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JOINT SPECIFIC CONTRIBUTION OF MECHANICAL POWER AND WORK DURING ACCELERATION AND TOP SPEED IN ELITE SPRINTERS

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The purpose of the study was to quantify and compare sprint mechanics of elite female sprinters (N=9; PB 11.4±0.2s) during acceleration (1^{st}, 2^{nd}, 3^{rd} step) and top speed ('flying 30m) running. Three dimensional kinetics and kinematics were measured on an IAAF indoor track armed with four force plates and 16 cameras. The comparison between the 1^{st}, 2^{nd} and 3^{rd} step and the 'flying 30m' (v_{ave}= 9.0±0.2 ms^{-1}) shows a progressive change in absorption and generation of mechanical power. Whilst the knee extensors where able to minimize energy absorption during acceleration, the ankle extensors showed a stretch-shortening cycle and a small absorption from the first step. This energy loss at the ankle joint does not necessarily leads to a decrease in sprint performance, it also offers the plantar flexors to work in an stretch-shortening cycle instead of concentric only mode.

KEY WORDS: sprint running, running mechanics, sports biomechanics.

INTRODUCTION: During sprint running the muscle-tendon units (MTU) of an athlete are alternately shortening and stretching to absorb and generate mechanical energy at the joints of the lower extremities resulting in a deceleration (braking) and acceleration (propulsion) of the sprinter's center of mass. In general, the aim of a sprinter is to generate as much net mechanical energy as possible and to maintain this energy as long as possible.

However, it can be assumed that the applied sprint mechanics to reach this goal differs between the acceleration phase and top speed running. The joint specific contribution (e.g.: metatarsal phalangeal joints (MPJ), ankle, knee, hip) to the mechanical work and power generated during these two different phases is not well understood.

Therefore the aim of the current study was to quantify and compare sprint mechanics during acceleration and top speed running to detect joint specific strategies of power generation. This might be helpful for athletes and coaches identifying individual potential to improve all-over sprint performance even on an elite level.

METHODS: All subjects (N=9, female, age: 23 ± 5 years, height: 172 ± 5 cm; mass: 61.5 ± 5 kg, personal best 100 m: 11.4 ± 0.2 s) completing five to eleven training sessions a week for the last two years prior to participation, and had been free of neuromuscular and musculo-skeletal impairments. The female sprinters are members of the national sprinting squad, competing in national and international elite sprinting competitions. Approval was obtained from the local committee for protection of human subjects and all subjects provided informed consent prior to participation in the study.

For a better understanding of a joint's role during sprinting we measured 3D kinetics and kinematics at four different times (1^{st} step, 2^{nd} step, 3^{rd} step, top speed). Sprinting characteristics were measured on an 8 x 100 m indoor track (IAAF standard). One of the lanes was armed with four floor mounted force plates (Kistler, Wintherthur, Switzerland, 900 x 600 mm) sampled at 1250 Hz and 16 infrared high speed cameras (Vicon, Oxford, United Kingdom) sampled at 250 Hz.

For the acceleration trials every athlete positioned the starting machine in front of the force plates with respect to their individual needs to hit the force plates three times as centered as possible. The first, second and third step was measured within one trial. All subjects performed a minimum of three valid accelerating sprint trials (starting machine to 10 m with 10 minutes resting period between trials) where the fastest trial was the relevant for data processing. For the 'flying 30 m' trial, the athletes were asked to start in front of the force plates with respect to their individual needs but having the maximum speed while running through the measurement volume.

After warm-up, all subjects were palpated and marked at relevant anatomical landmarks for inverse-dynamic calculations regarding to Hof 1992. Prior to testing, subject calibration trials (upright standing centered on force plate) were performed to locate anatomical landmarks and define joint coordinates systems. Timing gates controlled average running speed, whereas the calculated virtual mid-pelvis marker (intersection of the four pelvis markers) represents the velocity profile of each subject during acceleration. All values are presented in mean±SD except Figure 2 and Figure 3 (mean±SE) due to clarity.

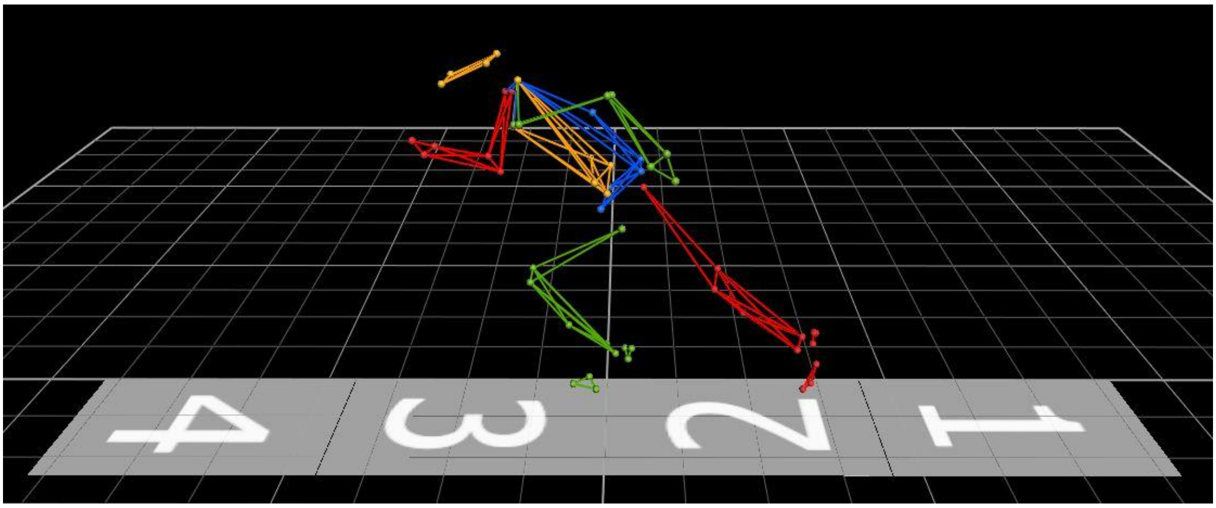

Figure 1: Measurement of 3D sprint mechanics (kinetics and kinematics) during acceleration and top speed phase with full body marker set whereas the relevant markers for this paper are: tip of hallux; MPJ-1; MPJ-5; lateral and medial part of the calcaneus; most distal aspect of the calcaneus; medio and lateral aspect of the malleolus; medial and lateral femoral condyle; greater trochanter for each leg as well as the left anterior superior iliac spine, right anterior superior iliac spine; left posterior superior iliac spine; right posterior iliac spine.

RESULTS and DISCUSSION: The mechanical power and work, generated by the specific joints of the lower extremities (MPJ, ankle, knee and hip) during ground contact is shown in figure 2A - 2D. The comparison between the first, second and third steps (red, blue and green curve) and the 'flying 30 m' trials ($V_{ave} = 9.0 \pm 0.2$ ms^{-1}) shows a progressive change and/or shift in the absorption and generation pattern of mechanical power and mechanical work. Especially the ankle joint (Figure 2 B) clearly shows that a decreased ground contact time from step 1 to 'flying 30 m' is attended with an increase of positive mechanical power whereas the positive mechanical work during this specific phase remains similar (1st step 1.71 ± 0.22 J/kg; 2nd step 1.68 ± 1.2 J/kg; 3rd step 1.70 ± 0.21 J/kg; 30m 1.77 ± 0.27 J/kg). In contrary, the absorption of mechanical work (approx. 0% - 50% of stance) is continuously increasing (1st step -0.35 ± 0.13 J/kg; 2nd step -0.37 ± 0.08 J/kg; 3rd step -0.52 ± 0.17 J/kg; 30 m -1.25 ± 0.16 J/kg). For the ankle joint angle (Figure 3A) during all conditions a stretch-shortening cycle pattern of the MTU could be detected, however the range of motion during top speed running is higher which enables the plantar flexors to absorb the higher energy.

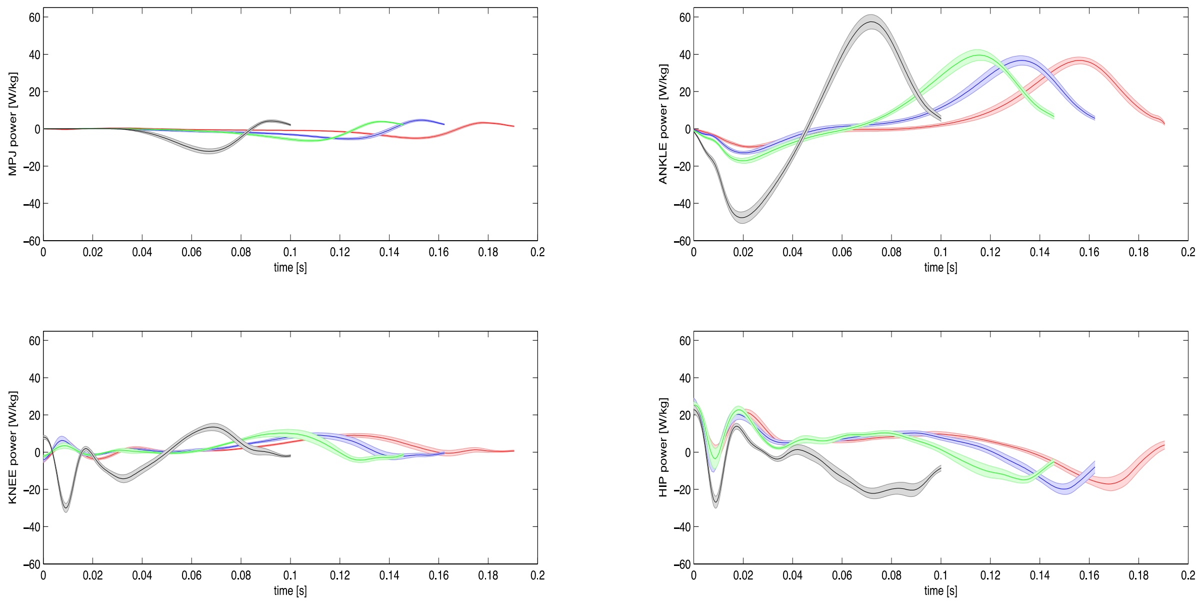

Figure 2: The joint specific mechanical power and work generation during ground contact phase. All data were averaged across subjects, and showed as mean (solid line) and standard error (shaded area).

The knee joint angles in Figure 3B showed during this first half of stance a different initial position and behaviour between the first three steps of acceleration and top speed sprinting. At the beginning of the acceleration phase (first to third step) the knee joint shows no bending for the whole ground contact phase, which implies that almost no energy was absorbed during this phase (Figure 2C).

During the ‘flying 30 m’ the knee joint showed a contrary behaviour with a classical stretch-shortening cycle where energy is absorbed by the MTUs during stretching. However, from a neuromechanical perspective it can be stated, that the present stretch-shortening cycle pattern can also be advantageous due to energy storage in series elastic structures and an optimized force generation of the knee extending muscles.

It is obvious that dividing the all-over sprint performance in sub phases (1st step, 2nd step, 3rd step, top speed), could not clarify a complex process like energy storage and recovery or inter-segment energy transfer but may give some further insights to athletes and coaches about the functional role of different joints within the lower extremities comparing the phase of acceleration to top speed.

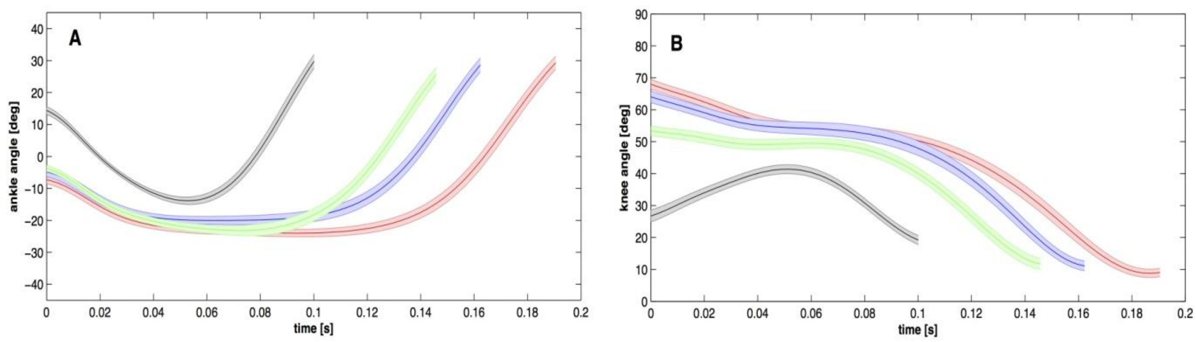

Figure 3: The joint specific kinematics during ground contact phase. All data were averaged across subjects, and showed as mean (solid line) and standard error (shaded area).

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