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EMS EFFECTIVENESS

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1 Time effectiveness of EMS

The electric impulses are generated by XBody EMS devices and delivered through cables to the electrodes on the skin surface of the muscles to be stimulated. Due to these impulses, the action potential is triggered in a similar way as in case of impulses coming from the central nervous system. The resulting muscle contraction is similar to the natural movement and regular contractions of the muscles. Depending on the parameters of the electrical impulses (impulse frequency, impulse width, ramp-up, impulse duration, duration of rest), different types of muscle work can be imposed thus improving and facilitating muscle performance of the stimulated muscles.

XBody EMS Training is a convenient and time-efficient way to increase training performance. To achieve this, EMS technology enables to stimulate the main muscle groups of the human body simultaneously. These muscle groups are the trunk muscles (abdominal, pectoral and back muscles), arm muscles (biceps, triceps, deltoids) and leg muscles (glutes, quads) all at the same time. Furthermore, there are several minor muscle groups that also contract, this way a very intensive whole body EMS training is utilized. Using the muscle distribution of Abe et al. [1], and a rough estimate of the percentage of muscles stimulated by XBody devices, it can be concluded, that more than 80% of total skeletal muscle mass (SM) is trained during XBody EMS exercises. The following figure summarizes their results, the trunk and limb SM was compared between weightlifters (WL) and moderately active men (CON).

	WL	CON	P-value
N	8	8	
Age, years	21 (1)	20 (2)	0.577
Standing height, m	1.71 (0.07)	1.71 (0.07)	0.944
Body mass, kg	78.8 (13.8)	59.2 (7.9)	0.004
Body mass Index, kg/m^2	26.9 (4.1)	20.3 (2.3)	0.002
Body fat, %	13.7 (5.5)	14.0 (4.4)	0.898
FFM, kg	67.5 (8.3)	50.8 (5.8)	<0.001
Total SM, kg	33.3 (4.3)	22.6 (3.7)	<0.001
Trunk SM, kg	14.7 (2.0)	9.4 (1.8)	<0.001
Appendicular SM, kg	18.6 (2.4)	13.2 (2.2)	<0.001
Arm SM, kg	3.4 (0.5)	2.2 (0.4)	<0.001
Upper leg SM, kg	12.3 (1.5)	8.5 (1.4)	<0.001
Lower leg SM, kg	2.9 (0.5)	2.6 (0.4)	0.189
Appendicular SM :			
Trunk SM ratio	1.27 (0.08)	1.42 (0.15)	0.030
Trunk SM : Total SM ratio	0.44 (0.02)	0.41 (0.03)	0.032

Table 1 : Total and segmental skeletal muscle mass and body composition

The distribution of muscle mass that is involved during EMS training is summarized in the following table.

	Weight (kg)	Percentage trained	Muscle mass trained (kg)
Trunk SM	14,7	85%	12,495
Arm SM	3,4	65%	2,21
Upper leg SM	12,3	85%	10,455
Lower leg SM	2,9	70%	2,03
Total SM	33,3	81,6%	27,19

Table 2 : Involved muscle mass during EMS training

During a normal push-up, squat, crunch and back extension one can only concentrate on one muscle group at a time meaning, that only by combining the above mentioned exercises can we train 80% of the total skeletal muscle mass.

This means that combining the above mentioned exercises, we receive nearly the same effectiveness of the XBody EMS training. This combined training process should last at least 20 minutes for 4 times, while still being less effective than XBody EMS training, as all of the before mentioned muscle groups are evenly stimulated in case of EMS training, while the utilization of the muscles is dependent on the chosen exercise in case of conventional training.

According to the before mentioned statements, one, 20 minute XBody EMS training roughly equals to 90 minutes of conventional training (including a short break between exercises). EMS trainings are not only four times less time consuming, but also proven to be an effective way of training.[2-4]

2 Effects of EMS on the human body

EMS technology is capable of increasing muscle mass, strength and muscle power. Beyond that, it helps with the conditioning of healthy muscles. Further beneficial effects of EMS are also known, such as helping in weight control or being a solution for conditions such as cellulite. EMS has several known beneficial effects in clinical applications. It can be used for preventive and rehabilitation purposes in neurology, orthopaedics, rheumatology and many other medical fields. It can be applied as a rehabilitation tool for balancing muscle imbalances caused by inappropriate muscle usage or restructure muscles damaged during aging or injuries.

2.1 Strength and performance among healthy individuals

Numerous studies have showed that EMS is an effective training method, thus it can significantly increase the muscular strength and performance among healthy individuals and professional sportsman.

2.1.1 Health-care

Scientific studies compared conventional training with EMS training and it was revealed by these publications that both training types have significant effect on transforming muscle components and characteristic. In addition, the usage of EMS technology as a complement of conventional training exercises is capable of enhancing muscular power and strength gains in healthy individuals. Furthermore, thanks to combing EMS with exercises, the stress on the joints can be reduced to a minimum level, compared to other sports (regular training with weights), thus EMS Training is highly recommended to the elderly and the sedentary population. [5, 17, 19]

- **Kemmler et al.** compared WB-EMS and High-Intensity training (HIT) effect on body composition and maximum dynamic leg-extensor strength in healthy, untrained male individuals by following a 16-weeks training program. The results demonstrated a decreased body fat percentage, an increased strength of the leg and back-extensor muscles and a significantly increased lean body mass in both group (HIT, WB-EMS), without significant group differences. In conclusion, the authors assessed that the time-efficient WB-EMS training has at least as beneficial effect on improving muscle strength and changing body composition as High-Intensity training exercises. [5]
- **Kemmler et al.** estimated the effectiveness of a 14-weeks WB-EMS training program (the combination of endurance and strength program) in regards to anthropometric,

physiological, and muscular parameters in case of postmenopausal women. The authors defined the hypothesis that WB-EMS has a positive impact on body composition and muscle strength in elderly women by completing a 14-weeks controlled WB-EMS training program. This hypothesis was proven because in anthropometric data (skinfolds and waist circumference) significant decreases were determined, whereas these improvements were not observed in the control group. In addition, a significant difference was found between WB-EMS group and the control group in terms of the maximal isometric strength of the trunk and leg extensor muscles. As deduced from the results, WB-EMS is capable of improving general physical fitness, thus the application of EMS technology shown as an effective training method for elderly individuals. [17]

- **Banerjee et al.** investigated the cardiovascular fitness and muscular strength of healthy individuals as a result of a 6 weeks EMS training program, without loading the limbs or joints. The study intended to examine the cardiopulmonary gas exchange, functional exercise capacity, quadriceps muscle strength, and body weight. These parameters were assessed with a treadmill test, a walking distance test, isometric muscle test with applying dynamometer, and a measurement of body mass index (BMI). According to the research, the significant improvements in cardiovascular fitness and muscle strength prove the effectiveness of unloaded EMS-induced muscle contractions. [19]

2.1.2 Sport-specific development

In the professional sports field, where strength, power, and speed is vital, this unique technology combined with sport-specific workout leads to a reduction of time needed for improving specific athletic skills and anaerobic power production. The EMS-evoked contractions have a beneficial effect on vertical jump ability (Squat Jump, Drop Jump, Counter Movement Jump), sprint performance (e.g. linear sprint running for 10 m, and sprint with direction changes) and sport-specific skills or tasks, such as kicking performance among soccer players or round-off salto backward tucked in case of gymnastics.

As deduced from the scientific results, it is recommended to integrate EMS training into the specific professional athlete's training protocol. By this integration diversity and variability can be ensured, which enhances motivation and results in better performance in shorter time. [6-11]

- **Deley et al.** examined the effect of a 6-weeks EMS training combined with gymnastics training program on isometric muscle strength and vertical jump ability of prepubertal women gymnasts. The measurement was evaluated by isokinetic tests, standard (Squat jump, Counter Movement Jump, Reactivity test) and 3 sport-specific jumping tests. In the group, which received EMS training in addition to the sport-specific gymnastic training, a significant improvement was observed in muscle strength of the knee extensors and vertical jumping performance. In the control group, which received only daily gymnastics training has no significant differences in the above mentioned parameters. The main findings of the study indicated that a 6-weeks combined EMS and daily gymnastic training is able to improve the muscle strength and jumping performance of prepubertal women gymnasts significantly. These increased values can be sustained for 1 month after the end of the 6-weeks EMS training program. [6]

- The experiment of **Babault et al**. was conducted to investigate the improvement of strength and power of professional rugby players due to a 12-weeks EMS training program. The maximal voluntary torque of the knee extensor muscles, a squat test as a concentric strength test, vertical jumping tests (Squat Jump, Drop Jump, Counter Movement Jump) and a sprint test were evaluated during the examination. After a 12-weeks training program, significant improvement was observed in the maximal eccentric and concentric torque of the knee extensor muscles, in concentric muscle strength and vertical jumping ability (Squat Jump and Drop Jump) compared with the control group, where these significant improvements were not demonstrated. As deduced from the results, EMS training can be an effective tool for increasing muscle strength and power in elite rugby players, however, EMS training did not result in any improvement of special rugby skills, such as sprinting and scrummaging. [7]
- **Filipovic et al.** investigated the effects of a 14-weeks WB-EMS training program on the performance of elite soccer players. The anthropometric parameters, sprinting performance (linear and sprint with direction changes), vertical jumping performance, maximal muscular strength and blood parameters (CK, IGF-1) were measured by the scientists. Significant changes were demonstrated in maximal muscle strength (1RM), sprinting and vertical jump performance, kicking capacity, and CK serum levels after 24 hours the training. Based on the results, the authors proved that the integration of a 14-weeks in-season WB-EMS training into soccer player training program has a beneficial impact on soccer-specific abilities. [8]
- **Billot et al.** designed the study to examine the effect of a 5-weeks EMS training program on sports performance in amateur soccer players. The supposed enhancement in strength production was measured by using an isokinetic dynamometer. The participants completed a ball speed measurement to evaluate the kicking performance, vertical jump tests, and 10m sprint test during the examination. A significantly increased eccentric, isometric, and concentric torques and ball speed were observed by the scientists whereas these improvements were not founded in the control group. It was concluded that the application

of EMS on the quadriceps muscles over 5 weeks is an effective tool for improving force and specific soccer tasks. [9]

- **Benito-Martínez et al.** examined the effects of an 8-weeks combined EMS and plyometric training on the ability of vertical jumping and speed in mid-level sprinter athletes. As deduced from the results, in order to improve vertical jump ability, the application of EMS before plyometric training is needed, for sprinter athletes, the same application (EMS prior to plyometric training) or the combination of the two training types is the best way. Despite this, for improving both vertical jump and speed performance the combined training version is not recommended. An increased muscle strength can be achieved in a shorter time compared to the speed ability by the application of the combined training method. [10]
- The study of **Maffiuletti et al.** provides a comparison between a 4-weeks EMS training program, plyometric training program, a combined EMS and plyometric training program on jumping ability, sprinting time, maximal voluntary isometric strength and muscle cross-sectional area among healthy adults. The results demonstrated that jumping ability and sprinting performance can be enhanced by a combined training (EMS and plyometric), furthermore EMS training or EMS combined with plyometric training is able to increase the maximal voluntary strength and achieve hypertrophy on the targeted muscle groups. According to the study, EMS without additional training type is not usable for developing jumping explosive strength or sprinting performance. [11]

2.2 Cardiovascular system and energy expenditure among healthy individuals

In the recent years, numerous scientific studies investigated the cardiovascular training effect of EMS technology in patients, who suffers from various diseases such as spinal cord injury, COPD (Chronic Obstructive Pulmonary Disease) and heart failure, but only a few publications focused on healthy individuals.

2.2.1 Prevention of cardiovascular diseases

EMS training is a very intensive whole-body workout, which provides a high load on the musculature as well as the cardiovascular system. The major purpose of studies related to healthy individuals is to achieve an EMS-evoked cardiovascular response in order to prevent cardiovascular diseases without performing gross movements and exercises, thereby avoiding stress on the supporting joints.

The measurement methods included anthropometric parameters, cardiopulmonary gas exchange, heart rate, exercise workload, cumulative energy expenditure and the relationship between these parameters.

Based on the results, EMS can be utilized as an effective method for eliciting a cardiovascular response, improving cardiovascular fitness, therefore substantially contributes to the reduction of incidence risk of cardiovascular diseases in healthy individuals. Thanks to the health promotion and prevention of diseases EMS is capable of reducing the costs of healthcare.

According to the below mentioned studies, however, EMS seems a unique, alternate method for eliciting cardiovascular exercise response, but further evidence-based research is needed. [12-14, 19]

- **Brian et al.** examined the cardiovascular effect of the EMS training in healthy individuals without performing joint loading, gross body movements. Based on the observed measurement values, such as average oxygen consumption (VO2), heart rate (HR), cumulative energy expenditure (Kcal) and exercise workload (METs) the article recommends the application of this technology with low-frequency electric impulses for eliciting a vigorous consistent cardiovascular exercise response. This cardiovascular response is similar to the response evoked by voluntary exercise, for instance, cycling or running. In summary, EMS technology can improve the condition of the cardiovascular system. [12]
- The experiment of **Banerjee et al.** was conducted to examine the cardiovascular effect of a prolonged EMS program in healthy individuals. The measurements include the application of a treadmill test for evaluating peak oxygen consumption (peak aerobic capacity), a 6-min walking distance test (functional exercise capacity), measurement of body mass index (BMI) and the isometric muscle strength of quadriceps femoris by a dynamometer. The improvement of all measured values was defined, thus the principal finding of this investigation is that EMS could be used for cardiovascular disease prevention due to the EMS-evoked proper physiological response. [13]
- **Banerjee et al.** provide an overview of the application of EMS training as a unique technology in cardiovascular exercise. This research summarizes the main findings of the collected studies regarding the cardiovascular effect of EMS. The study concludes that EMS can be utilized as an effective cardiovascular training method, but further evidence-based research is needed to confirm the conclusion of this article. [14]
- In this research **Banerjee et al.** investigated the cardiovascular fitness and muscular strength of healthy individuals as a result of a 6 weeks EMS training program, without loading the limbs and joints. The study intended to examine the cardiopulmonary gas exchange, functional exercise capacity, quadriceps muscle strength, and body mass index (BMI). These parameters were assessed with a treadmill test, a walking distance test, and an isometric muscle test by applying dynamometer. According to this research, the observed significant

improvements in cardiovascular fitness and muscle strength prove the effectiveness of EMS-induced muscle contractions. [19]

2.2.2 Help in weight control

The objective of other investigations was to demonstrate how WB-EMS technology affects the resting metabolic rate, body composition, fat reduction, therefore how the application of EMS would play a major role in weight control and could be an effective training tool within the field of health, fitness, and beauty.

The technology has a positive influence on cumulative energy expenditure (oxygen and calorie) when it is recommended to reach the motoric threshold or maximal intensity zone, which increases the energy expenditure significantly.

In conclusion, EMS technology is capable of achieving an enhanced fat reduction, an improved functional and muscle endurance, thus EMS can be a time-efficient training method especially for people, who are unwilling or unable to perform a conventional training. [15-18]

- **Miao-Ju Hsu et al.** examined the effect of low-frequency NMES (Neuromuscular electrical stimulation) on oxygen and calorie expenditure by applying different stimulation intensities (for reaching sensory level, motoric threshold and maximal intensity comfortably tolerated) in healthy individuals. The authors investigated the relationship between energy expenditure enhanced by NMES in different intensity levels and personal demographic or anthropometric characteristics including gender, age, body mass index, weight, body fat percentage and waist/hip ratio. Among the stimulation intensities, the motoric threshold and maximal intensity stage increased the energy expenditure significantly, which was still maintained higher than in baseline state during the recovery period. The mentioned factors of personal characteristic are not significantly correlated with the energy expenditure in any stimulation intensity stages. [15]
- **Kemmler et al.** determined the acute effect of WB-EMS during low-intensity resistance exercise on energy expenditure by indirect calorimetry in healthy individuals. It was found that energy expenditure and rating of perceived exertion were significantly higher in the group where the exercise protocol was complemented by WB-EMS application compared with the control group (exercises were performed without WB-EMS). The main finding of the study is that the additive effect of WB-EMS has a positive influence on energy expenditure during low-intensity resistance exercise training in moderately trained healthy

adults, therefore the authors recommended WB-EMS technology as a time-saving training method for people who are unable or unwilling to complete a conventional workout. [16]

- In a trial of **Kemmler et al.**, the effectiveness of a 14-weeks WB-EMS training program (the combination of endurance and strength program) was estimated in regards to anthropometric, physiological, and muscular parameters in case of postmenopausal women. The authors defined the hypothesis as WB-EMS has a positive impact on body composition and muscle strength in elderly women by completing a 14-weeks controlled training program. This hypothesis was proven because in anthropometric data (skinfolds and waist circumference) significant decrease were determined, whereas these improvements were not observed in the control group. In addition, in terms of maximal isometric strength of the trunk and leg extensor muscles a significant difference was found between the WB-EMS group and the control group. As deduced from the results, WB-EMS is capable of improving general physical fitness, thus it is an alternative training method for elderly individuals. [17]
- **Veldman et al.** provided an overview about the effects of NMES training on endurance performance in healthy individuals and patient population as well. In this article, recommendations are represented for the better clinical use of NMES types. For instance, the application of high-frequency NMES on muscle endurance is not recommended, because it may have an undesired effect on this ability, but low-frequency NMES training seems favorable for improving functional endurance in case of healthy individuals. In patient populations, both high- and low-frequency NMES training are able to increase functional endurance, but further research is needed to expand the knowledge of the effect on muscle endurance. [18]

2.3 Neural drive, muscle architecture and metabolic changes among healthy individuals

2.3.1 Neural and muscular adaptations

There are only a few studies that have examined the effect of EMS training on neural activity, but publications prove the responsibility of neural adaptations in achieving muscle strength gains. According to clinical studies, EMS training program can improve the overall activity of the stimulated muscles, because neural (e.g. increased EMG activity during maximal voluntary contraction) and muscular adaptations (e.g. changes in muscle anatomical cross-sectional area and the pennation angle) were observed due to the EMS training. These adaptations are supposedly contributed to maximal voluntary torque gains of the stimulated muscles. [20-21]

- The purpose of **Gondin et al.** was to investigate the neural and muscular adaptations of the knee extensors induced by EMS training in healthy male individuals. The recorded parameters were the torque at the knee joint (by isokinetic dynamometer) and the EMG activity of the knee extensors (the vastus lateralis and medialis, rectus femoris, and biceps femoris) during voluntary and electrically evoked contractions. Ultrasonography diagnostic imaging technique was applied for measuring muscle architecture (the pennation angle of Vastus lateralis) and muscle anatomical cross-sectional area (ACSA).

  A significant increase was found in muscle activation and maximal voluntary contraction (MVC) of the knee extensor, furthermore in quadriceps ACSA and pennation angle of vastus lateralis. After an 8-weeks EMS training program, a significant increase was found in normalized EMG activity and the ACSA of the vastus lateralis, medialis and intermedius muscles as well. It was concluded that EMS may be an effective tool for achieving both neural and muscular adaptations, which play a major role in MVC torque increment after an 8-weeks EMS training program. [20]
- A study of **Maffiuletti et al.** investigated the influence of a 4-weeks period EMS training on the activation of plantar flexor muscles in healthy individuals. The measured parameters include the maximal voluntary torque and the associated EMG activity of the plantar flexor and dorsal flexor muscles during isometric, concentric, and eccentric contractions. After the 4-weeks EMS training, the absence of a change was observed in plantar flexor muscle contractile properties, but significant torque gains (increment in isometric and eccentric voluntary torque) were found. A higher EMG activity of soleus and gastrocnemius muscles was found as well. [21]

2.3.2 Metabolic changes

A clinical publication confirms that EMS-evoked muscle contraction resulted in greater enhancement of growth hormone response and markers of muscular damage (blood lactate concentrations, serum creatine kinase activity, and muscle soreness) compared to voluntary muscle contraction, but further research is needed in this issue. [22]

- The purpose of **Jubeau et al.** was to compare the changes in muscle strength, growth hormone (GH), blood lactate, and markers of muscle damage evoked by voluntary and stimulated contractions after a 2-weeks training program. The measurements regard to the maximal isometric voluntary isometric strength, GH and blood lactate concentrations, in addition, the serum creatine kinase (CK) activity and muscle soreness assessments. A significantly larger decrease was experienced in maximal voluntary strength after electrical stimulation compared to voluntary exercise at the same force output. In addition, the serum GH, lactate and CK level were significantly higher after EMS exercises as well. It was deduced that EMS-induced contractions lead to greater increases in GH response and markers of muscle damage than conventional, voluntary exercises. These significant hormonal changes caused by EMS can lead to faster muscle size and strength gains than conventional exercises. [22]

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