratory bulbospinal neurones in cats. These results support the hypothesis that descending influences from the cortex excite both the respiratory motoneurones and the output stage of the respiratory bulbar oscillator, while inhibiting the latter's oscillatory activity (Hugelin, 1986). Along with previous results on kinematic aspects of breathing (Gallego & Camus, 1988; Gallego & Perruchet, 1988), this also suggests that voluntary control of breathing is similar to most other motor acts, as noted by Sears (1971).

One problem in physiological research is that inferences concerning the functioning of the bulbopontine centers are often derived from analysis of breathing patterns of subjects placed in an experimental environment. Because these subjects are likely to exert some control on breathing, it is unwise to interpret their breathing pattern directly in terms of functional properties of the respiratory centers, even though that is often done. This difficulty, sometimes termed the "behavioral bias," affects most respiration physiology research in humans.

This obstacle has rarely been addressed by physiologists. Some authors have used distractors to prevent subjects from focusing on their breathing, but have not investigated to what extent the resultant

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breathing was really spontaneous or attentionally controlled. This lack of theoretical and methodological tools for assessing the attentional control of breathing is possibly due to the fact that the concepts underpinning this bias (attention, voluntary control, automaticity, etc.), which are current concepts in contemporary experimental psychology, are not part of the traditional knowledge of physiologists.

Accordingly, the first aim of the present study was to develop a methodological tool capable of differentiating spontaneous breathing from attentionally controlled breathing. The basis for this distinction was defined as the difference in attentional resources presumably available in each case. These resources were operationally investigated using reaction time (RT) to an auditory stimulus. Due to the greater resources used when subjects exert attentional control of breathing, a lengthening of this probe reaction time was expected. Under this assumption, spontaneous and controlled breathing can be differentiated by differences in reaction time to the auditory stimulus.

The second purpose was to use RT performance to investigate differential allocation of attentional resources to inspiration or expiration. Differences in reaction time as a function of the breathing phase have been analyzed by many authors for theoretical purposes different from ours, and with highly contradictory results (Beh & Nix-James, 1974; Biro & Sebej, 1979; Blinkov & Nikandrov, 1985; Buchsbaum & Callaway, 1965; Coles, Pellegrini, & Wilson, 1982; Engel, Thorne, & Quilter, 1972; Gaskill, 1928; Hildebrandt & Engel, 1963; Kuzmenko, 1978; Loskutova, 1975; Nikandrov & Blinkov, 1983; Obrist, Webb, & Sutterer, 1969; Weiss, 1960). For instance, Buchsbaum and Callaway (1965) report that reaction time is slower during inspiration, a characteristic they attribute to an inhibitory effect of inspiration mediated via the vagus. According to these authors, vagal discharge on inspiration stimulates the nucleus tractus solitarius, and this nucleus, in turn, is credited with having widespread inhibitory effects. This implies that stimulation of the vagus during inspiration creates reflex motor inhibition. Conversely, Beh and Nix-James (1974), who found that reaction time was significantly shorter during inspiration, attribute this difference to the degree of muscle involvement in both phases. During inspiration, thoracic and diaphragm muscles contract, whereas during normal expiration these muscles relax. On the basis of previous findings indicating that the presence of mild tension facilitates motor responding, Beh and Nix-James conclude that muscle tension during inspiration might have a facilitating effect on motor responding that could account for the shorter reaction time during inspiration. In the Engel et al. (1972) and Biro and Sebej (1979) studies, no clear relationship was found between reaction time and the phase of the breathing cycle. These examples clearly show the perplexing status of this question. Without challenging previous interpretations, it seemed useful to reappraise these conflicting results by analyzing the attentional aspects of the question, and especially the degree of attentional control of breathing, which has commanded practically no experimental interest up to now.

Methods

Subjects

Thirty healthy subjects volunteered for this experiment. Subjects were undergraduate students, mostly enrolled in medical school or psychology. They were not informed of the purpose of the experiment. None were familiar with breathing experiments. Three were rejected, one because of a technical failure, and two for inability to follow instructions. These two subjects could not complete a normal session. The remaining 27 subjects (8 males and 19 females; mean age 27.7 ± 5.2 years) took part in one experimental session. Subjects were paid for participation.

Apparatus

The experimental setup was composed of a heated Fleisch pneumotachograph (no. 2) with a pressure transducer (Schlumberger CH510510, no. 13, conditioner CA1065), an analog processing device built in the laboratory which detected the transitions between inspiration and expiration and integrated the flow signal for the calculation of tidal volume (V_T), an analog-to-digital converter (Selia PA300), a microcomputer (Olivetti M24), and an oscilloscope (Tektronix 5103N). An airtight facial mask attached to the pneumotachograph was then suspended at the appropriate height and fastened to the subject's head (no leakage was observed). The two inputs to the computer were tidal volume (V_T) and a signal from a relay that shifted each time the flow crossed zero. The computer used this binary signal to compute inspiratory times and expiratory times (T_I and T_E). The sampling frequency for this signal was about 500 Hz. Volume was calibrated before each session in Ambient Temperature, Pressure, and Saturation (ATPS conditions) with a sinusoidal pump built in the laboratory. All volume measurements were then converted into BTPS units (Body Temperature, Pressure, and Saturation). The 50-ms auditory stimuli were generated at a comfortable audible volume (about 20dB) by the computer and delivered binaurally to the subject via headphones. The intertrial period varied randomly from 2–10 s. The reaction time task consisted of depressing one particular key of the computer keyboard placed near the right arm of the subject's chair. Visual feedback used in the controlled breathing task was presented on the computer monitor just after the end of every tenth inspiration; a horizontal segment moved up to a position corresponding to the mean duration of the ten preceding T_Is (terminal, intermittent, and proportional feedback). Two horizontal lines (minimum and maximum values) represented the target. The screen resolution allowed 200 vertical steps corresponding to 4 s. Computer programs were written in Basic and compiled by Quick Basic Compiler. Computer measures of time durations were electronically validated with the oscilloscope.

Procedure

Subjects were tested individually. Each subject was seated in an armchair opposite the computer display with his or her right hand resting comfortably on a support. The subject was shown how to operate the key and instructed to press it as quickly as possible whenever a sound was delivered through the headphones. Ten practice trials were then run, followed by the 50 experimental trials (which constituted Phase 1). Next, the subject was given standardized instructions concerning Phases 2–5. During Phase 2 (20 cycles) the subject read a text chosen by the experimenter for its neutral emotional impact. While the subject was reading, the experimenter monitored breathing signals on the oscilloscope, and the numerical values of T_I, T_E, and V_T on the computer display. After allowing a 10-min period for the subject to adapt to the apparatus, 20 reference values were collected for T_I, T_E, and V_T. Phase 3 (50 trials) was devoted to the reaction time task, like Phase 1, but was performed with the respiratory apparatus. At the beginning of Phase 4, a training period corresponding to the first 15 cycles with continuous feedback was provided. The subject then carried out the controlled breathing task and the reaction time task simultaneously (50 RT trials). During this phase, the subjects had to maintain T_I at individually predetermined target intervals. This target was displayed as two horizontal lines at the beginning of the phase. The distance between these lines corresponded to an interval of .2 s, and the center of that interval corresponded to the mean T_I value calculated during Phase 2. The visual feedback informed the subject of the duration of each inspiration. The significance of this feedback was explained with instructions to keep the moving segment inside the target delimited by the two horizontal lines. The visual feedback appeared only every ten breathing cycles, in order to limit possible interference with the RT task. Subjects were instructed to give priority to the breathing task over the RT task. At the end of Phase 4, the mask was removed. The last phase (Phase 5, reaction time) was identical to Phase 1 (50 trials of reaction time only).

Data Analysis

Repeated measures ANOVAs were used to evaluate the effects on reaction time of respiratory phases (two levels inspiration and expiration) and time of stimulus delivery (four levels, corresponding to a division into four equal time intervals of the total duration of respiratory phases during which the stimulus was delivered). A further ANOVA was performed on the ventilatory data (T_I, T_E, and V_T) to evaluate the effect of auditory stimulation on breathing. These analyses were coupled with planned comparisons between experimental phases. All main effects and interactions involving repeated measures were tested using degrees of freedom adjusted in terms of asymmetry of the covariance matrices (Howell, 1982). In reporting the analyses, the Greenhouse and Geisser epsilon value and the appropriately adjusted degrees of freedom are provided.

Results

Performance on the Breathing Task

Three classical performance indices were used—absolute, constant, and variable error (AE, CE, and VE, respectively; see Schmidt, 1988). The corresponding formulas are:

$$\mathrm{AE} = \Sigma \mid T_{I,i} - T^* \mid / \mathrm{N} ;$$
$$\mathrm{CE} = \Sigma\, (T_{I,i} - T^*) / \mathrm{N} ;$$
$$\mathrm{VE} = (\Sigma(T_{I,i} - T)^2 / \mathrm{N})^{1/2}$$

where $T_{I,i}$ are the successive inspiratory durations, T is their mean value, T^* is the target T_I, and N is the number of values. The means and standard deviations over the subjects for these indices (in ms) were 222 ± 88, −76 ± 130, and 247 ± 78. This high accuracy in the control of breathing indicates that the subjects correctly followed instructions to focus on this control in Phase 4.

Effects of Respiration on Reaction Time

Variations in reaction time across the experimental phases. The raw data for each subject consisted of the 200 RT values (50 RTs for all phases, except Phase 2, which did not include any RT trials). These reaction times were averaged over 20 blocks of 10 successive trials (5 trial blocks per phase). These means (SDs) were: Phase 1 (reaction time only), 249 (38) ms; Phase 3 (reaction time with respiratory apparatus), 261 (39) ms; Phase 4 (reaction time plus control of breathing), 374 (85) ms; and Phase 5 (reaction time only), 280 (45) ms. An ANOVA was performed with experimental phase and blocks as within-subject factors. This analysis revealed significant changes across experimental phases, $F(1/34) = 96.30$, $p < .001$, $\epsilon = .44$. Partial comparisons showed a significant increase in reaction time between Phases 1 and 3, $F(1/26) = 13.73$, $p < .001$, and between Phases 3 and 4, $F(1/26) = 116.69$, $p < .001$, and a decrease from Phases 4 to 5, $F(1/26) = 71.48$, $p < .001$. The major change in reaction time during Phase 4 reflects the attentional control devoted to breathing. After the learning effect indicated by the decrease in reaction time at the beginning of Phase 1, a slight increase in reaction time was observed in Phases 1 and 3, possibly due to the subjects' fatigue. At the beginning of Phase 4, the marked increase in reaction time reflects the initial difficulty of carrying out the reaction time and breathing tasks simultaneously. The long reaction times observed during Phase 4 did not diminish immediately after the breathing task was over, as shown by the gradual decrease in the RT curve at the beginning of Phase 5. This decrease in reaction time was probably due to the gradual reorientation of attention from the breathing task to the RT task. At the end of the phase, a slight increase in reaction time was observed, presumably due to fatigue. These changes across experimental phases are illustrated in Figure 1.

Comparison of reaction time during inspiration and expiration. An ANOVA was performed with experimental phase and breathing phase as within-subject factors. During spontaneous breathing (Phase 3) there was no difference between the reaction times to the stimuli delivered during inspiration and those to the stimuli delivered during expiration (see Figure 2). However, during controlled breathing (Phase 4), reaction times were significantly longer during expiration, $F(1/26)=5.06$, $p<.05$. These observations were supported by a reliable Breathing × Experimental Phase interaction, $F(1/26)=7.23$, $p<.05$.

Relationship between reaction time and time of stimulus delivery during inspiration or expiration. Inspiratory and expiratory phases were divided into four equal intervals 0–25, 25–50, 50–75, and 75–100 percent of the duration of the respiratory phase. An ANOVA was performed with interval and breathing phase as within-subject factors. During spontaneous breathing, reaction time did not depend on the time of stimulus delivery. Conversely, a clear dependence was observed during controlled breathing, as confirmed by a reliable Phase × Interval interaction, $F(2/69)=3.15$, $p<.05$, $\epsilon=.89$. However, Figure 2 clearly shows that reaction time reliably depended on time of stimulus delivery only during the controlled expiratory phase, $F(2/56)=5.00$, $p<.01$, $\epsilon=.73$, during which the reaction times corresponding to the four intervals displayed a decreasing linear trend, $F(1/26)=12.76$, $p<.01$. The possibility that the high mean value of reaction time at the beginning of expiration was due to the occasional simultaneous occurrence of the auditory stimulus and visual feedback in certain cycles was ruled out. This was clearly shown by the absence of any marked differences between the reaction times corresponding to the cycles with or without visual feedback (394 ms vs. 386 ms respectively, $F(1/26)<1$). More generally, the proximity of each cycle to the last or next feedback had no significant effect on reaction time. This lack of interference between the auditory stimulus and the visual feedback is easily explained by the fact that the visual feedback was provided only every tenth breathing cycle.

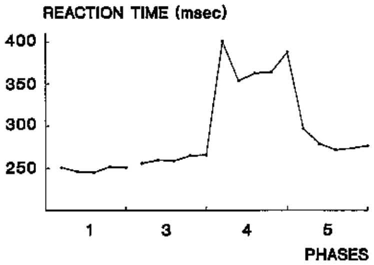

Figure 1. Reaction times for the 27 subjects are averaged over 5 successive trials. Phases 1 and 5: reaction time task only (without apparatus); Phase 3: reaction time task (with apparatus); Phase 4: control of breathing and reaction time task.

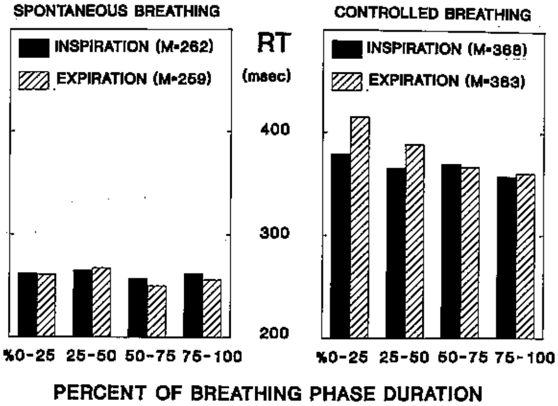

Figure 2. Comparison of reaction times during spontaneous breathing (Phase 3) and controlled breathing (Phase 4). Inspiration and expiration are divided into four equal periods corresponding to 0–25, 25–50, 50–75, and 75–100 percent, respectively, of the total duration of the phases concerned. For each interval, reaction times are averaged over all the cycles and then for the 27 subjects.

Effect of Probe Reaction Time and Breathing Task on Ventilatory Parameters

The comparison between the experimental phases with and without probe RT (Phases 2 and 3) showed that the RT task significantly reduced V_T, $F(1/26)=17.64$, $p<.001$. The other changes were not significant (see Figure 3). During Phases 3 and 4, the intertrial period varied from 2–10 s, and the breathing cycle lasted about 4 s. Because of this, not all breathing cycles were interrupted by an auditory stimulus. The cycles with and without stimuli were compared. During spontaneous breathing (Phase 3), when an auditory stimulus occurred dur-

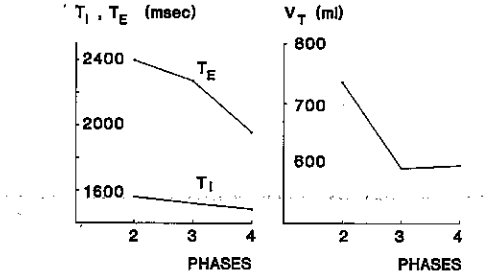

Figure 3. Ventilatory data. T_I, inspiratory time; T_E, expiratory time; V_T, tidal volume; Phase 2, spontaneous breathing without reaction time; Phase 3, spontaneous breathing with reaction time; Phase 4, controlled breathing with reaction time. Values are averaged over all the breathing cycles of the corresponding phase, and then for the 27 subjects. Mean number of cycles per phase: 75 for Phase 3 and 105 for Phase 4.

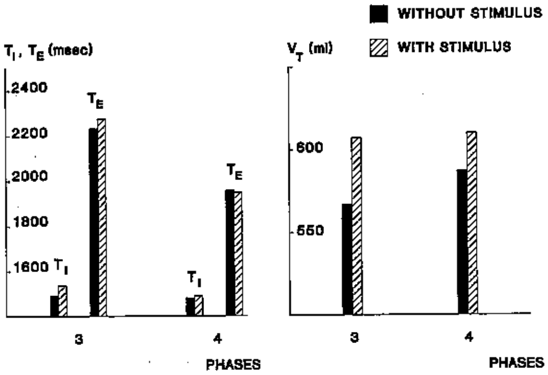

Figure 4. Inspiratory and expiratory times (T_I and T_E), and tidal volume (V_T) during spontaneous breathing (Phase 3) and controlled breathing (Phase 4). Auditory stimuli were delivered in 40% of the cycles in Phase 3 and 55% of the cycles in Phase 4. Values are averaged for the 27 subjects.

ing inspiration, T_I and V_T reliably increased, $F(1/26)=6.75$, $p<.05$, and $F(1/26)=10.53$, $p<.01$, respectively (see Figure 4). During controlled breathing (Phase 4), only V_T increased, $F(1/26)=9.42$, $p<.01$. These comparisons indicated that the decrease in V_T from Phase 2 to Phase 3 did not correspond to the specific effect of the auditory stimuli on the cycles, which tended instead to increase V_T.

Discussion

The present study assessed the importance of attentional control of breathing using a secondary task technique. When the subjects focused some of their attentional resources on breathing, the attentional resources available for processing the secondary task diminished, and the reaction time rose considerably. Hence, this deterioration in the performance on the concurrent secondary task may reflect the extent of attentional demands associated with control of breathing.

In our experiment, the increase in reaction time was considerable because voluntary control induced by the breathing task was particularly attention-demanding. In more common experimental situations, such as those frequently encountered in physiological research, voluntary control might be less pronounced, as in the beginning of the last phase of our experiment, after the breathing task was over. At this point, the decrease in reaction time signified the gradual reallocation of the subjects' attentional resources from the breathing control to the probe reaction time. This suggested that attentional control of breathing is maintained for some time after the cessation of instructed control, an eventuality that must be borne in mind whenever subjects' breathing is experimentally manipulated.

Our results showed that during spontaneous breathing, there was no difference between reaction time to stimuli presented during inspiration and reaction time to stimuli presented during expiration. This spontaneous breathing did not require high attentional resources and, consequently, did not noticeably interfere with the RT task. As a result, reaction times were short and were not related to the breathing phase. On the other hand, controlled breathing was attention-demanding, and the concurrent reaction times were therefore long. It must be stressed that this interference does not imply that the resources involved in the two tasks are identical, but rather that these tasks require some of the same processes or resources. Actually, various studies have justifiably argued that attention should not be conceptualized as a single resource, but rather as a set of pools of resources, each with its own capacity, and each designed to handle a certain kind of information processing (McLeod, 1977; Navon & Gopher, 1979; Wickens, 1976, 1980).

Our results for spontaneous breathing are at variance with several studies reporting either longer or shorter reaction times during inspiration. This may be due to methodological differences across studies, as Buchsbaum and Callaway (1965) and Engel et al. (1972) have rightly pointed out. For instance, several authors used a warning signal; second, in this case, the foreperiod was rarely controlled for; third, subject populations differed in age, occupation (students or laboratory staff), acquaintance with experimental environments, and control of breathing; fourth, adaptation to the apparatus—and the correlative change in breathing behavior—was not assessed. Further, only one of these studies examined whether subjects exerted attentional control on their breathing (Blinkov & Nikandrov, 1985), but did not measure the time course of this control during the different phases of the breathing cycle. Attentional focus could account for most of the differences in reaction time during inspiration and expiration reported in the present paper, and might also explain some of the contradictions in previous studies. From an attentional point of view, a crucial distinction must be made between studies that use a warning signal and those that do not. A warning signal momentarily reallocates attentional resources from breathing to the RT task. Consequently, no differences are expected between reaction time during inspiration and expiration, because neither is attention demanding at the moment of stimulus onset. This is what was actually found by Engel et al. (1972) and Loskutova (1975). Similarly, no difference should be found between controlled and spontaneous breathing, because all the attentional resources are momentarily reoriented toward the external stimulus after the warning signal. Blinkov and Nikandrov (1986) report this kind of data. In contrast, when no warning signal is given (as was the case in our study) reaction times reflect the amount of attentional resources devoted to breathing (spontaneous or controlled). One plausible hypothesis is that reaction times will be longer during controlled than during spontaneous breathing (this was actually found in our study), and that no difference will be found between the different phases of *spontaneous* breathing. If no precautions are taken to ensure the spontaneity of breathing (adaptation to the apparatus, instructions, secondary tasks, etc.), subjects may focus on their breathing and, in this case, certain differences in reaction time may parallel the varying amount of attentional resources devoted to breathing. This may lead to different relationships between reaction time and breathing according to the way breathing was attentionally controlled. This may be one of the reasons for the conflicting results in previous studies. The similarity between Beh and Nix-James's finding and ours, as far as controlled breathing is concerned, may be due to the fact that these authors' subjects controlled their breathing during the experiment. In our experiment, subjects were instructed to read for 10 min before breathing data were collected, and this familiarization period is the minimum required to limit the attentional control of breathing created by the breathing devices. Indeed, it may justifiably be concluded from all previous studies on the relationship between reaction time and breathing that no consistent results can be obtained as long as the level of attentional control of breathing is not experimentally controlled.

During controlled breathing, reaction times were longer than baseline during both inspiration and expiration; reaction times were also shorter during inspiration than during expiration. However, this latter effect depended entirely on the significant increase in reaction time at the beginning of expiration, i.e., at the transition from inspiration to expiration. These results might be explained by the strategy adopted by most subjects. This strategy consisted of a swallow and a regular pattern of control of expiration as well as inspiration, as shown by the substantial decrease in expiratory duration when subjects were required to control only for inspiration. Due to this, reaction times were long during both phases. The peak reaction times at the beginning of expiration indicate a transient increase in attentional demands, possibly due to the specific role of the diaphragm at this particular stage. It is known that when inspiration ceases, the diaphragm remains contracted during the initial phase of expiration, relaxing gradually and acting as a brake on expiratory flow (Derenne, Macklem, & Roussos, 1978). The decision to stop inspiration (i.e., to start expiration) therefore implies precise control of the diaphragm. The time course of the antagonist activity of the diaphragm in the initial stage of expiration, as reported by Delhez (1975), fits nicely with the decreasing trend of reaction time during expiration observed in our study. Given the difficulty for untrained subjects to exert accurate control over the diaphragm (Delhez, 1975), this shift from agonist to antagonist activity of the diaphragm might give rise to a transient difficulty in controlling breathing and processing the auditory stimuli simultaneously.

Because of the close connection between cardiac and respiratory activities, the question of possible mediating effects of the heart on the relationship between breathing and reaction time is a justifiable one. This would involve two components: first, the effect of breathing pattern on heart rate (respiratory sinus arrhythmia, RSA); second, the effects of heart rate on receptivity to external stimuli, i.e., the Laceys' baroreceptor hypothesis. RSA is principally reflected by the fact that at rest, heart rate increases on inspiration and decreases on expiration (see Grossman, 1983). The baroreceptor hypothesis states that the cardiovascular system can exert a modulating influence on higher centers of the brain, including the cortex, via the afferents from the baroreceptors in the ventricles of the heart, the aortic arch, and the sinus of the arterias carotis (Lacey & Lacey, 1978). Behaviorally, this influence should be observable in reduced perceptual and perceptual-motor performance in the case of an increase in baroreceptor activity and, accordingly, a performance increase in the case of reduced baroreceptor activity. A link between breathing and receptivity to external stimuli could have affected reaction time, with the mediation of heart rate and baroreceptor activity. Crucial data (heart rate, blood pressure, etc.) for testing this hypothesis were not measured in the present experiment. However, this hypothesis—in conjunction with the RSA—is poorly suited to explaining the observed differences in reaction time between inspiration and expiration, for the following two reasons. The first reason is that spontaneous variations in heart rate, such as those produced by breathing, are not associated with variation in auditory sensitivity and RT performance. This point has been addressed by Lacey and Lacey (1974), who concluded, on the basis of Edwards and Alsip's studies (1969) that unprovoked and spontaneous variations in heart rate, such as those accompanying respiration in young adults, are not associated with variation in auditory sensitivity, and more generally, that heart rate variation that occurs spontaneously is not a "sufficient condition" for variation in sensory sensitivity. Iacono and Lykken (1978) provide further evidence. Their findings show that expectant bradycardia deliberately provoked by breath-holding during the foreperiod does not speed reaction time either. The second reason is that the changes in reaction time as a function of the mode of breathing (spontaneous or controlled) are difficult to account for by the baroreceptor hypothesis. Hirsch and Bishop (1981) provided evidence that the relationship between RSA amplitude and breathing pattern is similar regardless of whether breathing is spontaneous or is voluntarily controlled. Accordingly, no difference in mean reaction times, and no interaction between the breathing phase and the mode of breathing can be predicted under the hypothesis of a causal role of RSA. Given that our results indicate different reaction times during spontaneous versus controlled breathing, it may be justifiably conjectured that cardiac mediation is not a critical factor.

The distinction made throughout this study between spontaneous and controlled breathing calls for some comment. The former is a breathing behavior that predominantly reflects the metabolic needs of the organism, and is less affected by attentional factors than the latter. Although the metabolic and behavioral components of breathing are often contrasted, it must be stressed that there are no circumstances under which breathing of normal individuals is determined only by either of these factors. In our study, the subjects had to perform an RT task, which affected the breathing pattern by reducing V_T markedly and T_E slightly. Analysis of our ventilatory data indicated that these changes in the breathing pattern were actually caused by the new situation created by this task, and did not correspond to the specific effect of the auditory stimuli on breathing cycles. This result points to the need to distinguish between the modifications of breathing induced by situational factors and momentary perturbations provoked by a wide variety of stimuli. The absence of these stimuli is by no means a guarantee that what is observed is in fact "metabolic breathing," contrary to what is often thought in physiological research.

Our findings show that the secondary task methodology, despite its numerous drawbacks (see Fisk, Derrick, & Schneider, 1986–1987, and Jonides, Naveh-Benjamin, & Palmer, 1985), provides a suitable means of measuring attentional control of breathing whenever direct analysis of breathing pattern is inconclusive (see Gallego & Camus, 1988). This methodology can also serve to indicate which components of the respiratory phase are most directly affected by this attentional control. Conversely, spontaneous breathing can be characterized by its lack of interference with any secondary task. Analysis of secondary task interference could enhance experimental control of attentional factors in respiratory physiology research. In the clinical field, interference analysis could also enhance various breathing therapies which aim at modifying the subject's spontaneous breathing, for example, in chronic obstructive pulmonary diseases. These therapies are based on the assumption that in conditions of extended practice, an initially controlled breathing pattern can become spontaneous. Numerous methodological and theoretical questions are raised by this particular kind of learning (Gallego et al., 1986), and among these questions, more are raised on how to investigate the progressive shift from controlled to spontaneous breathing. These interesting issues call for further research on controlled and spontaneous breathing.

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