# The Influence of Different Modes of Ventilation on Standing Balance of Athletes

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**Background:** The respiratory movements are one of the factors influencing standing balance. Although well-trained athletes have better postural performance compared to untrained men, it's not quite clear, if the formers' upright posture would be more stable during different ventilation modes, maximal voluntary hyperventilation and inspiratory breath-holding. There are no studies on this subject in the available literature.
**Objectives:** The aim of this study was to investigate an influence of maximal inspiratory breath-holding and maximal voluntary hyperventilation on the standing balance of athletes.
**Patients and Methods:** We assessed the amplitude and the velocity of postural sway in the athletes (n = 38) and untrained subjects (n = 28) by the force platform. The frequency characteristics of the center of pressure (CP) oscillations' were also analyzed. The amplitude and the frequency of respiratory movements were estimated by the strain gauge.
**Results:** It was found that during quiet breath velocity and frequency of CP oscillations were lower in the athletes. Breath holding led to an increase of velocity and frequency of CP displacement in both groups, increase of these indices was more pronounced in the athletes. Maximal voluntary hyperventilation caused a significant increase of all stabilographic indices in both groups. Increase of frequency and amplitude of respiratory movements were mainly observed during hyperventilation in athletes and it caused an increase of the velocity of CP displacement. Changes of sway amplitude were the same in both groups.
**Conclusions:** Breath holding led to activation of the postural control, which was more pronounced in the athletes. Hyperventilation caused an impairment of the postural stability. The athletes' postural system compensated the impact of hyperventilation more efficiently versus controls, but it was achieved at the expense of greater effort.

*Keywords:* Hyperventilation; Breath Holding; Sport

## 1. Background

It is known that well-trained athletes demonstrate better postural stability compared to untrained men (1, 2). Physical training influences the postural control in several possible ways. First, athletes integrate information from different sensory systems much better than non-athletes (3). Second, regular sport activity leads to an improvement of sensitivity of proprioceptors. Proprioceptive afferences, in turn, are important sensory cues to the postural control system (4). Balter et al. postulate that a superior balance of athletes is a result of their better motor abilities (5). Respiration is one of the factors influencing standing balance, since the respiratory movements perturb postural stability (6). However, these perturbations are compensated by the movements of other parts of the body during quiet breathing (7). On the contrary, deep and fast breathing causes a decrease of postural stability due to more pronounced impact of the respiratory movements on the balance (8). Since ventilation increases during exercise, one can assume that respiration is one of the factors decreasing postural performance. So it can be speculated that fast and deep breath is an important factor influencing balance in athletes during training and competitions. On the other hand, regular physical training improves respiratory functions (9). During maximal voluntary hyperventilation, athletes probably breathe faster and deeper versus sedentary men. Hence, the impact of maximal hyperventilation on a postural stability of athletes could be stronger versus non-athletes. Therefore, athletes may not demonstrate better balance during hyperventilation. It is not quite clear if athletes' upright posture would be more stable under the influence of increased ventilation compared to sedentary subjects or not. Athletes are known to hold their breath during different sport activities. For example, weightlifters hold breath after maximal inspiration during lifting tasks (10). A breath-holding preceding a trigger pull takes place in rifle shooters (11). It is considered that apnea improves postural stability due to the absence of impact of respiratory movements on the postural control system (12). But such a proposition, possibly, is doubtful.

There is evidence (13) that during breath holding respiratory muscles make strong low amplitude high frequency contractions. Perhaps, these contractions are a perturbing factor for postural stability, so apnea doesn't improve standing balance. In summary, it can be speculated that understanding of the influence of hyperventilation and breath-holding on a postural stability in athletes is rather important. Meanwhile, there are no studies on this subject in the available literature.

## 2. Objectives

The aim of this study was to compare the standing balance of athletes and non-athletes during maximal inspiratory breath-holding and maximal voluntary hyperventilation.

## 3. Patients and Methods

### 3.1. Subjects

Sixty-six volunteers participated in the study. The volunteers were divided into two groups: "Athletes" and "Controls". The "Athletes" group included 19 men and 19 women aged 19.8 ± 1.0 years, they regularly (11.2 ± 4.5 hours a week) trained during 7.6 ± 4.6 years in field athletics, combative and team sports. The "Control" group consisted of healthy untrained volunteers (10 men and 18 women) aged 22.4 ± 4.6 years. All participants gave informed consent, and approval of the local Ethics Committee was obtained before the study.

### 3.2. Procedure

Standing balance was assessed using the force platform "Stabilan 01-2" (ZAO OKB "RITM", Russia). The data from the force platform were sampled at 50Hz and were filtered by two analog low-pass filters with a bandwidth of 7 kHz and a bandwidth of 15 Hz. Then the signal was filtered in the analog-to-digital converter using a third-order Sinc filter with a frequency of 50 Hz resection. The study consisted of three trials: "Quiet breath", "Apnea" and "Hyperventilation". During the "Quiet Breath" trial the participants breathed quietly, during the "Apnea" they held their breath after maximal inspiration, and during "Hyperventilation" the subjects breathed as deep and fast as possible. Duration of all trials was 20 seconds with a rest period (10 minutes) between them. During the tests the participants stood upright as still as possible on the force platform with their heels 2 cm apart, feet at an angle of 30 degrees and looked at the white circle on the black background. The stabilographic signals from the force platform were filtered and processed by specialized software (StabMed 2010, ZAO OKB "RITM", Russia). The following stabilographic parameters were calculated: the mean velocity ($V$, mm s$^{-1}$) and variance of the center of pressure (CP) displacement in the medio-lateral ($Q_{mL}$, mm) and the antero-posterior ($Q_{ap}$, mm) plane and the surface area covered by the trajectory of the CP with a 90% confidence interval ($S$, mm$^2$). The mean velocity of CP movement shows an amount of activity required to maintain stability, i.e. this index provides an assessment of functional activity of the postural control system. The variance of CP displacements characterizes, essentially, the amplitude of postural sway, so the smaller the variance, the better postural stability (14). A frequency analysis of the stabilographic signal was also performed by the StabMed software. The whole frequency band was divided into three ranges: low frequency (0-0.2 Hz), medium frequency (0.2-2 Hz) and high frequency (2-6 Hz) (15). The following indices were calculated: spectrum power (%) in the low (Pw1), medium (Pw2) and high (Pw3) frequency range in the medio-lateral ($Pw1_{mL}$, $Pw2_{mL}$ and $Pw3_{mL}$) and the antero-posterior ($Pw1_{ap}$, $Pw2_{ap}$ and $Pw3_{ap}$) plane. We also estimated the frequency corresponding to 60% level of the total spectral power in the medio-lateral (60% Pwml, Hz) and the antero-posterior (60% Pwap, Hz) plane. Frequency of CP oscillations reflects the mechanisms of postural control. It is considered, that high frequencies are related to using proprioceptive infor-mation, medium frequencies are responsible for the cerebellar one, and low-for the visual (16).

### 3.3. Ventilation Assessment

The respiratory indices were estimated using strain gauge, which was wrapped around the participants' chest. The strain gauge sensor recorded the alteration of the chest circumference during respiratory movements (17). So we measured the respiration frequency ($f$, min$^{-1}$) and the respiratory amplitude (RA). The last parameter was calculated as mean of differences between maximum of the inspirations and minimum of the expirations of all breathing cycles during the trial. We also calculate the indirect ventilation index (Vent) as the product of $f$ and RA.

### 3.4. Statistics

All results are expressed as Mean ± standard deviation. The data analysis was performed with a two-way analysis of variance with one between-groups factor (two levels: athletes and non-athletes) and one within-groups factor with repeated measures (two levels of respiration: quiet breath and hyperventilation for the respiratory indices and three levels of respiration: Apnea, Quiet breath and Hyperventilation for the stabilographic indices). Posthoc comparisons were made using the least square differences (LSD) criterion. Pearson's correlation ($r$) was used to investigate the relations between the respiratory and stabilographic indices.

## 4. Results

### 4.1. Ventilation

All respiratory parameters were increased during hy-

perventilation trial in both groups (Table 1). However, in the athletes elevation of RA (P = 0.01) and Vent (P = 0.003) parameters was higher, so the athletes breathed deeper and faster compared to controls.

## 4.2. Postural Indices

We found that during quiet breath V and Pw3ap were lower in the athletes versus control subjects. There was an increase of V during the inspiratory breath-holding in both groups (Table 2), and it was more pronounced in the athletes. Sway amplitude didn't change during apnea in both groups. Besides, there was shift of the spectrum of

stabilographic signal toward the high-frequency range: $Pw1_{ap}$ decreased, $Pw3_{ap}$ and 60% Pwap increased in both groups, $Pw2_{ap}$ increased in the athletes (Table 2). All stabilometric indices were significantly increased in both groups during maximal voluntary hyperventilation, reflecting a severe impairment of the postural stability (Table 2). The velocity of the CP displacement (P = 0.005) as well as the power of the high-frequency spectrum range (P = 0.002 for $Pw3_{mL}$, P = 0.0003 for Pw3ap) and the 60% level of total spectral power in the antero-posterior plane (P = 0.01) increased to a greater extent in the athletes whereas other indices changed in the same way in both groups.

**Table 1.** Respiratory indices in the Athletes and the Control [a]

| | Quiet Breath | | | Hyperventilation | | | |
|---|---|---|---|---|---|---|---|
| | Control | Athletes | P Value [b] | Control | Athletes | P Value [b] | P Value [c] |
| **RA** | 0.62 ± 0.42 | 0.48 ± 0.27 | 0.4 | 2.06 ± 0.85 [d] | 2.48 ± 0.96 [d] | 0.03 | 0.01 |
| **RF, min⁻¹** | 14.79 ± 5.37 | 13.32 ± 5.25 | 0.7 | 52.07 ± 14.43 [d] | 58.89 ± 21.62 [d] | 0.05 | 0.1 |
| **Vent** | 8.4 ± 4.5 | 6.12 ± 3.48 | 0.8 | 102.5 ± 41.8 [d] | 136.49 ± 50.3 [d] | 0.0002 | 0.003 |

[a] Abbreviations: RA, respiratory amplitude; RF, respiration frequency; Vent, ventilation index (product of respiratory amplitude and respiration frequency).
[b] Between-groups interaction factor.
[c] Group-by-breathing mode interaction (ANOVA).
[d] P < 0.001 versus Quiet breath in the same group (within-groups factor).

**Table 2.** Stabilographic Indices [a, b]

| | Apnea | | | Quiet Breath | | | Hyperventilation | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Control | Athletes | P Value [c] | Control | Athletes | P Value [c] | Control | Athletes | P Value [c] | P Value [d] |
| **$Q_{mL}$, mm** | 2.63 ± 1.11 | 2.24 ± 0.82 | 0.2 | 2.31 ± 0.67 | 2.11 ± 0.81 | 0.5 | 4.02 ± 1.33 [e] | 3.98 ± 1.35 [e] | 0.9 | 0.6 |
| **$Q_{ap}$, mm** | 3.16 ± 1.51 | 2.78 ± 1.21 | 0.8 | 3.02 ± 1.09 | 2.7 ± 0.82 | 0.8 | 6.17 ± 2.00 [e] | 6.55 ± 2.40 [e] | 0.7 | 0.3 |
| **V, mm s⁻¹** | 9.83 ± 2.86 [e] | 8.81 ± 2.51 [e] | 0.8 | 8.51 ± 2.28 | 7.06 ± 1.68 | 0.02 | 25.45 ± 11.12 [e] | 37.76 ± 29.00 [e] | 0.0006 | 0.005 |
| **S, mm²** | 117.30 ± 89.09 | 84.76 ± 51.3 | 0.38 | 98.53 ± 57.29 | 76.22 ± 34.15 | 0.54 | 346.1 ± 205.51 [e] | 386.7 ± 245.6 [e] | 0.3 | 0.3 |
| **60% $Pw_{mL}$, Hz** | 0.67 ± 0.21 | 0.71 ± 0.2 | 0.45 | 0.66 ± 0.21 | 0.66 ± 0.17 | 0.98 | 0.83 ± 0.25 [f] | 0.99 ± 0.31 [e] | 0.007 | 0.1 |
| **$Pw1_{mL}$, %** | 25.25 ± 9.85 | 25.03 ± 7.13 | 0.92 | 29.29 ± 10.90 | 27.97 ± 8.73 | 0.56 | 25.26 ± 9.24 | 21.39 ± 9.51 [f] | 0.08 | 0.5 |
| **$Pw2_{mL}$, %** | 64.15 ± 8.97 | 63.97 ± 6.55 | 0.93 | 60.43 ± 8.98 | 61.53 ± 7.68 | 0.59 | 61.43 ± 7.79 | 61.03 ± 8.36 | 0.8 | 0.8 |
| **$Pw3_{mL}$, %** | 10.68 ± 2.74 | 10.92 ± 2.70 | 0.81 | 10.29 ± 2.54 | 10.39 ± 2.89 | 0.92 | 13.32 ± 3.52 [f] | 17.45 ± 6.25 [e] | 0.0002 | 0.002 |
| **60% $Pw_{ap}$, Hz** | 0.77 ± 0.21 [g] | 0.81 ± 0.21 [f] | 0.64 | 0.66 ± 0.16 | 0.59 ± 0.19 | 0.43 | 1.00 ± 0.24 [e] | 1.23 ± 0.52 [e] | 0.006 | 0.01 |
| **$Pw1_{ap}$, %** | 28.54 ± 10.34 [g] | 25.71 ± 9.7 [g] | 0.27 | 33.93 ± 6.95 | 33.47 ± 10.32 | 0.86 | 22.82 ± 7.60 [e] | 20.29 ± 9.71 [e] | 0.3 | 0.7 |
| **$Pw2_{ap}$, %** | 56.36 ± 8.56 | 59.32 ± 7.84 [g] | 0.20 | 53.00 ± 6.11 | 55.13 ± 8.89 | 0.35 | 57.96 ± 7.50 | 55.45 ± 8.73 | 0.3 | 0.09 |
| **$Pw3_{ap}$, %** | 15.11 ± 4.37 [f] | 15.00 ± 3.56 [e] | 0.94 | 13.07 ± 3.02 | 11.39 ± 2.83 | 0.02 | 19.25 ± 4.67 [e] | 24.34 ± 9.46 [e] | 0.001 | 0.0003 |

[a] Abbreviations: 60% $Pw_{mL}$, and 60% $Pw_{ap}$, 60% level of the total spectral power in the medio-lateral and the antero-posterior planes respectively; $Pw1_{ap}$, $Pw2_{ap}$ and $Pw3_{ap}$, spectrum power in the low, medium and high frequency range respectively in the antero-posterior plane; $Pw1_{mL}$, $PW2_{mL}$ and $Pw3_{mL}$, spectrum power in the low, medium and high frequency range respectively in the medio-lateral plane; $Q_{mL}$, $Q_{ap}$: variance of the CP displacement in the medio-lateral and antero-posterior planes respectively; S, the surface area covered by the trajectory of the CP with a 90% confidence interval; V, mean velocity of the CP displacement.
[b] Data are presented as Mean ± SD.
[c] Between-groups interaction factor.
[d] Group-by-breathing mode interaction (ANOVA).
[e] P < 0.001 versus "Quiet breath" (within-groups factor).
[f] P < 0.01 versus "Quiet breath" (within-groups factor).
[g] P < 0.05 versus "Quiet breath" (within-groups factor).

## 4.3. Correlations Between Respiratory and Stabilographic Indices During Hyperventilation

We found that at hyperventilation f was related to $Q_{mL}$, S, V, 60% $Pw_{mL}$, 60% $Pw_{ap}$, $Pw1_{ap}$, $Pw3_{mL}$, $Pw3_{ap}$, and Vent correlated with V, $Pw3_{ap}$, 60% Pwap and $Pw3_{ap}$ (Table 3). One can see that the closest correlations were obtained for the frequency of respiratory movements with the velocity of CP displacement, 60% power of total spectral energy and the spectrum power in the high-frequency range. The respiratory amplitude wasn't related to any stabilographic parameter.

## 5. Discussion

When comparing standing balance in the athletes and non-athletes during different modes of ventilation (hyperventilation and inspiratory breath holding) we obtained the following main results:

1. The mean velocity and the frequency of CP oscillations were lower in the athletes versus sedentary subjects during quiet breath.
2. Maximal inspiratory breath-holding led to an increase of mean velocity of CP displacement in both groups.
3. Maximal voluntary hyperventilation caused a severe

impairment of the postural stability. The hyperventilation was accompanied by a greater increase of the velocity and the frequency of CP oscillations in the athletes versus the controls.

### 5.1. Respiratory Indices During Hyperventilation

We found that all respiratory parameters were significantly higher during hyperventilation versus quiet breath. However, in the athletes an elevation of the Vent parameter was greater (Table 1). This fact, obviously, reflects the better functional capacity of their respiratory system. Such assumption is confirmed by the results of other authors [9].

### 5.2. Stabilographic Indices During Quiet Breath

We found that at the quiet breath V was lower in athletes versus controls. This suggests lower activity of the postural control system in athletes during quiet breath standing, in other words, the athletes expended less effort to maintain standing balance [14]. Noteworthy is, that $Pw3_{ap}$ was also lower in the athletes. So during routine postural tasks the athletes, obviously, use less short-loop information from the proprioceptors. This also indicates less strenuous activity and higher efficiency of their postural regulation versus the controls [16].

**Table 3.** Correlations (r) Between Respiratory and Stabilographic Indices During Hyperventilation

| | Respiratory Amplitude | Respiration Frequency | Ventilation Index |
|---|---|---|---|
| **variance of the CP displacement in the medio-lateral plane, $Q_{mL}$** | 0.03 | 0.30 [a] | 0.21 |
| **variance of the CP displacement in the antero-posterior plane, $Q_{ap}$** | 0.05 | 0.13 | 0.10 |
| **Mean velocity of the CP displacement** | -0.15 | 0.56 [b] | 0.25 [a] |
| **Surface area covered by the trajectory of the CP with a 90% CI** | -0.003 | 0.29 [a] | 0.15 |
| **60% level of the total spectral power in the medio-lateral plane $Pw_{mL}$** | -0.10 | 0.39 [c] | 0.22 |
| **Power in the low frequency range in the medio-lateral plane $Pw1_{mL}$** | 0.09 | -0.17 | -0.07 |
| **Power in the medium range in the medio-lateral plane, $Pw2_{mL}$** | -0.08 | -0.23 | -0.21 |
| **Power in the high frequency range in the medio-lateral plane, $Pw3_{mL}$** | -0.04 | 0.63 [b] | 0.41 [c] |
| **60% level of the total spectral power in the antero-posterior plane, $Pw_{ap}$** | -0.10 | 0.58 [b] | 0.35 [c] |
| **Power in the low frequency range in the antero-posterior plane, $Pw1_{ap}$** | 0.09 | -0.32 [c] | 0.001 |
| **Power in the medium frequency range in the antero-posterior plane, $Pw2_{ap}$** | -0.13 | -0.18 | -0.29 [a] |
| **Power in the high frequency range in the antero-posterior plane, $Pw3_{ap}$** | 0.03 | 0.54 [b] | 0.47 [b] |

[a] P < 0.05.
[b] P < 0.001.
[c] P < 0.01.

It should be noted that most other authors also report better postural stability in athletes versus sedentary men during quiet standing (1, 2).

### 5.3. Stabilographic Indices During Breath-Holding

We found an increase of V during the inspiratory breath-holding in both groups (Table 2), and it was more pronounced in the athletes. Besides, there was shift of the spectrum of stabilographic signal toward the high-frequency range. Based on these results, it can be assumed that inspiratory breath holding caused an activation of the postural control system, i.e. more effort was necessary to maintain stability during breath-holding versus quiet breath (14). So our data contradict the results of (12), where an improvement of the standing balance was found during apnea. It is known that respiratory muscles participate in maintenance of upright posture (18). The respiratory center stimulates the diaphragm and intercostal muscles in response to blood gas alterations during voluntary breath holding, so contractions of the respiratory muscles take place. But as soon as glottis is closed, lung volume doesn't change, and pressure in the airways increases, so the respiratory muscles are significantly loaded. Therefore during breath holding they make strong low-amplitude high-frequency contractions (13). Perhaps, since these contractions are perturbing factor for the postural control, they cause a strain of the postural control system and also lead to an increase of the CP oscillations' frequency.

### 5.4. Stabilographic Indices During Hyperventilation

We found that all stabilometric indices were significantly increased in both groups during maximal voluntary hyperventilation, reflecting a considerable decrease of the postural stability. We believe that a decrease of the postural stability was related to 1) a dysfunction of the nervous system and also to 2) an elevation of the frequency and the amplitude of respiratory movements (7). It's known that hypocapnia and respiratory alkalosis are almost immediate effects of hyperventilation, they lead to ischemia and hypoxia of the central nervous system (19). This, obviously, causes an impairment of the postural stability. Besides, alkalosis induces an increase of nervous fibers' excitability, this, in turn, is a reason of distortion of impulsation from the proprioceptors. Since proprioceptive afferences are an important cue for the postural control system, distortions of the proprioceptive information can induce a decrease of the postural stability (20). We suppose, that the shift of spectrum of the stabilographic signal toward high-frequency range (Table 2) was also related to the distortion of proprioceptive signals, since high-frequency CP oscillations reflect involvement of the proprioceptive system in the postural control (15). The influence of hyperventilation on the postural stability is also confirmed by the correlations of the stabilographic and respiratory indices (Table 3). According to our data during hyperventilation the velocity of the CP displacements increased to a greater extent in the athletes (P = 0.005), whereas other indices changed in the same way in both groups. So, obviously, the degrees of a decrease of postural stability in the athletes and the controls did not differ, but the postural control system demonstrated greater activity in the athletes. Vent elevated greater in the athletes versus the sedentary subjects during hyperventilation (P = 0.003), so one can assume that the impact of increased respiration was stronger on the athletes' postural stability. So the same change of the sway parameters in the athletes and the controls shows that a greater impact on a postural stability of the athletes didn't lead to a greater decrease of their balance. In other words, a postural control system in the athletes compensated perturbations of upright posture more efficiently, but it was achieved at the expense of greater effort. According to our data the power of the high-frequency spectrum range and the 60% level of total spectral power increased to a greater extent in the athletes during voluntary hyperventilation. It's known that high-frequency CP oscillations reflect the use of mainly proprioceptive information for maintaining balance (16). We've suggested above that hyperventilation led to distortion of the proprioceptive impulses due to influence of alkalosis on the nervous system excitability. Perhaps, since at the hyperventilation trial the respiratory movements were deeper and faster in the athletes versus the controls, the distortion of proprioceptive information was more pronounced in the athletes, leading to a more significant elevation of high-frequency spectrum indices. The distortion of the short-loop information, however, didn't cause a greater impairment of the postural stability in the athletes, possibly, due to more efficient performance of their postural system. The postural stability of the athletes and sedentary men didn't differ during quiet breathing, however, maintenance of upright posture was achieved through less effort in the athletes. During maximal inspiratory breath-holding postural sway remained unchanged, but activity of the postural regulation increased significantly. Maximal voluntary hyperventilation led to a considerable decrease of the postural stability in both groups. Greater ventilation in the athletes didn't lead to more significant impairment of their postural stability, but caused greater activation of their postural control system. We found a better postural stability in athletes compared to untrained men during maximal respiratory loading.

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## Authors' Contributions

Maxim Malakhov: Concept and Design, Acquisition

of Data, Data Analysis and Interpretation, Manuscript Preparation; Elena Makarenkova: Acquisition of Data, Data Analysis and Interpretation; Andrey Melnikov: Concept and Design, Data Analysis and Interpretation, Manuscript Preparation, Critical Revision of the Manuscript, Approval of the Article.

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