The Use of Mechanical Power Analysis in Understanding and Coaching Sport Skills: Sprinting

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INTRODUCTION

The purpose of this paper was to present and explain in terms of generation, absorption and transfer of energy, the significance of power curves, obtained during sprinting, in understanding and coaching sports skills. Power curves were obtained from segmental kinematic data, as well as joint moments. Two international level sprinters were filmed over the full speed phase of an 100 m sprint for 6 trials. The interpretation of the net joint powers for the hip and knee joints in terms of generation absorption and transfer of energy was done according to the polarity of the net joint tendon tension moment M(j), the joint angular velocity w(j) and the polarity and absolute value of the absolute angular velocities of the segments adjacent to the joint w(1) and w(2). Power values calculated over 6 trials for each subject were found to be reliable and similar in pattern shape and magnitude. Power analysis allowed: 1) for calculation of the amount of energy generated, absorbed or transfered, 2) identification of muscle groups dominating the activity, 3) identification of the range of joint motion during which each muscle group dominates the activity, 4) calculation of the magnitude of net torques around the joint and 5) identification of the type of contraction of the muscle group dominating the activity. In the same way energy curves have been useful in correcting walking patterns in handicapped individuals, mechanical power analysis of sport skills may be useful to coaches in improving sports skills.

A major dilemma facing many coaches, is the application of scientific findings and knowledge to coaching in the field. Research often provides them with useful information which however is not easily applied during training sessions. In order to apply the principle of specificity to training programs coaches must have a thorough understanding of the skill. Power analysis can provide the coach with the following skill information: (a) the muscle groups which are active during the skill performance, (b) which muscle groups are critical to the skill, (c) the range of joint action each muscle group contracts, (d) the magnitude of torques (force times its vertical distance from the axis of rotation) developed by each muscle group, (e) the type of contraction (eccentric - concentric), (f) the velocity of contraction (joint angular velocity), (g) the type of joint movement (flexion - extension), (h) the task duration (time for skill execution), and (i) the timing of muscle group activity (coordination).

The power analysis of a skill can provice detailed diagnostic information that the coach needs by measuring the net joint powers and relating them to the muscle tension moments and the joint angular velocities along with the absolute velocities of the two segments adjacent to the joint. In addition to the above information, the amount of energy generated, absorbed or transfered during the course of action can also be calculated for a more complete description of the skill.

The purpose of this paper was to present and explain in terms of generation, absorption and transfer of energy, the significance of power curves, obtained during sprinting, in understanding and coaching sports skills. An example is provided in the form of the maximum velocity stride during sprinting.

METHODS

Two national level sprinters volunteered as subjects, their masses were 61.3 kg and 69.7 kg, their height 1.75 m and 1.83 m and their age 25 and 23 years respectively. Each subject completed 100 m sprint for a total of six trials allowing adequate time for complete recovery betweenn trials. The subjects had markers on 14 body landmarks and wore their own footwear. To film the maximum velocity phase of the sprint, a high speed camera filming at 100 frames/s was positioned 55 meters from the starting blocks.

Coordinates of the body markers were extracted from the film using a Summagraphics digitizer. The original coordinates were filtered using a butterworth digital filter with the cut-off frequency setted at 6 Hz. The filtered coordinates were transfered to an IBM Amdahl main frame computer for kinematic analysis.

Segmental weights and the radius of gyrations were obtained using tables provided by Dempster 1955 via Winter 1979. The height and segmental lenghts were measured for each individual subject. A standard link segment program was used for the kinematic and power analysis of the data.

The net joint moments and the joint angular velocities at the hip and knee joints, and the absolute angular velocities of the body (trunk - head), thigh and shank segments were calculated for one complete stride commencing with heel contact.

The power of each joint (hip, knee) was calculated using the formula presented by Robertson and Winter (1980)

$$P(j) = M(j) \cdot w(j) \qquad \text{(Watts)}$$

— M(j) is the net moment of force at joint (j),
— w(j) is the angular velocity of joint (j).

The convention of M(j) and w(j) is such that P(j) is positive if M(j) and w(j) are of the same polarity, representing concentric contraction of the dominating the activity muscle group, while negative power P(j), represents eccentric muscle contraction.

Depending on the polarity of the joint angular velocity and the muscle moment we have either generation or absorption of energy. The polarity of the absolute angular velocity of each segment establishes whether or not there is a transfer of energy, and finally according to the magnitude of the absolute value of each of the angular velocities of each segment the direction of energy flow can be determined (table 1).

TABLE 1

The power generation or absorption at each joint in relationship to the polarity of the M(j), w(j), w(1), w(2) and the power transfer in relationship to the absolute value of w(1) and w(2)

M(j)	w(j)	Energy
> 0	> 0	Generation
< 0	< 0	Generation
> 0	< 0	Absorption
< 0	> 0	Absorption

w(1)	w(2)	Energy
> 0	> 0	Transfer
< 0	< 0	Transfer
> 0	< 0	No Transfer
< 0	> 0	No Transfer

Given that w(1) and w(2) have the same polarity the direction of power transfer can be found

if $|w1| > |w2|$ Power is transfered to w2 from w1
or if $|w1| < |w2|$ Power is transfered to w1 from w2

RESULTS AND DISCUSSION

For purposes of documentation a representative sample curve presenting power for one trial of one subject is presented. Power values over 6 trials for four sprinters of two different ability levels advanced and intermediate were found to be reliable in shape, but varied in magnitude related to ability level, (Vardaxis and Hoshizaki, 1987).

For trial TR# 136 the stick figure using the smoothed data of the lower limb and trunk segments during the sprinting stride is presented for the left leg for two consecutive touch downs.

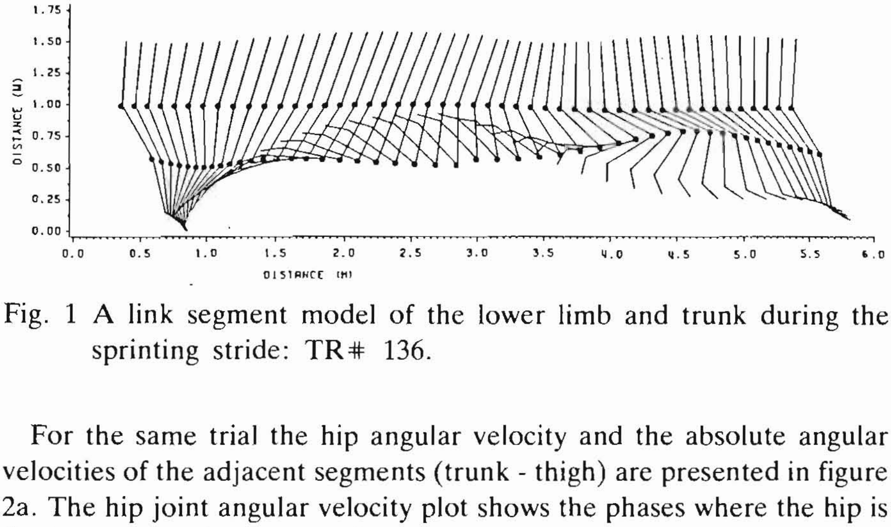

Fig. 1 A link segment model of the lower limb and trunk during the sprinting stride: TR# 136.

For the same trial the hip angular velocity and the absolute angular velocities of the adjacent segments (trunk - thigh) are presented in figure 2a. The hip joint angular velocity plot shows the phases where the hip is flexing or extending as positive and negative respectively. The absolute angular velocities of each segment are positive as the rotation of the segment is counter clockwise, and negative if it rotates clockwise. The stride phases (support, lift-off, swing through and landing) are also presented on each figure.

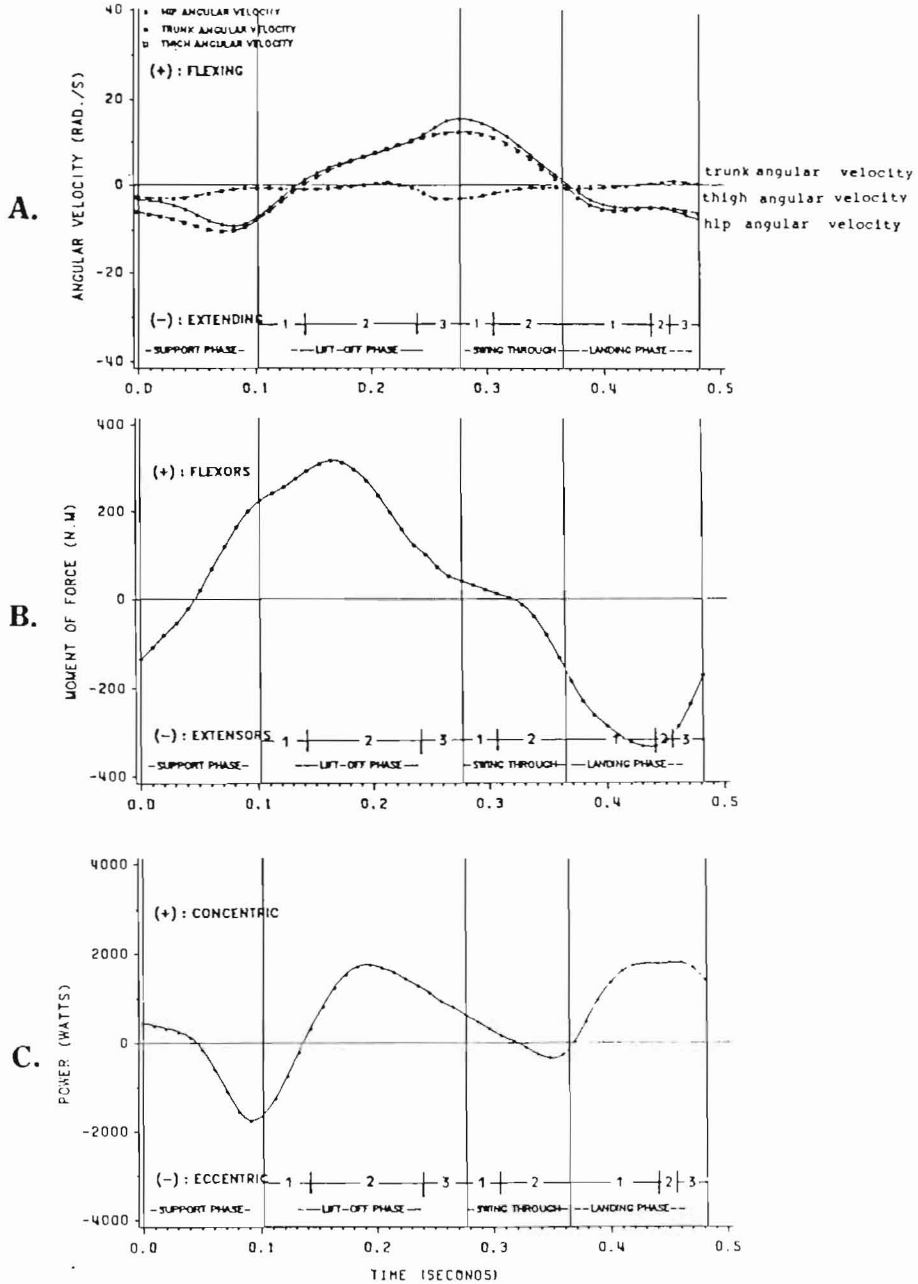

Fig. 2 Hip angular velocity, absolute angular velocities of the adjacent segments to the hip joint (trunk-thigh), and the net moments and net powers of the muscle group tension dominating the activity.

The net tendon tension moment at the hip joint during the stride is presented on Figure 2b. The moment curve for the hip joint has flexor dominant moment as positive and extensor as negative. The product of net tendon tension moment (Figure 2b) and the joint angular velocity (Figure 2a) is the net joint power curve. In Figure 2c the hip joint net power curve is plotted, representing the amount of power generated, absorbed or transfered instantaneously by the muscle group dominating the activity. The power pattern is positive if the muscle group dominating the activity contracts concentrically generating energy and negative if the muscle group dominating the activity contracts eccentrically, absorbing energy.

Similar interpretations can be made for Figures 3a, b and c, which show identical information for the knee joint. The polarity of the angular velocity of the knee joint in terms of flexion and extension and the net joint tendon tension moment in terms of muscle group dominating the activity are reverse to those of the respective variables for the hip joint.

The recovery phase during sprinting can be divided into three main phases, (1) take-off, (2) swing through and (3) landing. The take off phase begins when the foot leaves the ground until the knee joint is at maximum flexion, the swing through phase begins from maximum knee flexion and ends at maximum hip flexion, and the landing phase begins at maximum hip flexion and continues until foot touch down. Each phase is then divided into subphases (table 1) depending on changes in the polarity of the tendon tension moment M(j), the joint angular velocities w(j), absolute angular velocities of adjacent segments w(1) and w(2) and the magnitudes of the absolute angular velocities of the adjoining segments. The phase and subphases for sprinting are presented in Figures 2 and 3 with description of the power flow at each subphase in tables 2 to 7.

The muscular activity at the hip joint appears to be essential for the recovery phase of the sprinting stride in agreement with the findings by Mann and Sprague (1983). The energy generated, absorbed or transfered by the musculature dominating the activity of the hip joint is presented in tables 2, 3 and 4 for the lift-off, swing through and landing phases of the sprinting stride. The overall muscle activity at the hip joint is characterized by energy generation. The hip flexors generate energy for the greater part of the lift-off phase with the hip extensors generating energy during the entire landing phase. Energy absorption is observed during the second part of the swing through phase (table 3, subphase 2) controlled by the hip extensors as they contract to stop the anterior rotation of the

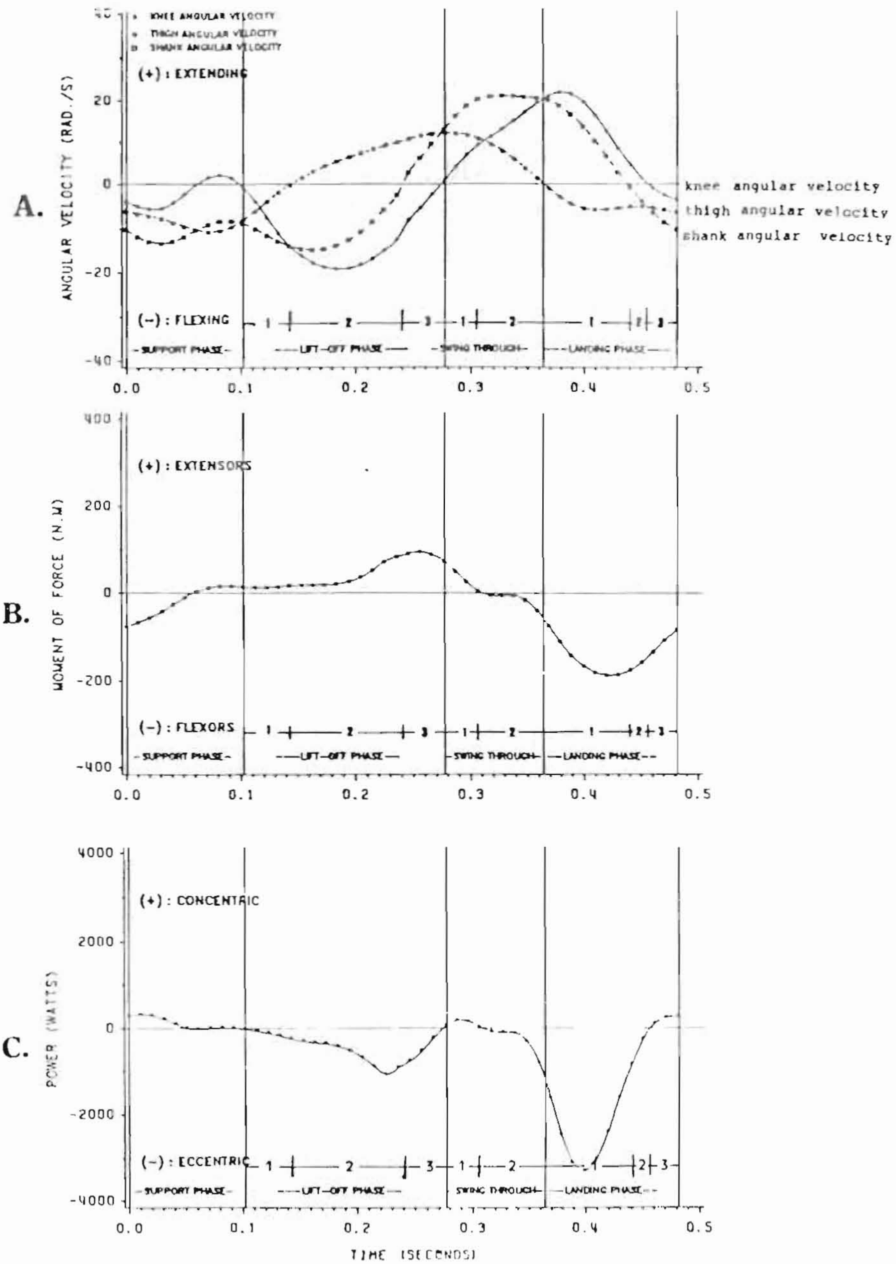

Fig. 3 Knee angular velocity, absolute angular velocities of the adjacent segments to the knee joint (Thigh - Shank), and the net moments and net powers of the muscle group tension dominating the activity.

thigh. Transfers of energy occur from the thigh to the trunk during the greater part of the lift-off phase (table 2, subphases 1 and 2), and during the initial part of the landing phase (table 4, subphase 1).

TABLE 2

Power flow for the lift-off of the recovery phase for a sprinting stride at the hip joint

LIFT-OFF PHASE		
(1)	(2)	(3)
$M(h)>0$ $w(h)<0$ $w(b)<0$ $w(t)<0$ $\lvert wt\rvert>\lvert wb\rvert$	$M(h)>0$ $w(h)>0$ $w(b)>0$ $w(t)>0$ $\lvert wt\rvert>\lvert wb\rvert$	$M(h)>0$ $w(h)>0$ $w(b)<0$ $w(t)>0$ $\lvert wt > wb\rvert$
Absorption & Transfer	Generation & Transfer	Energy Generation
M(wt−wb) Abs. by Thigh M(wb) Transfered to Body by the Thigh	M(wt−wb) Gener. to Thigh M(wb) Transfered to Body by the Thigh	M(wt) Generated to Thigh M(wb) Generated to Body

TABLE 3

Power flow for the swing through of the recovery phase for a sprinting stride at the hip joint

SWING THROUGH PHASE	
(1)	(2)
$M(h)>0$ $w(h)>0$ $w(b)<0$ $w(t)>0$ $\lvert wt\rvert<\lvert wb\rvert$	$M(h)<0$ $w(h)>0$ $w(b)<0$ $w(t)>0$ $\lvert wt\rvert<\lvert wb\rvert$
Energy Generation	Energy Absorption
M(wt) Generated to Thigh M(wb) Generated to Body	M(wt) Absorbed by Thigh M(wb) Absorbed by Body

TABLE 4

Power flow for the landing of the recovery phase for a sprinting stride at the hip joint

LANDING PHASE	
(1)	(2) & (3)
$M(h)<0 \quad w(h)<0$ $w(b)<0 \quad w(t)<0 \quad \lvert wt \rvert > \lvert wb \rvert$	$M(h)<0 \quad w(h)<0$ $w(b)>0 \quad w(t)<0 \quad \lvert wt \rvert > \lvert wb \rvert$
Generation & Transfer	Energy Generation
M(wt−wb) Generated to Thigh M(wb) Transfered to Body by the Thigh	M(wt) Generated to Thigh M(wb) Generated to Body

The net knee joint energy generated, absorbed or transfered is presented on tables 5, 6 and 7 for the lift-off, swing through and landing phases of the sprinting stride respectively. In contrast to the hip joint, energy absorption and transfer characterizes the knee joint activity during the greater part of the recovery phase. The knee extensors dominate the activity for the entire lift-off phase as well as the first part of the swing through phase (Figure 3b), with the knee flexors dominating the rest of the swing through and the entire landing phase. Energy generation at the knee joint is only observed at the beginning of the swing through phase (table 6, subphase 1) at the start of knee joint extension, generated by the knee extensors and at the end of the landing phase (table 7, subphase 3) by the knee flexors, just before touch down.

TABLE 5

Power flow for the lift-off of the recovery phase for a sprinting stride at the knee joint

LIFT-OFF PHASE		
(1)	(2)	(3)
$M(k)>0 \quad w(k)<0$ $w(t)<0 \quad w(s)<0 \quad \lvert ws \rvert > \lvert wt \rvert$	$M(k)>0 \quad w(k)<0$ $w(t)>0 \quad w(s)<0 \quad \lvert ws \rvert > \lvert wt \rvert$	$M(k)>0 \quad w(k)<0$ $w(t)>0 \quad w(s)>0 \quad \lvert ws \rvert < \lvert wb \rvert$
Absorption & Transfer	Energy Absorption	Absorption & Transfer
M(ws−wt) Abs. by Shank M(wt) Transfered to Thigh by the Shank	M(ws) Absorbed by Shank M(wt) Absorbed by Thigh	M(wt−ws) Abs. by Thigh M(ws) Transfered to Shank by the Thigh

TABLE 6

Power flow for the swing through of the recovery phase for a sprinting stride at the knee joint

SWING THROUGH PHASE	
(1)	(2)
$M(k)>0$ $w(k)>0$ $w(t)>0$ $w(s)>0$ $ws > wt$	$M(k)<0$ $w(k)>0$ $w(t)>0$ $w(s)>0$ $\|ws\| > wt$
Generation & Transfer	Absorption & Transfer
M(ws−wt) Generated to Shank M(wt) Transfered to Thigh from the Shank	M(ws−wt) Absorbed by Shank M(wt) Transfered to Thigh from the Shank

TABLE 7

Power flow for the landing of the recovery phase for a sprinting stride at the knee joint

LANDING PHASE		
(1)	(2)	(3)
$M(k)<0$ $w(k)>0$ $w(t)<0$ $w(s)>0$ $\|ws\|>\|wt\|$	$M(k)<0$ $w(k)>0$ $w(t)<0$ $w(s)<0$ $\|ws\|<\|wt$	$M(k)<0$ $w(k)<0$ $w(t)<0$ $w(s)<0$ $\|ws\|>\|wt\|$
Energy Absorption	Absorption & Transfer	Generation & Transfer
M(ws) Absorbed by Shank M(wt) Absorbed by Thigh	M(wt−ws) Abs. by Thigh M(ws) Transfered to Shank from the Thigh	M(ws−wt) Gener. to Shank M(wt) Transfered to Thigh from the Shank

When training for the recovery phase during sprinting, coaches should be concerned with training the hip flexors using concentric contraction from 190° to 90° (flexion) at maximal angular velocity of 20 (Rads./s) and for the hip extensors, concentric muscle contraction should be used from 90° to 130° (flexion) at a maximal angular velocity of 15 (Rads./s). The knee extensors should be trained using eccentric contraction from 160° to 30° (flexion) at maximal angular velocity 25 (Rads./s) and for knee flexors, eccentric muscle contaction should be used from 30° to 160° (flexion) at a maximal angular velocity of 25 (Rads./s).

CONCLUSIONS

Pertinent information for coaching which is obtained from power flow analysis includes the following:

1. Calculation of the amount of energy generated, absorbed or transfered.
2. Identification of muscle groups dominating the activity.
3. The range of joint motion each muscle group is dominating the activity.
4. The magnitude of net torques around the joint.
5. The type of contraction of the muscle group dominating the activity.

REFERENCES

Dempster, W. T., Space requirements of the seated operator. *Wright Patterson Air Force Base, OH:* US Air Force, (WADC-Tech. Rept. 55-159), 1955.

Mann, R. and Sprague, P., Kinetics of Sprinting. *Biomechanics in Sports,* (ed. by J. Terauds) pp. 305-316. Academic Publishers, Del Mar, California, 1983.

Robertson, D.G.E. and Winter, D. A., Mechanical energy generation, absorption and transfer amongst segments during walking. *Journal of Biomechanics,* 13:845-854, 1980.

Vardaxis, V. and Hoshizaki, T. B., Power patterns of the lower limb during the recovery phase of sprinting for advanced and intermediate sprinters. *Poster Presentation,* International Congress of Biomechanics, Amsterdam, Holland, 1987.

Winter, D. A., Biomechanics of human movement *In John Wiley & Sons Inc. (eds.),* Toronto, 1979.