Can the Center of Mass Reflect the Metabolic Expenditure?

身體質量中心可以評估身體耗能嗎?

Ying-ki FUNG
Department of Physical Education,
National Taiwan Normal University, TAIWAN

Tyzz-yuang SHIANG
Institute of Exercise and Sport Science,
National Taiwan Normal University, TAIWAN

馮英騏
國立台灣師範大學體育學系

相子元
國立台灣師範大學運動科學研究所

Abstract

In the past studies, the movement of center or mass (COM) was one of the descriptor to estimate the metabolic expenditure. However, the sensitivity of this method among the wide range speed, the locomotion pattern and during the Energetically Optimal Transition Speed (EOTS) is still unexplored. Hence that, the purpose of this investigation was to determine the metabolic and COM pattern differences between walk and run among the EOTS with a reflective marker motion analysis system and indirect pulmonary ventilation machine. The results showed that there is a metabolic intersection on two locomotion patterns (walk and run) between 100 and 125% Preferred Transition Speed (PTS), which coincides with the past EOTS studies, whereas, COM result showed that the variation of vertical COM displacement for running is significantly higher than walking among the entire tested speed. The pattern between the metabolic and COM variables is an inverse relation after the EOTS. Hence, the present investigator doubted that there would be a reliability problem for those instruments which use the COM displacement to estimate the metabolic cost or the intensity of physical activity among 5.15 to 9.82km/h for walk and run.

Keywords: center of mass, preferred transition speed, energetically optimal transition speed, metabolic expenditure

摘　要

在過去的研究，身體質量中心移動常常被用作評估身體耗能的一種方法。可是這種方法在不同速度、動作型態及最佳轉換速度(EOTS)之可信範圍一直都沒有作出深入探討。因此本研究目的希望利用動作及生理分析系統對身體中心及身體耗能在兩種動作型態(走和跑)和在EOTS的情況底下的趨勢上作出分析及探討。結果顯示在兩個動作型態上在100及125%自然轉換速度情況下身體耗能出現交叉點(EOTS)，而此發現與過去EOTS之文獻相吻合，反之身體質量中心結果顯示，跑步在身體質量中心之穩定性在所有測試速度情況下都比走路有統計上之差異，跑步的垂直位移變異量明顯比走路大。由此可見身體耗能及身體質量中心變異量顯示出兩者在EOTS出現後是反比關係。因此本研究結果可推斷現在有利用身體質量中心變異量去推估身體耗能或身體活動量的儀器在速度5.15—9.82公里的情況底下可能會出現信度問題。

Introduction

Walking and running are two of the fundamental locomotion in human. In the last two decade, scientist have explored there is a metabolic cost (ml/kg/min) junction between walk and run when the locomotion speed increase (Hreljac, 1993, 1995; Mercier et al., 1994). This junction is commonly defined as EOTS. In the other words, it means the oxygen expenditure for walking became higher than running when the movements speed is above the EOTS, whereas it is lower when the speed below the EOTS. Moreover, walking or running with decrease or increase the speed around the EOTS can also address the preferred gait change from walk to run or from run to walk (Thorstensson & Roberthson, 1987).

In recent research, researcher have tempted to recognize that this metabolic change may be influenced by several kinematic factors such as gait variable, angular movement, muscle mechanics and the variation of vertical COM (Cappellini, Ivanenko, Poppele, & Lacquaniti, 2006; Jordan, Challis, & Newell, 2007a, 2007b; Li et al., 1999; Ortega & Farley, 2005; Sasaki & Neptune, 2006; Schwartz, Rozumalski, & Trost, 2008). Although these factors have revealed some correlations about the interpretation of the metabolic change on the EOTS, but by reviewing these literatures, it also shows that there are some inadequate applications of conventional theory among the range of EOTS such as COM.

The vertical COM variability has been used to indicate the changes in potential energy, and the vertical COM variability increase with a concomitant greater work done (Cavagna, Saibene, & Margaria, 1963, 1964). Traditionally, researchers associate with the correlation between vertical COM variability and energy cost to predict the work done in exercise like step tests (Nagle, Balke, & Naughton, 1965). Nowadays, there are numerous of activity monitor instrument design, such as Accelerometer, was designed according to this theoretical background to measure the activity intensity (Chu, McManus, & Yu, 2007; Henriksen, Lund, Moe-Nilssen, Bliddal, & Danneskiod-Samsøe, 2004; Norman, 2006; Swan, Byrnes, & Haymes, 1997). However, in the recent research, researchers have reported that decrease the vertical COM variability or walking with a flat trajectory may result in higher the metabolic expenditure (Hreljac & Martin, 1993; Ortega & Farley, 2005).

In generally, human perform a greater vertical COM variation run contrasting to walk. Nevertheless, under the ratiocinate by the EOTS finding, the result of metabolic expenditure and vertical COM variation will be refuted by each other when the locomotion speed over the EOTS. Hence the purpose of the present study is to explore the relationship between EOTS and vertical COM variation.

Methods

Participants

Participants were 12 male graduate students with a mean age of 25.5±2.5 yrs, mean weight of 70.65±12.75 kg, mean height of 172.15±6.15 cm from the Physical Education Department, National Taiwan Normal University. All the participants were informed consent before the experiment. All of them were free from chronic, cardiovascular problems.

Equipments

Optical motion capture system

The COM displacement was measured with a VICON MX system (Vicon Motion Systems Ltd., Oxford, UK) at a sampling rate 250Hz. Ten infrared cameras were used to capture a 39 reflective marker set for Vicon® Plug-In Gait, which is positioned on specific anatomical landmarks for compute the location of COM by Vicon Nexus® software (McGinley, Baker, & Wolfe, 2006).

Metabolic measurements system

Pulmonary gas exchange indexes were measured by the use of breath-by-breath apparatus (Cosmed Quark® PFT, Rome, Italy). Participants wore a facemask which passed expired air into a photoelectric digital turbine. O_2 and CO_2 concentrations were determined by rapid response analyzers (O_2 zirconium, CO_2 infrared). Calibration of the system was performed immediately before each test, using a 3L syringe and a gas mixture from a tank (O_2 - 16%, CO_2 - 5%, N_2 - balance).

Treadmill

According to the previous research, PTS determination was a standard procedure to determine the EOTS (Hreljac, 1993). Hence, a SensorMedics 200 motor-driven treadmill (series 200 Treadmill, Marquette, WI) would be used to control the walking/running speed to the participants.

Data Collection

Pre-test

Pre-test was preceded two days before the experiment. The purpose of the pre-test was aim to determine the PTS and $\dot{V}O_2$ maximum for define the 100% PTS and normalize the exercise $\dot{V}O_2$ for the experimental day use.

PTS determination was separated into two parts (from walk to run and from run to walk). Participant needs to perform walking (from walk to run) with an initial speed 6 km/h, furthermore, the speed then increase by 0.4km/h per 30 seconds, until the first flight off phase appeared (Gait change). After that, participant should have a 15 minutes rest before the run to walk determination. During the run to walk determination, participant needs to perform running with an initial speed of 9 km/h, furthermore, the speed was then decrease by 0.4km/h per 30 seconds, until the first flight off phase disappeared. Lastly, the ending speeds on the two determinations were then calculated by the following equation:

$$[(W-R)/2+(R-W)/2]/2 = 100\%PTS$$

To reduce the individual deviation of cardiovascular capacity differences, the experimental $\dot{V}O_2$ data would be compared to individual's $\dot{V}O_{2max}$ for normalization and express in % $\dot{V}O_{2max}$ in the results and the equation is as follow:

$$[\text{Exercise } \dot{V}O_2 - \text{Resting } \dot{V}O_2] \;/\; \dot{V}O_{2max} = \%\ \dot{V}O_{2max}$$

During the $\dot{V}O_{2\ max}$ determination, participant was required to run on a treadmill to exhaustion according to the Bruce protocol test, which is a general assessment to estimate the level of $\dot{V}O_{2\ max}$ for human (Bruce, 1972).

Experimental Design – Post test

During the testing, participant was required to perform both 5 minutes walk and run in 3 selected locomotion speeds (75, 100 and 125%PTS) and the sequence was in random design. Moreover, there was a 5 minutes rest between each determination and both of the mean metabolic and kinematic result at the last minute per trial would be recorded for analysis use.

Statistical Analysis

Statistical analyses were run by the SPSS version 15.0 (SPSS Inc., Chicago, IL). Descriptive were computed and were used to shown the mean value with the standard deviation. In present study, it would compare the mean of the consolidate results to show the characteristic between two locomotion conditions and three controlled speeds. Furthermore, the 2 x 3 repeated measure ANOVA test was chosen as the statistical analysis to determine the main effect between the tested factors with the alpha value $p<0.05$. If there was a significant value between two independent variables, Bonferroni post hoc comparisons would be used to compare the differences between two locomotion conditions under three tested speed independently. There were three dependent measures (3 different %PTS) repeated under two conditions (walk and run). Moreover, the independent factors were set as conditions and speeds (Table 1).

Table 1. Statistic Description.

Independent Variable	Dependent Variable
Conditions (Walk, Run)	Mean standard deviation (stdev.) of vertical COM
Speeds (3 tested PTS)	Mean % $\dot{V}O_{2max}$

Results

From the pre-test, the mean 75, 100 and 125%PTS was 5.15km/h (σ=0.22), 6.86km/h (σ=0.29) and 8.58km/h (σ=0.36), respectively, moreover, the average $\dot{V}O_{2max}$ determined by Bruce protocol was 49.80 ml kg^{-1} min^{-1} (σ=6.52).

The statistical results showed that both of the measured dependent variables (stdev. of vertical COM and % $\dot{V}O_{2max}$) were having the interaction effect (p<.05), the select locomotion speed and locomotion pattern affect the tested dependent variables significantly (Table 2). However, the trends of the tested dependent variables (% $\dot{V}O_{2max}$ and stdev. of vertical COM) differed from one another (Fig. 1 and 2). For the mean % $\dot{V}O_{2\ max}$ result, there was a significant difference between walk and run during 75 and 100%PTS. Running under these two tested % PTS, participants were required more metabolic cost contrast to walking, whereas, there was no significant different under 125%PTS (Fig. 1). For the mean stdev. of vertical COM result, there was a significant difference between walk and run during all tested %PTS. Running under the entire tested %PTS, participants were performing a larger variation of vertical displacement contrast to walking.

Table 2. Multivariate Tests of Within-Subjects Effects[b].

Effect	Value	F	Hypothesis df	Error df	Sig.
Conditions * Speeds (Mean % $\dot{V}O_{2\ max}$)	.901	45.456[a]	2.000	10.000	.000
Conditions * Speeds (Mean stdev. of vertical COM)	.769	16.673[a]	2.000	10.000	.001

a Exact statistic

b Within Subjects Design (Pillai's Trace): Conditions * Speeds

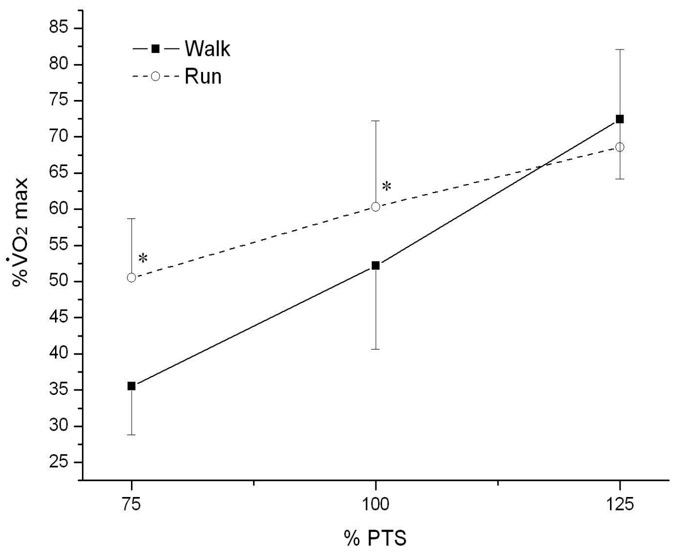

Figure 1. Estimated marginal means result of % $\dot{V}O_{2\ max}$ under two tested locomotion conditions and three speeds. Adjustment for multiple comparisons by Bonferroni post hoc test *p<.05. The interception between 100 to 125% PTS indicated the metabolic change of walking and running and so call EOTS.

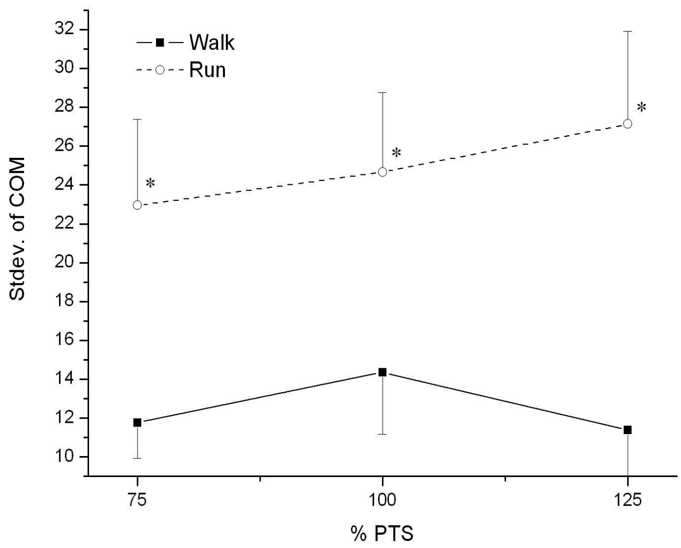

Figure 2. Estimated marginal means result of standard deviation of vertical COM displacement under two tested locomotion conditions and three speeds. Adjustment for multiple comparisons by Bonferroni post hoc test *p<.05

Discussion and Conclusion

The result showed that a typical metabolic trend of EOTS appear at between 100 to 125%PTS, which is coincide with the past literature (Hreljac, 1993; Thorstensson & Roberthson, 1987). There was no metabolic difference between walk and run under 125%PTS. However, the COM result showed that walking is significant smoothing that running under the entire tested speeds and the multivariate test has also revealed the trend of walk and run would develop inversely. That means there was more unstable vertical oscillation when the speed increases, whereas, walking was trend to stable when the speed increases. This phenomenon is corresponding with the hypothesis made by Ortega and Farley (2005). Hence, from that point of view, the results can be one of the evidence to illustrated the variation of vertical displacement is inadequate to indicate the metabolic expenditure among EOTS (5.15 – 9.82 km/h in present study).

References:

Bruce, R. A. (1972). Multi-stage treadmill test of maximal and sub maximal exercise. In AHA (Ed.), *Exercise testing and training of apparently health individuals: A handbook for physicians*. New York.

Cappellini, G., Ivanenko, Y. P., Poppele, R. E., & Lacquaniti, F. (2006). Motor patterns in human walking and running. *Journal of Neurophysiology, 95,* 3426-3437.

Cavagna, G. A., Saibene, F. P., & Margaria, R. (1963). External work in walking. *Journal of Applied Physiology, 18,* 1-9.

Cavagna, G. A., Saibene, F. P., & Margaria, R. (1964). Mechanical work in running. *Journal of Applied Physiology, 19,* 249-256.

Chu, E. Y. W., McManus, A. M., & Yu, C. C. W. (2007). Calibration of the RT3 accelerometer for ambulation and nonambulation in children. *Medicine & Science in Sports & Exercise, 39*(11), 2085-2091.

Henriksen, M., Lund, H., Moe-Nilssen, R., Bliddal, H., & Danneskiod-Samsøe, B. (2004). Test-retest reliability of trunk accelerometric gait analysis. *Gait & Posture, 19,* 288-297.

Hreljac, A. (1993). Preferred and energetically optimal transition speeds in human locomotion. *Medicine & Science in Sports & Exercise, 25,* 1158-1162.

Hreljac, A. (1995). Effects of physical characteristics on the gait transition speed during human locomotion. *Human Movement Science, 14,* 205-216.

Hreljac, A., & Martin, P. E. (1993). The relationship between smoothness and economy during walking. *Biological Cybernetics, 69,* 213-218.

Jordan, K., Challis, J. H., & Newell, K. M. (2007a). Speed influences on the scaling behavior of gait cycle fluctuations during treadmill running. *Human Movement Science, 26,* 87-102.

Jordan, K., Challis, J. H., & Newell, K. M. (2007b). Walking speed influences on gait cycle variability. *Gait and Posture, 26*(1), 128-134.

Li, L., Elizabeth, C. H., Bogert, V. D., Caldwell, G. E., Richard, E. A., Emmerik, V., et al. (1999). Coordination patterns of walking and running at similar speed and stride frequency. *Human Movement Science, 18*(1), 67-85.

McGinley, J., Baker, R., & Wolfe, R. (2006). Quantification of kinematic measurement variability in gait analysis. *Gait & Posture, 24,* S55-S56.

Mercier, J., Le Gallais, D., Durand, M., Goudal, C., Micallef, J. P., & Préfaut, C. (1994). Energy expenditure and cardiorespiratory responses at the transition between walking and running. *European Journal of Applied Physiology, 69,* 525-529.

Nagle, F. J., Balke, B., & Naughton, J. P. (1965). Gradational step tests for assessing work capacity *Journal of Applied Physiology, 20,* 745-748.

Norman, J. F. (2006). Accelerometry as an estimate of energy expenditure in healthy children and children with cerebral palsy during self-paced ambulation. *The Internet Journal of Allied Health Sciences and Practice, 4*(1), 1-5.

Ortega, J. D., & Farley, C. T. (2005). Minimizing center of mass vertical movement increases metabolic cost in walking. *Journal of Applied Physiology, 99,* 2099-2107.

Sasaki, K., & Neptune, R. R. (2006). Differences in muscle function during walking and running at the same speed. *Journal of Biomechanics, 39*(11), 2005-2013.

Schwartz, M. H., Rozumalski, A., & Trost, J. P. (2008). The effect of walking speed on the gait of typically developing children. *Journal of Biomechanics, 41*(8), 1639-1650.

Swan, P. D., Byrnes, W. C., & Haymes, E. M. (1997). Energy expenditure estimates of the caltrac accelerometer for running, race walking, and stepping. *British Journal of Sports Medicine, 31,* 235-239.

Thorstensson, A., & Roberthson, H. (1987). Adaptations to changing speed in human locomotion: speed of transition between walking and running. *Acta Physiologica Scandinavica, 131,* 211-214.

Correspondence:

Prof. Shiang, Tyzz-yuang
Institute of Exercise and Sport Science,
National Taiwan Normal University.
No 88, Sec. 4, Ting-Zhou Road.
Taipei, Taiwan. 116
E-mail : tyshiang@ntnu.edu.tw
Tel : (886) 2-29329318 ext. 16
Fax : (886) 2-29329318