CHANGES IN FOOT PRESSURE DISTRIBUTION DURING A COMBINED RUNNING AND CYCLING EXERCISE

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INTRODUCTION: The great demand in training of long distance runners very often causes overload of the muscular-sceletal-system with typical injuries and overuse syndromes, i.e., fascitis of the plantar fascia, „skin-split"-syndrome and patellar and achilles fasciitis. Alternative training methods like cycling seem to be useful to reduce overload. However, knowledge about how triathlon specific combined exercises effect running economy and foot pressure distribution is required to evaluate this training in long distance running and cycling. The following analysis of a combined running and cycling exercise provides data on these effects and shows a relation to cross-training as described previously (6).

METHODS AND PROCEDURES: 24 national and international elite triathletes (7 females aged 22.3; weight 61.5 kg; height 167.8 cm; $V0_2max$ 64.3 ml kg^{-1} min^{-1}; 17 males aged 24.6; weight 73.2 kg; height 180.5 cm; $V0_2max$ 71.2 ml kg^{-1} min^{-1}) were tested under standardized conditions. Each of them performed a combined indoor running-cycling-test with three running-step-tests (R1, R3, R4) with two different speed levels (v1, v2), a 20 min running-endurance-test (R2) and a 30 min endurance-test in cycling at an intensity level of 80% $V0_2max$ (fig. 1).

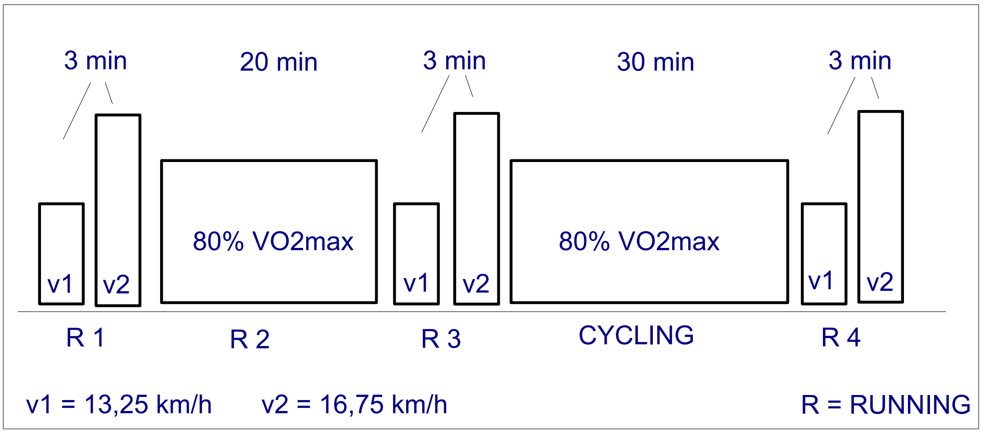

Fig. 1: Test design

Measurements (simultaneous): **F**oot **P**ressure **D**istribution (FPD) was recorded on the sole of the foot (bipedal) with Pedar-System (© Novel Munich, Germany). In every measurement 99 sensors were used in every sole. 9900 sensor impulses per second were detected (50 Hertz). For determination of the pedar masks the soles were divided into 9 anatomic areas (Bontranger et al. 1997). For further statistical calculation the data was standardized in relation to the size of the pedar masks.
EMG-activity of the following 6 superficial muscles of the lower limb was detected: M. tibialis anterior (TA), M. gastrocnemius medialis (GA), M. vastus medialis (VM),

M. rectus femoris (RF), M. biceps femoris (BF) (16-channel-EMG-system - © Biovision Wehrheim, Germany). For appropriate adhesion of leads on the skin type N-00-S self-adhesive Blue-Sensor-Chloride-Electrodes (Medicotest, ∅lstykke, Denmark) were used. The bipolar derived electromyographical signals were preamplified with the factor 2500 and sampled with 2000 Hertz.

Statistics: One-way analysis of variance (ANOVA) and a paired-T-test were computed with SAS (© SAS Institute Inc., Cary, NC, USA). Level of significance: $p < 0.001$ highly significant (**); $p < 0.05$ significant (*).

RESULTS:

FPD: The data demonstrates an increase of maximum vertical force parallel to an increasing running speed (comparison v1 versus v2). Interesting are the different vertical forces at the same running speed detected after cycling exercise compared to running exercise. Vertical force values (R3) are decreased after a 20 minute running exercise, but rise significantly ($p<0.01$) after the cycling period. V1 showed an increase of 15%, v2 of 12%. The rate of change between R1 and R4 is identified as 9% each and is highly significant ($p<0.001$)(fig. 2).

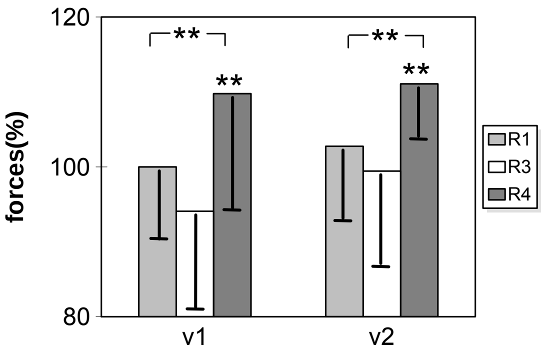

Fig. 2: The rate of change of maximum vertical forces between R1, R3 and R4 at different running speed.

With regard to vertical displacement (fig. 3) a similar course is seen. After the running period vertical displacement values drop significantly ($p<0.05$) about 5% each and increase again in R4 after the cycling period. Furthermore it can clearly be demonstrated that the increase of vertical displacement values after cycling is lower with high running speed v2 (+9%, $p<0.01$) than with lower speed v1 (+23%, $p<0.05$). In conclusion, cycling leads to significantly higher vertical displacement and therefore puts more a strain on the entire musculo-sceletal system.

Focused on the separate analysis of the anatomical areas of the pedar mask, a significant increase of vertical displacement and of vertical forces was detected.This could be demonstrated especially for the areas of the medial arch and the medial metatarsal bones. In all anatomical areas of the pedar mask stable contact areas were seen at both speed levels. Contact time was prolonged after cycling especially during high speed exercise v2.

EMG: For evaluation of EMG-signals only noise-free-signals were accepted. After full wave rectification the AEMG was derived by taking 4 movement cycles into account. As an example the typical AEMG of the medial head of the gastrocnemius muscle from 5 runners in v1 phase is depicted. The single dots in figure 4 represent means of AEMG-values measured at different times (R1, R3, R4). All values were calculated in percent compared to the base-value R1. AEMGs were significantly decreased (p<0.001). In the final running period (R4) after the cycling exercise this tendency reversed: AEMG-values increased about 16% above the start-value of R1.

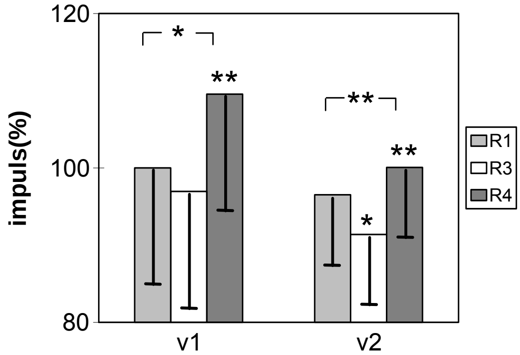

Fig. 3: The rate of change of maximum vertical forces between R1, R3 and R4 in different running speed.

For better differentiation of EMG-activity time periods of GA-acitivity were subdivided functionally by using a goniometer (©Biovision) and a contact sensor for runner's soles (Trigger). The differentiated subcategories were described as preactivation-phase (100 ms before ground contact), eccentric and concentric phase of muscle activity (related to flexion and extension status of knee joint and initial ground contact). Eccentric phase was the time period between the largest and smallest internal angle of the knee joint during supporting phase, concentric phase began directly after eccentric phase and lasted till toe-off.
In figure 5 the rate of change of AEMG in these functional phases is demonstrated in comparison to the value. The sole influence of running (R1 and R2) shows a drop in the AEMG-activity within all three functional phases. This confirms the fact of a significant entire-reduction of the AEMG from R1 to R3 (see fig. 4). The following cycling exercise reverses this tendency. A tremendous increase

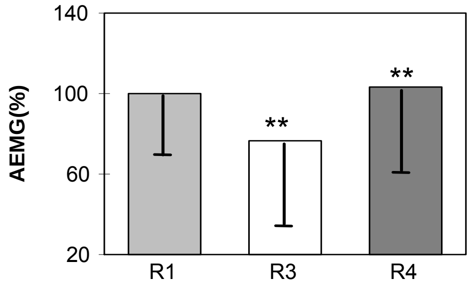

Fig. 4: AEMG-changes of M. gastrocnemius.

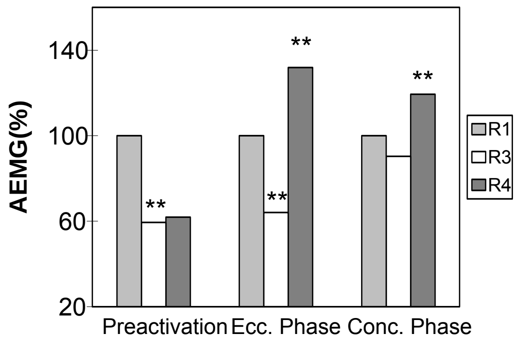

Fig. 5: Rate of change of AEMG in the three functional muscle-activity-phases.

of the AEMG in R4 is to be seen during eccentric and concentric phases (+70% and +30%), whereas the values are relatively stagnant during preactivation (+3%). The increase in the concentric phase is highly significant ($p<0.001$). The analysis of other assessed muscles confirms these results for the leg extensors, medial vastus muscle, lateral vastus muscle and rectus femoris muscle.

DISCUSSION: Slight reduction of vertical forces and decreased vertical displacement seem to mirror an optimized muscle activity in terms of cushioning and economy. Changes in other physiological parameters like lactate and heart rate support this thesis. This optimizing effect is disturbed during cycling exercise, which is reflected through an increase in force peaks and vertical displacement under continuous running speed. This may be explained by the altered muscle-work in a sitting position during cycling. The flexion of the hip joint during cycling and the strictly limited range of motion do change angle of movement in these joints and also alter the force-length-relation for the working muscles (3, 4). Additionally, it is concluded that a lower amount of elastic energy can be stored and reused because of the lower stretch-amplitude and reduced stretch-velocity of GA during cycling exercise compared to running. This leads to a non-optimal stiffness of the tendo-muscular system, which is essential for optimal work under SSC conditions (2). All these factors lead to loss of running economy due to specific fatigue which is expressed as increased vertical displacement and vertical force peaks.

CONCLUSION: Athletes should be careful when practicing running immediately after cycling in order to reduce vertical stresses. New programs of physical exercise are required to optimize muscular efficiency after cycling.

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