IS AVERAGE SPEED CONTROL SENSITIVE ENOUGH TO ENSURE NON-ACCELERATED RUNNING IN THE ANALYSIS OF RUNNING MECHANICS?

Steffen Willwacher, Katina Fischer and Gert-Peter Brüggemann

Institute of Biomechanics and Orthopedics, German Sports University Cologne

The purpose of this study was to investigate whether average speed control by means of photocells is sufficient to guarantee the absence of center of mass velocity changes (CoMVC) and possible effects of such changes on running mechanics. A standard 3D inverse dynamics model was used to calculate kinematics and kinetics of 19 subjects running at 3,5m/s over a 25m track. CoMVC were controlled by calculating the ratio of propulsive to braking impulse (RPBI) of the GRF. Higher braking forces were achieved by increased negative work of the knee extensors while greater propulsive forces were mainly the effect of increased positive work of the plantar flexors. Differences in impact force were related to CoMVC. Implementation of RPBI control is recommended especially when sagittal plane mechanics and impact forces are to be investigated.

KEY WORDS: methods, braking, propulsion, ground reaction forces.

INTRODUCTION: The study of running mechanics is a frequently performed practice to gain insight into factors relating to injury development and performance (Cymet & Sinkov 2006, Saunders et al. 2004). Oftentimes constant speed conditions (CSC) are in the focus of interest. CSC are usually controlled by checking the average speed of the subject by means of two photocells. While it is likely impossible to have a perfectly constant overground speed condition, it is unclear whether minor or major deviations from CSC can be avoided by just checking the average speed of the subject.
Therefore the purpose of this study was to examine the accuracy of average speed control in the examination of CSC. It was hypothesized that deviations from CSC would occur. The second purpose of this study was to analyze possible effects of CoM acceleration and deceleration on sagittal plane joint kinematics and kinetics during running. By this further insight into the contribution of selected muscle groups to braking and propulsion of the CoM during the stance phase of running might be gained.

METHODS: Thirty subjects (13 men, 17 women, age: 38.5±14.7, mass: 68.1±12.2kg, height: 1.73±0.1m) participated in this study. Subjects were asked to run with 3,5m/s +- 5% along a 25m track incorporating a Kistler force platform (1250Hz). Average speed was checked for by means of two photocells positioned one meter before and behind the edges of the force plate. Lower extremity kinematics of the right leg were captured using a 10 camera Vicon Nexus system running at 250Hz. 3D joint angles, moments and powers were calculated using a standard 5 segments inverse dynamics model. Only sagittal plane kinematics and kinetics were analyzed, since braking and propulsion were assumed to affect mechanics in this plane the most. Subjects were advised to run with constant speed without altering their running technique. All subjects wore the same kind of neutral running shoes. CSC were checked for each trial by means of the RPBI using customized software. Each subject performed a number of running trials until 5 trials with a RPBI of 1 +- 10% were captured. All trials captured until this point with acceptable speed, no change in running technique and foot placements on the force platform were included into the analysis. Three groups of trials based on RPBI (braking: 0.7-0.9, neutral: 0.9-1.1, accelerating: 1.1-1.3) were created for each subject. Each subject contributed at least one trial to each group. Trials lying outside this range were not included into the mechanical analysis, but were included into the description of CSC deviation (see fig. 1). The influence of RPBI on mechanical parameters was tested by means of repeated measures ANOVA (general linear model). If a significant ($p<0.05$) influence of RPBI on a variable was found, a post hoc test (Bonferroni correction) was performed to check for differences between individual groups.

RESULTS: Figure 1 displays the distribution of RPBIs found for all analyzed trials.

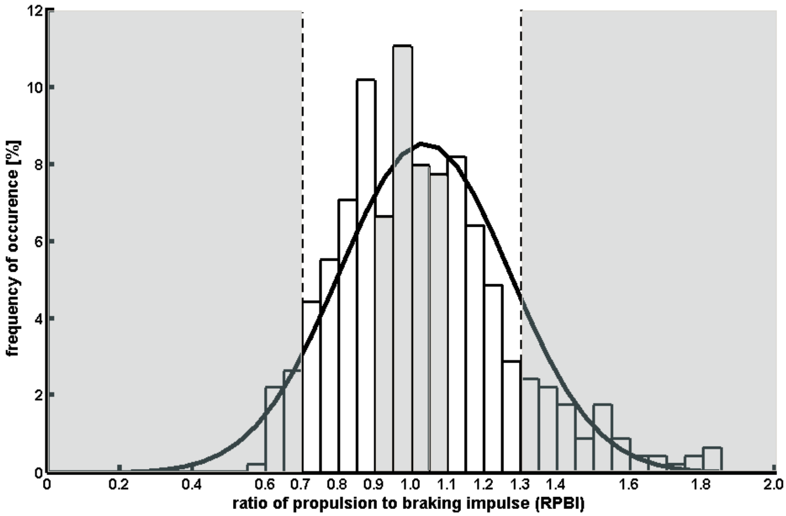

Figure 1: Distribution of RPBI values of the complete dataset.

A Kolmogorov-Smirnov test revealed that a normal distribution with a mean of 1.03 and standard deviation of 0.23 can be assumed.

The mechanical analysis of the three RPBI groups showed that higher braking forces were achieved by increasing the CoM to center of pressure (CoP) distance at heel strike. This caused an increased initial plantar flexion movement at the ankle joint with corresponding higher plantar flexion velocity.

This variation of leg configuration at heel strike led to a significant change in impact force characteristics (see Figure 2).

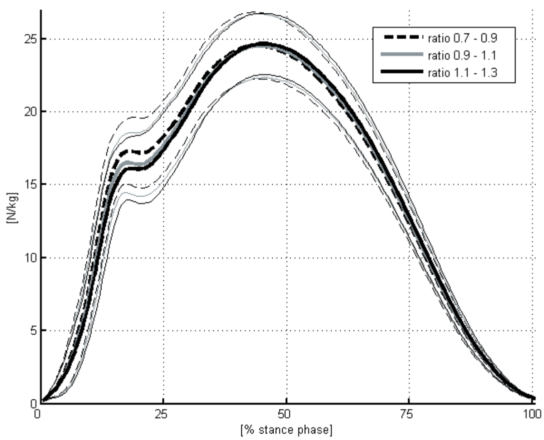

Figure 2: Mean ± one standard deviation of the vertical GRF curves for the three analyzed groups.

In the first half of stance the braking group exhibited significantly higher joint moments at the knee and dissipated significantly more energy at this joint (Figure 3). The accelerative group showed an increased push with higher extension angles at the knee and the ankle at toe off.

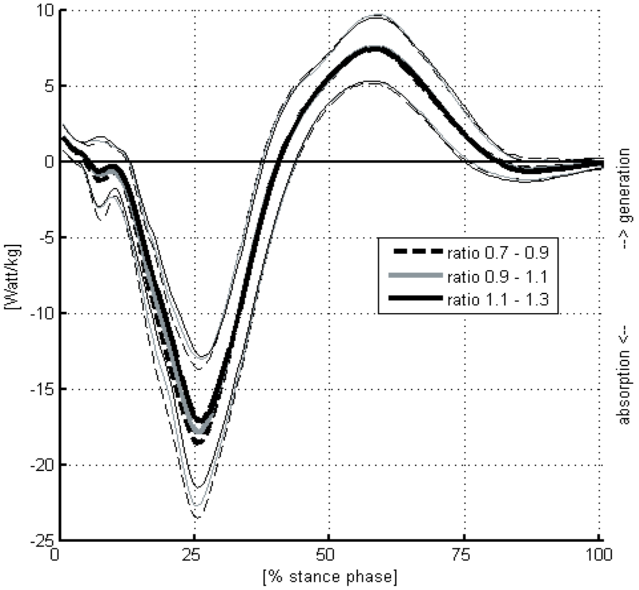

Figure 3: Mean ± one standard deviation of knee joint power curves in the sagittal plane of 3 RPBI groups.

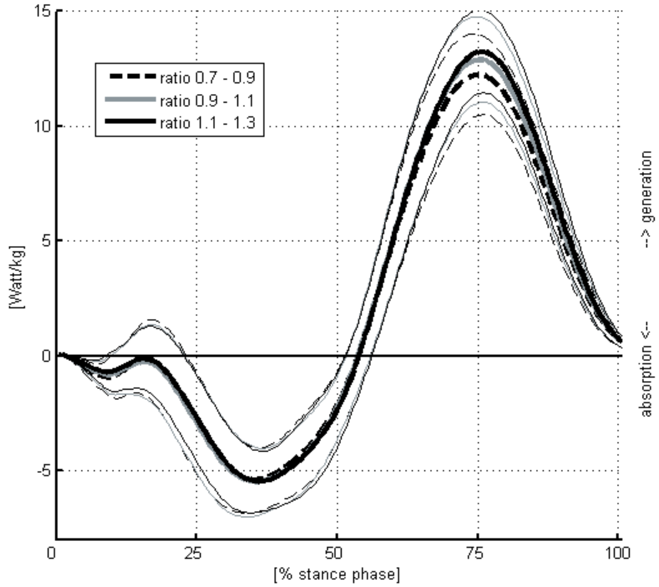

Figure 4: Mean ± one standard deviation of ankle joint power in the sagittal plane of 3 RPBI groups.

Increased propulsion was mainly achieved by higher ankle joint moments and energy generation in the second phase of stance (Figure 4). Table 1 summarizes the differences of main parameters of the analysis.

Table 1
Means and standard deviations of main parameters of interest. All parameters are significantly different to each other ($p<0.05$).

group	RPBI	F_{impact} [N/kg]	RFD_{IF} [N/kg/s]	$M_{knee}max$ [Nm/kg]	$M_{ankle}max$ [Nm/kg]	$P_{knee}min$ [Watt/kg]	$P_{ankle}max$ [Watt/kg]
0.7-0.9	0.82±0.03	17.42±3.0	590.3±116.8	2.92±0.37	2.47±0.27	-19.67±4.61	12.48±1.82
0.9-1.1	1.00±0.03	16.89±2.5	551.0±102.0	2.89±0.38	2.53±0.28	-18.90±4.50	13.16±1.86
1.1-1.3	1.17±0.03	16.48±2.7	523.1±123.9	2.86±0.36	2.54±0.28	-17.98±4.09	13.50±1.78

DISCUSSION: From a theoretical point of view a RPBI of little higher than 1 is necessary for CSC to compensate for speed loss during the flight phase due to air drag. Nonetheless a clear left shift in the distribution of RPBIs is observable from figure 1 indicating that a slight overall braking tendency is existent in the data set. It is reasonable to argue, that in laboratories with restricted acceleration or deceleration distances, a pronounced shift of RPBI distribution to the left or the right might occur.
Mean values for RPBIs varied by approx. 26%. This variation led to considerable changes in impact force (F_{impact}) and rate of force development of the impact force (RFD_{IF}) (see table 1 and figure 2). Joint moments and joint power at the knee and the ankle joint ($M_{knee,\ ankle}$, $P_{knee,\ ankle}$) showed a systematic variation with RPBI.
These results are in line with recent findings of Hamner et al. (2010), stating that in distance running, braking in the first half of stance is mainly achieved by negative work of the quadriceps femoris muscle tendon units while propulsion in the second phase of stance is generated by positive work of the gastrocnemius and soleus muscle tendon units.

CONCLUSION: Average speed control e.g. by light barriers seems not sensitive enough to guarantee non-accelerated running in distance running research.
When joint mechanics or impact force characteristics in the sagittal plane are in the focus of interest, individual control of RPBI is mandatory to observe comparable results. RPBI inspection is even more critical in laboratory environments which might restrict acceleration or deceleration to or from the force platform. Future research should investigate possible effects of CoMVC on joint kinematics and kinetics outside the sagittal plane.

REFERENCES:

Cymet CT, Sinkov V., Does long distance running cause osteoarthritis? *Journal of the American Osteopathic Association* 106(6), 342-345, 2006

Hamner SR, et al. Muscle contributions to propulsion and support during running. *Journal of Biomechanics* 43, 2709-2716, 2010

Saunders PU et al., Factors affecting running economy in trained distance runners. *Sports Medicine* 34(7):465-485, 2004.