Assessing the effects of training with electrical muscle stimulation

(Summary Report)

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1 Introduction

Since the 1960s, there have been continuous attempts to enhance the method of muscle stimulation. It did not take long for this technology to be also introduced in the world of professional sports. At first, it was used for the rehabilitation of athletic injuries. However, since research results suggested that it could greatly improve stamina, endurance and overall fitness, it began to be used as a training method as well. Developed in Germany in the 1990s, the latest generation of EMS equipment became marketed for mass retail and therefore was no longer a privilege of professional athletes. These machines involve full-body stimulation combined with active muscle workout. An unusually high workload is provided by the simultaneous and parallel stimulation of key muscle groups (thigh, rear, abdomen, back and arm) while performing various exercises on them. Its effectiveness was said to be due to the fact that low-current electricity causes muscle fibres to contract and then relax in rapid succession, which boosts their aerobic metabolism. Under conventional exercise, there is a more pronounced muscle activity that leaves behind a calorie-burning effect for days, which could provide a solution for those struggling with overweight or cellulitis, as well as for pain relief, conditioning or improving one's overall sense of well-being.

However, to date, no credible scientific impact study that is confirmed by objective data concerning the effects of these devices on the musculoskeletal, cardiovascular and hormone system or the general and lipoprotein metabolism has been released. When using electrical devices, many contraindications ought to be taken into account. Cancer patients, as well as those with pacemakers or suffering from inflammatory disease cannot use these types of treatments. Parallel to the system that was developed in Germany, additional equipment that, while based on the same principle, outperform one another in terms of effectiveness have also been released. Relying on the studies of electromechanics, sports physiology and exercise theory, Hungarian researchers have developed an advanced device but found the indirect application of a scientific background to be insufficient. For purposes of bettering their own system, as well as to optimise and distinguish the local and general effects of EMS technology on the human body while also taking individual differences into consideration, they have set out to prepare a comprehensive impact study.

2 Purpose of the study

Assess the local and general effects of EMS technology on the human body. Define and identify the various factors of impact optimisation.

3 Literature Review

The fact that electricity can have a beneficial effect on the human body was discovered already in ancient Egypt and Rome, where electric rays and fish were used for various treatments. In 1747, a Frenchman by the name of Jean Jallabert was able to subject the paralysed upper arm of one of his patients to prolonged electric stimuli using a Leyden jar, the early version of today's batteries, yielding improvements in muscle function after a three-month treatment.

Galvani's basic discovery that electric current can induce muscle contractions was proven correct. His findings became pivotal to all engagements concerning electric stimuli that followed.

Guillaume Duchenne de Boulogne (1806-1875), a pioneering figure in electrotherapy, was among the first to stimulate facial muscles using dampened surface electrodes (Gondin et al. 2011).

Massive numbers of combat injuries during the first half of the 20th century helped electrical stimulation become a useful tool in the treatment and prevention of denervation-induced muscle atrophy (Jackson and Seddon 1945; Osborne 1951). In 1961, Liberson et al. were the first to describe a process called functional electrical stimulation (FES), whereby the stimulation of paralysed muscle can be used to control artificially induced contractions so that they can substitute the functions that have been lost (dorsal flexion of the foot, hand grips, standing, the ability to ride a bicycle or walking). In 1971, Russian scientist Yakov Kots figured that electrical muscle stimulation could be more effective in increasing muscle force than voluntary contraction (Ward and Shkuratova 2002). The device he had developed was, however, only treated as a curiosity without ever realising its potential for practical use. It was in the 1970s that a procedure called TENS (transcutaneous electrical nerve stimulation) was developed, reducing pain in the treated area by applying low-intensity and high-frequency electric pulses (Shealy and Maurer 1974). Given that muscles and nerves are the quickest to react to stimuli, electricity can be used for both.

Depending on the strength of muscle contraction, which is defined by the stimulation parameters, the outcome may vary: 1 – gain in muscle strength as a result of repeated stimuli; 2 – pain relief; 3 – establishment of movement function.

EMS: Electrical Myostimulation (or Muscle Stimulation)

FES: Used to recreate functions of muscles denervated (paralysed) due to injuries to the central nervous system (stroke, spinal cord injury or accident-related nerve injury) by way of artificial external stimulation.

Electric pulses can be characterised by current intensity, frequency and amplitude. Muscle stimulation is based on the use of electric pulses that are sent to the muscle. The current intensity specified for stimulation refers to the top of the pulse amplitude; therefore, it is not meant to be understood as a continuous value. Muscle contraction is elicited by the appropriate combination of pulse frequency and duration. Stimulation frequency refers to the number of signals sent by the stimulation equipment to the muscle in one second. In healthy muscles, tetanic contraction, or effective muscle operation, occurs when subjected to a stream of stimuli of appropriate frequency. Low-frequency treatments between 0 and 1,000 Hz (e.g. galvanic current, iontophoresis and impulse current treatments) are suitable for areas susceptible to nervous stimuli and can improve cellular functions. The duration of maximum amplitude of the electric pulse changes in inverse proportion to both current intensity and frequency. The size and placement of electrodes, too, have a significant impact on the efficiency of stimulation (Late 1992; Lloyd et al. 1986).

4 The issue at hand

A relatively new method to improve one's level of conditioning is the use of electrical muscle stimulation during strength training exercises. Already a widespread practice, the targeted application of electrical muscle stimulation is past its popularity peak as a passive fitness trend and has become established as a standard tool of medical rehabilitation with recognised efficiency. However, its use during active workout is considered an advanced and novel field that raises endless questions as regards effective use. As the method's factors of intensity, as well as its impacts on training-induced adaptation have yet to be fully understood, basic assessments and studies facilitating a safe and effective application must be carried out, which is the fundamental goal of this paper.

5 Sample size and the underlying assessment procedure

A total of 40 people were assessed in our study (average age: 31 years). Of the 30 male (average age: 31 years) and 10 female (average age: 36 years) participants, respectively, 4 and 6 were subjected to a repeated series after a total of 8 training sessions that were performed at a frequency of twice a week. Therefore, our test results contain performance diagnostic data for 40 people about the effects of a single physical exercise by way of electrical muscle stimulation, whereas for a total of 10 people (average age: 32 years) we also obtained information on training-induced adaptation after four and eight-week training series. Following a training session, the physiological effects of electrical muscle stimulation (50 – 110V) were studied:

In a total of 10 people (8 males and 2 females), none of whom were engaging in regular physical exercise and thus were considered inactive and unfit at the time. In a total of 13 people (6 males and 7 females) who regularly engaged in cardio and resistance training 3 to 5 times a week and thus were considered relatively in shape. In a total of 7 professional male athletes engaging in cardio and resistance training more than 10 times a week and therefore considered relatively fit. The physiological effects of a single cardio session with electrical muscle stimulation were studied in a total of 6 male and 4 females, all of whom were professional athletes and thus considered relatively fit (3 males and 1 female). In a total of 10 subjects (6 males and 4 females) considered relatively fit and subjected to a total of 8 training sessions that were performed at a frequency of twice a week, the effects of electrical muscle stimulation were studied after each session. On a supplementary basis, an additional test with higher-intensity electrical impulses (250 V) was performed on a sample of 4 relatively fit male participants, using another stimulation device that is currently available on the market.

Physiological indicators describing the operation of various functional organs in the human body can help keeping track of the training-induced adaptation process. Deviations between the functional characteristics of unfit and fit people imply different adaptation patterns in people with varying levels of fitness. Adaptational changes of physiological indicators reveal how the human body reacts to adaptation-triggering stimuli interpreted as stress on the short versus the long term. When examining the impacts of workout by electrical muscle stimulation, physiological characteristics at rest, under exercise stress and in recovery were assessed, as part the application of a so-called functional sensory network theory. In essence, this involves the study of a large number of functional physiological variables within a relatively short interval in order to describe the equilibrium state of the body covering body composition, cardiovascular, respiratory, musculoskeletal and autonomic nervous systems, metabolism, as well as the spine and certain functional biomechanical parameters. Prior to the electrical muscle stimulation exercise, once the subjects' personal details and status information relating to health and lifestyle were recorded, the following resting state physiological data were established: indicators on body composition and physique, the cardio-vascular, autonomic nervous and musculoskeletal systems and spine, as well as on metabolism and functional biomechanics. Under exercise stress, the following variables could be measured: sensory threshold, as well as certain functional parameters of the cardiovascular and respiratory systems. 5 minutes after the workout, the cardiovascular and autonomic nervous systems and metabolism were examined. One hour after the workout, we were looking at metabolic and functional-biomechanical parameters. Recovery parameters assessed 24, 48, 72 and 96 hours after the workout were focussed on the cardiovascular and autonomic nervous systems and metabolism. Training-induced adaptation due to a total of 8 training sessions performed at a frequency of twice a week was measured before, during and after the eighth session similarly to the first assessments.

6 The training method and equipment used for electrical muscle stimulation

The state-of-the-art E-Fit EF-1280 has been specially designed for EMS training combined with full-body muscle stimulation. Key parameters of the EF-1280: Electrical parameters: switchable between power supply and battery operation, low input voltage: 12V DC 1400mA (minimal power consumption), restricted proportional output: max $1mA/cm^2$ max 70mA/channel, maximum overall output: 7.5W, variable voltage: max 50V. The EF-1280 operates on 12 independent channels, which accommodates the accurate placement of electrodes for each muscle group, thus allowing for a near-complete coverage of all body muscles.

Since waves travelling in opposite direction degrade the adaptation capacity of muscles and nerves; electrostatic discharges and interferences within the body have been completely eliminated, and the device works consistently across the entire muscle surface.

Fitness can be interpreted as an adaptation occurring at physiological and psychological levels in response to physical exercise. The training method used comprises electrical muscle stimulation applied during gymnastic exercise. A training session began with the recording of subjects' medical history and getting dressed, after which basic adjustments were made. This was followed by a warm-up, the main exercise segment and finally the warm-down. During the warm-up segment (3 minutes, program 3), dynamic exercises representing a low workload were performed within the subjects' comfort zone (at 60-70 percent), with the device set at 0 for all body parts. Afterwards, device settings were adjusted (2 minutes on program 1, 15-20% above the sensory threshold and 15-40% comfort zone), and concentrated exercises began with stimulation intensity within the upper one-third of the comfort zone. Gymnastic exercises involving the use of all superficial and deep muscle groups were then performed outside the comfort zone, with the level of stimulation raised at gradual intervals, followed by a warm-down segment.

7 Assessment methods

Body composition has a key role in physical performance; therefore, when it comes to the use of training methods affecting the body composition it is important to define and keep track of pertaining indicators. Before a training session, segmented body composition (four limbs and the torso) was examined with the Biospace Inbody 230 multi-frequency bioelectrical impedance analyser, after which skinfold thickness underneath the electrodes of the electrical muscle stimulation exercise device was measured with a Harpenden Caliper.

Systolic and diastolic **blood pressure** was measured in millimetres of mercury using an oscillometric device, the Omron M6 upper arm sphygmomanometer, both before and after workout**. Heart rate** is a key workload parameter for the heart and the circulatory system, conveying vital information about their functioning both at rest and during workout. Heart rate variability assessment is a relatively new method, in which mathematical models are applied to describe the adaptability of the circulatory and autonomic nervous systems. The heart rate and its time and frequency-domain variability were measured using a Polar WindLink and the ProTrainer software, with the subject lying at rest, then five minutes after the exercise, and then again at rest, 24, 48, 72 and 96 hours thereafter. **Heart rate** and **oxygen saturation** during workout were measured with a CMS 50 D Plus fingertip pulse oximeter. The primary objective of assessments on the locomotor system was to describe its biomechanical changes taking place when subjected to electronic muscle stimulation. For the examination of **foot pressure** and the **structural characteristics of the pectoral girdle**, an EPS platform and the Footchecker 4.0 software, both by Loran Engineering, were used with the subject in basic position and also in a push-up position with arms bent and stretched, both before and after the exercise (kPa, %). When applying electrical stimuli on core muscles, the structural status of the **spinal cord** and accurate data about its deformation are of key importance. We used an Idiag SpinalMouse for assessing the spine, mapping out the mobility of the cord based on the angle formed by the spinous processes of vertebrae as well as the functioning of deep muscles of the back. A Dyna-09 computerised manual dynamometer was used to evaluate the impact of the electrical muscle stimulation exercise on the **nervous and muscular system** in terms of functional biomechanical parameters. This involved the assessment of maximum handgrip strength (N) and the maximum rise time of a grip started at maximum velocity, plotted over time, as an indicator describing an individual's explosive capacity (N/s).

As far as **metabolism** was concerned, glucose levels were checked in capillary blood both before and after workout with an Omron Multicare IN amperometric tester. Lactic acid was measured in capillary blood with a NOVA Lactate Plus tester before and immediately after training, as well as 1, 24, 48, 72 and 96 hours thereafter. Used as a marker for muscular micro-injuries, **creatine kinase** values were quantified in capillary blood with a Roche Reflotron Plus, a desktop dry chemistry analyser working on the principle of reflective photometry, before the training as well as 1, 24, 48, 72 and 96 hours thereafter.

Parameters for **blood gas** such as oxygen, electrolytes and pH levels were checked in arterialised earlobe with a Radiometer ABL80 Flex Astrup Trolley before and immediately after the workout, as well as one hour thereafter. Quantities of **urine protein** were checked using Cybow 5 urine test strips 1, 24, 48, 72 and 96 hours after training.

According to our hypothesis, EMS training has no negative effect on the biological systems reviewed.

8 Assessment results

Anthropometric variables measured at single-exercise assessments perfectly illustrate the differences in terms of gender, lifestyle and physical activity.

8.1 Body composition

As for **body composition by electrical impedance**, the test performed on the sample of 10 participants following the eighth training session basically showed no changes in body mass and average body mass index (change was below 0.1). Muscle mass of the sample shrank by an average of 0.16 percent. Body water percentage was down 0.1%, with both intercellular (0.21%) and extracellular (less than 0.1%) fluids having been decreased. Fat and muscle mass asymmetry on arms shrank by less than 0.1 kg. Leg muscle mass showed a similar change pattern. As for the torso, muscle mass was down 0.12 kg and fat 0.36 kg. The combined amount of segmented fat and muscle mass of the 10-person sample, respectively, were down 1.41% and 0.15 kg.

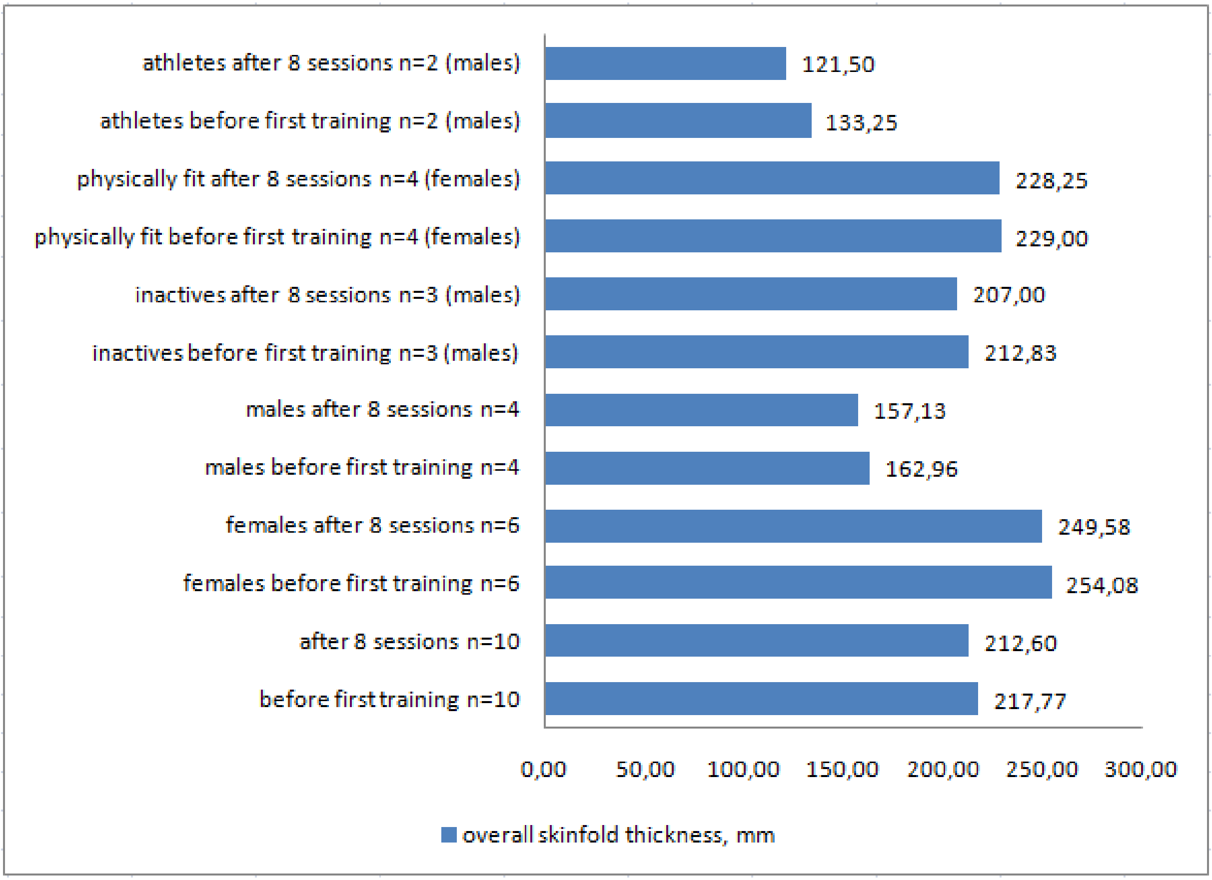
statistical unit	Wkg	BF%	MM%	BW%	BWIC%	BWEC%
before first training n=10	79,58	24,35	42,25	54,86	34,42	20,60
after 8 sessions n=10	79,62	24,26	42,09	54,76	34,21	20,56
females before first training n=6	72,32	29,07	38,09	50,17	31,50	18,94
females after 8 sessions n=6	72,48	28,85	37,84	50,15	31,15	19,00
males before first training n=4	90,48	17,28	47,23	60,49	37,91	22,58
males after 8 sessions n=4	90,33	17,38	47,19	60,31	37,89	22,45
inactives before first training n=4	86,28	27,93	40,91	53,03	33,41	19,97
inactives after 8 sessions n=4	86,23	27,38	41,20	53,46	33,38	20,12
physically fit before first training n=4	70,08	27,45	38,53	50,77	31,68	19,09
physically fit after 8 sessions n=4	70,53	26,88	38,35	50,80	31,62	19,18
athletes before first training n=2	85,20	11,00	51,06	65,32	40,96	24,35
athletes after 8 sessions n=2	84,60	12,80	50,12	64,01	40,25	23,76

Changes in body weight (Wkg), body fat percentage (BF%), muscle mass (MM%), body water percentage (BW%), as well as intracellular and extracellular (BWIC% and BWEC%) fluids on the entire sample after 8 training sessions for both genders and according to fitness level

8.2 Skinfold measurement

Single-exercise **skinfold** measurements for the entire sample and individual groups indicated deviations between gender and physical activity. Moreover, in connection with social trends, age also had to be taken into account, as the average age of separate physical fitness categories reveals social correlations between physical activity and age even on a relatively small sample.

At the **measurement following the eighth training session**, average values for the entire sample indicate the proportional locations of fat stored beneath the skin, characterised by functional asymmetry and dominated by the abdominal area and the lower legs. Quantitative indicators for either gender reflect on well-known functional gender features, i.e. the percentage of body fat is greater in females than in males. After a series of eight workouts, the amount of skinfold in males showed a more pronounced decrease than in females (5.83 mm versus 4.5 mm). The distribution of subcutaneous storage in body parts is also in line with generally known gender features. The highest extent of skinfold decrease was observed in professional athletes, with the sample of generally fit subjects showing the least amount of reduction. On the entire sample, the average skinfold shrinkage after 8 training sessions was 5.64 mm, which suggests a decline in subcutaneous fat storage.



8.3 Blood pressure

The amplitude of **blood pressure** fluctuations at single-exercise measurements for the entire sample was up 5.58 mmHG at the end of the training. Males tended to register higher values and differences than females. The lowest fluctuation in blood pressure amplitude was observed in currently inactive and unfit females, with relatively fit professional male athletes showing the highest fluctuation. There was no difference between pre- and post-training measurements of the sample of relatively fit females, meanwhile the most marked deviation was observed in the sample of currently inactive and unfit females. Males registered higher values than females.
As for mean arterial pressure, post-training measurements were higher than those recorded before the exercise. Male registered higher values than females, and only the sample of currently inactive and unfit males showed post-training values exceeding the upper threshold of the normal range. When subjected to more intense electrical stimuli, mean arterial pressure exceeded 100 mmHG both before and after training.

At the test following the 8th session, fluctuations in blood pressure amplitude as measured before the exercise decreased for both sexes by the measurement preceding the 8th training session. Post-training averages rose in females and, to a lesser degree, decreased in males. When compared to the first measurement, deviations between pre and post-training values registered after the 8th training session increased for both sexes. Amplitude fluctuations in pre-training blood pressure after the 8th session decreased for the samples of inactive males, fit females and professional male athletes alike. As regards post-training measurements after the 8th session, averages for the samples of professional male athletes and fit females indicated growth meanwhile that of inactive males registered a decrease. By the measurement preceding the 8th training session, the lowest level of decrease in pre-training blood pressure fluctuation was observed in inactive males and the highest in physically fit females. As regards post-training averages, the sample of physically fit females indicated the most striking growth, whereas inactive males registered a decrease.

stat	TEVNY IA mmHG	TU VNY IA mmHG	Change TEVNY	Change TUVNY
before first training n=10	40,50	46,20		
after 8 sessions n=10	38,70	47,10	-1,80	0,90
females before first training n=6	37,50	39,84		
females after 8 sessions n=6	35,84	42,00	-1,66	2,16
males before first training n=4	45,00	55,75		
males after 8 sessions n=4	43,00	54,75	-2,00	-1,00
inactives before first training n=3 (males)	41,00	54,25		
inactives after 8 sessions n=3 (males)	40,00	48,50	-1,00	-5,75
physically fit before first training n=4 (females)	37,25	34,00		
physically fit after 8 sessions n=4 (females)	34,50	41,00	-2,75	7,00
athletes before first training n=2 (males)	46,00	52,50		
athletes after 8 sessions n=2 (males)	44,50	56,50	-1,50	4,00

Changes in the pre-training (TE) and post-training (TU) amplitude of blood pressure fluctuation after a series of 8 workouts

Pre and post-training mean arterial pressure values measured through a series of 8 sessions showed the most marked change (decrease) in the sample of physically fit females, with inactive males and professional male athletes registering the lowest level of change (minor growth).

stat	TE mean art. press. mmHG	TU mean art. press. mmHG	Change in TE mean art. press. mmHG	Change in TU mean art. press. mmHG
before first training n=10	92,80	93,40		
after 8 sessions n=10	87,70	89,80	-5,10	-3,60
females before first training n=6	93,00	91,61		
females after 8 sessions n=6	85,78	87,67	-7,22	-3,94
males before first training n=4	92,50	96,08		
males after 8 sessions n=4	90,58	93,00	-1,92	-3,08
inactives before first training n=3 (males)	93,42	95,08		
inactives after 8 sessions n=3 (males)	93,58	91,17	0,17	-3,92
physically fit before first training n=4 (females)	94,17	94,58		
physically fit after 8 sessions n=4 (females)	83,75	88,67	-10,42	-5,92
athletes before first training n=2 (males)	88,83	89,00		
athletes after 8 sessions n=2 (males)	83,83	89,33	-5,00	0,33

Changes in pre-training (TE) and post-training (TU) mean arterial pressure after a series of 8 workouts

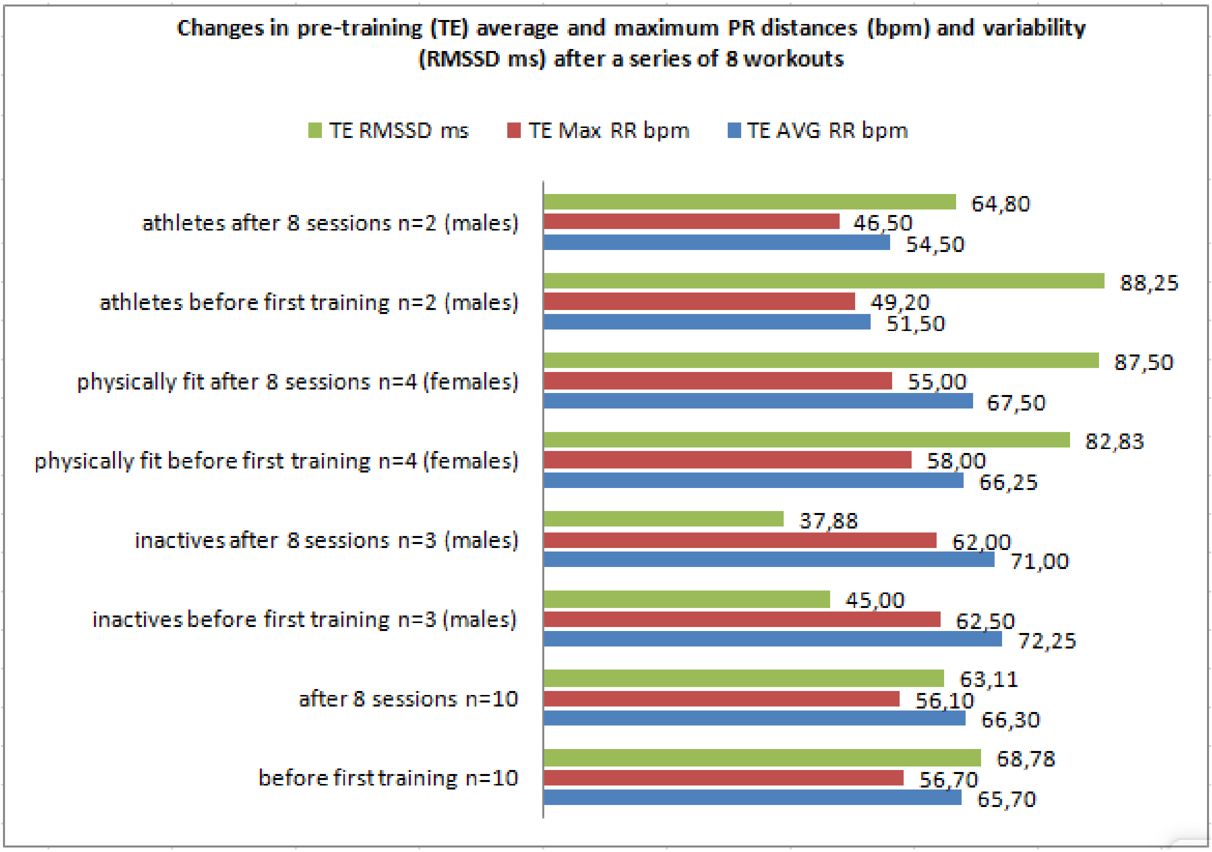
8.4 Heart rate

Heart rate values recorded for the sample indicate a lower at-rest pulse, which can be interpreted as training-induced adaptation, and a higher variability in more physically fit subjects. Through heart rate values recorded during workout, gymnastic routines and indoor rowing showed considerable differences in intensity. More intense electrical stimulation induced the highest extent of sympathetic post-measurement imbalance in the autonomic nervous system.

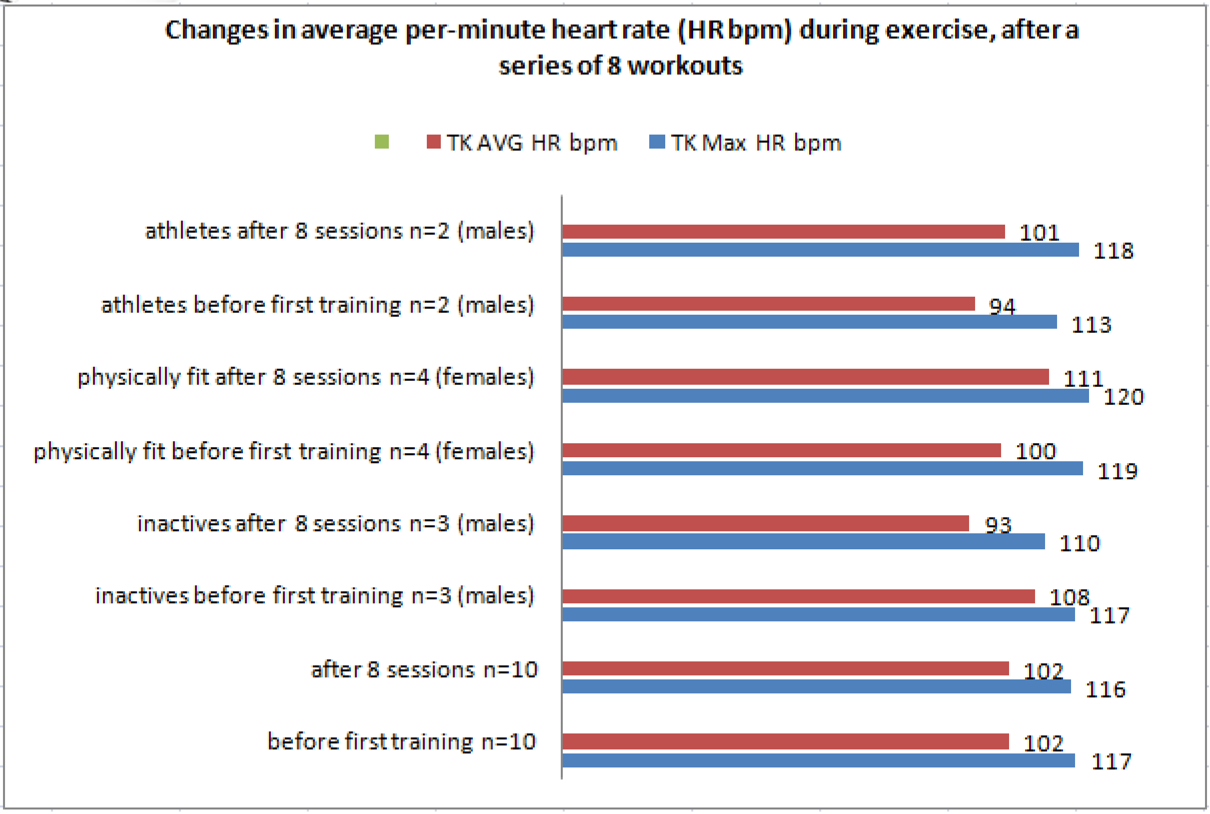
At measurements performed in the 8th training session, based on pre-training RR averages and maximums, the indicators for both actual and absolute endurance stood in the vicinity of 1000 ms (60 bpm), showing minor increases and/or decreases as a result of the 8th training session. Pre-training average and maximum RR distances decreased in inverse proportion to fitness level, thus recording the lowest levels in the sample of professional athletes and the highest among inactive subjects. Average and maximum RR distances decrease in the inactive sample. The samples of physically fit subjects and professional athletes both demonstrated an increase in the average RR distance and a decrease in its maximum value.

Pre-training RMSSD, a variability parameter indicating the heart's adaptive capacity, was higher among physically fit subjects and professional athletes, then, after a series of 8 workouts, showed an increase in the physically fit sample and a decrease in both inactives and professional athletes.

As regards the overall sample average, heart rate measured during workout does not change significantly following the 8th session. Per-minute average heart rate is the highest in the sample of inactive males and decreases parallel to the improvement of fitness level. Following the 8th session, there was a marked decrease in the average per-minute heart rate of inactive males, with physically fit subjects exhibiting an increase: 11 bpm for the sample of physically fit females and 7 bpm for professional male athletes.



Maximum heart rate averages measured during the first training were higher among inactive males and physically fit females than in the sample of professional athletes. When measured at the 8th session, the same values showed a decrease among inactive males and an increase among both physically fit females and professional athletes.



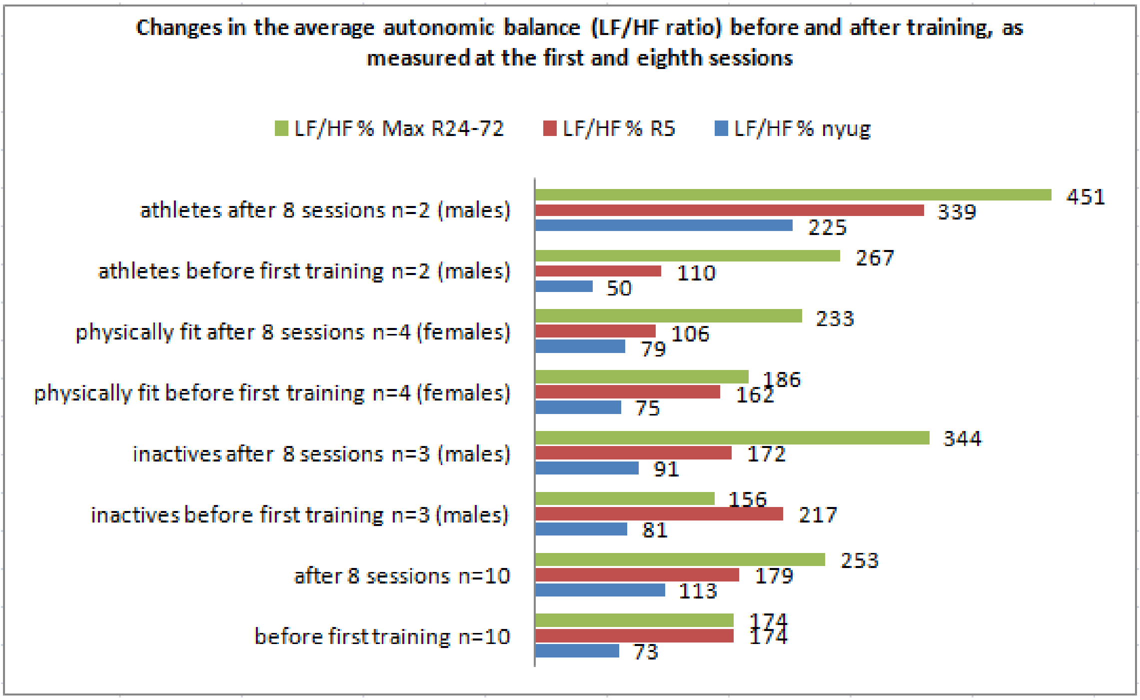
Measured during the recovery phase 5 minutes after training, RR averages remained virtually unchanged (change less than 1 bpm) for the entire sample after the 8^{th} session, meanwhile the maximum RR average rose by 2 bpm. Variability across the entire sample decreased by almost 6 ms. Average RR distances measured 5 minutes into the recovery phase registered above 70 bpm for inactive males and physically fit females and were significantly lower in the sample of professional male athletes, that is, it decreased in inverse relation to the growth in fitness level since the first measurement. Measured 5 minutes into the recovery after the first training, the maximum RR distance for inactive males and physically fit females were higher than in the sample of professional male athletes, therefore, it decreased in inverse relation to the growth in fitness level. Variability measured 5 minutes into the recovery after the first training was lower in the inactive sample than in those of physically fit subjects and professional athletes. When measured 5 minutes into the recovery following the 8^{th} session, a slight decrease (1 bpm) was registered in the average RR distance for inactive males, and similarly modest increases were observed for physically fit subjects and professional athletes (1 and 1.5 bpm, respectively). All three samples demonstrated a modest increase in maximum RR value when measured after the 8^{th} session. Variability rose in the sample of physically fit females and, to a minor extent, decreased in that of inactive subjects. By 72 hours into the recovery following the first training, average and maximum RR distances both registered moderate growth, while variability decreased. When measured 72 hours into the recovery after the 8^{th} session, the same pattern could be observed. In all but the inactive sample, average RR distances measured both before the first training and 72 hours thereafter showed an increase – a pattern that remained unchanged even after the 8^{th} session.

8.5 Autonomic balance

Used as a measure for average **cardiac autonomic balance**, the LF/HF ratio shifted from a parasympathetic to a notably sympathetic tone during the first measurement and, after a series of 8 training sessions, this sympathetic imbalance increased. At the initial assessment, regardless of fitness level, all sample groups were characterised by a parasympathetic tone, which grew at a moderate degree before the 8th session. Control measurements performed 24 and 72 hours into the recovery following the 8th session indicated a higher extent of sympathetic imbalance than what was registered after the first training. This was most apparent in the sample of professional male athletes and least apparent in that of physically fit females.

Prior to the first measurement, the LF/HF ratio, which indicates autonomic balance averages for the entire sample, showed a parasympathetic tone for professional athletes, an autonomic balance for physically fit subjects and a sympathetic tone in the sample of inactives.

The initial autonomic indicator for the assessment **following the 8th** session was, for all three groups of different fitness levels, shifted towards a considerable sympathetic imbalance. At the first training, this was most apparent in the samples of physically fit females and inactives, and least apparent in the sample of professional male athletes. Measured immediately after the 8th session, this sympathetic imbalance was somewhat above its already high initial value. At control measurements performed 24 and 72 hours into the recovery, maximum values also increased in relation to those registered in the corresponding phase of the first training. The maximum imbalance, while representing a considerable sympathetic shift, was most apparent among inactives and professional male athletes, and least apparent in the sample of physically fit females.



8.6 Structural balance

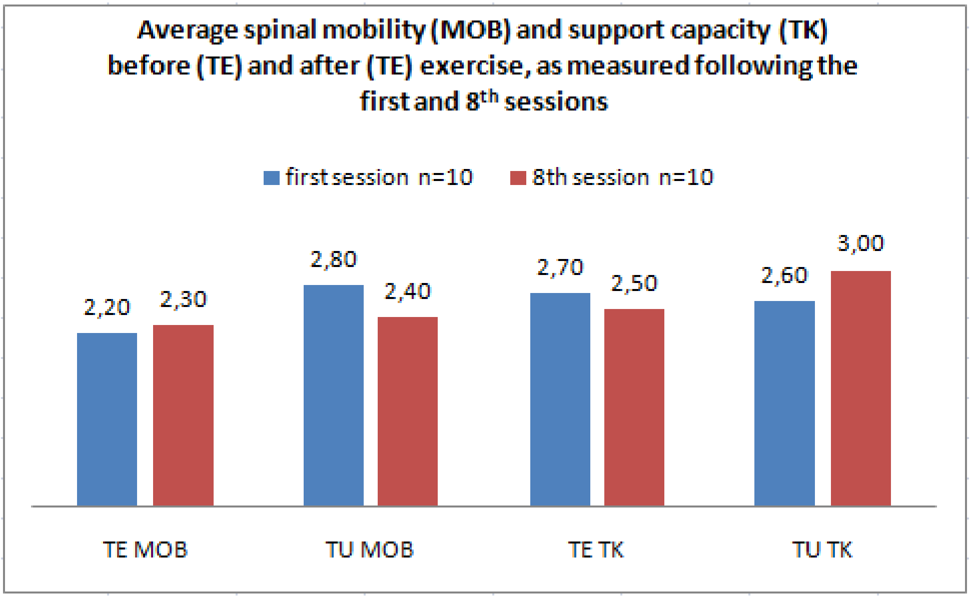
Foot pressure exerted by the skeletal system, when measured before the first training with the subjects standing in a comfortable basic position, showed a right-side structural dominance of 11.31% as the pressure difference of lower limbs, which later dropped to 10.24 percent. Before the training with the subjects in push-up position, a right-side structural dominance of 4.67% was measured as the pressure difference of upper limbs, which dropped to 3.91% following the exercise. Before the training with the subjects in push-up position and arms bent, a right-side structural dominance of 7.99% was measured as the pressure difference of upper limbs, which dropped to 6.88% following the exercise.

Before the 8th training session, with the subjects standing in a comfortable basic position, a right-side structural dominance of 13.33% was measured as the pressure difference of lower limbs, which grew to 13.87% after the session. **Before the 8th training session with the subjects in push-up position**, a right-side structural dominance of 4.13% was measured as the pressure difference of upper limbs, which increased to 6.83% after the session. **Before the 8th session, with the subjects in push-up position and arms bent**, a right-side structural dominance of 8.47% was measured as the pressure difference of upper limbs, which dropped to 3.91% following the exercise. Therefore, structural asymmetry grew when measured in positions at rest and decreased in positions requiring muscle engagement.

8.7 Spinal balance

When measured for a single training session and compared to pre-training values, **spinal mobility** increased in all but the higher-intensity groups, with the sample of professional athletes registering the highest level of growth. Support capacity decreased in the samples of females, currently inactives and professional athletes and increased in all other groups, which was most apparent under more intense electrical stimuli.

When measured after the 8th session, spinal mobility averages for the 10-person sample rose 0.6 points before and after the first measurement within the normal range, meanwhile, the support capacity of muscles surrounding the spine increased 0.1 points within the same range. Accordingly, both parameters showed improvement, with evaluation averages ranging between 2 and 3 on a scale of 0-5, which can be considered normal. While at-rest spinal mobility improved, when measured after training, certain groups showed a minor decline, parallel to a significant improvement in the support capacity of spinal muscles.

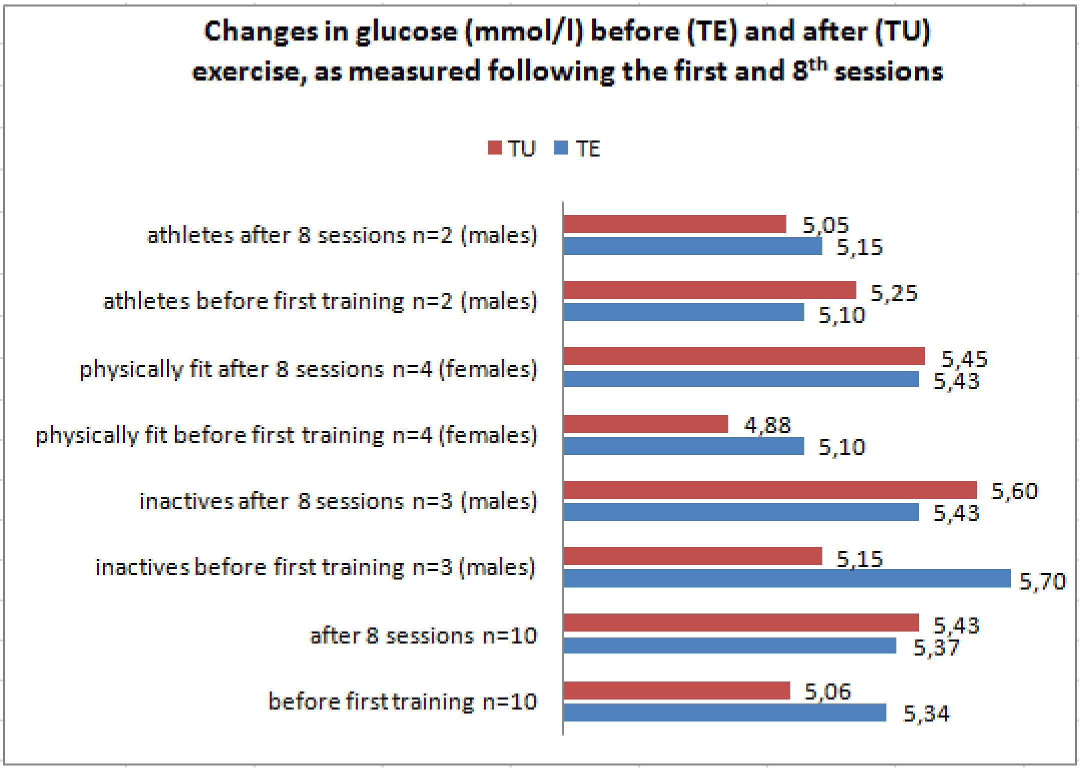


8.8 Neuro-muscular system

Our assessment findings concerning the **neuro-muscular system** indicated that the 8-session E-fit combined workout programme brought about statistically significant changes neither in terms of **general absolute and relative strength** nor in **explosive strength**. **General intra- and intermuscular coordination**, which is responsible for **motor units** under intense and rapid **muscle contractions**, was neither improved nor deteriorated. Since no or only minimal significant changes could be detected in body composition muscle mass and muscle percentage, we were led to the conclusion that the assessed workout programme elicited significant changes neither in general absolute and relative strength nor in explosive strength. The increasing asymmetry in relative strength was the only variable that registered significant albeit unfavourable changes. However, since anthropometric indicators showed signs of minimal improvement, it was clearly in the area of neuro-muscular coordination where adverse changes took place. There are numerous examples in scientific literature about strength gain in muscles subjected to stimulation, which we accepted and therefore did not form the subject of our assessment. However, we intended to examine a global effect of a considerably larger scale. That is, our aim was to find out whether a combination of peripheral electrical stimuli and voluntary movement controlled by the central nervous system, performed over a series of 8 training sessions, would cause any permanent changes, be it positive or negative. Results of this study confirm that the generally applied protocol did little to improve or deteriorate the level of neuro-muscular coordination neither in unfit subjects nor in professional athletes.

8.9 Glucose

When measuring the effects of a single exercise on **glucose level**, values for the sample subjected to more intense electrical stimuli demonstrated a rather minuscule increase, with all other groups indicating a decrease from the values measured before the exercise. Females registered a more pronounced decrease in average glucose level than males. When measured over a series of 8 training sessions, pre-training glucose averages – for the entire sample, as well as for physically fit females and inactive males – were down at the first and increased at the 8th session. Glucose levels in professional male athletes increased at the first training session and were lowered following the 8th session.

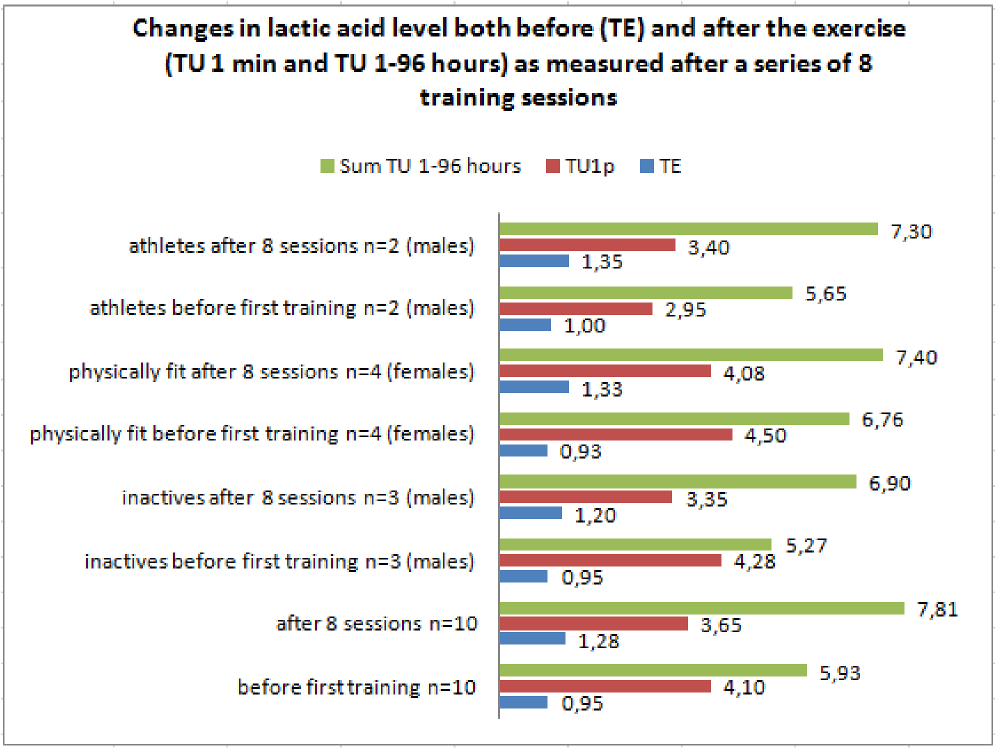


8.10 Lactic acid

When assessing the effects of a single exercise on **lactic acid** in blood, at-rest and elimination indicators throughout the entire sample were in line with normal values. However, the amount of lactic acid generated due to physical exercise varies from one group to the next. The steepest increase in lactic acid content was observed under more intense electrical stimuli, significantly exceeding 4 mmol/l, which is considered a fixed anaerobic threshold.

The average for the sample completing cardio intervals combined with electrical stimulation – thus subjected to the highest cumulative level of functional physiological workload – was also registered above this value. Other than the group completing cardio intervals, all groups performed gymnastic exercises while under electrical stimulation. The aforementioned groups notwithstanding, inactives registered the highest average level of lactic acid, measured exactly at the fixed anaerobic threshold. The overall sample average and the subjects in the relatively fit sample both stood at 3.5 mmol/l, with the average of professional athletes measured at more than 1 mmol/l below this figure. As the effect of electrical stimulation combined with gymnastic exercise, the amount of lactic acid generated was in inverse relation to improvements in fitness level.

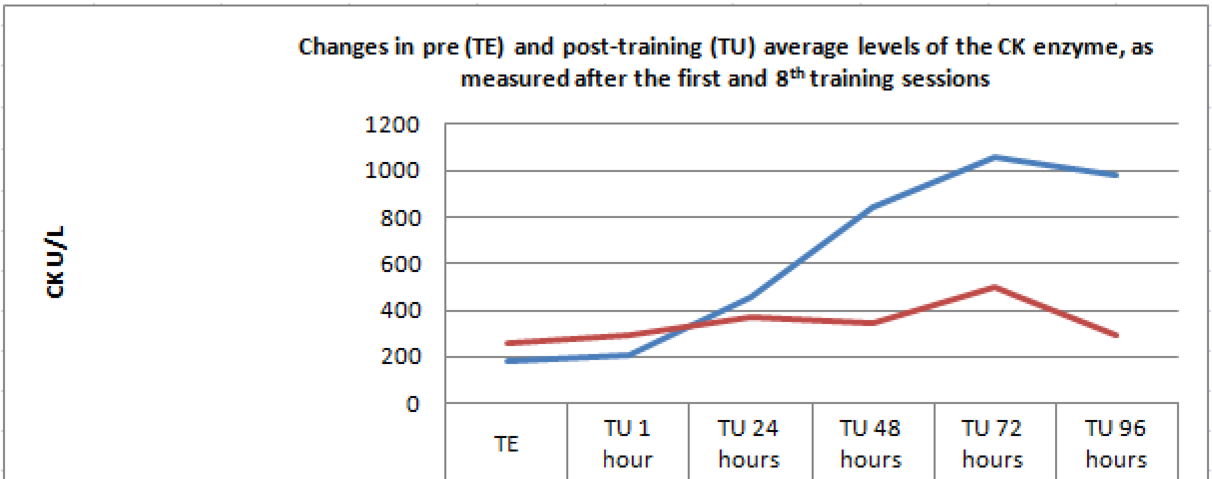
Measured **at the 8th training session**, the at-rest average of lactic acid levels in the mixed sample increased by 0.33 mmol/l, which was observed in both genders and in all three fitness categories. When measured immediately after training, average maximums at both the first and 8th sessions were highest in the sample of physically fit females and lowest for professional male athletes. Maximum post-training lactic acid levels decreased in all but the professional athlete sample. When measured 1-96 hours into the rest period following an exercise, morning levels of lactic acid demonstrated a considerable increase following the 8th session across the entire sample and for each individual group. Therefore, similarly to the measurements at the first session, at-rest levels of lactic acid were higher at the 8th session and lower immediately after the training; meanwhile the average values measured 1-96 hours into the rest period afterwards demonstrated an increase.



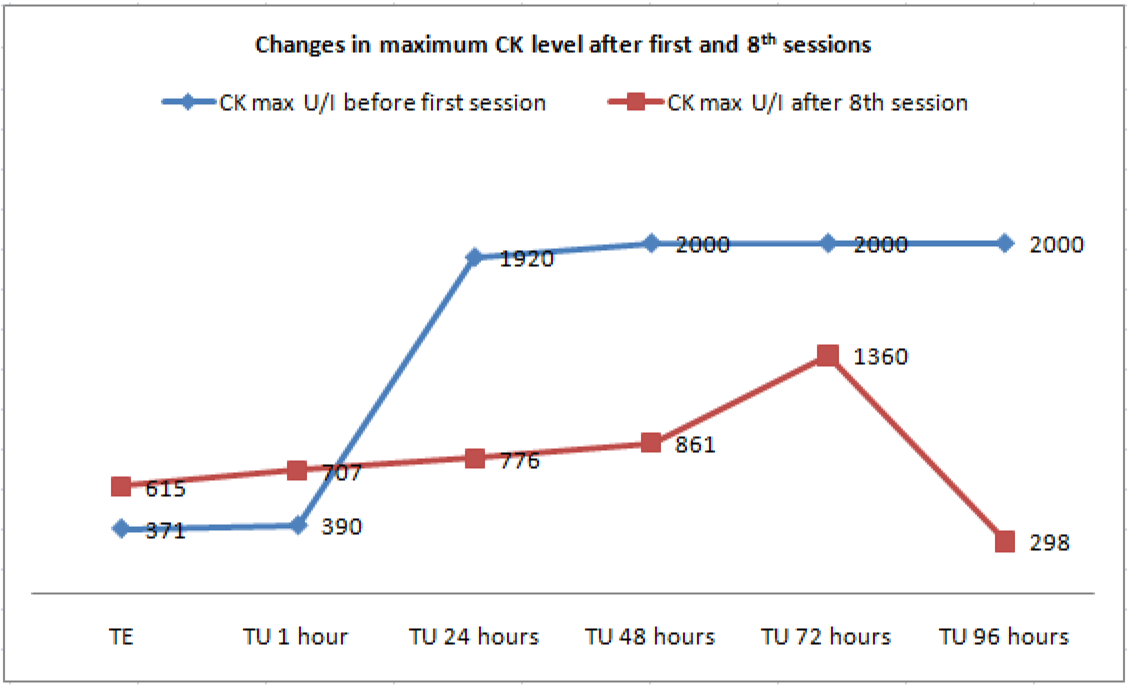
8.11 Creatine kinase

When assessing the effects of a single exercise on **creatine kinase** (CK) levels, a distinction must be made between male and female values. Intense physical activity performed on a regular basis resulted in higher peak CK values. In comparison with gymnastic exercises, a workout programme combining cardio intervals with electrical stimulation elicited higher CK peaks, but the highest level, exceeding the upper measurement threshold of our equipment, was produced by more intense electrical stimulation.

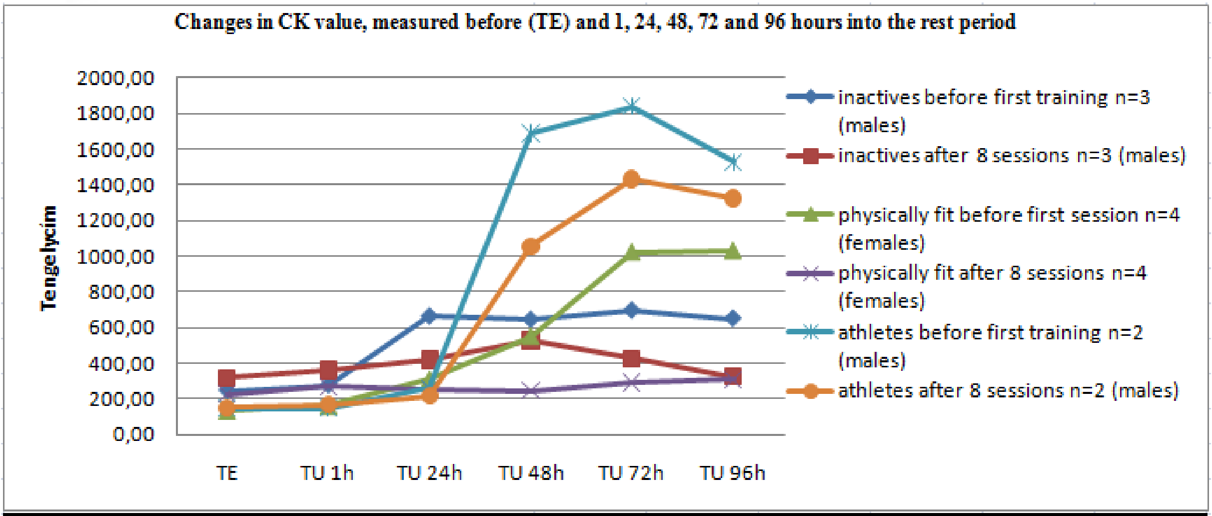
At the measurement following the 8^{th} session, pre-training CK averages for the entire sample registered near the upper threshold of the normal range. After the exercise, this average grew further and fell outside the reference range by 75 U/l. This parameter continued to grow significantly over the first 72 hours into the recovery following this measurement, only to demonstrate a considerable decline at the next control check 24 hours thereafter. Values measured after the 8^{th} training session were significantly lower than those recorded in the first. In other words, the slope of the pre-training graph is steeper – the beginning of the adaptation process is characterised by the disruption of a higher equilibrium state, which could be considered as shear.



	TE	TU 1 hour	TU 24 hours	TU 48 hours	TU 72 hours	TU 96 hours
Avg CK U/l before first session	181,99	205,8	456,11	845,78	1054,4	977,9
Avg CK U/l after 8th session	256,78	296,41	367,53	341,4	502,81	296,5



Changes in the group's maximum values indicate a similar tendency, even though pertaining pre-training values already reach our measurement threshold as early as 24 hours into the recovery period. Initial averages for all three groups (inactives, physically fit and professional athletes) showed an increase after the 8th training session, in comparison with values measured before the first. As for maximum values, this pattern could only be observed in the inactive sample. The steepest rise time in average values was registered in professional male athletes 48 hours into their recovery – following both the first and 8th training session. By contrast, the sample of physically fit females showed the longest rise time after both the first and 8th workouts. Average values peaked at 72 hours into recovery for the unfit and professional athletes, and at 96 hours for the physically fit female sample. The highest in-group values were registered at 48 hours into the recovery period for male inactives and professional athletes and at 72 hours for physically fit females. For both genders and all three categories of physical activity, average and maximum values showed a decrease while remaining in the above-normal range.



Avg CK U/l	TE	TU 1h	TU 24h	TU 48h	TU 72h	TU 96h
inactives before first training n=3 (males)	246,25	276,50	662,75	644,00	695,25	650,75
inactives after 8 sessions n=3 (males)	319,05	362,43	419,37	529,50	426,67	325,67
physically fit before first session n=4 (females)	134,48	163,28	310,67	552,00	1020,75	1029,00
physically fit after 8 sessions n=4 (females)	227,95	268,75	252,75	247,35	293,23	307,00
athletes before first training n=2 (males)	148,50	149,45	261,00	1690,00	1840,00	1530,00
athletes after 8 sessions n=2 (males)	152,00	167,50	216,50	1057,00	1435,00	1325,00

8.12 Blood gas

Assessing the effects of a single workout on **blood gas parameters**, oxygen pressure (pO2) averages for the entire sample deviate considerably from the reference range. According to the literature available, depending on peripheral circulation, capillary pO2 can often deviate significantly from arterial values and is therefore not suitable for assessing accurate oxygen status. Our measurements also confirmed this. On average, measurement values showed minor decrease across the entire sample. Average values that were measured in males and could be considered invalid demonstrated a decrease, with females registering a decline even in their at-rest averages to below the recommended reference range. Across the entire sample, haematocrit (HCT) averages, which correspond to the reference values of male subjects, increased after the exercise and then dropped one hour into the rest period. As regards potential oxygen transport capacity (ctHb), averages for the entire sample tended to increase at the end of the exercise within the male reference range and then decreased after one hour of recovery. For the entire male sample, haemoglobin levels by the end of the workout rose from their at-rest value but remained below the reference range, and then decreased one hour thereafter. As regards potential oxygen transport capacity (ctHb), averages for the male sample tended to increase at the end of the exercise within the male reference range and then decreased after one hour of recovery. For the entire female sample, haemoglobin levels by the end of the workout rose from their at-rest value but remained below the reference range, and then continued to increase one hour thereafter.

The average potential oxygen transport capacity (ctHb) for the female sample rose within the reference range, only to decrease by the end of the workout. Female HCT averages continued to grow even one hour after workout, as opposed to the decrease observed in males. Oxygen transport capacity for both genders first registered an increase then a decline. Oxygen saturation (sO_2) for the entire sample decreases, whereas arterial total oxygen concentration (ctO_2) first rises and then decreases. Oxygen saturation (sO_2) for the male sample decreases, whereas arterial total oxygen concentration (ctO_2) first rises and then decreases. Oxygen saturation (sO_2) for the female sample decreases, whereas arterial total oxygen concentration (ctO_2) first rises and then decreases. Tendencies are identical in both genders.

8.13 Blood pH

As far as the **blood pH value** is concerned, measurements indicated a shift towards acidity immediately following workout across the entire sample. One hour into recovery, however, an alkaline shift restored the initial value. This worked similarly in males and females alike. Across the entire sample, low pH values, a low bicarbonate concentration and normal levels of pCO_2 after a workout indicate training-induced metabolic acidosis. Parallel to this, exercise causes bicarbonate levels to drop and then rise one hour afterwards, with changes in base excess (BE) following similar trends. Across the entire sample, training causes the anion gap to increase and then decrease one hour thereafter. Post-training elevation of the anion gap indicates the presence of organic acids, which is parallel to bicarbonate depletion, resulting in a more pronounced training-induced metabolic acidosis. This latter was equally perceived in both male and female subjects, with females exhibiting lower levels of initial base excess. A training-induced rise in the potassium concentration of plasma (cK^+) is also indicative of metabolic acidosis. Change patterns of all assessed blood gas parameters are identical in all categories (unfit, physically fit and professional athletes). Levels of anion gap associated with metabolic acidosis increased due to exercise in all categories. The lowest pre-training average was detected in the sample of inactive unfit subjects, with professional male athletes exhibiting the highest averages. By contrast, the lowest post-training average was found in professional athletes and the highest in inactive females. The difference between pre and post-training levels of anion gap was the lowest in the sample of professional athletes and highest in inactive females.

Both at the first and **8th training sessions**, **blood gas parameters** were checked before training as well as five and 60 minutes thereafter. Oxygen pressure (pO_2) averages measured on the entire sample deviate significantly from the reference range. According to the literature available, depending on peripheral circulation, capillary pO_2 can often deviate significantly from arterial values and is therefore not suitable for assessing accurate oxygen status. Our measurements also confirmed this. On average, measured values for the 10-person sample decreased at the first training session. At the 8th session, they were up by 2.40 mmHG when measured 5 minutes into recovery and then decreased 60 minutes thereafter.

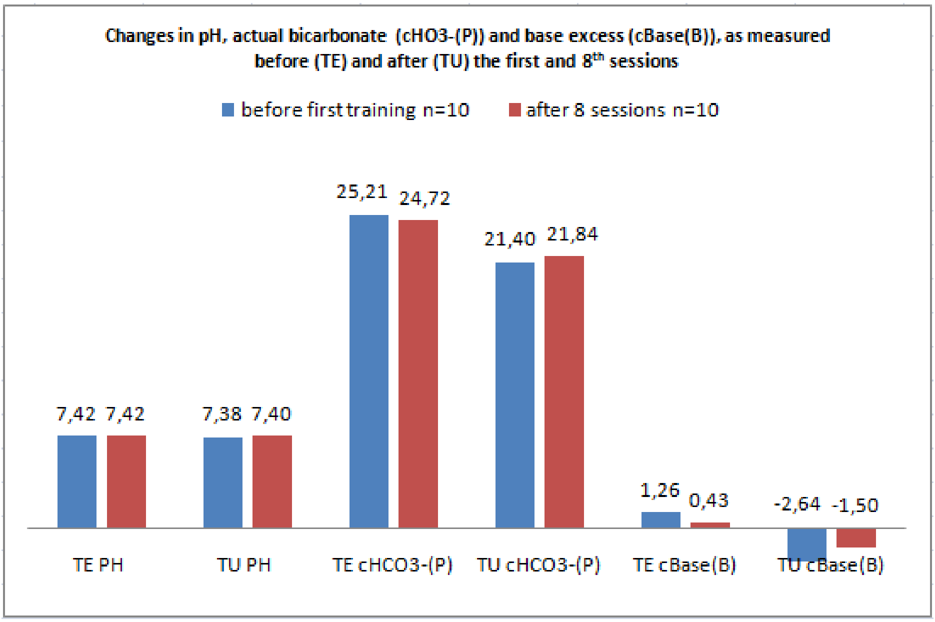
Across the entire sample, **haematocrit** (HCT) averages, which correspond to the reference values of male subjects, increased after the exercise and then dropped one hour into recovery both at the first and 8th sessions. However, at the 8th session, the initial parameter was higher and both peak and finish values were lower than at the first session. For both genders, such fluctuations took place within their respective reference ranges. As regards potential oxygen transport capacity (ctHb), averages for the entire sample tended to increase at the end of the exercise within the male reference range and then decreased after one hour of recovery at the first training session. At the 8th session, averages for the entire male sample rose by the end of the exercise and then decreased after a one-hour recovery. That is, on average for the 10-person sample, potential pre-training oxygen transport capacity increased by the 8th training session, meanwhile both peaks and final values decreased.

8.14 Oxygen saturation

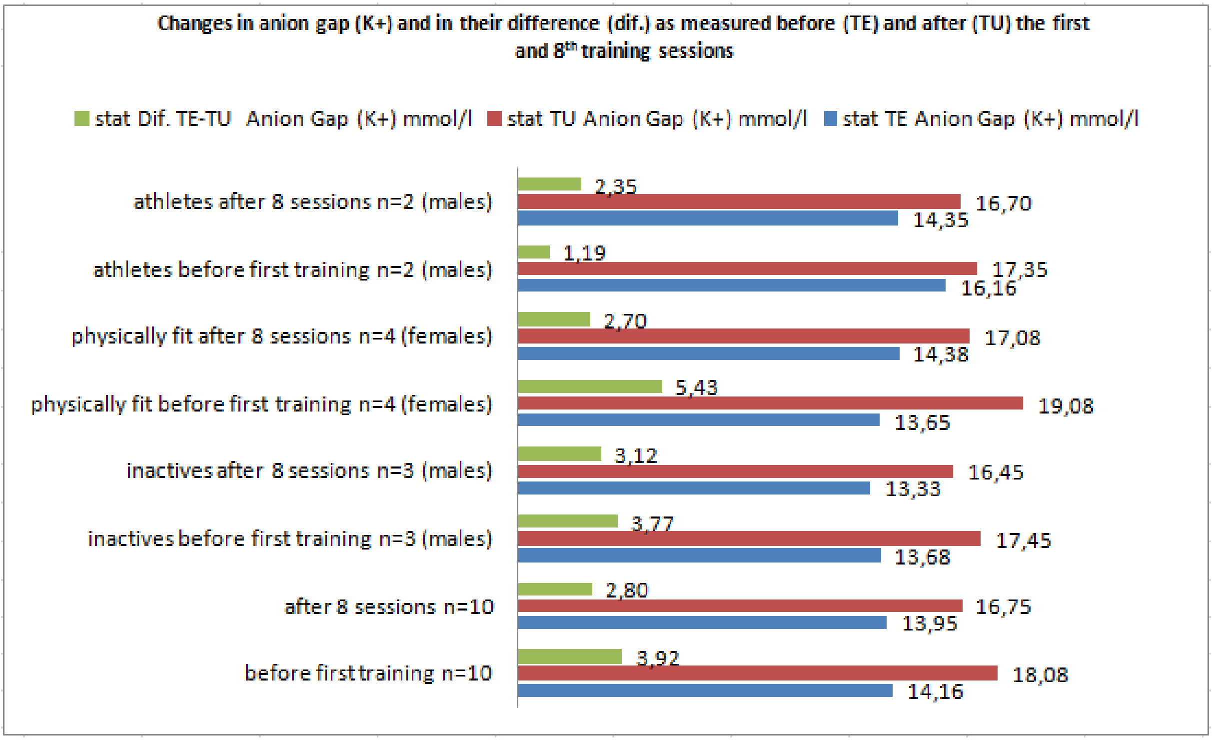
Oxygen saturation (sO2) for the 10-person sample decreased, when measured before the first session as well as immediately thereafter and 60 minutes into recovery. At the 8th session, at-rest averages decreased immediately after the workout and then rose 60 minutes into the recovery.

Arterial total oxygen concentration (ctO2) at the 8th session increased and then declined. That is, there is an increase from the initial pre-training value measured at rest, which decreases immediately after the workout and also 60 minutes into recovery.

By the 8th training session, the values measured at the first session in male subjects exhibited a positive shift in all three measurements. In females, this held true for at-rest measurements and those completed 60 minutes into recovery, meanwhile peak values measured immediately after training decreased. For both genders, measurement values remained within their respective reference ranges.



As far as the blood pH value is concerned, measurements indicated a shift towards acidity following workout across the entire 10-person sample. One hour into recovery, however, an alkaline shift restored the initial value. This worked similarly in males and females alike. Across the entire sample, low pH values, a low bicarbonate concentration and normal levels of pCO2 after a workout indicate training-induced metabolic acidosis. Parallel to this, exercise causes bicarbonate levels to drop and then rise one hour afterwards, with changes in base excess (BE) following similar trends. Across the entire sample, exercise causes the anion gap to increase and then decrease one hour thereafter. Post-training elevation of the anion gap indicates the presence of organic acids, which is parallel to bicarbonate depletion, resulting in a more pronounced training-induced metabolic acidosis. This latter was equally perceived in both male and female subjects. For the entire 10-person sample, when measured at the 8th session before and after workout, levels of anion gap indicating metabolic acidosis as well as their subtracted values were lower than those registered at the first session. There were two exceptions: in the sample of physically fit females, pre-training anion gap increased by the 8th session, with professional male athletes also exhibiting a rise in the subtracted value of pre and post exercise measurements.



8.15 Urine and creatinine measurement

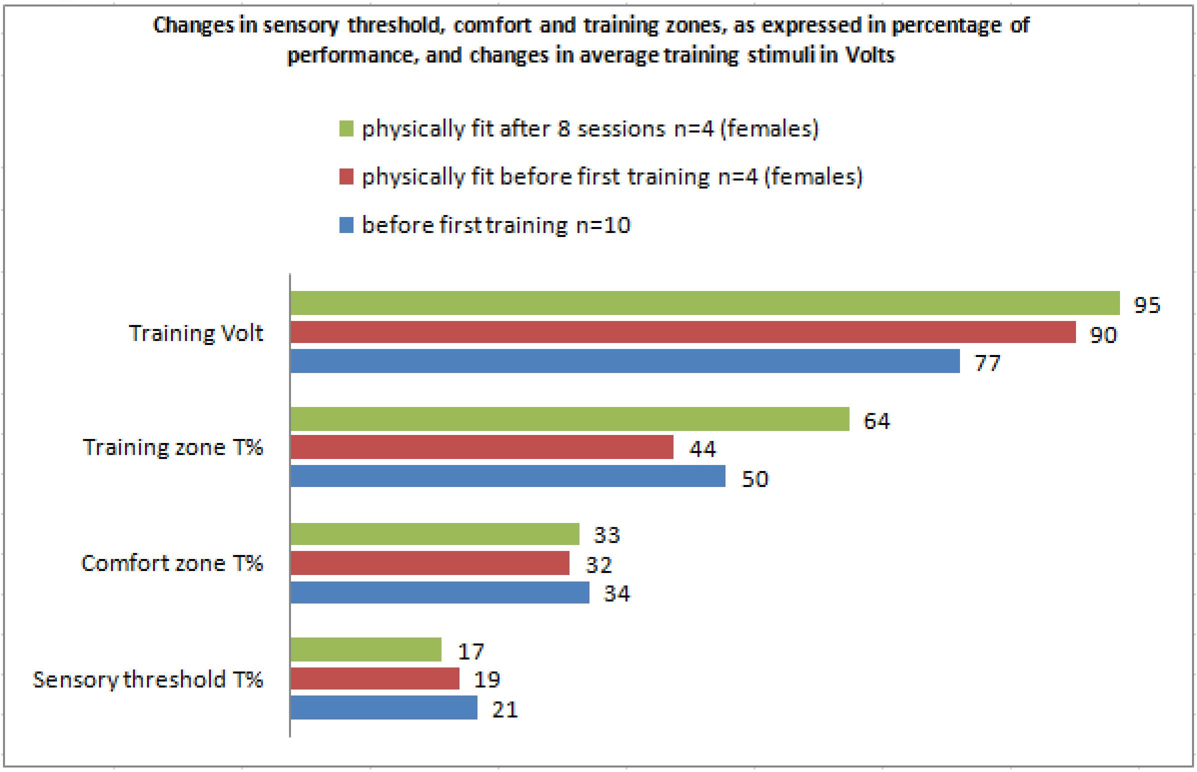
When assessing the effects of a single training session, 36 of the 50 participants tested positive for **urine protein**. One hour into recovery, this number dropped to 9. At the 24-hour test, there were 7 subjects with protein in their urine. At the 48, 72 and 96-hour tests, respectively, 5, 6 and 7 subjects tested positive for protein in urine, averaging between 16 and 22 mg/dl. In 10 subjects, **creatinine** levels in capillary blood were also checked. Creatinine is a break-down product of protein originating in muscles and is discharged from the body via the kidney. Its levels are indicative of kidney function. Elevated levels demonstrate kidney deficiency. Pre-training averages within the normal range dropped by the test performed 24 hours into recovery and then kept increasing until the 96-hour control, never falling outside the normal range.

In the 8-session protocol, all 10 subjects following the first test were tested positive for urine protein at one of the post-training tests (1, 24, 48, 72 and 96 hours thereafter). At the tests conducted after the 8th training session, 4 out of the 10 subjects were tested positive at one of the pot-exercise tests (1, 24, 48, 72 and 96 hours thereafter). Average post-training quantities decreased from 97.33 mg/dl at the first session to 50.25 mg/dl at the eighth.

8.16 Sensory threshold, comfort- and training zone

When assessing the effects of a single training session, females demonstrated a lower **sensory threshold** than males. This was the lowest in unfit females and highest in professional male athletes, the two representing a performance difference of 8.86 percent. Males showed a comfort zone exceeding that of the female sample by 3.82 percent. The lowest comfort zone was observed in inactive females and the highest in the sample of professional male athletes, with the two representing a performance difference of 11.07 percent. To a minimal extent of 1.64 percent, training zone averages for males were higher than for females. The highest training zone averages were observed in professional male athletes (51.43) and the lowest for the sample of currently inactive females (48.40). Differences between genders and in terms of fitness level are apparent in training and comfort zones and sensory thresholds alike.

When measured after 8 training sessions, the sensory threshold in the sample of physically fit females dropped from 19 to 17 per cents in performance. In the same sample, the comfort zone increased from 32 to 33 per cents of performance, and the training zone rose from 44 to 54 percent. In relation to the entire 10-person sample, physically fit subjects showed a lower sensory threshold that decreased over the 8 sessions. They also tended to have a lower comfort zone but the difference was reduced by the 8th session. The training zone initially stood at a lower level but then increased by the 8th session even when compared to the initial values of the 10-person sample.



Summary and conclusions

The combined use of electrical muscle stimulation and gymnastic exercise is a training method suitable to elicit adaptation stimuli with positive physiological effects. In order to effectively select the level of intensity for the workload applied, it is necessary for prior medical history and possible risk factors to be assessed and, ideally, to seek advice from a healthcare professional versed in exercise workload selection. In addition, the optimal selection of workload indicators require that fundamental information of the person concerned such as the age, gender, level of physical fitness and basic body composition (e.g. body weight and body fat) be available. The workout method, classified as resistance training, can be used to boost metabolism and enhance fat-free body mass and muscle strength. If applied as part of an appropriate training regimen, it may also lower levels of basal insulin and increase insulin sensitivity while also lowering blood pressure. When used as part of strength and endurance training, it can help improve cardio-respiratory and metabolic parameters; however, no significant improvement in key cardio endurance markers can be expected without reaching heart rate ranges typical of cardio training. It should be noted that combining the method with cardio workout is not yet recommended due to a lack of information about impact assessments. With appropriate intensity settings, it can improve the support capacity of muscles responsible for spinal movement.

The method's training-induced adaptation has a beneficial effect on balancing the autonomic nervous system (sympathetic shift and the extent of its impact), as well as on various markers indicative of mechanical strain (e.g. the enzyme creatine kinase) and energy background (e.g. lactic acid in blood). Use of electrical stimuli at settings higher than necessary may result in muscle contraction fatigue, causing micro-injuries that may require longer recovery (at a minimum of 5 days to 1 week). Therefore, optimal application ought to commence at low electrical loads that can be carefully increased at gradual intervals while avoiding shear. Taking the above into account, the availability of electrical load adjustment and safe uninterrupted control is recommended by all means.

When assessed, the method, categorised based on relevant physiological variables as resistance training, was found to deliver structural and metabolic workloads. At the same time, however, electrocardiogram tests performed before the combined use of electrical muscle stimulation and cardio training, the evaluation of cardiac markers (e.g. CK/MB) as well as the arteriography of blood vessels before and immediately after training and during a prolonged recovery period reveal further directions in research, the findings of which can then be used as relevant feedback.

9 Recommendations

One of the most important areas is the target-oriented overlap of successive workout regimes, which must replace conventional protocol-like routines and training management. This could be based on an objective diagnostic test of any level, provided it gives the trainer an objective yet realistic outline of options, elbow room and limitations for each person. Then, while also taking subjective individual targets and needs into account, at least a schematic training programme should be drafted for each guest, by which to guarantee the implementation of general training principles (gradation, progression, abundance and enhancement of stimuli etc.).

We recommend a fundamental change in training structure. From a professional aspect, this is based on the latest laws in methodology according to which work on peripheral segments must always be preceded by the mobilisation of the spine by way of active stretching exercises and by the optimisation of related deep core muscle tone. Therefore, this workout segment must represent the initial step of warm-up, in which the spine is mobilised both segmentally and globally, after which the tone of deep core muscles is adjusted under a strict protocol. Rather than referring to the actual exercises and their sequence, the term protocol stands for the logical order of exercise types according to mechanism of action, in which the professional trainer uses his/her own expertise and creativity to leave room for overlaps for various exercise routines.

When it came to the optimisation and harmonisation of mechanisms of action, it was an important finding for synchronisation by way of muscle contraction in the assessed workout structure that the (temporal and dynamic) pattern of electrical stimuli was significantly different from the naturally wired-in coordination pattern and movement structure (spatial-temporal-dynamic) of the exercises instructed. The method in which larger muscle groups fitted with electrodes are activated while being stimulated to the limits of tolerance, even though this is markedly different from the kinetic sequence required for the completion of a given exercise, is seen as a 'dead end' in many aspects. There is room for development primarily in terms of coordinating the two stimuli both in time and in dynamics. To that end, it is of utmost importance that the skills and expertise of a professional trainer enable him to orchestrate the electrical stimuli applied to individual muscles as well as the sequence of contractions administered and the range of movements with confidence. As far as I know, flexible settings of the device allow for a sufficiently wide spectrum to be covered.

The types of muscle contractions used during these exercises and the pattern of muscles electrically stimulated in parallel entail a host of methods the application of which can have a more optimal effect on various biological systems.
One such pattern type involves the targeted stimulation of agonist muscles (training zone) together with deep core muscles, while keeping antagonists and other muscle groups within the comfort zone just above the sensory threshold. In this case, it is very important to apply external resistance (functional equipment, G-Flex, TRX, progressive resistance, dumbbells, spotting partner etc.) in the positive work phase of movement, as this could greatly improve efficiency because of a near-natural coordination pattern, meanwhile a moderate increase in peripheral resistance also has a beneficial effect on central circulation. Naturally, appropriate impact studies should and must be used to optimise the stimulus level of muscle groups not involved in performing a given exercise.
Another possible synchronisation strategy is where, together with deep core muscles, antagonist muscles that act in opposition to the positive work phase are stimulated at training zone level; meanwhile those responsible for movement by concentric contraction are kept within the comfort zone and the rest at sensory threshold. In this scenario, agonist muscle groups are working to counter the eccentric force of antagonists, which could be more beneficial as far as adaptation of the respiratory and circulatory systems is concerned. Naturally, in order to optimise the settings of muscles stimulated at different levels, further examinations would be required.

When it comes to the goal-oriented enhancement and selection of exercises applied, a systemic approach in putting together a training routine also has a key role. According to one of the most important training principles, the training process must employ series of overlapping stimuli expanded in a circular pattern, with their complexity and intensity both increased at gradual intervals. Therefore, the training practices used during our assessment is but a representative sample, the efficiency of which cannot be confirmed. In this field, highly advanced instructor training courses can be contrived, which could lead to a quantum leap in efficiency.

In certain areas, such as special skills development, prevention of athletic or lifestyle-related hazards and post-injury rehabilitation, the E-fit system can be an integral part of the process and, in specific cases, could even have a prevalent role. To that end, it can be integrated in traditional systems at a given field of application by having the level of stimuli adjusted according to the appropriate training and/or therapy regime. Through the utilisation of objective measurement results, this also allows for the system integration of programmable modular units as well.

The mechanism of action of the separate recovery programme also has a key role as far as post-workout recovery is concerned. Expanding the post-workout recovery programme and/or its development into a standalone unit is another key aspect. Studying it at various workload levels and thresholds on different types of movements might even prove valuable in professional sports as well.

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