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Expiratory time determined by individual anxiety levels in humans

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Masaoka, Yuri, and Ikuo Homma. Expiratory time determined by individual anxiety levels in humans. *J. Appl. Physiol.* 86(4): 1329–1336, 1999.—We have previously found that individual anxiety levels influence respiratory rates in physical load and mental stress (Y. Masaoka and I. Homma. *Int. J. Psychophysiol.* 27: 153–159, 1997). On the basis of that study, in the present study we investigated the metabolic outputs during tests and analyzed the respiratory timing relationship between inspiration and expiration, taking into account individual anxiety levels. Disregarding anxiety levels, there were correlations between \dot{V}_{O_2} consumption (\dot{V}_{O_2}) and minute ventilation (\dot{V}_E) and between \dot{V}_{O_2} and tidal volume in the physical load test, but no correlations were observed in the noxious audio stimulation test. There was a volume-based increase in respiratory patterns in physical load; however, \dot{V}_E increased not only for the adjustment of metabolic needs but also for individual mental factors; anxiety participated in this increase. In the high-anxiety group, the \dot{V}_E -to- \dot{V}_{O_2} ratio, indicating ventilatory efficiency, increased in both tests. In the high-anxiety group, increases in respiratory rate contributed to a \dot{V}_E increase, and there were negative correlations between expiratory time and anxiety scores in both tests. In an awake state, the higher neural structure may dominantly affect the mechanism of respiratory rhythm generation. We focus on the relationship between expiratory time and anxiety and show diagrams of respiratory output, allowing for individual personality.

physical load; mental stress; respiratory rate; expiratory time; anxiety

BREATHING APPEARS TO BE REGULATED in the brain stem for metabolic, homeostatic purposes. During a physical workload, increases in tidal volume (V_T) and respiratory rate (RR) contribute to a rise in ventilation (13). The reflexes of respiratory drive have been shown in the V_T -inspiratory time (T_i) relationship (6); in addition, certain stimuli alter respiratory drive (9).

In the awake state, the breathing pattern comes from the complex interaction between matching for metabolic requirements and the nonhomeostatic demands. It has been reported that auditory or visual input alters the breathing patterns under the condition of rest (23), and the production of various emotions affects breathing patterns (4); furthermore, different personality factors have affected different responses of sensitivity toward carbon dioxide (24). Research on ventilation, taking into consideration the personality factor, has been evaluated by a number of studies. People breathe in different ways in defining a resting state, and these

patterns of breathing, referred to as “ventilation personality,” are reproduced over long periods of time (22). Breathing patterns in patients with chronic anxiety have showed irregularities of rhythm (29), and our previous study demonstrated that individual anxiety levels greatly influence respiratory patterns, in particular the RR (18). Curiously, our study found that significant correlations were not observed between the scores that indicated how the subjects feel and variables of breathing parameters, but significant correlations were found between RR and state anxiety scores in the isometric leg exercise (indicated as “physical load” in the following pages) and between RR and trait anxiety scores in the mental stress test. It was Sigmund Freud who first proposed a role for anxiety in personality theory, and anxiety was described as “a specific unpleasant emotional state or condition of the human organism” (27). Since 1950, research on human anxiety has been facilitated by using scales that have been created for measuring anxiety, and the concept of state and trait anxiety was introduced in the 1960’s (26, 27).

Each person has his or her own personality traits; therefore, the psychological or physiological response toward stimulation may depend on the individual. In physiology, research on the relationship between psychological factors and respiratory parameters has not been carried out. Psychological symptoms such as fear of dying or anxiety are common feelings in patients complaining of dyspnea or a feeling of breathlessness. It has been reported that anxious patients’ perceptions were less sensitive toward added loads (28). Another study suggested that defensive subjects tend to impair accurate respiratory sensation (15). The study of the relationship between anxiety levels and respiratory parameters and between anxiety levels and sensation could assist the understanding of symptoms reported from patients.

In a pilot study, a correlation between state anxiety and RR in a physical load test, and between trait anxiety and RR in a mental stress test, was found in 10 normal subjects (18). In this study, in a new set of experiments, we tested the hypothesis that exceeding increases in RR are not related to differences in the metabolic rate but are caused by individual anxiety that enhances the respiratory drive.

We investigated breath-by-breath metabolic outputs during physical load, comparing the outputs during noxious audio stimulation and identifying the relationship between these respiratory timings and metabolic outputs between two groups of subjects, one with high anxiety and one with low anxiety.

Because our previous study found the state anxiety scores related to the RR in physical load and the trait anxiety scores related to the RR in mental stress, we

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focused on the influences of both state anxiety levels on respiratory parameters in physical load and of trait anxiety levels on respiratory parameters in noxious audio stimulation.

METHODS

Subjects

Ten undergraduate students (all men; mean age 21 ± 1.6 yr), who were naive to the purpose of the study, participated. Before the experiments the subjects signed an informed consent, and all were tested for anxiety levels by using Spielberger's State-Trait Anxiety Inventory (STAI) (26).

Two sets of experiments were carried out in each subject, a study of physical load and a study of noxious audio stimulation. The subjects were examined twice for each study, and the raw data of *trial 1* and *trial 2* were combined statistically.

Measurements

STAI. Before they entered a dark, soundproof room, subjects' anxiety levels were evaluated by Spielberger's STAI (26) translated into Japanese (19). The reliability and validity of this version have been evaluated by many researchers (26). The STAI is designed to be self-administered and consists of two anxiety scales, state anxiety and trait anxiety. Each test form has 20 statements and requires ~15 min to complete both. The state anxiety scale is used to evaluate how people feel ("right now") in a variety of situations. For example, the scale has been used to assess the level of state anxiety induced by a stressful experimental situation or an important school test. The trait anxiety scale is used to assess how people generally feel, referring to stable individual differences in proneness to anxiety. Accordingly, the trait anxiety scores are generally not influenced by any conditions. The purpose of using this scale is to measure the state and trait anxieties separately. Because the experiment was performed in a laboratory situation, the subjects might be in a nervous state or be sensitive toward these procedures. Therefore, we wanted to understand how the subjects were feeling right then at the moment. In addition, in a future study we intend to investigate different state anxieties in individuals and whether the anxieties affect subjects' respiratory parameters.

O₂ consumption ($\dot{V}O_2$) and CO₂ production ($\dot{V}CO_2$) during tests. Other measurements were made in the dark, soundproof room separated from the investigator. The subjects were seated on a chair, wore a face mask, and kept their eyes open; a 10-min rest period was allowed for them to adapt to the apparatus. An aeromonitor (AE280, Minato Medical Science, Osaka, Japan) (16) was installed outside the soundproof room. The AE280 consists of a microcomputer, a hot-wire flowmeter, O₂ and CO₂ analyzers, (Zr element-based O₂ analyzer and infrared CO₂ analyzer). Gas was sampled by pumping it through a filter into the analyzers at the rate of 220 ml/min. On a breath-by-breath basis, the AE280 continuously calculated minute ventilation ($\dot{V}E$), V_T , RR, $\dot{V}O_2$, $\dot{V}CO_2$, end-tidal fraction of CO₂ (F_{ETCO_2}), T_I , and expiratory time (T_E). The system was calibrated before each study. The accuracy of the system measuring the breath-by-breath calculation of $\dot{V}O_2$ and $\dot{V}CO_2$ was confirmed with the same results in measuring $\dot{V}O_2$ obtained by the gas-collection method (20).

Physical load. For physical load (isometric leg exercise), a Velcro belt attached to a spring balance was wrapped around the subjects' knees; the subjects were asked to stretch their knees, holding a 7-kg load, in an outer direction. The reason for choosing this physical load is that a prior exercise study

reported that breathing frequency is entrained by the rhythm of the exercise (3), so we omitted this factor.

Noxious audio stimulation. For noxious audio stimulation, subjects wore headphones to deliver noxious sounds: incessant sawmill noise from a compact disk of environmental sounds, with a volume set at 73 dBA (King Record). The sound was delivered by a digital portable stereo compact disk system (Panasonic RX DT7). Through a study of aggregation of noise (7), 73 dBA is a level characterized as "moderately loud."

Measurement during the resting state for a baseline over 3 min during physical load or over 2 min during noxious audio stimulation, and 3 min after the tests were over, was monitored after a 10-min interval for subjects to adapt to the apparatus. As mentioned above (see *Subjects*), subjects were tested twice for each study, and results of the two trials were combined statistically. In one report, only 2 min of noxious stimulation were administered for fear of causing adaptation to the stimulation (17). We used this time period for one trial, and the trial was recorded twice because we wanted to have more data to analyze each subject. In addition, we wanted to avoid emotional factors that might arise if one trial were over a long period of time, such as, for example, fatigue toward the physical load or any feeling caused by the subjects not being acclimatized to the apparatus. Statistically, 20 breaths before each test were reserved for baseline and 20 breaths during the test for the physical load or noxious audio stimulation.

Statistical Analysis

Differences between the raw data before and during the manipulations were analyzed by a repeated-measures ANOVA. To calculate repeated-measures ANOVA, we entered each subject's raw breath-by-breath data, not the means. The probability values applying the Greenhouse-Geisser correction procedure for ANOVA were used to control for possible violations of the assumption of homogeneity of variance. We calculated a correlation coefficient for the linear regression analysis. Data are reported as means \pm SD in Tables 1–4, and the scatterplots indicate mean value of each subject in Figs. 1–5.

RESULTS

Age and individual STAI scores are shown in Table 1. In the STAI, subjects blacken a number beside each

Table 1. Individual STAI scores of 10 normal subjects

Subject No.	Age, yr	Wt, kg	STAI	
			State	Trait
1	20	60	43	46
2	22	72	42	46
3	21	65	51	59
4	22	88	44	49
5	21	62	37	46
6	20	70	33	51
7	25	67	37	39
8	20	76	38	42
9	20	53	28	38
10	20	55	34	42
Mean \pm SD	21 \pm 1.6	66.8 \pm 10.39	38.7 \pm 6.53	45.8 \pm 6.21

STAI, Spielberger's State-Trait Anxiety Inventory. Brackets denote high state or trait values; bold numbers denote low state or trait values.

Table 2. Effects of physical load on respiratory parameters in subjects with low and high state anxiety

Parameter	Subjects With Low State Anxiety		Subjects With High State Anxiety	
	Baseline	Physical load	Baseline	Physical load
\dot{V}_E , l/min	7.84 ± 1.76	10.1 ± 2.74†	7.19 ± 1.94	9.97 ± 2.31†
V_T , ml	642 ± 163	811 ± 289†	588 ± 171	730 ± 277†
RR, breaths/min	12.8 ± 3.2	13.6 ± 4.7*	13.1 ± 4.6	15.1 ± 4.9†
\dot{V}_{O_2} , ml/min	218 ± 77	289 ± 108†	208 ± 65	275 ± 80†
\dot{V}_{CO_2} , ml/min	199 ± 65	278 ± 105†	183 ± 64	271 ± 84†
FET _{CO₂} , %	5.54 ± 0.58	5.62 ± 0.75*	5.49 ± 0.91	5.43 ± 0.84*
Ti, s	2.14 ± 1.08	2.04 ± 1.13	2.38 ± 1.05	2.12 ± 0.91†
TE, s	2.95 ± 0.83	2.94 ± 1.1	2.83 ± 0.98	2.39 ± 0.93†
\dot{V}_{O_2}/kg , ml·min ⁻¹ ·kg ⁻¹	3.36 ± 0.94	4.54 ± 1.59†	2.94 ± 0.94	3.89 ± 1.18†

Values are means ± SD; *n* = 10 subjects. \dot{V}_E , minute ventilation; V_T , tidal volume; RR, respiratory rate; \dot{V}_{O_2} , O₂ consumption; \dot{V}_{CO_2} , CO₂ production; FET_{CO₂}, end-tidal CO₂ fraction; Ti and TE, inspiratory and expiratory time, respectively. Statistically different from control: **P* < 0.05, †*P* < 0.001.

item that best describes their feelings. The scores for state anxiety and trait anxiety were obtained by adding the weighted scores of the 20 items. STAI scores were graded on a scale of five according to the normalization for the Japanese version evaluated by Mizuguchi et al. (19). Trait anxiety scores were divided into I (“very low,” <23), II (“low,” 24–32), III (“normal,” 33–43), IV (“high,” 44–52), and V (“very high,” >53). State anxiety scores were also divided into I (very low, <22), II (low, 23–31), III (normal, 32–40), IV (high, 41–49), and V (very high, >50). As shown in Table 1, the subjects were divided into groups with high state anxiety or high trait anxiety (denoted by brackets) and groups with low state anxiety or low trait anxiety (denoted by bold numbers).

Effect of Physical Load and Noxious Audio Stimulation on Respiratory Parameters

Comparison between parameters for the baseline period and during physical load in each group are presented in Table 2. As metabolism changed in \dot{V}_{O_2}

Table 3. Effects of noxious audio stimulation on respiratory parameters in subjects with low and high trait anxiety

Parameter	Subjects With Low Trait Anxiety		Subjects With High Trait Anxiety	
	Baseline	Noxious audio stimulation	Baseline	Noxious audio stimulation
\dot{V}_E , l/min	7.29 ± 2.26	7.4 ± 1.85	7.49 ± 1.72	8.26 ± 1.8†
V_T , ml	640 ± 260	699 ± 283*	539 ± 169	542 ± 131
RR, breaths/min	12.7 ± 4.3	12.1 ± 4.8*	14.5 ± 3.5	15.6 ± 3.3†
\dot{V}_{O_2} , ml/min	207 ± 86	306 ± 74	189 ± 63	205 ± 63*
\dot{V}_{CO_2} , ml/min	179 ± 83	185 ± 65	167 ± 57	187 ± 59*
FET _{CO₂} , %	5.27 ± 0.62	5.47 ± 0.53†	5.38 ± 0.7	5.35 ± 0.68*
Ti, s	2.18 ± 1.57	2.43 ± 1.7	1.93 ± 0.61	1.77 ± 0.48*
TE, s	3.39 ± 1.36	3.67 ± 1.79*	2.55 ± 0.85	2.18 ± 0.48†
\dot{V}_{O_2}/kg , ml·min ⁻¹ ·kg ⁻¹	3.22 ± 1.17	3.37 ± 1.03	2.73 ± 0.92	2.95 ± 0.9*

Values are means ± SD; *n* = 10 subjects. Statistically different from control: **P* < 0.05, †*P* < 0.001.

Table 4. Effects of physical load and noxious audio stimulation on \dot{V}_E/\dot{V}_{O_2} and \dot{V}_E/\dot{V}_{CO_2} in subjects with low and high state anxiety and low and high trait anxiety

	Subjects With Low State Anxiety		Subjects With High State Anxiety	
	Baseline	Physical load	Baseline	Physical load
\dot{V}_E/\dot{V}_{O_2}	0.039 ± 0.010	0.038 ± 0.017*	0.036 ± 0.009	0.046 ± 0.086†
\dot{V}_E/\dot{V}_{CO_2}	0.041 ± 0.009	0.042 ± 0.042†	0.041 ± 0.009	0.043 ± 0.046†
	Subjects With Low Trait Anxiety		Subjects With High Trait Anxiety	
	Baseline	Noxious audio stimulation	Baseline	Noxious audio stimulation
\dot{V}_E/\dot{V}_{O_2}	0.036 ± 0.008	0.035 ± 0.009*	0.038 ± 0.011	0.052 ± 0.072*
\dot{V}_E/\dot{V}_{CO_2}	0.040 ± 0.006	0.037 ± 0.007†	0.041 ± 0.010	0.046 ± 0.056*

Values are means ± SD; *n* = 10 subjects. \dot{V}_E/\dot{V}_{O_2} and \dot{V}_E/\dot{V}_{CO_2} , \dot{V}_E -to- \dot{V}_{O_2} and -to- \dot{V}_{CO_2} ratio, respectively. Statistically different from control: **P* < 0.05, †*P* < 0.001.

and \dot{V}_{CO_2} (*P* < 0.001 in both groups), \dot{V}_E (*P* < 0.001 in each group) increased. Both V_T (*P* < 0.001) and RR (*P* < 0.05 in the low-state-anxiety group, *P* < 0.001 in the high-state-anxiety group) increased to contribute to the increase in \dot{V}_E . In subjects with low state anxiety, FET_{CO₂} increased (*P* < 0.05) and Ti and TE remained unchanged. On the contrary, FET_{CO₂} decreased (*P* < 0.05) and significant decreases in Ti and TE were observed in the high-state-anxiety group. \dot{V}_{O_2}/kg increased in both groups (*P* < 0.001) in the physical load test. With regard to the effect of physical load, differences in the ventilatory response between the high-state-anxiety and the low-state-anxiety groups were not observed, except for changes in FET_{CO₂}, Ti, and TE.

Table 3 shows that noxious audio stimulation affected V_T (*P* < 0.05) and RR (*P* < 0.05) in the low-trait-anxiety group, but the increase in \dot{V}_E was not significant. FET_{CO₂} (*P* < 0.001) significantly increased, whereas FET_{CO₂} (*P* < 0.05) decreased in the high-trait-anxiety group. This decrease was caused by an increase in RR (*P* < 0.001) as a result of both Ti (*P* < 0.05) and TE (*P* < 0.001) decreases. Although an increase in \dot{V}_{O_2}/kg was observed in the high-trait-anxiety group, \dot{V}_E increased not only for the fulfillment of the metabolic demand but also for the trait anxiety factor involved as a result of dominant RR increases reflected by Ti and TE decreases.

Correlation Between Both Anxiety and \dot{V}_{O_2} and Respiratory Parameters

A comparison of the relationship between \dot{V}_E and \dot{V}_{O_2} in both tests, disregarding anxiety levels (Fig. 1), showed linear relationships between the baseline of \dot{V}_E and \dot{V}_{O_2} (*r* = 0.6505, *P* < 0.05, ○ and solid line) and between \dot{V}_E and \dot{V}_{O_2} (*r* = 0.6571, *P* < 0.05, ● and dashed line) during the physical load (Fig. 1A). On the other hand, a correlation between \dot{V}_E and \dot{V}_{O_2} was observed during the baseline period (*r* = 0.6664, *P* <

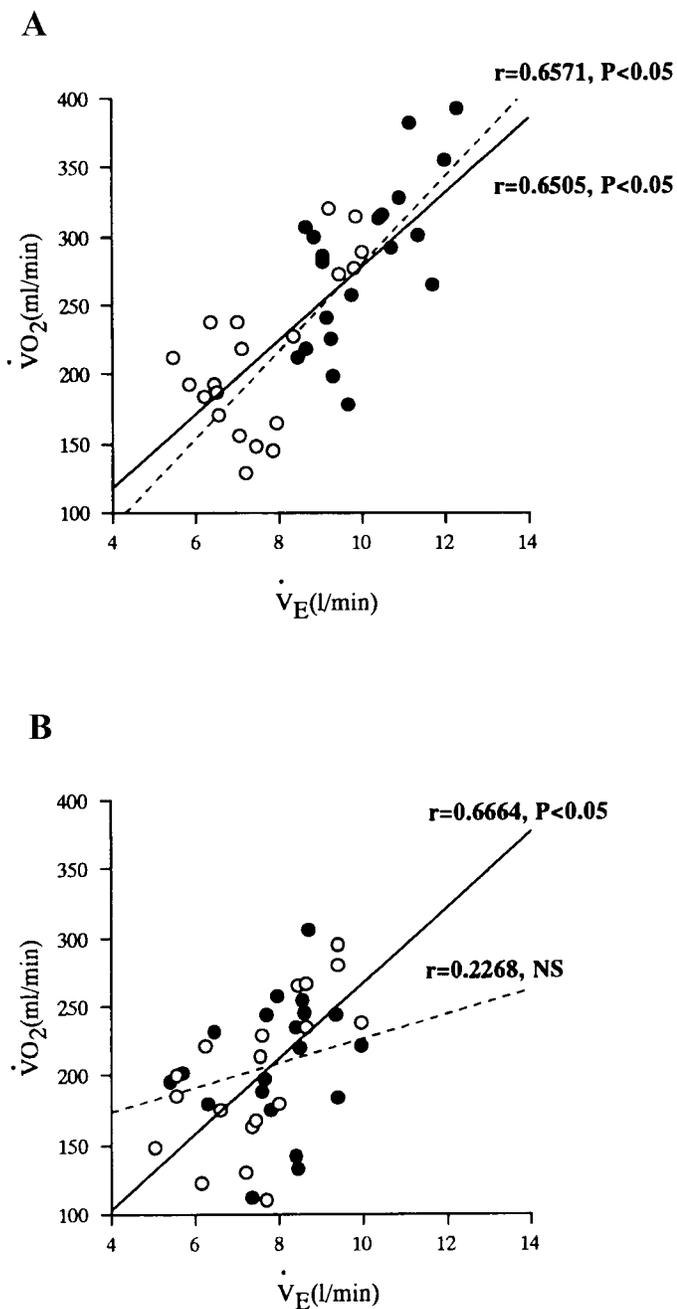


Fig. 1. A: linear plots of O_2 consumption ($\dot{V}O_2$) and minute ventilation ($\dot{V}E$) during baseline (\circ with solid line) and during physical load test (\bullet with dotted line) in normal subjects. Each state shows a significant correlation ($r = 0.6505, P < 0.05$ during baseline; $r = 0.6571, P < 0.05$ during physical load test). B: plots of $\dot{V}O_2$ and $\dot{V}E$ during baseline (\circ with solid line) and during noxious audio-stimulation test (\bullet with dotted line) in normal subjects. There was a significant correlation between $\dot{V}O_2$ and $\dot{V}E$ during baseline ($r = 0.6664, P < 0.05$), but no correlation was observed during noxious audio-stimulation test. NS, not significant.

0.05, \circ and solid line), but only $\dot{V}E$ increased while $\dot{V}O_2$ remained unchanged during the noxious audio stimulation test ($r = 0.2268, P < 0.05$, \bullet and dashed line) (Fig. 1B). There was a nonlinear relationship between $\dot{V}E$ and $\dot{V}O_2$ during noxious audio stimulation. This increase in $\dot{V}E$ was not caused by an increase in

metabolic demand. Relationships between metabolic output, RR, V_T , and anxiety scores are indicated in Figs. 2 and 3.

During physical load, as a whole V_T and $\dot{V}O_2$ correlated positively and significantly ($r = 0.448, P < 0.05$). There were no correlations between RR and $\dot{V}O_2$ ($r = 0.129$) and between $\dot{V}O_2/\text{kg}$ and state anxiety scores ($r = 0.367$); however, during noxious audio stimulation, there were no correlations between these variables as shown in Fig. 3.

Ventilatory Efficiency Observed in Subjects with Low and High Anxiety

A rise in $\dot{V}E$ over the metabolic demand in the high-anxiety group during the physical load test and the noxious audio stimulation test was also observed compared with baseline and during physical load of the $\dot{V}E$ -to- $\dot{V}O_2$ ($\dot{V}E/\dot{V}O_2$) and $\dot{V}E$ -to- $\dot{V}CO_2$ ($\dot{V}E/\dot{V}CO_2$) ratio (Table 4). In the high-anxiety group, the $\dot{V}E/\dot{V}O_2$ ratio ($P < 0.001$ in physical load, $P < 0.05$ in noxious audio stimulation) and $\dot{V}E/\dot{V}CO_2$ ratio ($P < 0.001$ in physical load, $P < 0.05$ in noxious audio stimulation) increased.

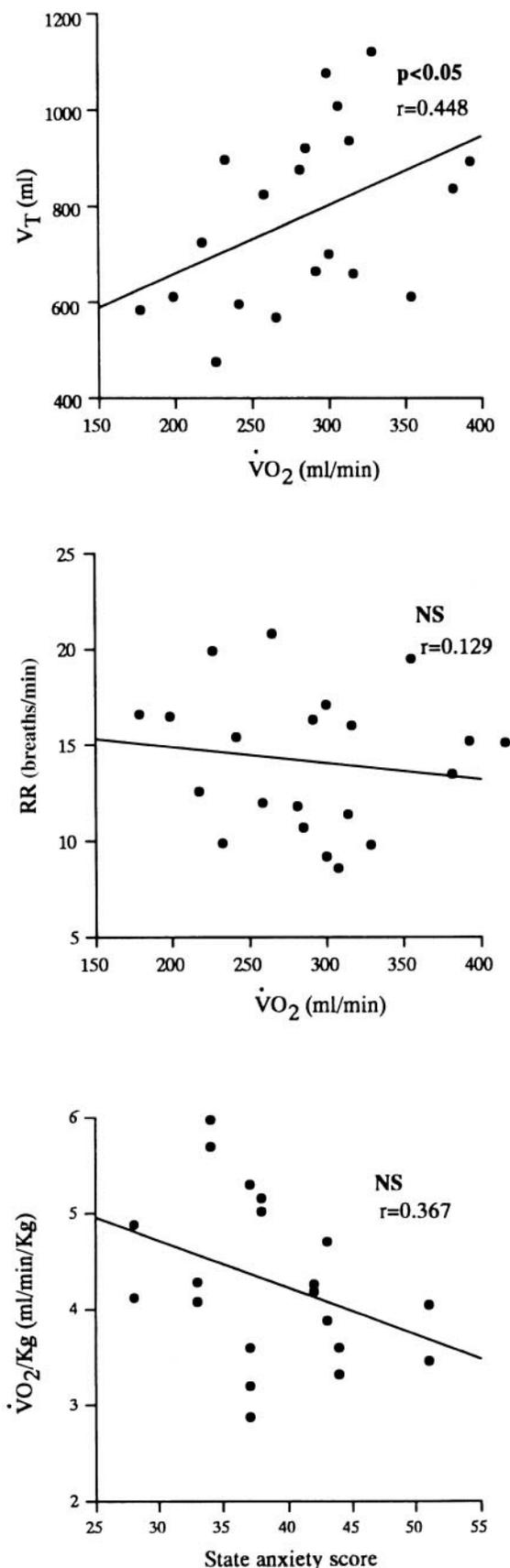
Analysis of Respiratory Timing Relationship Between Both T_I and T_E and Anxiety Scores

Figure 4 shows the relationship between decreases in T_I (\circ and dashed line) and T_E (\bullet and solid line) and state anxiety scores during physical load (*top*) and between T_I and T_E and trait anxiety scores during noxious audio stimulation (*bottom*). Taking into consideration the individual anxiety level, the difference between T_E during baseline and T_E during physical load and the state anxiety scores had a negative correlation ($r = -0.5930, P < 0.05$) (Fig. 4, *top*); in addition, a negative correlation was observed in the noxious audio stimulation test, but it was of a trait anxiety score ($r = 0.4936, P < 0.05$) (Fig. 4, *bottom*). Thus an increase in RR in people with high anxiety is related to a decrease in T_E .

DISCUSSION

A previous study showed that there was no correlation between emotion scores (feeling of unpleasantness or difficulty continuing the task) and respiratory parameters, but there was a correlation between anxiety level and RR in the physical load and the noxious audio-stimulation tests (18). In addition, interestingly, this study found that significant correlations were found between RR and state anxiety scores in the physical load test and between RR and trait anxiety scores in the mental stress test.

As we hypothesized, from the viewpoint of Spielberger's concept that explains the distinction between state and trait anxiety, an increase in RR in the physical load may change if a subject is in a different anxiety state, but an increase in RR with mental stress may not change because trait anxiety is conceptualized by a potential tendency (18). We did not examine the effect



of different state anxieties on respiration for each subject; however, from this result, we could suggest that emotional state caused by a particular situation or physical condition may affect respiratory patterns in physical workload. Spielberger (26) proposed that physiological indexes are likely to be affected by state anxiety rather than trait anxiety, but we also found that an increase in RR was related to trait anxiety in the noxious audio stimulation test. Therefore, our result suggests that the effect of psychological stimulation may be involved in a potential anxiety trait.

The present study focused on the relationship between the level of either individual state or trait anxiety and RR; we analyzed whether anxiety participates in metabolic output, whether this exceeding increase in RR was not caused to fulfill the metabolic demand, and whether the respiratory timing relationship is related to anxiety. In observing the data of physical load in Table 2, we saw that there was a similarity in most parameters comparing the high-state-anxiety and low-state-anxiety groups. However, in the high-state-anxiety group, F_{ETCO_2} decreased significantly and T_I and T_E shortened. As a whole, there was a V_T -based increase in respiratory patterns reflected by a correlation between \dot{V}_E and $\dot{V}O_2$ and between V_T and $\dot{V}O_2$. However, the result indicates that \dot{V}_E increased not only for the metabolic demand, indicating an increase in the $\dot{V}_E/\dot{V}O_2$ ratio expressed as ventilatory efficiency during physical load. In Table 2, $\dot{V}O_2/kg$ is shown to have increased in the high-state-anxiety group; however, there was no correlation between metabolic output and individual state anxiety scores. In COPD patients, the $\dot{V}_E/\dot{V}O_2$ ratio increased as a result of a decrease in ventilatory efficiency (25). An increase in ventilatory efficiency was influenced by individual high state anxiety even in normal subjects as a result of a dominant increase in RR reflected by a fall in F_{ETCO_2} . Analysis of the increase in RR in the physical load test shows there was no correlation between T_I and state anxiety scores, but there was a correlation between T_E and state anxiety scores. It has been reported that breathing frequency is entrained by the rhythm of exercise (3), but in this study the physical load test was performed without the rhythmic factor.

An increase in \dot{V}_E with a nonmetabolic purpose was also observed in the noxious audio-stimulation test. In the noxious audio-stimulation test, constancy of $\dot{V}O_2$ with noxious audio stimulation suggests that a \dot{V}_E increase is not due to increased metabolism. As also shown in ventilatory efficiency, an increase in the $\dot{V}_E/\dot{V}O_2$ ratio was observed in the high-trait-anxiety and not in the low-trait-anxiety group; there was an RR-based increase in \dot{V}_E without any metabolic factor. RR increased as a result of T_I and T_E decreases, whereas

Fig. 2. Tidal volume (V_T ; top) and respiratory rate (RR; middle) plotted against $\dot{V}O_2$ in subjects while performing physical load. A significant positive correlation between V_T and $\dot{V}O_2$ ($r = 0.448$, $P < 0.05$) was observed. No correlation between $\dot{V}O_2/kg$ and state anxiety scores (bottom) was observed.

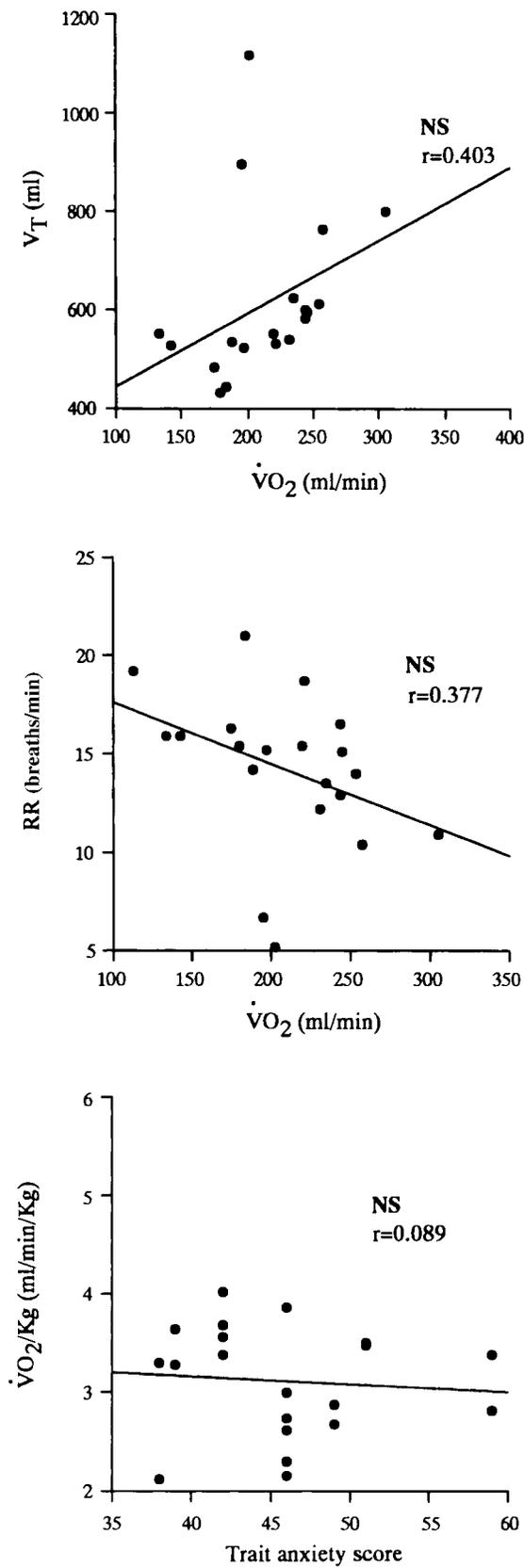


Fig. 3. V_T (top) and RR (middle) plotted against $\dot{V}O_2$ during noxious audio stimulation. There were no correlations between V_T and $\dot{V}O_2$ and between RR and $\dot{V}O_2$. No correlation between $\dot{V}O_2/kg$ and trait anxiety scores (bottom) was observed.

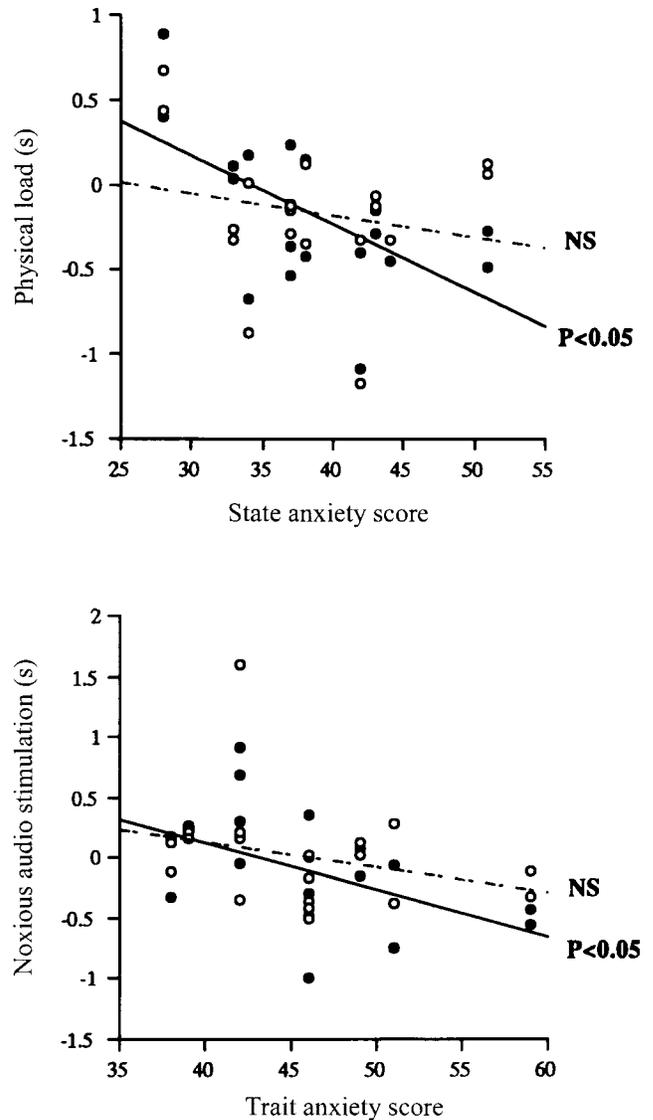


Fig. 4. Decrease in inspiratory time (T_i ; \circ with dotted line) and expiratory time (T_E ; \bullet with solid line) while subjects perform physical load test plotted against state anxiety score (top). There was a significant negative correlation between decrease in T_E and state anxiety scores. Decrease in T_i (\circ circle with dotted line) and T_E (\bullet with solid line) while noxious audio stimulation was given is plotted against trait anxiety score (bottom). There was a significant negative correlation between decrease in T_E and trait anxiety scores.

V_T was unchanged in high trait anxiety; a correlation between T_E and trait anxiety scores was also observed in the noxious audio-stimulation test.

A number of investigators have presented irregular breathing patterns during auditory stimulation (12). The increase in $\dot{V}E$ was achieved by RR without a V_T increase in audiovisual stimulation, whereas increases in both V_T and RR were observed in noxious audio stimulation (17). Our study suggests that an increase in $\dot{V}E$ is related not only to a fulfillment of the metabolic demand but also to the mental factor, in particular anxiety. Fear and anxiety behaviors are associated with elicitation of physiological changes such as increases in blood pressure and respiration (11). Gardner (10) suggested a shortening of T_E caused by anxiety in their

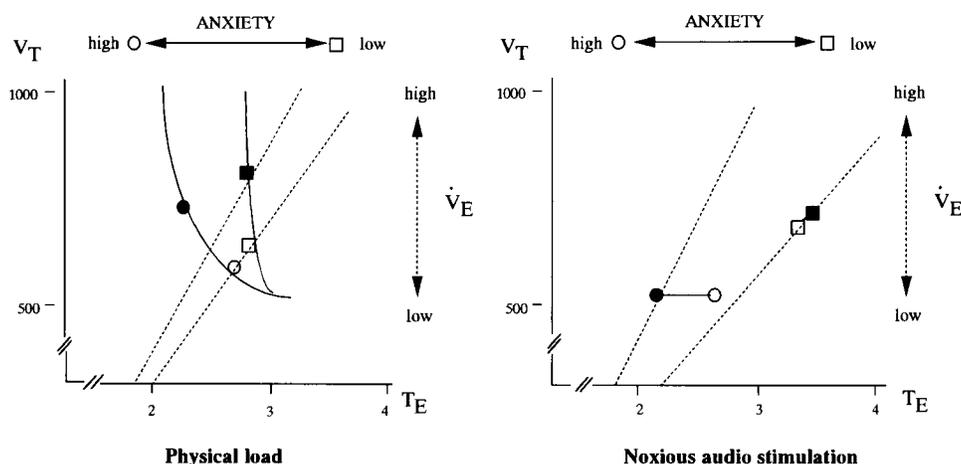


Fig. 5. Diagrams illustrating possible mechanism of V_T - T_E graphs, taking into account individual anxiety levels. Dotted lines, isoventilation lines; \square , baseline period; \blacksquare , values during physical load (*left*) and during noxious audio stimulation (*right*) in subjects with low anxiety; \circ , baseline; \bullet , during physical load and noxious audio stimulation in subjects with high anxiety. In physical load, an increase in \dot{V}_E was achieved by an increase in V_T in low-anxiety group; on the other hand, in high-anxiety group, a combination of an increase in V_T and decrease in T_E achieved a \dot{V}_E increase. In noxious audio stimulation, there was no change in \dot{V}_E and parameters in low-anxiety group, but in high-anxiety group an increase of \dot{V}_E was achieved by a T_E decrease in unchanged V_T .

subjects in a steady state. Another study demonstrated that anxiety affects both T_I and T_E (2). Although there was a difference between state anxiety and trait anxiety in each test result, this study confirmed that the anxiety level is related to the RR, particularly to T_E .

Shea and Guz (22) suggested that wakeful perception, like unpleasantness or comfort, is not an essential factor in the genesis of the breathing pattern in the normal individual. We found that change in respiratory parameters did not correlate with scores indicating how subjects feel but did correlate with anxiety levels: RR and T_E are changed not by sensation or emotion caused by sensory experience but by a factor more central, one related to the core of the human condition.

We hypothesized that, in subjects in the awake state, the mechanism of determination of T_E or determination of initiation of inspiration is greatly influenced by the individual anxiety level. Homma (14) showed, in humans, the mechanism determining the rate of increase in inspiratory activity by V_T - T_I and V_T - T_E relationships during rebreathing, which were indicated by slopes of regression lines. In Fig. 5, we drew the regression lines of the V_T - T_E relationship during the physical load and the noxious audio-stimulation tests, which accounted for the individual anxiety level. In the physical load, there was an increase in \dot{V}_E achieved by V_T in people with low state anxiety; on the other hand, integration of V_T and T_E contributed to an increase in \dot{V}_E in people with high state anxiety. In the noxious audio-stimulation test, there was little effect on \dot{V}_E and respiratory patterns in people with low trait anxiety, but, in people with trait anxiety, an increase of \dot{V}_E was achieved by a T_E decrease with unchanged V_T .

In a consideration of different baselines in high- and low-anxiety levels, it could be suggested that the anticipation of stimulation affects the RR even in a steady, nonstimulation state. It has been reported that

respiratory center drive is enhanced before actual exercise (30). Because this study was performed in a laboratory situation, the state anxiety level would most likely increase in an anxious subject before the beginning of stimulation. According to Spielberger (26), the state anxiety score is higher under stressful conditions than normal conditions.

It is also possible that there was discomfort with the instrumentation, thus causing anxiety (21). In this study, the subjects were tested twice for each 2-min test. These repeated measurements may have caused the problem of adaptation. It would be interesting to examine the relationship between personality and the effect of each test, taking adaptation into account; however, we did not study this in detail.

In summary, we demonstrated that there were negative correlations between anxiety levels and decrease in T_E in both the physical load test and the noxious audio-stimulation test. In an early study by Euler's group (5), respiratory patterns changed because of the different metabolic demand as shown in V_T - T_I or V_T - T_E relationships; it was suggested that the V_T - T_I curve fluctuated, possibly by the general state of "arousal." In our study, the V_T - T_E curves shifting to the left were reflected by individual anxiety levels. Respiration is regulated by the automatic metabolic system in the brain stem (8) and is still referred to as "the black box" (1), an area between the forebrain or the cortical structure and respiratory outputs. Our study suggests that the higher neural center may dominantly affect the RR, especially the T_E in an awake state.

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