COMPARISON OF METHODS TO DETERMINE MECHANICAL ENERGY EXPENDITURE OF WALKING AT VARIOUS VELOCITIES

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INTRODUCTION

Two experimental techniques have dominated the literature concerning the estimation of mechanical energy expenditure (MEE) in human motion. The first method, the absolute power method (APM), is a kinetic based approach that utilizes inverse dynamics to determine MEE from the net moments and powers. The absolute work method (AWM), is a kinematic approach which determines MEE from the changes in kinetic and potential energy of the segments. Although classical mechanics implies that these two methods should produce similar results, differences have been determined with the AWM underestimating the APM[1,2]. As well, a theoretical analysis has been performed proving the validity of the APM as the best estimate of MEE and the invalidity of the AWM except in a limited number of situations[1]. The purpose of this study was to compare the MEE results of the APM and AWM of normal walking over a range of velocities and to investigate the relationship between MEE and walking velocity.

MATERIAL AND METHODS

Ten healthy and active subjects (5 female and 5 male) were required to walk at five velocities: 40% below normal (B40), 20% below normal (B20), normal, 20% above normal (A20) and 40% above normal (A40). The normal walking condition was the velocity the subjects achieved when given the instructions to walk as naturally as possible. Overall average required velocities ranged from 0.85 to 1.99 m/s. Velocities were determined by two photoelectric Micro Switches (Honeywell) placed 6.5 m apart in the middle of a 14 m walkway. Five trials of each walking condition were gathered from all subjects. Acceptable trials were those with no visible stride modifications and that fell within a range of ±2.5% of the required velocity. A single video camera (Panasonic AG-456UP) recorded the two-dimensional (2D) movement of one complete stride of the right side of the body. Walking was considered symmetrical with the movement occurring predominantly in the sagittal plane of motion[2,4]. Motion analysis of a 7 segment rigid body model was achieved with the Ariel Performance Analysis System (APAS). The x and y coordinate data were smoothed using a 4^{th} order, zero-lag, low-pass Butterworth filter with the cutoff frequencies determined by residual analysis. Ground reaction forces were obtained with a force platform (Kistler) at a sampling rate of 200 Hz. All kinematic and MEE calculations were derived using Biomech Motion Analysis software[4]. Statistical analysis included repeated measures analysis of variance, Games and Howell *post hoc* testing and curve fitting techniques using the method of least-squares to examine the relationship between MEE and walking velocity.

RESULTS

The repeated measures ANOVA found that there was no significant difference between the MEE results of the APM and AWM. The AWM, with mean normalized MEE results ranging from 1.54 to 4.26 J/kg, overestimated the APM, with results ranging from 1.50 to 3.32 J/kg. Using the APM, a significant difference was determined between all walking conditions except between A20 and A40. The AWM failed to differentiate between any of the individual walking conditions. Furthermore, variation increased within the AWM results as walking velocity increased. This was evident in the curve estimation results. Even though all normalized MEE trial results from both methods were significantly represented by a second-order polynomial ($P \leq 0.001$), the AWM (r^2=0.769) demonstrated a larger variability than the APM (r^2=0.854) whose values are shown in figure 1.

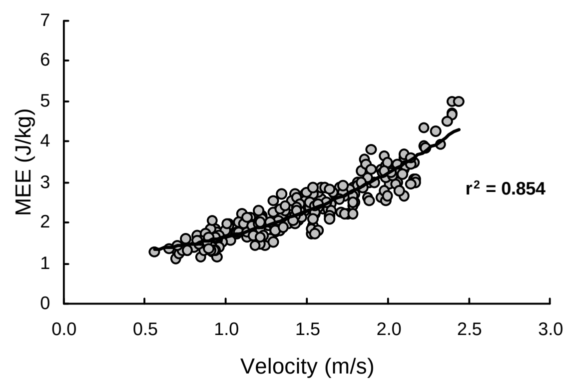

Figure 1. Normalized MEE results of the APM (n=250).

DISCUSSION AND CONCLUSION

Contradicting previous research[1,2], no significant difference was found between the two methods with the mean normalized results of the AWM actually overestimating the APM. This similarity might be due to the fact that the analysis was undertaken in 2D. By taking into account only one side of the body, anti-symmetrical movements which reduce the MEE calculations of the AWM would not have been as great as a 3D analysis of both sides of the body[1,2]. However, this is not inferring that the AWM is as valid as the APM when it comes to deriving MEE of walking in 2D. The APM is still a more valid method since it was able to significantly determine differences between the majority of the individual walking conditions. As well, the variability in the velocity of walking can be accounted for by approximately 9% more with the MEE using the APM than using the AWM. Furthermore, the APM allows one to gain an understanding of the causes of the movement because of the calculations of the net moments of force and powers at each joint. In fact, ensemble averaged net moment and power curves displayed characteristic patterns in which the magnitude increased in proportion to the velocity change with the shape of the curves remaining the same[3].

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