THE EFFECTS OF EXTERNAL ELECTROMYO-STIMULATION ON SELECTED MOVEMENT PARAMETERS OF THE LOWER EXTREMITIES

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Abstract

The increase in sporting performance naturally, without doping and medicine abuse, requires further progress in the understanding of the load methodic procedure in training processes. An attempt assumes that the human body is able to compensate neuromuscular function deficits appearing locally. Moreover, nationally and internationally there are few results which are discussed in a controversial way. The contribution submitted here is concerned with compensation mechanisms resulting from local / differential muscular loads by means of external electromyostimulation. For it, the M. rectus femoris of the checked advantage leg was charged to in a fatigue study with 11 athletes by means of a standardised external electromyostimulation program. A "drop jump" functioned as a controlled exercise. From this exercise, the following results were recorded and then validated by test repetition:

I) By means of external electromyostimulation, muscle fatigue can be produced in a locally restricted area.

II) Setting a local muscle fatigue doesn't lead to a decrease of the sporting performance (flying time, flying altitude).

III) A local muscle fatigue triggers the complex system reactions which preserve the performance (declining joint resistance; changing leg kinematics; increase of the muscle action potentials of unfatigued muscles involved in the movement; decrease of the muscle action potential of the stimulated M. rectus femoris in connection with the increasing activity of the M. vastus medialis).

1 Introduction

The increase in sporting performance naturally, without doping and medicine abuse, requires further progress in the understanding of the load methodic procedure in training processes. In the area of training science it is so far tried to formulate laws and principles of sporting training on the basis of legitimate oriented research results (base and contact sciences: for example Travnik et al., 1995; Weir et al., 1996; Bernardi et al., 1997; Linke et al., 1998; Scholle et al., 2001; Pincivero et al., 2001; Seyfahrt et al., 2001). The combination of technique and strength training (Martin, 1989) offers an attempt at this, for example as already asserted by Djajkov in 1972. However, it has to be said that in the context of this combination there are experimentally verified solution strategies but they are only in parts. An approach which was concerned with the creation of complex, sports species - specific gauges and training equipment, has been followed up within the last 20 years. So, for example Hellmann developed - in cooperation with the former research institute for physical culture and sports Leipzig - a "(strength-) training device javelin" in the early 1980s which contributed to the optimisation of the parameter assisted technique training and the improvement in the special strength training to a large extent. The "(strength-) training device javelin" was designed to make exercises possible in relatively high agreement of structural elements in the competition movement both temporal - spatial and dynamic (Felke, 1990). Feigning competition specific movement
and load requirements in the training process by means of complex gauges has also gained acceptance in other sports and disciplines (Daug, 2000). Constructions such as the “Saltodrehgerät” approved in the gymnastics and high diving (Krug, 1993) or the one known in boxing as a “Messplatz Boxen” (Daug, 2000) can exemplary be named. However, there is a high degree of complexity in this research approach. Computer-assisted measurement procedures allow for objective analysis of competition exercises and for complex sub-specific movements. The data from the analysis allows for specific training methods based on scientific evidence. It doesn’t have to be valued negatively but suggests a cognition deficit in the area of differential concepts of strength—technique—training. Therefore, Thorhauer et al. demand following up these strategies or concepts just mentioned more strongly (2001). A promising approach is seen in the differential drive and regulation of the muscular movement system, that is the neuromuscular drives. Questions of the fatigue (fatigue = reversible decline in function ability of single organs and organ systems resulting from local and/or global psycho-physical stresses) play a key function in the design of the training load, especially with muscular endurance and power endurance (Thorhauer et al., 2001). Different approaches offer aspects of the energy metabolism regulation (Mader, 2001) or neuromuscular fatigue phenomena (Wittekopf and Rühl, 1984; Basmajian and de Luca, 1985; Gollhofer et al., 1987; van Dien et al., 1993; Aohnen, 1994; Anders et al., 1998; Roy et al., 1998; Puta and Türk–Noack, 2001; Thorhauer and Türk–Noack, 2001; Michel, 2003) to this. The latter requires a special dedication due to the lack of published research results particularly for dynamic and sports species-specific processes. A first step should be far-reaching examinations regarding load, fatigue and adaptation processes (qualitative and quantitative description of use reactions: Gollhofer et al., 1987; Williams et al., 1991; Seyfang et al., 2001; Hiemstra et al. 2001). From these results conclusions have to be drawn for the load methodic procedure in the training process aiming at an improvement in the sporting performance (Olivier, 1996; Killing, 2002: formation of training scientific theories, modification of training scientific theories). The following training experiments represent the third step and check the aforementioned cognitions (consequences for the load methodic procedure) with regard to their training effectiveness (effectiveness verdict).

The examination of fatigue phenomena still represents a relatively young research object in training science (Olivier, 1996; Thorhauer et al., 2001; Michel, 2001; Michel, 2003). In this respect it is necessary to clear up the load reactions of athletes more profoundly due to the low level of knowledge connected with that just as it becomes necessary because of the contradictory general impression the topic-related literature evaluation leaves. A very controversial discussion about this topic reveals, for example, how far the temporal behavior of strength and the electromyogram is changed in the course of a fatigue process. Therefore a number of authors describe an increasing electrical muscle activity, together with growing fatigue, and then at times the strength performance is compensated to resist the effects of this fatigue (Wittekopf and Rühl, 1991; Pollmann, 1993; Schmidt and Thews, 1997). However, opposite views are published with a comparable safety (Dietz, 1978; Vitasalo and Komi, 1978; Jones, 1979; Petrofsky, 1980; Strass, 1994; Gollendorfer, 1997) or it is stated that the innervation and the electrical qualities of the muscle fibre diaphragm are not changed due to fatigue (Möckel and Laube, 1991). Similar facts are offered in the context of the joint resistance. Thorhauer et al. (2001), for example, conclude a rise of the joint resistance with an increasing amount of fatigue (decrease of joint flexion corresponding with a shortening of support time). On the contrary, Seyfang et al. (2001) sums up that fatigue reduces the capability to adjust the joint resistance (increase of joint flexion corresponding
with lengthening of support time). Also under kinematic points of view there are different opinions. Williams et al. (1991) observed an unchanged flexion and an amplified extension in the knee joint after race fatigue. In turn, Türk – Noack (1999) covers exactly the turning back of the aforementioned leg kinematics. Therefore, the research group “Training Science Jena” first devotes itself to the clarification of these shown contradictions. Mainly dynamic, kinematic, metabolic and bioelectric parameters during a local muscle fatigue are followed up and compared. Generally valid fatigue reactions shall consequently be revealed and exposed to describe which muscular mechanisms serve the sporting performance in the compensation or for the time wise retention in the course of a local muscle fatigue process despite considerable local muscular function deficits (Thorhauer and Türk – Noack, 1997). The aim is to improve these mechanisms by a systematic training so that the nerve – muscle – system reacts with a rise of efficiency in an unfatigued state for concrete sports technical requirements. The central research approach is consequently the following:

A local / differential muscle – pre – fatigue permits the specific construction of neuromuscular compensation mechanisms which lead to an increasing capability of muscular drives of the operating intermuscular system in an unfatigued state.

2 Methods

Altogether eleven male, healthy athletes (calendrical age: 23.6 ± 2.5 years, body mass: 85.5 ± 8.5 kg, body height: 183.9 cm ± 6.4 cm, body fat: 16.2 ± 1.5 %) were included in the examination, they participated in a strength training program in their leisure time for more than five years, training about five times a week. The examination was carried out according to the test – retest – procedure. The topic of the examinations was the local fatigue of the M. rectus femoris (advantage leg only, counter – lateral side for control) under laboratory conditions. The fatigue was performed by means of external electromyostimulation (Compex Sport P). To assure the same load for every athlete the stimulation device had been programmed as follows: impulse strength: 40 mA, impulse frequency: 120 Hz, duration of the contraction: 4 s, duration of the break: 2 s, numbers of repetitions: 10, complete duration: 60 s, complete work quantity of one cycle consisting of contraction and break: 486 J, complete work quantity: 4860 J. The controlled exercise was a drop jump (height of fall 40 cm, target orientation: jump height or flying altitude, analysis of landing and jumping-off A = phase of the first ground contact). This was checked beforehand both by an interview with experts and by comparison with statistical safe tests (validity; results see Michel, 2003).

The examination proceeded with every athlete in 21 standardized steps: localisation of the muscles and setting of electrodes (EMG / eEMS); general warming up (bicycle ergometer: 5 min / 120 W / 75 rpm); specific warming up (50 rope jumps, barefooted); measuring of the skin temperature (athlete in seated supine position); measuring of the extent of the thigh (Athlete in eased supine position); wiring (EMG), attaching the acceleration sensor and attaching the pressure strength sensor; at rest – measuring (EMG) at visual and acoustic quiet (athlete in sitting position); at rest – measuring (EMG) at visual and acoustic quiet (athlete in the relaxed stand); 5 drop jumps (barefooted, 15 s break between the jumps) with EMG – measuring; wiring (eEMS); load of the M. rectus femoris (advantage leg) by means of the eEMS (athlete in sitting position); drop jump – test (barefooted); taking the seated position; 5 s break (athlete in seated position); 19 – fold repetition of the last 4 steps; at rest – measuring (EMG) at visual and acoustic quiet (athlete in seated position); at rest – measuring (EMG) at visual and acoustic quiet (athlete in relaxed stand); solving the wiring (EMG / eEMS); measuring of the skin temperature (athlete in eased supine position);
measuring of the extent of the thigh (athlete in eased supine position); removal of the marking (video analysis) and electrodes (EMG, eEMS).

The recording and evaluation of the measurements is carried out by means of video analysis (digital – video – camcorder Canon XL 1 / 50 Hz; measuring system DIVAS 2.0 / synchronous recording of arbitrary analogous measuring signals to video sequences / integrated analog -digital – board / Datenhaus Berlin; 2 – D – software „Motolyse“ of the field of work II: movement and motor behaviour, Prof. Dr. Dr. K. Williamczik, University Bielefeld), kinematic short time measurement (optical short time measuring system „Opto Jump“, supported by light barriers, precision: 1 / 1000 sec, Miugrate Bozen), bipolar surface electromyography (EMG – notebook – system: surface electrodes with Ag / AgCl – sensors / diameter: 2.3 cm / Kendall; amplifier of the company Biovision Frankfurt a. Main; 2 connection devices à 32 channels / Biovision Frankfurt a. Main; A / D – transducer / National – InstrumentsTM; notebook with 1600 MHz Intel Pentium IV processor / 512 MB working memory / Gericom; software Atisa for Windows V 1.1), acceleration sensor (50 g, BIOVISION Frankfurt a. Main), pressure strength sensor (measurement range 50 to 10000 N, BIOVISION Frankfurt a. Main), infrared surfaces measuring (Thermo – Check Masterline Berlin) and a customary measuring tape.

3 Results

Sporting performance (see figure 1): The size of the target was to ensure a maximum flying altitude or flying time. From figure it can be shown that only a small (not significant) decrease in performance can be noted despite a solid fatigue of the M. rectus femoris (advantage side) offside. This is accompanied, however, by a significant increase in the ground contact time.

Skin temperature and thigh extent: The determined skin temperature values show significant differences between pretest and post-test only for the part of the muscle fatigue, i.e. the test points “middle ligamentum patellae” and “middle distance spina iliaca anterior - the top edge of the patella in line". The determined thigh extent values show significant differences between pretest and post-test only for the part of the muscle fatigue, i.e. the test points "20 cm proximal patella" and "middle distance spina iliaca anterior - top edge patella in line".

Kinematics: Despite different degrees of fatigue, the angle courses are almost identical. Only a closer consideration yields significant changes at certain road junctions (for example: movement turning back). Altogether it can be said that in landing a stronger flexion is recognizable both in the ankle joint (3,2° on average) and the knee joint (4,0° on average) with increasing amounts of fatigue, thus the angle amplitudes also enlarge (ankle joint: 4,5° on average, knee joint: 4,0° on average). Furthermore, there is an amplified extension in the ankle joint (2,4° on average). The analysis of the knee joint - angle yields no changes in the phase of the jump-off with increasing amounts of fatigue. A significant sinking in the fatigue process can also be proved (2 cm on average) in the body's centre of gravity.

Electromyography (see figure 2 and 3): The comparison between an eEMS - loaded and unloaded lower extremity shows a significant reduction of the integrated EMG - value (IEMG) for the M. rectus femoris of the loaded leg. The unloaded M. rectus femoris, however, reacts as any other muscles involved in the movement with only a significant increase of the aforementioned value. Furthermore, a significantly higher integrated EMG - value can be noted for the M. vastus medialis and the M. adductor magnus on the eEMS - loaded side. Moreover there is an increase for the M. erector iliocostalis in individual cases. There is no generally valid reduction or increase pattern that can be found for the M. obliquus externus abdominis, the M. obliquus internus abdominis, the M. multi- fidus, the M. gluteus medius and the M.
gluteus maximus, neither for the right nor the left. These fundamental statements are confirmed by further checks of the EMG – parameters: duration of pre – innervation, maximum amplitude (pre – innervation), integrated EMG (pre – innervation), maximum amplitude (ground contact phase), integrated EMG (ground contact phase).

4 Summary

Altogether, the following mechanisms for maintaining sports performance despite local muscular function deficits can be exposed:

• Increasing muscle fatigue goes along with a significantly stronger flexion in both the ankle and knee joint during landing A.

• With increasing muscle fatigue the angle amplitude of both the ankle and knee joint significantly rise during the landing and take - off phase A.

• During take - off A a stronger extension in both the ankle and hip joint can partially occur with increasing muscle fatigue.

• With increasing muscle fatigue the angle amplitude of the hip joint can partially increase during the landing and take - off phase A.

• With increasing muscle fatigue the lowering of the centre of gravity increases significantly during landing A.

• With increasing muscle fatigue the joint stiffness decreases in the ankle and knee joint.

• With increasing muscle fatigue the muscular activity (IEMG, maximum amplitude) of following muscles increases significantly during landing and take - off phase A:
  - M. tibialis anterior (on both sides),
  - M. peroneus longus (on both sides),
  - M. gastrocnemius caput mediale (on both sides),
  - M. vastus medialis (on both sides),
  - M. rectus femoris (non - fatigued side),
  - M. adductor magnus (on both sides),
  - M. biceps femoris (on both sides).

• With increasing muscle fatigue the muscular activity (IEMG, maximum amplitude) of the M. erector iliocostalis (on both sides) can increase during landing and take - off phase A.

• In contrast to the non-fatigued M. rectus femoris the fatigued one (advantage leg) shows with increasing fatigue level a significantly higher muscular activity (IEMG, maximum amplitude) of the following muscles: M. vastus medialis (advantage leg), M. adductor magnus (advantage leg).

• Regarding the landing and take - off phase A the pre - innervation (duration, IEMG, maximum amplitude) of the following muscles rises significantly with increasing muscle fatigue levels: M. tibialis anterior (on both sides), M. peroneus longus (on both sides), M. gastrocnemius caput mediale (on both sides), M. vastus medialis (on both sides), M. rectus femoris (non - fatigued side), M. adductor magnus (on both sides), M. biceps femoris (on both sides).

• Regarding the landing and take - off phase A the pre - innervation (IEMG, maximum amplitude) of the M. erector iliocostalis (on both sides) can rise with increasing muscle fatigue levels.

• Compared with the non-fatigued M. rectus femoris, rising fatigue of the M. rectus femoris (advantage leg) goes along with a significant increase of the pre – innervation (duration, IEMG, maximum amplitude) of the following muscles: M. vastus medialis (advantage leg), M. adductor magnus (advantage leg).

5 References


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Figures

**statistical basic items** (ground contact time in s)

- \( \text{max} \) : 0,345
- \( \text{min} \) : 0,270
- \( \text{R} \) : 0,075
- \( \text{\( \mu \)} \) : 0,305
- \( \sigma \) : 0,025
- \( \text{v} \) : 8,1 %

**statistical basic items** (flying time in s)

- \( \text{max} \) : 0,584
- \( \text{min} \) : 0,533
- \( \text{R} \) : 0,051
- \( \text{\( \mu \)} \) : 0,562
- \( \sigma \) : 0,013
- \( \text{v} \) : 2,3 %

**statistical basic items** (flying altitude in cm)

- \( \text{max} \) : 41,9
- \( \text{min} \) : 34,9
- \( \text{R} \) : 7,0
- \( \text{\( \mu \)} \) : 38,8
- \( \sigma \) : 1,8
- \( \text{v} \) : 4,6 %

**statistical basic items** (performance identification value)

- \( \text{max} \) : 2,077
- \( \text{min} \) : 1,594
- \( \text{R} \) : 0,483
- \( \text{\( \mu \)} \) : 1,854
- \( \sigma \) : 0,168
- \( \text{v} \) : 9,1 %

**Figure 1.** Results Opto Jump – to athlete 1
Figure 2. EMG of the M. rectus femoris and the M. vastus medialis – athlete 1, left leg, stimulated by eEMS

Figure 3. EMG of the M. rectus femoris and the M. vastus medialis – athlete 1, right leg, without stimulation