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Effects of Improved Cardiovascular Performance on Vascular Function – a Pilot Study

Auswirkungen einer verbesserten kardiovaskulären Leistung auf die vaskuläre Funktion – eine Pilotstudie

ORIGINALIA

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Summary

- **There is a well-known association** between improved endurance performance and lower cardiovascular risk, although the exact physiological mechanisms underlying this association have not been fully elucidated.
- **To investigate this,** 21 subjects completed a structured, 10-week, polarized and periodized running training program. Cardiovascular parameters were determined using lactate performance diagnostics, the salt-blood test (SBT)-mini as marker for the glycocalyx, and pulse wave analysis (PWA) at baseline and follow-up examinations. In addition, blood lipid and sugar levels, as well as blood pressure progression, were documented to provide information on the general health of the subjects.
- **The main effects** of the 10-week polarized and periodized running training were (i) an improvement in performance, (ii) reduced total and HDL cholesterol, (iii), lowered blood pressure, and (iv) a decrease in the augmentation index (p=0.012). For the entire cohort, the SBT mini values were not changed after the intervention. Interestingly, the improved vascular function correlated with greater performance gains for subjects under 45 yrs (r=-0.636; p=0.019 and r=-0.771; p=0.003).
- **Here, we showed** that polarized and periodized running training has positive effects on the vascular system, with the augmentation index being a suitable marker for early detection of vascular changes. Of note, only young subjects benefited from a greater increase in performance regarding vascular function. However, further investigations are needed to clarify whether this result is based on an age-dependent, longer regeneration time.

Zusammenfassung

- **Es gibt einen bekannten Zusammenhang** zwischen einer verbesserten Ausdauerleistung und einem geringeren kardiovaskulären Risiko, wobei die genauen physiologischen Mechanismen noch nicht vollständig aufgeklärt sind.
- **Um dies zu untersuchen,** durchliefen 21 Probandinnen und Probanden mit einer Altersspanne von 23 bis 62 Jahren ein strukturiertes, 10-wöchiges, polarisiertes und periodisiertes Lauftraining, wobei kardiovaskuläre Parameter mithilfe spezifischer Laktatleistungsdiagnostiken, dem Salz-Blut-Test (SBT)-Mini und Pulswellenanalysen (PWA) in einer Baseline und Follow-Up Untersuchung bestimmt wurden. Zusätzlich wurden Blutfett- und Zuckerwerte, sowie der Blutdruckverlauf dokumentiert, um Aufschluss über den generellen Gesundheitszustand der Probanden und Probandinnen zu bekommen.
- **Die Hauptauswirkungen** des 10-wöchigen, polarisierten und periodisierten Lauftraining waren (i) objektiv messbare Leistungsverbesserungen, (ii) eine Gesamt- und HDL-Cholesterin-Senkung, (iii), Blutdrucksenkungen, sowie (iv) eine Reduktion des Augmentationsindex (p=0,012) und (v) eine Korrelation zwischen verbesserter vaskulärer Funktion und höheren Leistungssteigerungen für <45Jährige (r=-0,636; p=0,019 bzw. r=-0,771; p=0,003). Für die gesamte Kohorte zeigte sich während der Intervention keine Veränderung im SBT-Mini.
- **Damit konnte in dieser Studie gezeigt werden,** dass das durchgeführte polarisierte und periodisierte Lauftraining positive Auswirkungen auf das vaskuläre System hat. Vor allem der Augmentationsindex ist ein zuverlässiger, vaskulärer Marker und damit für die Früherkennung von Gefäßveränderungen geeignet. Hervorzuheben ist, dass besonders junge Probanden und Probandinnen von einem höheren Leistungsfähigkeitszuwachs im Hinblick auf die vaskuläre Funktion profitierten. Ob dies in einer altersabhängig längeren Regenerationszeit begründet liegt, gilt es in weiteren Untersuchungen abzuklären.

KEY WORDS:
Physical Exercise, Glycocalyx,
Pulse Wave Velocity, Cardiovascular Fitness

SCHLÜSSELWÖRTER:
Körperliche Aktivität, Glykokalyx,
Pulswellengeschwindigkeit, kardiovaskuläre Fitness

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Introduction

Cardiovascular diseases (CVD) are still the leading cause of death worldwide, although numerous advances in treatment have been made (43). In turn, one of the causes of CVD is endothelial dysfunction and the resulting damage of arterial vessels, and arterial hypertension constitutes one of the risk factors of the disease (30). Almost half of all European adults >35 years suffer from hypertension (42). It has been shown that modifying lifestyle through exercise intervention, in addition to improving blood lipids (13, 37),can reduce arterial hypertension to the same extent as drug monotherapy, with the effect of endurance training appearing to be particularly large (7).

Improvements in endothelial function (through the release of vasoactive substances such as nitric oxide, NO) and vascular compliance have been

Table 1

Subject characteristics and physiological parameters at baseline. BMI=Body-Mass-Index; Bpm=Beats per minute.

	GENDER					
	OVERALL		FEMALE		MALE	
	MEAN	SD	MEAN	SD	MEAN	SD
n	21		14		7	
Age (years)	37,71	±13,42	35,57	±13,30	42	±13,61
Height (m)	1,76	±0,095	1,72	±0,09	1,83	±0,05
Weight (kg)	75,1	±11,52	68,36	±6,70	88,57	±5,26
BMI (kg/height^2)	24,26	±2,32	23,2	±1,96	26,37	±1,31
Resting pulse (bpm)	69,67	±13,71	69,93	±14,80	69,14	±12,31
Systolic blood pressure (mmHG)	128,33	±17,02	133,5	±17,98	118	±8,87
diastolic blood pressure (mmHG)	81,57	±6,39	82,71	±6,51	79,29	±5,94
Mean arterial blood pressure (mmHG)	104,95	±10,49	108,11	±11,14	98,64	±5,31

described as the main reasons for reduced mortality through exercise intervention (19, 22). As an important prognostic parameter of aortic vascular stiffness, pulse wave velocity (PWV) assessment has entered the European Society of Hypertension (ESH) and European Society of Cardiology (ESC) guidelines as a gold standard measurement (41). A chronically stiff endothelial surface causes pathological changes to the vessel wall and, as a consequence, reduces compliance. Over time, this results in an increased PWV, which can used as a marker for cardiovascular risk stratification (18). In normotensive patients, an aortic pulse wave velocity (aPWV) of 4-9m/s is considered normal, whereas aPWVs of >10m/s are deemed pathological. An increase in aPWV of as little as 1m/s appears to increase the risk of a cardiovascular event by 15% (23). This can also be translated into a 'biological vascular age', which can be easily understood by patients and helps to communicate the potential issues surrounding the disease to them.

Another prognostic marker for the development of endothelial dysfunction is the integrity of the endothelial glycocalyx, a glycoprotein- and proteoglycan-rich structure on the surface of vascular endothelial cells, erythrocytes, and other somatic cells (32). Various diseases cause severe damage to the glycocalyx, such as vascular inflammation, sepsis, stroke, or renal insufficiency (10, 34). On the other hand, it has been shown that high-intensity interval training (HIIT) can significantly improve glycocalyx quality (36).

The primary aim of this study was to investigate the effects of a structured, 10-week polarized and periodized running training on performance and glycocalyx integrity as a marker of vascular function. In addition, vascular stiffness was recorded and blood lipids and glucose levels as well as blood pressure profile were assessed as general parameters for the health status of the subjects.

Material and Methods

Study Design

A longitudinal interventional study was performed in which the subjects initially received an entry examination, consisting of PWV and SBT measurements, blood sampling, blood pressure measurement, and a first performance diagnostic assessment in the form of a lactate level test. Over the following 10 weeks, the subjects completed a cycle of cardiovascularly effective, polarized, and periodized training. After this exercise intervention, the subjects were tested again as described above and a second lactate level test was performed. This was followed by statistical analysis of the collected data and interpretation with regard to their clinical relevance.

Acquisition of Subjects and Inclusion and Exclusion Criteria

A case number of n=30 was aimed for a priori. This is sufficient to estimate a sufficiently precise confidence interval for a correlation of 0.9, which excludes true correlations below 0.8 or above 0.95 with a certainty of 95%. Due to the pandemic situation, we had a drop-out of 9 study subjects and it was not possible to recruit more. Thus, healthy subjects >21 years of age and of both sexes, sport and running beginners, were included. Human subjects consented in written form to the procedure, which included blood sampling of approx. 5-15 ml from the arm vein as well as capillary blood. Exclusion criteria were detected infectious diseases, especially HIV, covid-19, or hepatitis. Nevertheless, all blood samples were considered potentially infectious and treated accordingly. Additional exclusion criteria included cardiovascular and renal disease, diabetes, vascular disease, obesity, and smoking. The study was approved by the Ethics Board of the University of Lübeck (20-221) in accordance with the Declaration of Helsinki.

Performed Examinations

The subjects were instructed not to perform any physically exhausting activities for 2 days prior to the examinations and the lactate level tests. In addition, caffeine consumption was also prohibited. For the PWV measurement, meals should also be avoided 3h beforehand.

Blood Sampling from the Arm Vein

At baseline and endpoint, 5-15ml of venous blood was collected in monovettes (serum, EDTA, NaF) as part of the entry/exit examination. CBC, cholesterol, LDL, HDL, TAG, potassium, sodium, calcium, high-sensitivity CRP, HBA1c, and blood glucose were quantified by a central laboratory.

Blood Pressure Measurement

After a rest period of 15min, automated blood pressure measurements were taken in a semi-darkened room using the MIT5 Connect device from OMRON ELECTRONICS GmbH (40764, Langenfeld, Germany). The same protocol was used for the follow-up examination.

Measurement of PWV

Central and peripheral PWV as well as the ankle-brachial index (ABI) were measured using the VASCASSIST2 device from iSYMED GmbH (35510 Butzbach, Germany). This device has a total of four blood pressure cuffs, so that blood pressure can be measured on all four extremities. Therefore, not only blood pressure, but also peripheral PWV and ABI of the right and left side of the body can be compared. In addition, the prognostic parameter of vascular stiffness can be determined noninvasively.

SBT-Mini

The SBT-Mini (kindly provided by CARE diagnostica, 46562 Voerde, Germany) was developed in the context of research on individual salt sensitivity determinations. It takes advantage of the fact that the surface structure of erythrocytes is a mirror of the endothelium and salt sensitivity can be measured by anyone at home in an uncomplicated way (26, 27, 28). Thus, in addition to providing information on salt sensitivity, it also gives general information on the integrity of the endothelial glycocalyx and can be used as a prognostic parameter for vascular disposition.

The test was performed as described previously (26, 27, 28). In brief, 50µl capillary blood is taken from the fingertip using a minivette and mixed with a 'Na+ cocktail'. This mixture is subsequently drawn into a hematocrit tube and positioned vertically. After 60 min, the length of the clear supernatant is measured, which reflects the sedimentation rate of the erythrocytes. This is mainly influenced by the sodium buffer behavior of the erythrocyte surface (as a result of the specific composition of the Na+ cocktail). The measured values are then related to a reference, reflecting the individual salt sensitivity and thus also the functional state of the glycocalyx in percent: 100 percent corresponds to the population average (29).

Lactate Level Test (Field Test)

An established lactate level field test was performed on a 400m running track (39). The usual standards of sports medicine diagnostics were applied (33): The duration of an exercise phase was >3 min, and the running pace was increased by 1 km/h with the next level. Importantly, the entry level was chosen so that the maximum capacity could be reached within 4-7 levels. Most subjects started with 7 km/h. The intensity levels were defined by a fixed length (800 m), so that the duration of each level was shortened with increasing speed. The time dependence of blood lactate concentration can affect the interpretation of lactate power curves (3, 4).

Before entering the next intensity level, heart rate was measured and capillary blood sampled at the earlobe. To determine individual exercise intensity, subjects were asked to indicate their subjective effort on Foster's modified Borg scale of 1-10 (5, 11, 12). In addition, resting lactate was measured and resting heart rate determined. Capillary blood lactate concentrations were analyzed using the BIOSEN C-Line (EKF Diagnostics, Barleben, Germany).

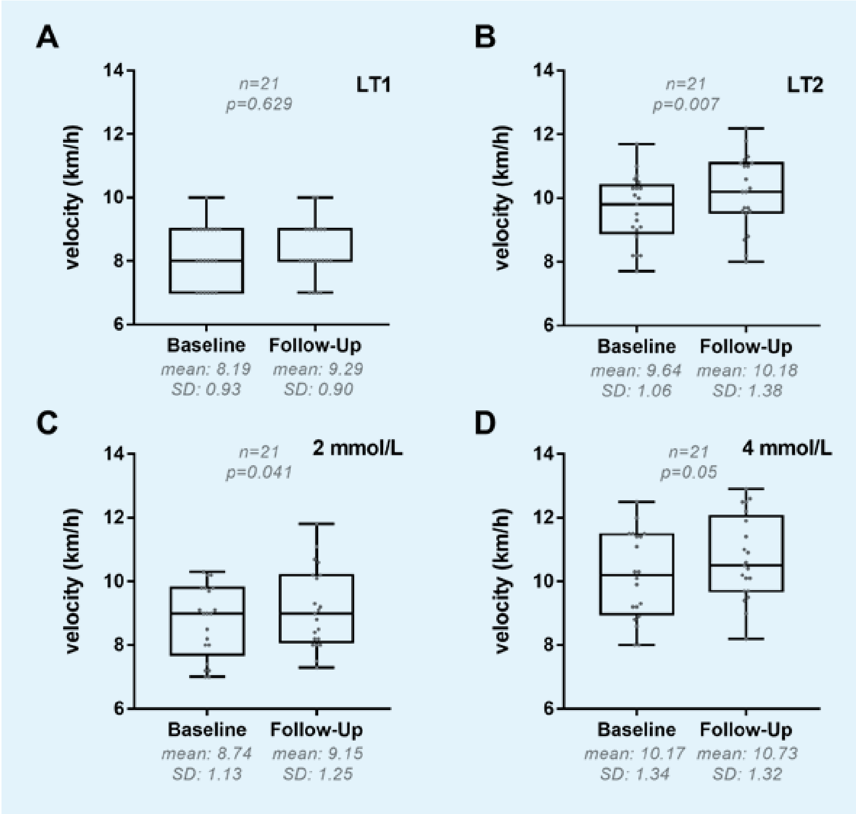

Figure 1

Effects of a 10-week polarized endurance training on the performance of the subjects with respect to their thresholds (upper chart A+B: LT1/LT2 and lower chart C+D: 2mmol/4mmol threshold) at baseline and follow-up. Shown here as a box plot are the velocity medians at the relevant thresholds with whiskers of length 1.5×IQR indicating the means and standard deviations (SD). All thresholds except LT1 were improved (t-test).

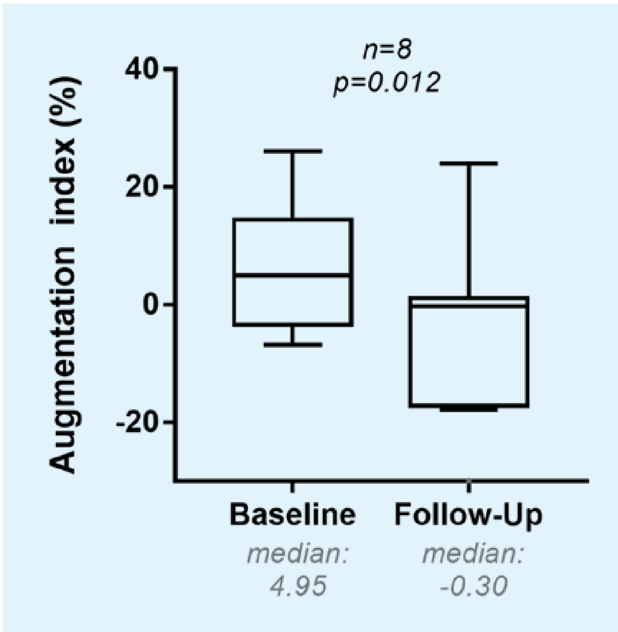

Figure 2

Augmentation index of subjects at baseline and follow-up examination (medians=line within box plots, whiskers of box plots with length 1.5×IQR, significance testing by Wilcoxon tests).

Afterwards, performance of the test subjects was evaluated using the modified Dmax method, in order to determine the aerobic (LT1) and anaerobic thresholds (LT2) as well

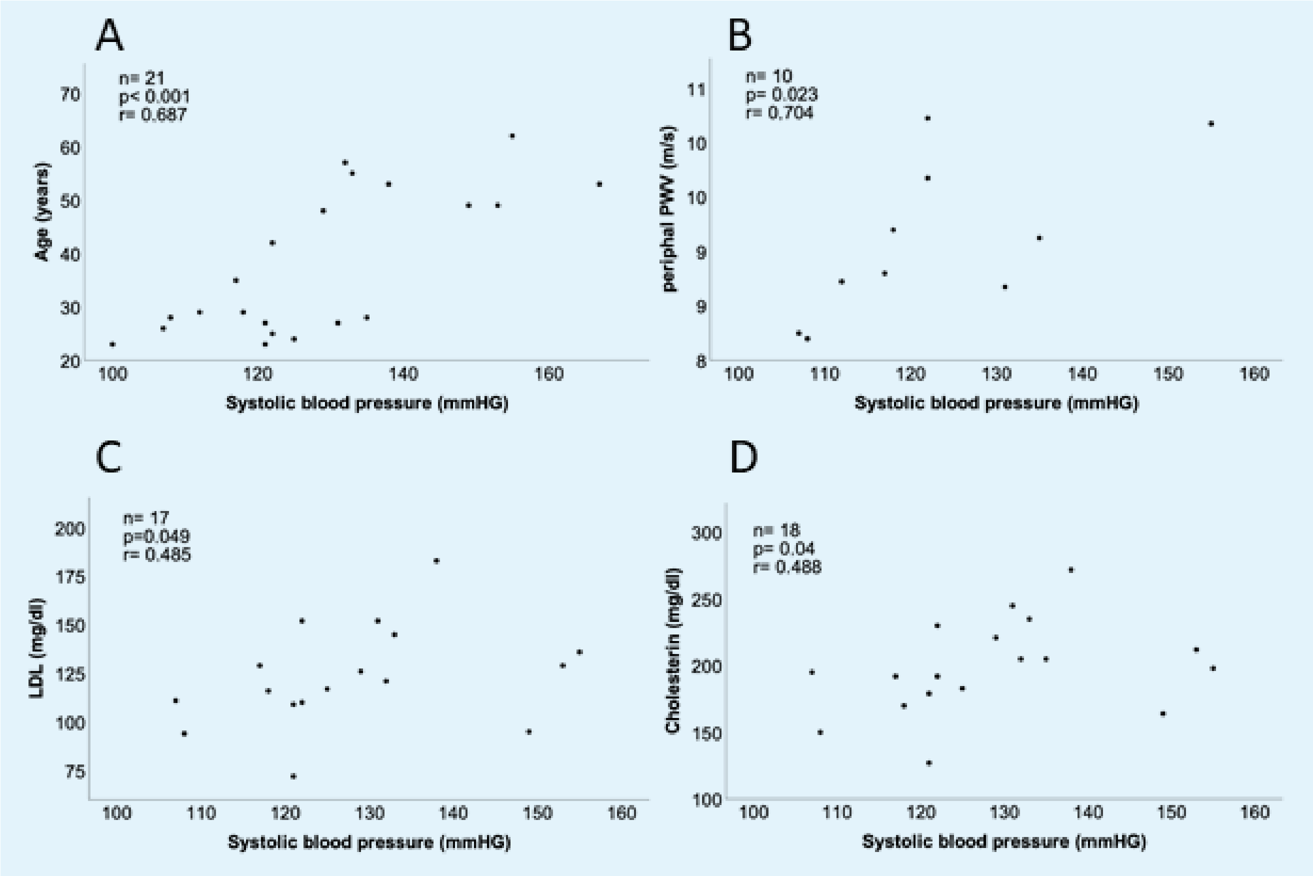

Figure 3

Correlations between elevated systolic blood pressure and A: age, B: peripheral pulse wave velocity (PWV), C: low density lipoprotein (LDL), and D: cholesterol levels at baseline (correlation analysis using Spearman rank test).

as the interpolated velocities at the 2-mmol and 4-mmol thresholds (6).

Sports Intervention

After the initial examination and the first performance diagnostic assessment, the 10-week training period started with a 2x weekly guided running training program. We decided on a polarized and periodized running training with two training sessions per week, consisting of a high-intensity interval unit and a low-intensity endurance run. Here, we were orientated to the zones 1-3 defined by Seiler (38), who determined them using the Foster load scale (Zone 1 ≤4; <4 Zone 2 <7; ≥7 Zone 3). These zones were also used to control the effort with the advantage of a correlation between the zones and the following lactate concentrations: zone 1 ≤2.0mmol/l; zone 2 >2mmol/l and <7mmol/l; and zone 3 ≥7 mmol/l) (38). Similarly, the fixed lactate values of 2 and 4mmol/l, which were also interpolated in the previous performance diagnostic assessments, correlate well with the lactate thresholds (LT1 and LT2) (20, 21).

Both the exercise time in the high-intensity range and the duration of the low-intensity session increased over the training period. Training time fluctuated consistently around 70% in zone 1 and 30% in zone 3. The efficacy of this highly polarized zone distribution and a skipping training intervention at the individual anaerobic threshold has been shown to be particularly effective in the past (38). Subjects trained at least once per week under the supervision of the study director and were asked to avoid additional cardiovascular effective stimuli performed in everyday life during the study period. The complete training plan can be found in the supplement.

Statistical Analysis

The graphs were created using the IBM SPSS Statistics 27 statistics program. Data are presented below as means ± standard deviation (SD), 95% confidence interval (CI), or whisker box plots as indicated at the respective location. The number (n) of individuals included in each analysis (baseline/follow-up studies) is explicitly referenced in each graph. If a normal distribution was assumed (analysis using the Shapiro-Wilk test), the two-sided t-test was used to test for significance; if not, the nonparametric Wilcoxon test for connected samples was used. Correlation analyses were performed using the Spearman rank test. The statistical significance level was set at $p<0.05$.

Results

In all, 21 subjects were included in the study. In the pulse wave examination, due to technical problems, only 10 data sets could be completed. In calculating the threshold values, intensity levels were not considered, and the analysis was based only on the available data.

Subject Characteristics and Physiological Parameters for the Initial Examination

The most important descriptive data for the subjects are summarized in table 1. The distribution between women and men was unequal (female n=14, ≈66.6%, male n=7, ≈33.3%). The majority of the subjects (n=12) were between 23 and 29 years of age, whereas a second age peak (n=8) was between 48 and 62 years; therefore, a cutoff of 45 years was used to isolate the age groups.

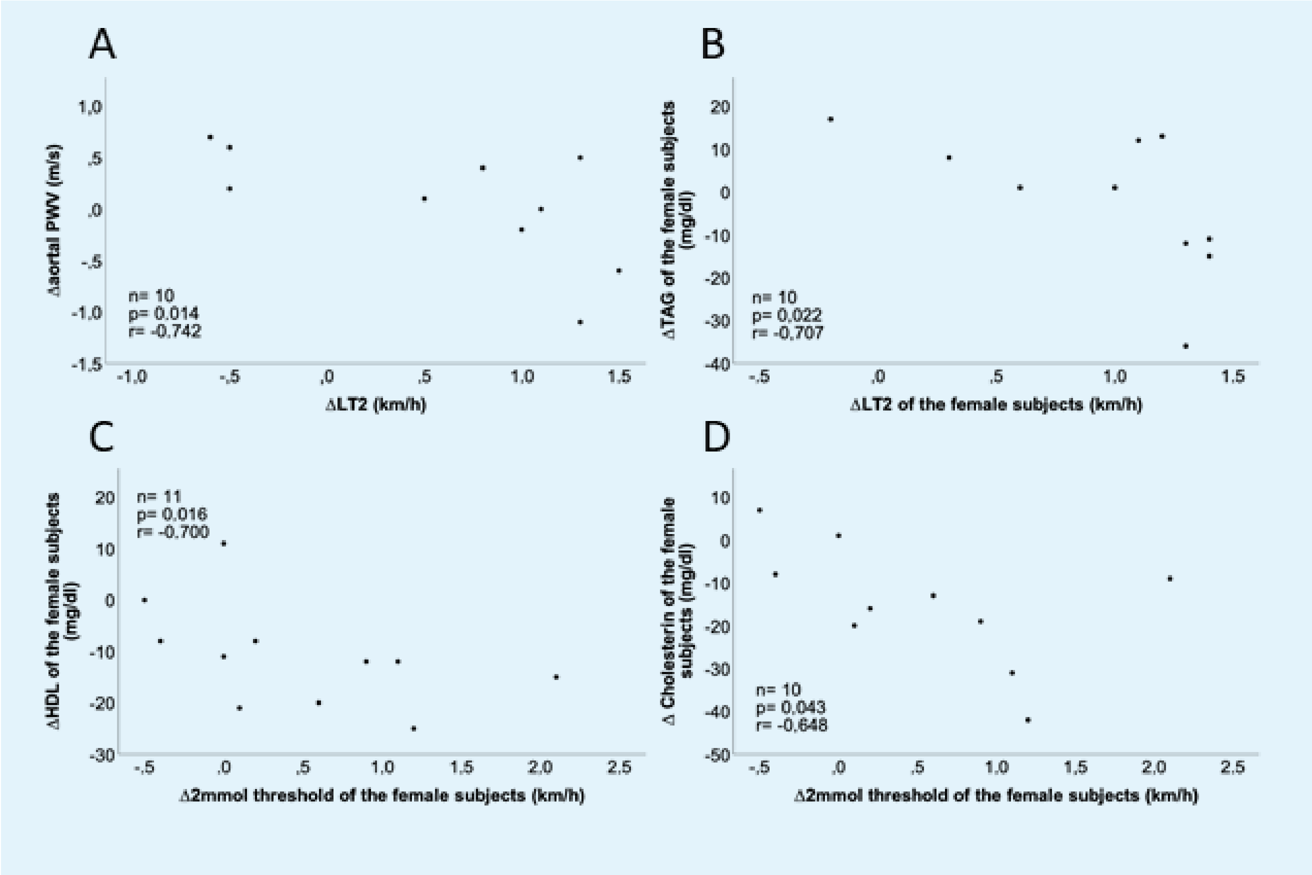

Figure 4

Correlations with threshold changes (correlation analysis with Speareman rank test). A: Correlation of lactate threshold 2 (LT2) and aortic pulse wave velocity (PWV) changes. B: Correlation of lactate threshold 2- (LT2) and triglyceride (TAG) changes for female subjects. C: Correlation of 2mmol threshold and high density lipoprotein (HDL) changes for female subjects. D: Correlation of 2mmol threshold and cholesterol level changes for female subjects.

Exercise-Induced Heart Rate, Lactate Concentration, and Exercise Perception Decreases at Fixed Speed Levels and Threshold Improvements

Here, we quantified performance over the duration of the study. Both heart rates and lactate concentrations were lower at the follow-up examination, while the participants subjectively perceived exertion to be lower (data not shown). Figure 1 shows the lactate thresholds [LT1 (figure 1A) /LT2 (figure 1B) and 2 mmol (figure 1C) /4 mmol threshold (figure 1D)] at baseline and follow-up examination. Here, improved performance abilities were recorded at all thresholds – with the exception of LT1. For example, while the average efficiency at the anaerobic threshold at the baseline measurement was 9.64±1.06 (LT2) and 10.17±1.34 km/h (4 mmol threshold), it increased to 10.18±1.38 (LT2) and 10.73±1.32 km/h (4 mmol threshold) at the follow-up examination [p(LT2)=0.007; p(4 mmol threshold)=0.05].

Similarly, the subjects were able to reach higher intensity levels in the lactate performance diagnostic assessment. While the subjects were able to complete an average of 5.6±0.74 levels (increase per level: 1 km/h each) during the baseline examination starting from 7 km/h, they managed an average of 6.3±0.96 levels during the follow-up examination. The difference was statistically highly significant (p=<0.001).

Exercise-Induced Total Cholesterol and HDL Reductions

In total, between 15 and 17 complete data sets could be collected for the blood parameters providing information on general health status. Means and standard deviations at baseline and follow-up are shown in table 2. Significant changes in the period from baseline to follow-up examination were seen in cholesterol levels (p=0.008) and highly significant changes in HDL levels (p<0.001). Effects on the inflammatory parameter CRP could not be detected (data not shown).

Exercise-Induced Change in Vital Parameters

Means and standard deviations for blood pressure at baseline and follow-up examination are summarized in table 3. No reduction was observed in systolic blood pressure (p=0.138), but diastolic blood pressure (p=0.015) and MAP (p=0.024) decreased over the course of the study. There were no effects on resting heart rate (baseline: 69.7±13.71 bpm; follow-up 70.4±11.26 bpm; p=0.82).

Exercise-Induced Change in Hemodynamic Parameters

No changes were found in PWV, vascular age, and aortic MAP after exercise intervention (see table 4). However, analysis of the AIX showed a significant reduction (p=0.012) here after the intervention (figure 2).

Correlation Between Elevated Blood Pressure and Older Age, High PWV, LDL, and Cholesterol Levels

Systolic blood pressure elevated at baseline was related to older age (figure 3A; n=21; r=0.687; p<0.001), increased peripheral PWV (figure 3B; n=10; r=0.704; p=0.023), and elevated LDL (figure 3C; n=17; r=0.485; p=0.49) and cholesterol levels (figure 3D; n=18; r=0.488; p=0.04).

Table 2

Blood parameters at baseline and follow-up with standard deviations and p-values indicating the corresponding reference values (t-test). *stated reference values of the laboratory commissioned (Laborärztliche Gemeinschaftspraxis Lübeck). LDL=Low Density Lipoprotein, HDL=High Density Lipoprotein, NCEP=National Cholesterol Education Program

	N	BASELINE		FOLLOW-UP		P	REFERENCE VALUES*
		MEAN	SD	MEAN	SD		
HbA1c (%)	17	5.4	±2.35	5.36	±2.36	0.47	Rating: Good< 6.5%. Acceptable< 7.5% Poor > 7.5%
Cholesterin (mg/dl)	16	198.61	±35.02	190.25	±29.94	0.008	130-200 mg/dl
Triglyceride (mg/dl)	15	95.67	±43.05	90.47	±31.21	0.314	40-150 mg/dL
LDL (mg/dl)	15	123.4	±26.03	123.9	±24.60	0.236	<115 mg/dL Reference intervals (NCEP): <100 mg/dl Optimal (target). 100-129 mg/dl Near Optimal 130-159 mg/dl Borderline 160-189 mg/dl High >190 mg/dl Very high
HDL (mg/dl)	17	78	±17.27	67.67	±11.87	<0.001	>35 mg/dL

Table 3

Blood pressure measurements with standard deviations at baseline and follow-up examination and p-values (t-test). SD=standard deviation.

	N	BASELINE		FOLLOW-UP		P
		MEAN	SD	MEAN	SD	
Systolic blood pressure (mmHG)	20	128.33	±17.02	123.85	±14.09	0.138
Diastolic blood pressure (mmHG)	20	81.57	±6.39	77.1	±8.75	0.015
Mean arterial blood pressure (mmHG)	20	104.95	±10.49	100.48	±10.19	0.024

Table 4

Vascular parameters of the VASCASSIST2 measurement with standard deviations at baseline and follow-up examination and p-values (t-test). PWV=Pulse wave velocity; MAP=Mean arterial blood pressure.

	N	BASELINE		FOLLOW-UP		P
		MEAN	SD	MEAN	SD	
Aortal PWV (m/s)	10	6.46	±0.93	6.52	±1.09	0.745
Peripheral PWV (m/S)	10	9.21	±0.77	9.11	±0.72	0.237
Vascular age (y)	10	31.5	±10.48	30	±10.52	0.436
Aortal MAP (mmHG)	10	84.7	±38.17	84.23	±7.25	0.869

Correlations of Lactate Threshold Improvements and aPWV, TAG, HDL, and Cholesterol reductions

Changes in LT2 values and aPWV between baseline and follow-up examination showed a correlation, as an increase in velocity at LT2 correlates with lowered aPWV. This correlation affected the entire cohort (see figure 4A; n=10; r=-0.742; p=0.014).

Correlations exclusive to the female study participants are shown in figure 4: changes over the training period in LT2 and triglyceride (TAG) levels (figure 4B; n=10; r=-0.707; p=0.022) and between the 2mmol threshold change and HDL levels (figure. 4C; n=11, r=-0.7; p=0.016) and cholesterol level differences (figure 4D; n=10; r=-0.648; p=0.043) are presented there. Correlations between an increase in performance at the two lactate thresholds and reductions in the aforementioned blood parameters were shown over the duration of the study.

Correlation of Lactate Threshold Improvements and SBT-mini

To obtain information on the state of the glycocalyx, and thus vascular function, the SBT-mini was assessed. For the entire cohort, no change could be registered over the training period (data not shown). However, inverse correlations (figure 5) were seen in subjects and volunteers under 45 years of age, with greater improvements in SBT values over the course of the study (=better glycocalyx quality) and higher performance increases at both the 2mmol lactate threshold (n=13; r=-0.636; p=0.019 and the 4mmol threshold (n=12; r=-0.771; p=0.003). Thus, a higher increase in performance correlated with an improvement in glycocalyx.

Discussion

In this study, the effectiveness of a highly polarized program and excluding training at the individual anaerobic threshold was demonstrated.

The main effects of the 10-week polarized and periodized running training were (i) objectively measurable performance improvements, (ii) lowered total and HDL cholesterol, (iii), reduced blood pressure, (iv) decreased AIX, and (v) a correlation between improved vascular function and higher performance gains for subjects under 45 years of age.

Total and HDL Cholesterol Reducing Effect of Running Training

We observed a significant reduction in total and HDL cholesterol with an almost constant LDL concentration. Triglycerides did not decrease over the course of the study. Changes in HbA1c and CRP were not observed in our study.

A possible explanation for the decrease in HDL levels in our study might be found either in the high baseline values of the subjects, which were clearly above the reference values (14), or in the short time period and the type of intervention in the study.

In this context, it has been reported that all-cause mortality and the risk of cardiovascular events increase when HDL levels are above 60 mg/dl (1). Thus, during the running training, the HDL levels returned to the reference range.

In addition, a greater LT2 threshold power increase was significantly detectable with a greater TAG reduction, and prominent 2mmol threshold power increases were detectable with greater HDL and cholesterol reductions in our female subjects. These results confirm the findings of other studies, in which high exercise capacity is associated with TAG reductions but not LDL reductions (31). Why this effect can only be found in the female participants of our study cannot be explained.

The present results indicate the success of the sports intervention in terms of an improvement in the general health status of our subjects over the course of the study.

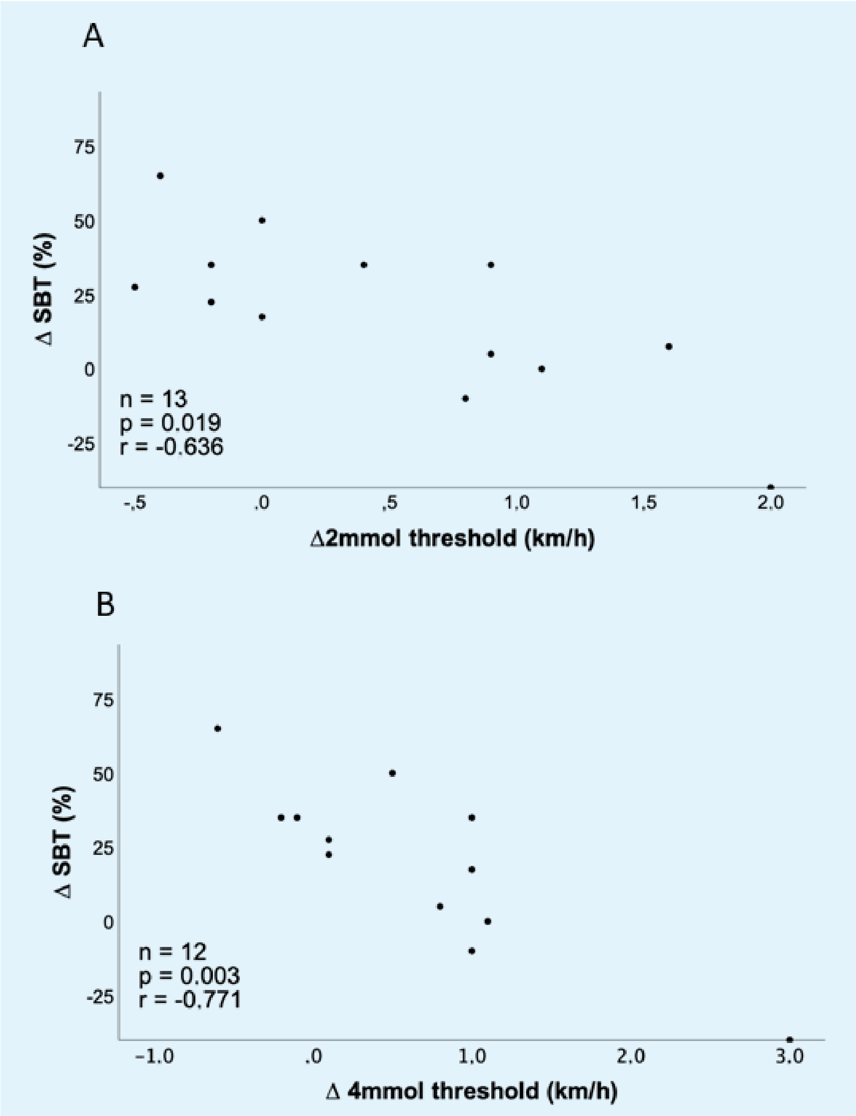

Figure 5

Age-separated (cut-off value 45 years) correlation of SBT mini-value changes for the subjects younger than 45 years with the 2 mmol threshold (A) and the 4 mmol thresholds (B) changes between the baseline and follow-up examination (correlation analysis with the Spearman rank test).

Blood Pressure Lowering Effect Through Running Training

The large-scale positive effects of aerobic training on resting blood pressure - not only in secondary prevention in hypertensive patients, but also in primary prevention in normotensive subjects (15) - were also demonstrated in our cohort for diastolic and mean arterial blood pressure. Recent studies underscore the fact that aerobic endurance training is superior to strength training, as well as a stronger reduction being associated with higher training volume (7).

The associations between increased systolic blood pressures at baseline and older age, increased peripheral PWV, and elevated LDL and cholesterol levels are in line with other studies (7, 9, 24, 40) In contrast, effects on resting pulse and systolic blood pressure were not observed. Here, the type of intervention could explain this difference: a greater reduction in systolic blood pressure has been reported with low-intensity and more voluminous training (15).

Running Training-Dependent Decrease in the AIX

While PWV is a direct measure of arterial vascular stiffness, the AIX represents a combined measure of the proportion of pulse wave reflection-induced pressure increase in central blood pressure and is used to estimate cardiovascular risk predisposition (2).

In the context of this study, PWV remained unaffected, but despite the small number of cases, a significant reduction in AIX was demonstrated over the training period. Associations between blood pressure and age, as well as between blood pressure and PWV, were also found at the time of the initial examination. In addition, higher velocity improvements at LT2 were associated with greater PWV decreases.

Age-related PWV and AIX increases can be regarded as (i) signs of degenerative structural processes, primarily on the basis of elastin fatigue, fragmentation, and vicarious incorpo- ›

ration of collagen, and (ii) functional changes, particularly via decreased NO availability and oxidative stress, with resulting increases in vascular stiffness (2, 35).

Aerobic forms of exercise lead to lower wave reflections via NO-induced vasodilation, through increased blood flow and shear stress, and are thus able to lower the AIX (25). Thus, our study results suggest that AIX may act as a suitable early parameter of vascular changes.

However, the intervention period of the studies seemed to be too short for PWV changes based on elastin and collagen adaptations, and thus they were more likely to be based on functional changes of the vascular system (16).

Age-Dependent Improvement in Glycocalyx by Running Training

In this study, an inverse dependence was shown in subjects younger than 45 years between higher performance gains at the 2mmol and 4mmol thresholds and glycocalyx improvement. Thus, only young subjects appear to benefit from higher power gains in terms of vascular function.

Whether this is based on the lifetime of the endothelium (100-1000 days) and a longer regeneration time of the glycocalyx in older subjects now needs to be clarified in follow-up studies (17). It is likely that a similar effect may also occur in the elderly after a longer intervention period.

Limitations of the Study

The limitations of the study are the small number of cases and the duration of the intervention. In addition, we hoped for stronger effects from polarized training with high intensities, but without a control group we cannot correlate them to other forms of intervention. Consequently, as a possible cause of absent changes, as it has already been reported for PWV or systolic blood pressure (8, 15), we cannot attribute the findings to the high-intensity intervention form. The lack of recording body weight in the follow-up examination should also be criticized. Thus, weight loss cannot be eliminated as a confounding variable for lipids and blood pressure. Due to technical problems a lower number of PWV measurements and blood analyses could be included.

Conflict of Interest

The authors have no conflict of interest.

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