國立體育學院九十四學年度研究所博士班入學考試試題

體育運動論文評論(生物力學組) （本試題共九頁）

注意:答案一律寫在答案卷上，否則不予計分

1. 請詳細閱讀所附之論文，並評論本篇論文之動機目的是否明確恰當。(20%)

2. 請詳細閱讀所附之論文，並評論本篇論文之方法步驟是否合宜。(20%)

3. 請詳細閱讀所附之論文，並評論本篇論文之結果討論及推論是否恰當。(30%)

4. 請針對本篇論文做一整體性之優缺點評析。(30%)

Use of Lumbar Point for the Estimation of Potential and Kinetic Mechanical Power in Running

Jean Slawinski[1], *Véronique Billat*[1], *Jean-Pierre Koralsztein*[2], *and Michel Tavernier*[3,4]

[1]*University Evry-Val d'Essonne;* [2]*Sport Medicine Center CCAS;* [3]*French Ski Federation;* [4]*University PM Currie and LMS Poitiers*

The purpose of this study was to estimate the difference between potential and kinetic mechanical powers in running (P_{ke}, P_{pe}) calculated from the center of mass and one anatomic point of the body located on the lower part of the runner's back, the "lumbar point." Six runners undertook a treadmill run at constant velocity and were filmed individually with a video camera (25 Hz). The 3-D motion analysis system, ANIMAN3D, uses a numerical manikin (MAN3D) which compares a voluminal subject (the athlete) directly to the manikin which possesses the same voluminal properties. This analysis system allows the trajectories of the center of mass and the lumbar point to be calculated. Then, from these trajectories, potential and kinetic mechanical powers in running are calculated. The results show that the utilization of the lumbar point rather than the runner's center of mass leads to a significant overestimation of P_{ke} and a significant underestimation of P_{pe} (both $p < 0.05$). In spite of these differences, however, both methods of calculating P_{ke} and P_{pe} are well correlated: respectively, $r = 0.92$; $p \leq 0.01$, and $r = 0.68$; $p \leq 0.05$. Taking into account that the trajectory of an anatomic point is experimentally easier to access than that of the center of mass, such a point could be used to estimate the evolution of kinetic or potential energy variation in different cases. However, when the lumbar point rather than the center of mass is used to estimate the mechanical energy produced in running, P_{ke} could appear to be a discriminating parameter, which it is not.

Key Words: center of mass, numerical manikin, energy

The mechanical energy of running (kinetic and potential energies of the center of mass) depends on the time course of the force that generates a nonuniform

---

[1]Dépt. STAPS, UFRSFA Université d'Evry-Val d'Essonne, Bd François Mitterand 91025 Evry cedex, France; [2]Centre de Médecine du Sport, CCAS, 2 ave. Richerand, 75010 Paris; [3]Fédération Française de Ski, 50 rue des Marquisats, 74011 Annecy, France.

movement of the center of mass. This force results from the internal forces generated by the muscles at the joints. However, the force developed by each muscle remains unknown and only a global external force resulting from internal forces generated by the different muscles of the body can be easily measured. In order to calculate the variation of mechanical energy produced by this external force, we need to know the instantaneous position and speed of the runner's center of mass. The energy value is obtained either by measuring the external forces with a force platform, or by determining the position of the center of mass given by a 2-D or 3-D motion analysis system.

Until now, various studies dealing with mechanical energy have used a system of measure that has not determined with precision the position of the center of mass (Bourdin, Belli, Arsac, Bosco, & Lacour, 1995; Candau, Belli, Millet, et al., 1998; Dalleau, Belli, Bourdin, & Lacour, 1998; Kyröläinen, Pullinen, Candau, et al., 2000). Indeed, these authors used a kinematic arm which determines the position of an anatomic point located on the lower part of the runner's back and which is different from the position of the center of mass. These authors calculated the mechanical energy variation and mechanical power from this particular point. The results have shown that the mechanical energy variation is overestimated when compared to that calculated with a force plate form. Bourdin et al. (1995) suggested that "at least a part of the tilting of the trunk is recorded by the kinematic arm. As a consequence horizontal kinetic energy changes would be overestimated. However, the exact reasons that could explain the mechanical energy variation overestimation are actually unknown" (p. 2083).

This point, called the "lumbar point" in the present study (Figure 1), does not represent the motion of the "real" center of mass. This difference may explain why mechanical energy is overestimated when it is calculated with a kinematic arm. However, we know of no study that has measured the effect of the choice of an anatomical point rather than the center of mass when estimating mechanical power. Therefore, this study aimed to test the hypothesis that the use of another point rather than the center of mass (such as the lumbar point) could lead to a significant difference in measuring mechanical power.

Method

Six runners volunteered for this study, which was approved by the Ethics Committee of Paris. Their average weight was 71.8 ± 8.6 kg and average height was 174.6 ± 6.5 cm. The runners undertook one treadmill run at a supra lactic-threshold speed at 90% of maximal oxygen uptake (5.2 ± 0.2 m·s^{-1}). During this test the runners were filmed from the left side. Two strides were analyzed 3 minutes after the exercise began, and two more were analyzed 1 minute before the end; exercise duration was 13 min 4 s ± 3 min 15 s. Therefore, for each runner we obtained two measures of the kinetic and potential mechanical power produced in running.

All tests were performed on a horizontal motorized treadmill (Gymrol 1800, Techmachine, Saint-Etienne, France). Belt speed was controlled with a controller provided by the CDEMS (Université Joseph Fourier, Grenoble, France). During the constant intensity test, the runners were filmed with a video camera using a sampling frequency of 25 images per second.

The video sequences obtained were digitized without geometrical distortion on a PC as a series of bitmap images with a perception video recorder card from

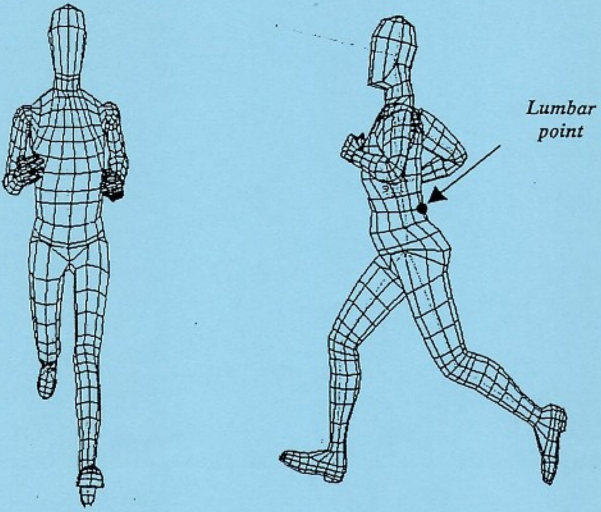

Figure 1 — 3-D human manikin representation.

Silicon Co. The 3-D motion analysis system (ANIMAN3D; Tavernier, Cosserat, Emmendoerffer, et al., 1997) uses the numerical human model MAN3D (Verriest, 1991; Verriest, Wang, Trasbot, & Tessier, 1997) (Figure 1). The position and posture of MAN3D can be adjusted to each runner. In order to obtain the best possible precision, the morphological properties of MAN3D were deduced from the runner's size and weight. The inertial properties of the limbs were taken from Dempster and Gaughran (1967).

Then MAN3D was superimposed to the images of the runner; the runner's position and posture were the same as that of MAN3D. The software, ANIMAN3D, determined the trajectories of the anatomic points of the manikin and the trajectory of the body's center of mass. Kinetic and potential mechanical powers were calculated from the body's center of mass, and one anatomic point of the body was located on the lower part of the runner's back, i.e., the lumbar point (Figure 1).

The vertical and horizontal trajectories of the center of mass of the lumbar point and of the body's center of mass were smoothed using a polynomial method (Tavernier, Casserat, & Ruby, 1996) in order to obtain by derivation the speed of the two points and their mechanical energy. The polynomial degree was determined individually for the trajectory of the center of mass and the lumbar point of each runner.

These analyses were conducted in two dimensions. The ΔE_{ke} can be disregarded in the transversal axis because in this direction the amplitude of the motion was negligible (Cavagna & Kaneko, 1977). Potential and kinetic mechanical power were calculated as the sum of positive energy variations, according to the following equation:

$$\Delta E_{pe} = M \times g \times (H_{max} - H_{min}) \quad (1)$$

$$\Delta E_{ke} = {}^{1}/_{2}\, M \times (V_{max}^{2} - V_{min}^{2}) \quad (2)$$

where M is the body mass (kg), g is the gravitational acceleration (9.81 $m \cdot s^{-2}$), H_{max} and H_{min} are the maximal and minimal heights of the body's center of mass (CM) during one step (m). V_{max} and V_{min} are the maximal and minimal horizontal velocities of the CM during one step ($m \cdot s^{-1}$). ΔE_{ke} and ΔE_{pe} are also calculated from the trajectory of the lumbar point.

This procedure has been conducted by several researchers (Candau et al., 1998; Cavagna & Kaneko, 1977; Willems, Cavagna, & Heglund, 1995). Only the energy necessary to lift and accelerate forward the center of mass or the lumbar point was considered. Then, kinetic and potential energy variations were divided by the stride time to be expressed in Watt, and named, respectively, kinetic mechanical power (P_{ke}) and potential mechanical power (P_{pe}).

The statistical analysis was done using the Wilcoxon nonparametric test. The mechanical power of the center of mass was compared with that of the lumbar point. Correlations between the two methods of calculus of P_{ke} and P_{pe} were also calculated with a Spearman test. Statistical significance was set at $p = 0.05$.

Results

The statistical analysis shows that the kinetic mechanical power calculated from the movements of the center of mass was about 50% lower, $p \leq 0.01$, than that calculated from the movements of the lumbar point (Figure 2a; Table 1). In the same way, the potential mechanical power calculated from the movement of the center of mass was significantly higher, about 12%, $p \leq 0.01$, than that calculated from the movement of the lumbar point (Figure 2b; Table 1). But in spite of these differences, both methods of calculating the kinetic and potential mechanical powers were well correlated: respectively, $r = 0.92$, $p \leq 0.01$; and $r = 0.68$, $p \leq 0.05$.

Figure 3 shows the characteristic horizontal (a) and vertical (b) trajectory of the body's center of mass and the lumbar point during four steps. This figure suggests that the amplitude of horizontal movement of the body's center of mass was smaller than that of the lumbar point. However, the vertical displacement of the center of mass was similar to vertical displacement of the lumbar point.

Discussion

The results show that utilization of the runner's lumbar point rather than his or her center of mass leads to a significant overestimation of kinetic mechanical power and a significant underestimation of potential mechanical power. In spite of these differences, however, both methods of calculating kinetic and potential mechanical powers are well correlated.

A comparison of kinetic and potential mechanical powers, as calculated with ANIMAN3D, with those in the literature (Table 1) shows that potential mechanical power is similar for all studies. However, kinetic mechanical power calculated in the present study was higher than that measured with a force plate form of about 200 W (40%). First, these differences may be due to the individual characteristics of the participants in the different studies. Second, large changes in mechanical power values, evaluated by video analysis, are related to changes in the cutoff frequency or to the choice of smoothing polynomial degree (Williams & Cavanagh, 1983). Moreover, the uncertainty associated with determining the trajectory of the body's center of mass with a video camera, especially during the flight phase, may also explain the great difference between video and force-plate form analysis.

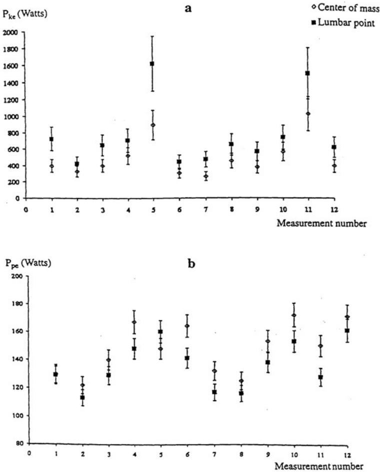

Figure 2 — (a) Kinetic and (b) potential mechanical power (P_{ke} and P_{pe}) of center of mass (CM) and lumbar point for each measurement. Vertical bars represent the uncertainties in P_{ke} or P_{pe}.

However, there are great differences between the kinematic arm and other systems of measure (Bourdin et al., 1995). Table 1 shows that when kinetic mechanical power is calculated with the parametric trajectory of the lumbar point, there is little difference with kinetic mechanical power as calculated with the kinematic arm. Now the kinematic arm computes the instantaneous displacement of

Table 1 Potential and Kinetic Power (P_{pe}, and P_{ke}) in Running Generally Reported in the Literature, for a Speed of ~5 $m \cdot s^{-1}$

	P_{ke} (W)	P_{pe} (W)	$P_{ke} + P_{pe}$ (W)
Cavagna & Kaneko, 1977 (force plate form)	293	157	450
Willems et al., 1995 (force plate form)	280	150	430
Bourdin et al., 1995 (kinematic arm)	839	172	1011
Candau et al., 1998 (kinematic arm)	617	153	770
Present study (CM)	492	148	640
Present study (lumbar point)	759	136	895

the runner's lumbar point, and the results of the present study show that kinetic mechanical power was greater when calculated with the lumbar point. Therefore, the choice of lumbar point as reference rather than the center of mass leads to an overestimation of kinetic mechanical power. The difference observed between kinetic mechanical power calculated with the center of mass and that calculated with the lumbar point is associated with different trajectories of the two points. Indeed, the lumbar point is a fixed point that follows all movements of the trunk.

By contrast, the center of mass is not a fixed point and its movement is smaller than that of the lumbar point (Figure 3a). As the position of the center of mass is calculated from the position of the center of mass of the body segments, and as the instantaneous position of the lumbar point depends on the movements of the trunk, the horizontal instantaneous position of both points is necessarily different. Notably during the flight phase, the horizontal position of the center of mass cannot be modified by movement of the segments, whereas the horizontal position of the lumbar point can be modified by the movement of the trunk. Similarly, the estimation of potential mechanical power is modified according to the point chosen. Indeed, the potential mechanical power calculated from the trajectory of the center of mass is 12% greater than that calculated from the trajectory of the lumbar point. These differences are also associated with the different vertical instantaneous position of both points.

The choice of an anatomic point rather than the runner's center of mass has a major influence on the calculation of kinetic mechanical power, but less influence on the calculation of potential mechanical power. Utilization of the lumbar point rather than the center of mass to estimate the "external" mechanical energy produced in running (W_{ext}) could give greater importance to kinetic mechanical power compared to potential mechanical power. Such an overestimation of kinetic mechanical power may explain why only the researchers who used a kinematic arm found significant correlations between the mechanical energy variation and the energy cost of running.

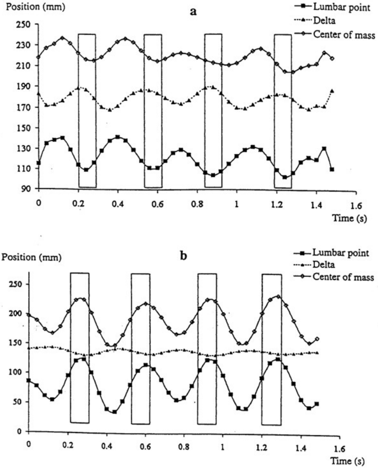

Figure 3 — (a) Characteristic horizontal and (b) vertical fitted trajectory of body's center of mass and the lumbar point of a runner. Vertical rectangles represent the flight phase.

A comparison of the kinetic and potential mechanical powers between studies or participants must take into account the method of measure used. Indeed, the present study demonstrated that the use of a different method of measure—the lumbar point rather than the center of mass—can lead to a 50% overestimation of kinetic mechanical power and a 12% underestimation of potential mechanical power.

A mechanical analysis and calculation of the mechanical energy during a run could only be carried out using equipment that allows a precise location of the runner's center of mass. Nevertheless, since the trajectory of an anatomic point is experimentally easier to access than that of the center of mass, this kind of point could be used to estimate the evolution of kinetic or potential energy variation in different cases. This study can contribute toward a better methodology for calculating with greater accuracy using another point near the center of mass.

References

Bourdin, M., Belli, A., Arsac, L.M., Bosco, C., & Lacour, J.R. (1995). Effect of vertical loading on energy cost and kinematics of running in trained male subjects. *Journal of Applied Physiology*, **79**, 2078-2085.

Candau, R., Belli, A., Millet, G., Georges, D., Barbier, B., & Rouillon, J. (1998). Energy cost and mechanics during a treadmill run to voluntary exhaustion in humans. *European Journal of Applied Physiology*, **77**, 479-485.

Cavagna, G., & Kaneko, M. (1977). Mechanical work and efficiency in level walking and running. *Journal of Physiology*, **268**, 467-481.

Dalleau, G., Belli, A., Bourdin, M., & Lacour, J.R. (1998). The spring mass model and the energy cost of treadmill running. *European Journal of Applied Physiology and Occupational Physiology*, **77**, 257-263.

Dempster, W., & Gaughran, G. (1967). Properties of body segments based on size and weight. *American Journal of Anatomy*, **120**, 33-54.

Kyröläinen, H., Pullinen, T., Candau, R., Avela, J., Huttunen, P., & Komi, P. (2000). Effects of marathon running on running economy and kinematics. *European Journal of Applied Physiology*, **82**, 297-304.

Tavernier, M., Cosserat, P., Emmendoerffer, S., Ruby, A., Lavest, J.M., Dhome, M., & Verriest, J.P. (1997). ANI-MAN3D: A 3D motion analysis system using a numerical human model. In *Proceedings of 16th Congress of the ISBC, Tokyo* (Vol. 19, p. 406).

Tavernier, M., Cosserat, P., & Ruby, A. (1996). Optimisation de l'ajustement de trajectoires par lissage avec des polynômes d'ordres multiples élevés: Comparaison avec le filtre de butterworth du second ordre [Optimization of adjustment of the trajectories with polynomial smoothing of high degrees: Comparison with Butterworth filter]. *Science et Motricité*, **28**, 53-56.

Verriest, J.P. (1991). MAN3D: A functional and geometrical model of the human operator. In W. Karwowski & J.W. Yates (Eds.), *Proceedings of the IFIESR Congress, Lake Tahoe* (pp. 901-908).

Verriest, J.P, Wang, X, Trasbot, J., & Tessier, Y. (1994). Application of 3D human model to computer aided engineering design of vehicles. In *Proceedings of Fisita* (pp. 53-61).

Willems, P.A., Cavagna, G.A., & Heglund, N.C. (1995). External, internal and total work in human locomotion. *Journal of Experimenal Biology*, **198**, 379-393.

Williams, K.R., & Cavanagh, P.R. (1983). A model for the calculation of mechanical power during distance running. *Journal of Biomechanics*, **16**, 115-128.