Ventilatory and heart rate responses at the onset of passive movement in endurance- and sprint runners

持久性およびスプリントランナーにおける受動的運動開始時の換気・心拍応答

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キーワード：換気量、心拍数、フェーズI、陸上競技選手、受動的運動

Abstract

In the present study, we attempted to confirm whether or not ventilatory and heart rate responses immediately after passive movement is the same in endurance runners (EN) and sprint runners (SP). Inspiratory minute volume ($\dot{V}_I$), tidal volume (V_T), respiratory frequency (f) and heart rate (HR) were determined by breath-by-breath and beat-by-beat techniques before and during passive movement for about 15 secs. In this study, the magnitudes of increment in the cardiorespiratory parameters were calculated, i.e., the difference (⊿) between the mean of the first and second breaths immediately after the onset of movement and the mean of five breaths preceding movement. It was found that there are no significant differences in the resting values of $\dot{V}_I$, V_T, f and HR between EN and SP groups. In addition, ⊿HR was significantly higher in the sprint runner group than in the endurance runner group, while no significant difference was found between the two groups in the ⊿$\dot{V}_I$, ⊿V_T and ⊿f. These results suggest that heart rate response mediated peripheral reflex through the group III and IV fibers at the onset of passive movement is influenced by training type in the track and field, but not ventilatory response.

要約

本研究の目的は、持久性ランナー (EN) およびスプリントランナー (SP) を対象に受動的運動開始直後における換気・心拍応答が同じであるか否かを確かめることである。被験者の両足首に取り付けたロープを検者が約１秒１回のテンポで15秒間交互に引っ張る受動的運動開始前および

運動中の毎分換気量、一回換気量、毎分呼吸数および毎分心拍数を一呼吸および一拍動毎に連続的に測定した。本実験では、受動的運動開始直後2呼吸の毎分換気量、一回換気量および毎分呼吸数における増加量（⊿$\dot{V}_I$、⊿V_T、⊿f）には持久性ランアーとスプリントランナーとの間に有意差は認められなかったが、心拍数の増加量（⊿HR）はスプリントランナーの方が有意に大きかった。これらの結果は、陸上競技におけるトレーニングの違いにより下肢の機械的受容器からの入力は本実験で行なったような短時間の受動的動作開始時の換気応答には影響を及ぼさないが、心拍応答に影響することを示唆するものである。

Introduction

When physical exercise starts, various cardiorespiratory adjustments take place for accommodating the greatly increased metabolic requirements. In particular, the transition from rest to light or moderate intensity exercise is typically accompanied by an abrupt in ventilation and heart rate at the first breath. The initial rapid increase in ventilation appearing at the onset of exercise has been referred to as phase I. (Whipp 1977). This phase I is observed during not only voluntary exercise and passive movement, but also during electrically induced muscle contraction. Nevertheless many investigators have pursued mechanisms that are responsible for the phase I response, and their opinions as to its nature are still a matter of dispute. Since the changes in ventilation are so rapid during the transition from rest to exercise, the phase I response cannot be explained by humoral agents because it appears to take at least about 10s for the metabolic substance from the exercising muscles to reach the arterial chemoreceptors. At present, it is considered that two neural mechanisms, central command and peripheral reflex, mainly trigger the increase in ventilation that appears at the onset of exercise (Mitchell 1990; Miyamura 1994; Mateika and Duffin 1995). Central command arises from the activation of the cerebral cortex and hypothalamus (Goodwin et al. 1972; Williamson et al. 2003) and peripheral reflex originates in the stimulation of group III and IV muscle afferents (McCloskey and Mitchell 1972; Kaufman et al. 1983), respectively.

It has been reported that the ventilatory response at the onset of the exercise is variable in magnitude. That is, the phase I is influenced by various factors, such as posture (Karlson et al. 1975; Weiler-Ravell et al. 1982; Miyamura et al. 2001), exercise frequency (Casey et al. 1987; Kelsey and Duffin 1992), exercise limb (Ishida et al. 1994), age (Sato et al. 2000; Ishida et al. 2000) and physical training. Concerning the last factor, data on the cardiorespiratory responses in the trained subject at the initial stage of exercise are still limited in number. In the previous our study, it was observed that the magnitudes of change of minute ventilation and heart rate at the onset of passive movement in the endurance runners and sprinters were significantly smaller than that in the untrained subjects (Miyamura et al. 1997; Sato et al. 2004). These results suggest that the magnitude of cardiorespiratory responses at the onset of passive movement in humans is influenced by endurance training and/or sprint training for long periods.

Although athletes in track and field have been divided into groups of endurance runners and sprint runners, contrary possibilities regarding ventilatory and heart rate responses at the onset of exercise in both runners could be shown. Therefore, if the muscle fiber composition may have some influence on ventilatory and circulatory responses during exercise (Fitton et al. 1991; Torok et al. 1995), it is possible to assume that sprinters who are presumed to have a higher percentage of fast twitch muscle fibers (Costill et al. 1976; Thorstensson et al. 1977; Torok et al. 1995) would have higher cardiorespiratory responses at the onset of exercise as compared with endurance runners who have a higher percentage of slow twitch muscle fibers. On the contrary, if the desensitization of the muscle mechanoreceptors due to long-term endurance training predominantly affects ventilatory and circulatory responses during exercise (Sinoway et al. 1996), these responses may be more attenuated in endurance runners with respect to total running distance as compared with sprinters. To our knowledge, however, there are no available data concerning comparison of cardiorespiratory responses at the onset of passive movement in the endurance runners and sprint runners. The purpose of this study, therefore, was to clarify whether or not the ventilatory and heart rate responses at the onset of passive movement in the endurance runners are the same as those in the sprint runners.

Methods

subjects

Twenty-three healthy men volunteered to participated in the present study as subjects. No subjects had a history of cardiorespiratory diseases, took medications that seriously affected cardiorespiratory responses and smoked. Twelve out of 23 subjects were endurance runners (EN) and the remainders were sprint runners (SP). All subjects were belonging to university athletic team. The endurance runners had trained mainly by running for about 3 - 4 h per day, 5 days a week all year round for 4 - 11 years. The ranges for the best performance of 5,000m in the endurance runners were 15 min 7 s - 17 min 7 s. On the other hand, sprint runners had trained sprint running, interval training, and weight training for about 2 - 3 h per day, 5 days a week all year round for 5 - 10 years. The range of the best times for a 100-m sprint running event among the sprinters were 10.5 - 10.9 s. Mean and standard deviations of age, height and body mass of the subjects were 20.5 (1.5) years, 172.6 (6.5) cm, and 58.1 (5.2) kg for the endurance runner group, and 19.9 (1.4) years, 171.3 (4.9) cm, and 62.5 (6.0) kg for the sprint runner group, respectively. No significant difference was found in age, height, or body mass between two groups. The subjects were instructed as to the experimental protocol and possible risks involved in this study before giving written consent. The present study was approved by the Human Research Committee of the Research Center of Health, Physical Fitness and Sports of Nagoya University.

Preliminary tests

All subjects came to the laboratory twice on separate days. On the first day, each subject was familiarized only with the apparatus and testing procedures involved in this study; subjects performed a preliminary test to become sufficiently accustomed to passive movement in sitting position. The actual experiment was conducted on separate days at least a few days after that 1st familiarization day. The subjects were usually studied in the afternoon at least 2h after they had eaten a meal.

Passive movement

Subjects were asked to refrain from performing rigorous exercise for 24 h prior to actual experiments. During experiment, subjects sat with their backs against an experimental chair, i.e., the subjects were rested comfortably on the chair in sitting position for 20 min, and then asked to relax during experimental periods. The passive movement was achieved in a sitting position without any external load. In order to prevent any possible involvement of those muscles which may come into play to maintain stable body position and keep the subject's posture as constant as possible, the subjects were asked to always sit with their backs lightly in contact with chair. This also served to further isolate the leg muscles in question.

The passive movement was initiate just before the start of the inspiratory phase; the experimenter checked this on an oscilloscope which monitored the hot-wire flow meter (RF-H, Minato Ikagaku, Japan) connected to subject's respiratory face mask. The flow curve registered on the screen in a series of up and down curves. Since it is virtually impossible to measure exactly the movement that the inspiratory cycle begins, the point as close as possible to beginning of the upward swing of the curve was determined to be start of the inspiratory period. In the passive movement, the experimenter pulled two ropes alternately, which was connected to the subject's ankle, at a rate of about 60 times/min as shown in Fig. 1. The knee joint was extended and flexed passively from

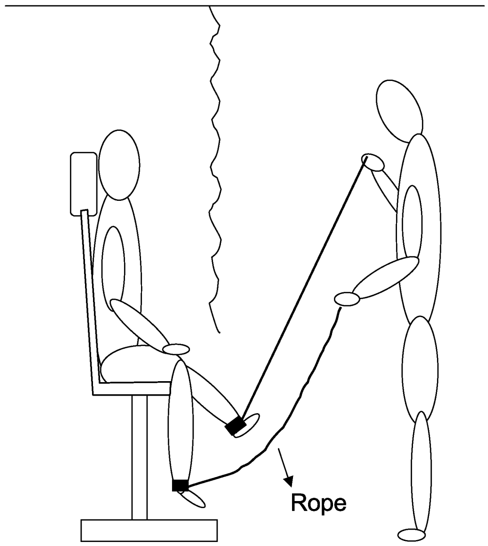

Fig. 1 Schematic diagram of experimental set-up.

approximately 90° to 30° in the flexed position, without any change in the hip joint angle. The subject was also instructed to relax and not to resist the motion, and care was taken to immobilize the body as much as possible to avoid muscle contractions and motion artifacts. These passive movements were performed behind a curtain without any signal so as to prevent the subjects from being aware of when they started. The passive movements were conducted five times, with about 2～3 min intervals between each without the influence of prior movement. All passive movement started using the left limb, because an electrogoniometer was attached to the left knee to detect the onset of motion.

Measurements

Inspiratory minute volume ($\dot{V}_I$), tidal volume (V_T), inspiratory periods, expiratory periods, and partial pressures of end-tidal carbon dioxide and oxygen (P_{ETCO2} and P_{ETO2}) were determined by the breath-by-breath technique before and during passive movement, i.e., $\dot{V}_I$ and V_T were measured continuously for 5 breaths before and 2 breaths after passive movement, respectively. The subject breathed through a respiratory face mask attached hot-wire flow meter. It was calibrated prior to each experiment using a 2-liter calibration pump at different flow rates before and after experiments. The dead space of the respiratory face mask was about 100 ml. Respiratory gases were sampled using a thin vinyl tube (inner diameter 1 mm) inserted into the face mask, with tip being positioned as close to each subject's mouth as possible. Respiratory frequency (f) was calculated from the total respiratory time, and $\dot{V}_I$ was obtained as the product of V_T and f. P_{ETCO_2} and P_{ETO_2} were calculated from end-tidal CO_2 % and O_2 %, which were obtained by analyzing gas samples being drawn continuously through the vinyl tube with the use of a gas analyzer (Minato Ikagaku, MG-360, Japan). As for circulatory responses, on the other hand, heart rate (HR) was monitored beat-to-beat before and during passive movement. HR was calculated beat to beat from R spike using an electrocardiogram through a bioamplifier (model AB-621G, Nihon Kohden). In the present study, we set the averaging time for two complete breaths of each subject according to the synchronization between respiratory and cardiac responses. A sensor for the electrocardiogram (ECG) was attached to the subject's chest to determine the to calculate the HR. The R spike on the ECG was the trigger signal for ensemble averaging.

All ventilatory and heart rate signals were converted from analogue to digital data using an A/D converter (Canopus, ADX 98H, Japan) at sampling frequency of 100Hz. These data were stored on hard disk unit, and analyzed afterwards on a personal computer (NEC, PC-9821Xa, Japan).

Statistical analysis

Means and standard deviations (±SD) were calculated by standard methods. First, the mean value was calculated for each subject; thereafter the mean value of all subjects were computed for each group. In comparing the endurance runners with the sprint runners, we conducted a Kolmogorov-Smirnov test to examine data normality. When data were normally distributed, a nonparametric test (Mann-Whitney's U-test) was performed. The SPSS statistical package was used for these analyses. The level of significant was set at 5 %.

Results

Figure 2 indicates an example of $\dot{V}_I$, V_T, f and HR values obtained before and during passive movement in subject YS. Table 1 shows the mean and standard deviations of $\dot{V}_I$,

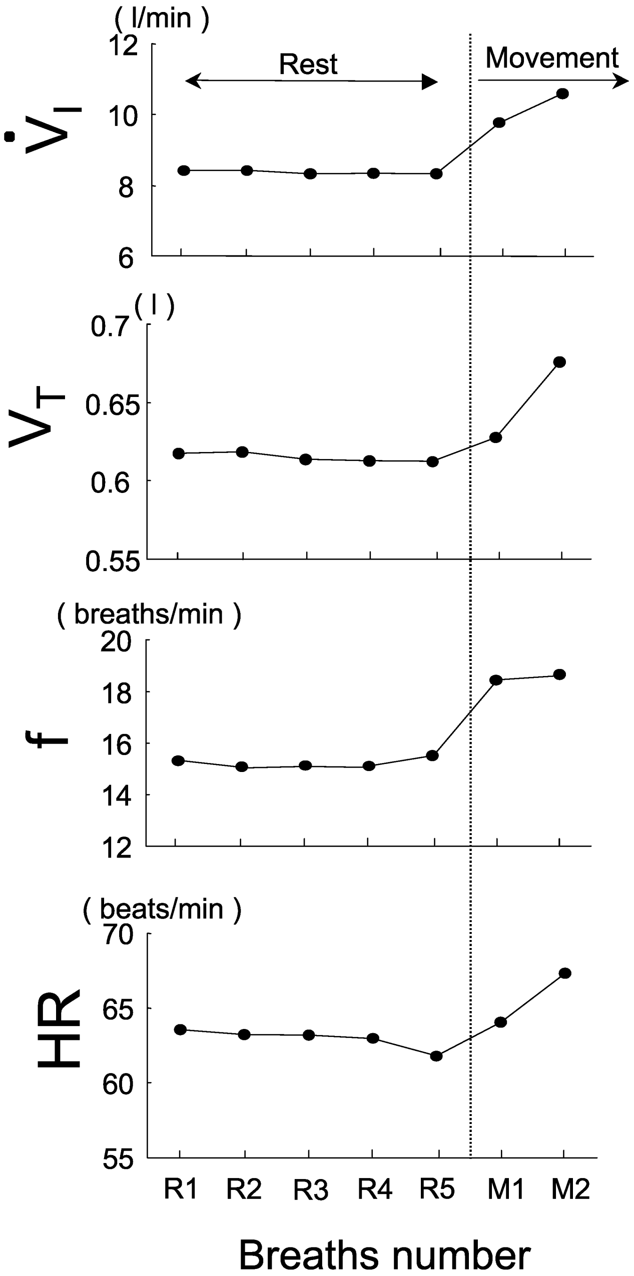

Fig. 2 An example of minute ventilation ($\dot{V}_I$), tidal volume (V_T), respiratory frequency (f) and heart rate (HR) before and after passive movement in subject YS.

V_T, f and HR at pre- and post-movement; these are the mean of five breaths preceding the movement and the mean of the first and second breaths immediately after passive movement. Mean values (±SD) of $\dot{V}_I$, V_T, f and HR at rest were 8.7 (1.5) l/min, 0.58 (0.08) liters, 15.5 (3.7) breaths/min and 64 (7) beats/min for the endurance group, and 8.4 (1.3) l/min, 0.61 (0.19) liters, 15.1 (5.9) breaths/min and 63 (9) beats/min for the sprint group, respectively. There are no significant difference in $\dot{V}_I$, V_T, f and HR at rest between sprint runners and endurance runners. Furthermore, mean values (±SD) of first and second breaths in $\dot{V}_I$, V_T, f and HR immediately after movement were 10.4 (1.7) l/min, 0.58 (0.15) liters, 19.2 (5.4) breaths/min and 67 (7) beats/min for the endurance group, and 10.2 (2.0) l/min, 0.65 (0.22) liters, 18.6 (9.8) breaths/min and 68 (10) beats/min for the sprint group, respectively. No significant difference was also found in $\dot{V}_I$, V_T, f and HR at the onset of passive movement between sprit runners and endurance runners (Table 1). In this study, the magnitude of the increase in the

Table 1 Ventilatory and heart rate responses before and immediately after passive movement in the endurance runners (EN) and sprint runners (SP). Mean values of minute ventilation ($\dot{V}_I$), tidal volume (V_T), respiratory frequency (f) and heart rate (HR) were calculated five breath at rest and first and second breaths immediately after passive movement, respectively

	$\dot{V}_I$ (l/min)		V_T (l)		f (breaths/min)		HR (beats/min)	
	Rest	Movement	Rest	Movement	Rest	Movement	Rest	Movement
Endurance runners	8.7±1.5	10.4±1.7	0.58±0.08	0.58±0.15	15.5±3.7	19.2±5.4	64±7	67±7
Sprint runners	8.4±1.3	10.2±2.0	0.61±0.19	0.65±0.22	15.1±5.9	18.6±9.8	63±9	68±10

cardiorespiratory parameters was calculated, i.e., the difference (delta, ⊿) between the mean of the first and second breaths immediately after the onset of movement, and the mean of five breaths preceding movement. Figure 3 shows the ⊿ values of $\dot{V}_I$, V_T, f and HR in the passive movement both in endurance and sprint runner groups. As shown in Fig. 3, ⊿HR was significantly ($p<0.05$) higher in the sprint runner groups (6 ± 2 beats/min) than in the endurance runner groups (3 ± 2 beats/min), while no significant difference was found between the two groups in the ⊿$\dot{V}_I$, ⊿V_T and ⊿f.

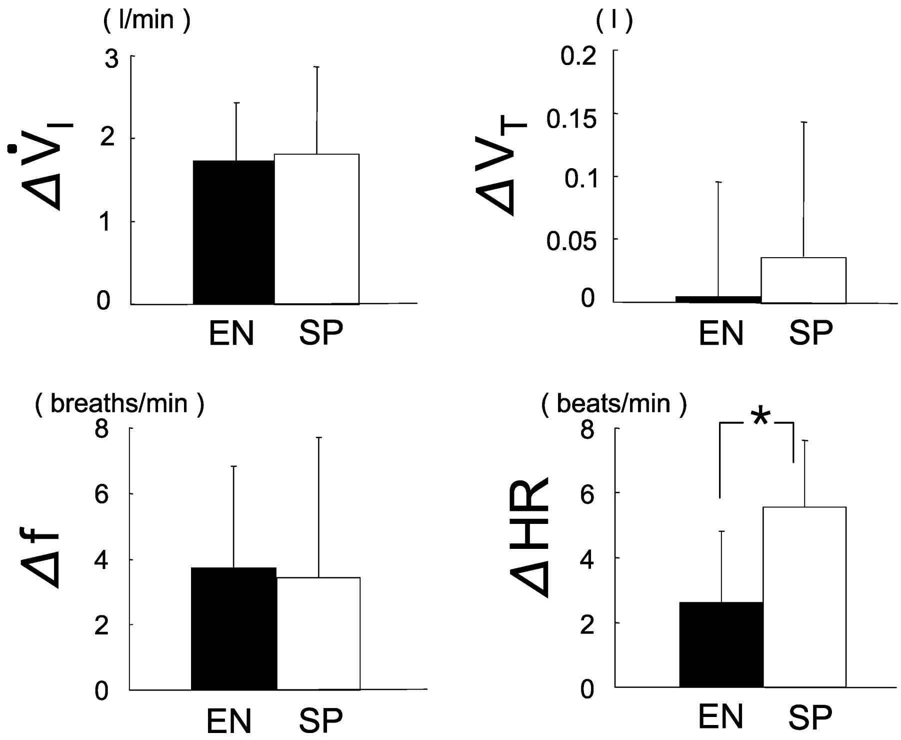

Fig. 3 Comparison of the difference (⊿) in $\dot{V}_I$, V_T, f and HR between endurance and sprint runners groups. The ⊿ value is calculated from mean response values minus pre-movement values. Asterisk (*) indicate a significant difference ($p<0.05$) between the endurance runners (EN) and sprint runners (SP). Values are mean and standard deviation.

Discussion

In the present study, we attempted to clarify whether or not ventilatory and heart rate responses at the onset of passive movement are the same in endurance runners and sprint runners. It was found that there are no significant difference in resting value of $\dot{V}_I$, V_T, f and HR between endurance runner group and sprint runner group. In addition, ⊿HR was significantly higher in the sprit runner groups than in the endurance runner groups, while no significant difference was found between the endurance and sprint runner groups in the ⊿$\dot{V}_I$, ⊿V_T and ⊿f. We believe that this is the first study showing ventilatory and heart rate responses at the onset of passive movement both in endurance and sprint runners.

It is well known that pulmonary ventilation and heart rate increase immediately after physical exercise, and that this increase usually occurs from the first breath, followed by an exponential rise with a time constant of about 60 s until finally reaching a new steady state (Wasserman et al. 1977; Eldridge and Waldrop 1991). The ventilatory profile in transition from rest to light or moderate intensity exercise is characterized by an abrupt step-like increment in ventilation without accompanying changes in alveolar partial pressures of O2 and CO2, and gas exchange ratio, and is termed phase I, as first defined by Whipp (1977). This phase I response, from the first breath and lasting for about 15 s, is observed not only during voluntary exercise, but also passive movement following electrically induced muscle contractions or flexion-extensions of the lower legs with ropes (Whipp et al. 1982; Adams et al. 1987; Miyamura et al. 1992). Why is the increasing pulmonary ventilation elicited so quickly just at the onset of exercise? Since the changes in pulmonary ventilation are so rapid immediately after voluntary exercise and/or passive movement, phase I response cannot be explained by humoral agents because of the delay in transport. It has hitherto been accepted that the causal factor of phase I are classified largely into three, i.e., central and peripheral neurogenic stimuli, or both (Miyamura 1994; Williamson et al. 2003). Bell et al. (2003) observed no increase in metabolic gas exchange and little increase in EMG during leg extension-flexion movement as compared with those during passive cycling movement. It was also observed in this study that end-tidal PCO2 and PO2 (P_{ETCO2} and P_{ETO2}) immediately after passive movement are almost the same as compared with rest. In other words, it is presumed that leg passive movement should minimize the effect of central command so that the mechanically sensitive peripheral neural reflex should be effectively isolated as described by Bell and Duffin (2003) and Bell et al. (2003).

It has been reported that ventilatory responses to hypercapnia and hypoxia were significantly lower both in trained athletes and swimmers than that in the untrained subjects (Byrne-Quinn et al. 1972; Miyamura et al. 1976; Ohkuwa et al. 1980; Ohyabu et al. 1990). In our previous study, the minute ventilation ($\Delta\dot{V}_I$) and tidal volume (ΔV_T) were significantly ($p<0.05$) lower in the endurance runners than that in the untrained both in voluntary exercise and passive movement (Miyamura et al. 1997). In addition, relative changes of $\dot{V}_I$ and HR in sprinter group were significantly ($p<0.05$) lower than those in untrained groups during passive movement (Sato et al. 2004). These results suggest that the sensitivities of peripheral chemoreceptors and mechanoreceptors in skeletal muscle were reduced by physical training for long periods.

As described previously, all runners participated in this study were belonging to university athletic team. The endurance runners had trained mainly by running for about 3 - 4 h, 5 days a week all year round for 4 - 11 years. The ranges for the best performance of 5,000m in the endurance runners were 15 min 7 s - 17 min 7 s. On the other hand, sprint runners had trained sprint running, interval training, and weight training for about 2 - 3 h per day, 5 days a week all year round for 5 - 10 years. The ranges of the best times for a 100-m sprint running event among the sprinters were 10.5 - 10.9 s. Since ranges of training periods were 4 - 11 years for the endurance runners and 5 - 10 years for the sprint runners, respectively, it is possible to assume that sensitivity of mechanoreceptor in the working muscle seems to be reduced, and that there are no difference in the magnitude of decrement of mechanosensitivity between endurance runners and sprint runners with respect to training periods.

On the other hand, if the muscle fiber composition may have some influence on ventilatory and circulatory response during exercise (Fitton et al. 1991; Torok et al. 1995), it is possible to suppose that sprinters who are presumed to have a higher percentage of fast twitch fibers (Costill et al. 1976; Thorstensson et al. 1977; Torok et al. 1995) would have higher cardiorespiratory responses at the onset of passive movement as compared with endurance runners who have a higher percentage of slow twitch muscle fibers. On the contrary, if the desensitization of the muscle mechanoreceptors due to long-term endurance training predominantly affects ventilatory and circulatory responses during exercise (Sinoway et al. 1996), these responses may be more attenuated in endurance runners with respect to running distance as compared with sprinters. It was found in this study that ⊿HR was significantly higher in the sprit runner groups than in the endurance runner groups, while no significant difference was found between the endurance and sprint runner groups in the $\Delta\dot{V}_I$, ΔV_T and Δf as shown in Fig 3. These results suggest that magnitude of desensitization of mechanoreceptor seems to be almost the same in endurance runner groups and sprint runner groups from view points of ventilatory response, but not heart rate response. In other words, effects of afferent stimulus through group III and IV fibers on ventilatory and heart rate responses at the onset of passive movement as applied here may be different in the two groups even if there are no difference in the training periods. At present, we cannot explain based on the physiological ground why heart rate response (⊿HR) was significantly higher in the sprit runner groups than in the endurance runner groups, while it was in a strikingly contrast to ventilatory response. It is possible to hypothesize that ventilatory and circulatory responses mediated peripheral reflex were related to the differences in integrative system between respiratory center and circulatory center, i.e., higher heart rate response at the onset of passive movement in the sprint runners may be due to increase of regulative action in circulatory center by sprint training for long periods even if decrement of mechanosensitivity by athletic training is the same both in the endurance- and sprint runners. However, it will be necessary to conduct further investigation about this hypothesis.

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