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HILDEBRANDT INDEX IN SKIERS AND TAEKWONDO ATHLETES AT REST AND UNDER STANDARD BICYCLE ERGOMETRIC LOADS

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Annotation. This study included examination of 15 skiers, developing endurance, and 17 taekwondo athletes, developing speed strength, under laboratory conditions. By using the Oxycon Pro system, we registered indicators of blood parameters and respiration in athletes. Skiers revealed higher values of lung capacity and vital index, Skibinskaya index, maximum oxygen consumption, but lower values of heart rate, double product, and Hildebrandt index at rest and under loads. Taekwondo athletes differ from skiers by an increased body mass index and higher strength indicators (strength and power index), increased "pulse and pressor cost" of physical loads.

Keywords: skiers, taekwondo athletes, bicycle ergometric loads, blood circulation, respiration, Hildebrandt index.

Introduction. Cardio-respiratory synchronization and its indicator, called the Hildebrandt index (HI), are used in human physiology and medicine for a long time [1-4]. Some authors noted changes in HI in case of increasing physical activity. However, there was no comparison between athletes of different sports. It is widely known that engaging in different sports has effects on morphofunctional and physiological indicators of a human. The literature sources have data on specific features of athletes' body in different sports [5-9]. Data on comparison of physiological features of those, who develop endurance and speed strength, are scarce [10-11]. That is the reason why it is interesting to compare the functional state of skiers, developing endurance, and taekwondo athletes, developing speed strength, on a united methodological basis, including the comparison of HI values.

The purpose of the study is to compare morphofunctional and physiological data and indicators of blood circulation and respiration, as well as HI, in skiers and taekwondo athletes at rest and under physical loads.

Methods and organization. We examined 15 male skiers and 17 male taekwondo athletes, who live in the Komi Republic, in comfortable laboratory conditions during warm time of the year. Both selections included rated athletes (about 30%), candidates to master of sports (about 30%) and master of sports (about 30%) in almost equal ratio. All of them gave consent to participate. The Bioethics Local Committee in the Komi Institute of Physiology approved the studies.

We registered morphofunctional and physiometric indicators using common methods. The lung capacity (LC) was registered with a dry spirometer. The heart rate (HR) and blood pressure (systolic – sBP and diastolic – dBP) – with a UA-767 device (A&D Company Ltd., Japan). We also calculated the body mass index (BMI), power index (strength/body mass – PI), vital index (LC/body mass – VI), double product (DP) according to Robinson, the Kerdo index (KI) and the Sibirskaya cardio-respiratory index (SI).

Athletes were tested on a bicycle ergometer with registration of cardio-respiratory indicators (HR, sBP, dBP, respiration rate – RR, respiratory volume – RV, respiratory minute volume – RMV, oxygen consumption – OC, degree of blood oxygen saturation – SO_2, oxygen pulse – OP) with the Oxycon Pro system (Germany) and calculation of DP, the oxygen utilization coefficient – OUC and the Hildebrandt index – HI, obtained through dividing

HR by RR. After the five-minute sitting on a bicycle ergometer at rest, we gave standard loads with a capacity of 50 W, 100 W and 150 W, 5 minute each. The maximum oxygen consumption (MOC) or aerobic threshold was calculated with the Astrand nomogram, taking into account values of HR and oxygen consumption after loads with a capacity of 150 W.

The data obtained was statistically processed with Statistics 6.0 and Biostat 4.03 software with checking on variational series for distribution type (according to the Shapiro-Wilk criteria). We applied mean arithmetic values with their errors (M±m) for indicators with normal (or close to normal) distribution. The differences were considered as statistically significant if $p<0.05$.

Results and discussion. Data from table 1 show that the compared selections of athletes are identical in age. However, skiers have a slightly greater height and lower body mass, which is why the body mass index is much lower than in taekwondo athletes. Taekwondo athletes have higher strength indicators (arm strength and power index), the difference is statistically significant. Hypoxemia resistance (data from tests on holding breathing) is almost equal in both selections.

Values of LV and VI are significantly higher in skiers than in taekwondo athletes. According to the sBP level, both groups are almost the same. However, other indicators of central hemodynamics show that these groups have substantial differences. Skiers have lower dBP, HR, DP and KI and higher Skibinskaya index.

Table 1

Comparison of morphological, physiometric and physiological indicators in athletes (M±m)

Indicators	Standard	Skiers, n=15	Taekwondo athletes, n=17	Difference level, p
Age, years		21.8±0.76	22.4±0.80	S.In
Height, cm		177.3±0.89	175.2±0.94	S.In
Body mass, kg		71.8±1.38	73.3±1.25	S.In.
BMI, kg/m²	20-25	22.8±0.33	24.1±0.37	<0.05
Right wrist strength, kg		48.8±1.17	53.5±0.92	<0.001
Left wrist strength, kg		45.7±0.99	49.8±0.89	<0.001
Power index, %	≥66	68.1±1.34	73.4±1.79	<0.01
Test of breath holding on inhale, s	≥50	77.0±3.84	79.2±2.92	S.In.
Test of breath holding on exhale, s	≥30	43.4±2.70	41.8±2.22	S.In.
LC, ml		4998±105	4580±101	<0.001
VI, ml/kg	≥56	69.9±1.34	62.5±1.49	<0.001
sBP, mm Hg	100-140	126±1.79	128±1.69	S.In.
dBP, mm Hg	60-90	69±1.60	72±1.25	<0.05
HR, beats/min	55-75	55±1.66	64±1.92	<0.001
DP, c.u.	<94	68±2.50	79±1.06	<0.001
KI, %	(-10)-(+10)	-27.8±3.94	-17.5±4.47	<0.05
SI, points	>31	72±4.60	60±4.21	<0.05

Note: here and in the next table, “S.In.” means “statistically insignificant differences”

When working with the bicycle ergometer (table 2), skiers, in comparison with taekwondo athletes, have significantly lower HR, DP, HI, RV, RMV and OP, but higher SO_2. Values of OC and OUC are almost equal in both groups. The situation is changing in case of applying 100 W and 150 W loads. Even though both groups have almost equal OP, HR in skiers is lower, while values of SO_2, OC and OUC is higher, than those in taekwondo athletes. Central hemodynamics indicators (sBP, dBP) at rest and under mild loads (50 and 1000 W) are approximately the same in both selections. However, higher level of loads (150 W) reveals difference in sBP reactions. Values of HR, DP and HI in skiers are significantly lower on each stage of the experiments. Aerobic capability indicators are also different. MOC values are higher in skiers.

Table 2

Comparison of load test indicators in athletes (M±m)

Indicators and loads	Skiers, n=15	Taekwondo athletes, n=17	Difference levels, p
HR, beats/min: at rest	50±1.38	75±1.13	<0.001
50 W	84±2.00	97±2.59	<0.01
100 W	99±2.19	119±2.84	<0.001
150 W	115±2.52	140±2.96	<0.001
sBP, mm Hg: at rest	109±1.95	108±1.88	S.In.
50 W	117±1.80	118±2.19	S.In.
100 W	129±2.02	133±2.95	S.In.
150 W	143±2.48	155±3.17	<0.01
dBP, mm Hg: at rest	73±1.53	72±1.64	S.In.
50 W	71±1.84	72±1.92	S.In.
100 W	69±1.35	72±2.29	S.In.
150 W	70±2.19	73±2.65	S.In.
DP, c.u.: at rest	55±1.88	80±1.97	<0.001
50 W	95±3.07	115±4.56	<0.01
100 W	126±3.43	156±5.88	<0.001
150 W	162±4.46	218±6.53	<0.001
RR, cycle/min: at rest	17.0±0.64	17.1±0.61	S.In.
50 W	18.8±0.68	18.3±0.62	S.In.
100 W	21.3±0.54	21.4±0.87	S.In.
150 W	24.6±0.74	24.8±0.95	S.In.
HI=HR/RR, beat/cycle:			
at rest	2.92±0.07	4.38±0.07	<0.001
50 W	4.39±0.08	5.27±0.08	<0.001
100 W	4.58±0.09	5.54±0.08	<0.001
150 W	4.61±0.08	5.62±0.09	<0.001
RV, ml: at rest	670±29	910±44	<0.001
50 W	1450 ± 44	1470±60	S.In.
100 W	1755 ± 44	1930±63	S.In.
150 W	2030 ± 67	2200±60	S.In.
MRV, l: at rest	11.3±0.41	14.8±0.61	<0.001
50 W	27.1±0.57	25.7±0.55	S.In.
100 W	37.0±0.71	39.7±1.02	S.In.
150 W	59.3±1.21	53.9±1.37	S.In.

Table 2 (continued)

OC, ml/min: at rest	390±20	538±28	<0.001
50 W	1208±20	1125±16	<0.05
100 W	1706±19	1690±19	S.In.
150 W	2305±31	2230±35	S.In.
OUC, ml/l: at rest	34.8±0.97	35.5±0.84	S.In.
50 W	44.6±0.66	43.8±0.64	S.In.
100 W	46.5±0.78	43.0±0.76	<0.01
150 W	46.4±0.77	42.1±0.83	<0.001
OP, ml/beats: at rest	7±0.40	7.4±0.42	S.In.
50 W	14.9±0.39	12.0±0.39	<0.001
100 W	17.9±0.49	14.6±0.36	<0.001
150 W	20.5±0.47	16.1±0.38	<0.001
SO_2, %: at rest	98.5±0.11	98.0±0.15	<0.01
50 W	96.8±0.43	95.1±0.70	<0.05
100 W	97.1±0.48	94.6±0.70	<0.01
150 W	96.9±0.44	93.4±0.88	<0.01
MOC, l/min	5.36±0.15	3.86±0.16	<0.001
ml/min*kg	73.9±1.87	54.5±2.30	<0.001

When analyzing HI dynamics in athletes of different sports, we have found a statistically significant growth of this indicator at rest to the 50 W load ($p<0.001$). When increasing loads to 100 and 150 W, we registered tendency of increasing HI in taekwondo athletes between loads of 50 W to 100 W ($p<0.05$) and tendency to load increase from 100 to 150 W. Therefore, less enduring taekwondo athletes have a more pronounced cardio-respiratory synchronization according to HI data.

As we can see from the received data, skiers, who mainly perform aerobic loads and develop endurance, have higher LC, LI and SI that show great capabilities of the cardiorespiratory system, but lower values of HR (bradycardia), HI, dBP that characterize an increased preparedness of the cardiovascular system and body in whole. Lower level of KI in skiers demonstrated a predominant parasympathetic influence of the vegetative nervous system on blood circulation. Scientific data also have evidence on aerobic capability and more sparing work of the cardiovascular system in skiers [12-13].

Taekwondo athletes, who develop speed strength, are different in higher strength indicators, both absolute and specific (per unit of body mass). Scientific data also notes significant strength and high anaerobic capability of taekwondo athletes and other martial artists [5, 14].

As it was revealed from the data of table 2, HR values in skiers, both at rest and under loads, are much lower than in taekwondo athletes. It allows us to note not only the sparing work of the heart, but also lower "pulse cost" of standard physical loads in skiers, who perform aerobic loads and develop endurance. Central hemodynamics indicators (sBP and dBP) at rest and under mild loads (50 и 100 W) in both groups are practically the same. Nonetheless, higher loads (150 W) reveal difference in sBP reactions in the compared groups. The "pressure cost" of these loads in taekwondo athletes is higher. Such indicator as DP that shows mechanical work of the heart is lower in this group both at rest and under physical loads. It is safe to assume that the less trained heart gives "excessive response" to standard physical loads.

Lower values of respiratory functions (RV and RMV) and OC at rest show more sparing work of the skiers' body. In case of loads, body of skiers and taekwondo athletes requires almost equal levels of RMV and OC. It means

that "ventilation" and "oxygen" cost of standard physical loads within the range of 50 to 150 W is not different in both groups.

At rest, as well under all applied loads, skiers have higher blood saturation, which is typical for people, who develop aerobic capability. Higher effectiveness of the cardiorespiratory system in skiers is shown when applying loads. It is demonstrated through higher values of OP (more oxygen is transferred with each systole) and OUC (more oxygen is taken out by blood from each liter of alveolar air). At rest, there are no differences.

MOC values (absolute and specific – per unit of body mass) that characterize aerobic capability or aerobic threshold is higher in skiers. That confirms fitness of their cardiorespiratory system and stayer endurance of the body. Sources also have data on high aerobic capability in skiers [12-13], low aerobic, but high anaerobic capability in taekwondo athletes [5, 14].

The cardio-respiratory synchronization method, suggested by V.M. Pokrovskij et al. [1], can be used as a model that allows evaluating regulatory and adaptive capabilities of the body. Interaction between two main life support systems, i.e. systems of blood circulation and respiration, was always of interest for physiologists and physicians [3].

One of indicators showing synchronization of the heart and respiration in human body is HI, which is informative and is characterized by its simplicity and accessibility. A group of researchers [10] suggested to 10 athletes to perform increasing stage-dosed physical loads on a bicycle ergometer. As physical loads increased, HI increased as well. This indicator is used as an accessible criterion of the body's physiological costs.

According to other data [16], 16 test subjects also had increased HI. It was a sign for stopping intense physical loads and a criterion for rejection diagnosis, in cyclists in particular.

The received HI values in skiers and taekwondo athletes in case of increasing physical loads on a bicycle ergometer correspond with scientific data [2, 4] on assessing physiological costs on similar bicycle ergonomic tests. Nonetheless, we also discovered substantial and statistically significant differences in HI levels among skiers and taekwondo athletes.

High capabilities of skiers' cardiorespiratory system, noted above, allow them to participate in stayer many-kilometer and many-hour ski races. Strength- and speed-based advantages of taekwondo athletes allow them to participate in short-term martial arts, which require increased strength and speed of movements.

Conclusion. As a result, we revealed economization of blood circulation functions both at rest and under standard physical loads, as well as an increased efficiency of the cardiorespiratory system and high aerobic threshold in skiers, who develop endurance. Taekwondo athletes, who develop speed strength, in comparison with skiers, have higher body mass index, increased indicators (arm strength and power index), "pulse" and "pressure" cost of standard physical loads. Research of cardiorespiratory indicators in case of substantial physical loads (150 W and higher) give more information for revealing body features of athletes, who develop various athletic qualities.

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REFERENCES

1. Pokrovskij V.M., Abushkevich V.G., Novikova V.A., Potyagajlo E.G., Pokhot'ko A.G., Tatulyan V.A., Khakon S.M., Kharitonova E.V. Cardio-respiratory synchronization in humans. *Kuban Scientific Medical Bulletin,* 2000, no. 2, pp. 42–47. (in Russ.)

2. Fudin N.A., Sudakov K.V., Khadartsev A.A., Klassina S.Ya., Chernyshev S.V. Hildebrandt index as an integral indicator of physiological costs in athletes within the process of increasing stage-dosed physical activity. *Bulletin of New Medical*

Technologies, 2011, vol. 18, no. 3, pp. 244–248. (in Russ.)
3. Zabolotskikh A.I., Zabolotskikh N.V. Effect of the cardio-respiratory synchronization test on the main parameters of central hemodynamics. *Kuban Scientific Medical Bulletin*, 2014, no. 5(147), pp. 52–55. (in Russ.)
4. Klassina S.Ya. Hildebrandt index as a prognostic criterion for rejection of intense physical activity. *Science and Sports: Modern Tendencies*, 2019, vol. 7, no. 2, pp. 68–73. (in Russ.)
5. Bridge C.A., Ferreira da Silva Santos J., Chaabene H., Pieter W., Franchini E. Physical and physiological profiles of taekwondo athletes. *Sports Med*, 2014, vol. 44, no. 6, pp. 713–733.
6. Monks L., Seo M.-W., Kim H.-B., Jung H.C., Song J.K. High-intensity interval training and athletic performance in Taekwondo athletes. *J. Sports Med. Phys. Fitness*, 2017, vol. 57, no. 10, pp. 1252–1260.
7. Polat M., Korkmaz E.S., Aydogan S. Seasonal variations in body compositions, maximal oxygen uptake, and gas exchange threshold in cross-country skiers. *Open Access J. Sports Med*, 2018, vol. 9, no. 3, pp. 91–97.
8. Butkov A.D., Lysenko E.A., Lemesheva Yu.S., Ustyuzhanin D.V., Grushin A.A., Vinogradova O.L., Popov D.V. Aerobic and speed-strength capabilities of skiers at the end of the preparatory and the beginning of the competitive periods of training. *Human Physiology*, 2017, vol. 43, no. 3, pp. 57–63. (in Russ.)
9. Solonin Yu.G., Loginova T.P., Garnov I.O., Markov A.L., Chernykh A.A., Boiko E.R. Cardiorespiratory system during bicycle ergometric testing in skiers of the Republic of Komi with different degrees of training. *Ulyanovsk Medico-Biological Journal*, 2019, no. 1, pp. 76–84. (in Russ.)
10. Zamchij T.P., Salova Yu.P., Koryagina Yu.V. Features of regional hemodynamics of athletes developing endurance, strength and endurance strength. *Therapeutic Physical Culture and Sports Medicine*, 2012, no. 7, pp. 23–27. (in Russ.)
11. Solonin Yu.G., Bojko E.R., Markov A.L., Varlamova N.G., Garnov I.O., Loginova T.P., Martynov N.A., Rastorguev I.A., Chernykh A.A. Comparison of physiological indicators and their responses to physical activity in ski racers and taekwondo athletes. *Sports Medicine: Science and Practice*, 2015, no. 2(19), pp. 33–38. (in Russ.)
12. Neumayr G., Hoertnagl H., Pfister R., Koller A., Eibl G., Raas E. Physical and physiological factors associated with success in professional alpine skiing. *Int. J. Sports Med*, 2003, vol. 24, no. 8, pp. 571–575.
13. Sandbakk O., Holmberg H.-C., Leirdal S., Ettema G. Metabolic rate and gross efficiency at high work rates in world class and national level sprint skiers. *Eur. J. Appl. Physiol.*, 2010, vol. 109, no. 3, pp. 473–481.
14. Ball N., Nolan E., Wheeler K. Anthropometrical, physiological, and tracked power profiles of elite taekwondo athletes 9 weeks before the Olympic competition phase. *J. Strength Cond. Res.*, 2011, vol. 25, no. 10, pp. 2752–2763.

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