Mechanical paradigms of human powered locomotion on wheels

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INTRODUCTION

In the last two centuries the strive for a greater autonomy and better economy of human-powered locomotion led to the introduction of several wheeled appendices to our body. They can be categorized into four main objects: 1) the Hobby Horse (HH, 1820), close to a modern bicycle without pedals, propelled by the rider pushing on the ground, 2) the modern bicycle (MB, (1890) 1970), 3) the in-line skates (IS, (1819) 1980) and 4) the recent and fashionable 'micro-scooter' (MS, 1999). While it is apparent that all the cited devices are metabolically advantageous when compared to walking (W) and running (R) at the same speed, the mechanical determinants and energetic gain of those 'wheeled gaits' haven not been studied so far. Their quantification is the aim of the present investigation.

MATERIALS AND METHODS

HH, MB, IS (Cross-Country Ski, Skating technique, has been analysed in order to estimate unknown parameters for IS, Minetti et al. 2000), and MS have been analysed for: i) the cadence (Hz), ii) the related mechanical internal work (Wint, J/(kg m)), necessary to move the limbs with respect to the centre of mass, iii) the mechanical external work (Wext, J/(kg m)), needed to lift and accelerate the body centre of mass with respect to the environment, iv) the energy recovery (%), describing how much pendulum-like energy transfer helps to save mechanical energy, and v) the metabolic cost (J/(kg m)). The first 4 variables were mainly assessed via 3D motion capture (18 markers at 100 Hz, Elite System, BTS, Italy), while for the last one a portable metabograph (K4, Cosmed,Italy) was used (Rollerblade website for IS).

RESULTS AND DISCUSSION

The following results refer to approximately the same metabolic power. In terms of metabolic cost, HH>MS>IS>MB (overall speed gain of 200% in MB for the same metabolic power in HH), while for the cadence MS>HH>IS=MB. Consequently, Wint was minimum for MB and maximum for HH. Wext showed that HH=MS>IS>MB. The energy recovery is quite high for HH and MS (about 38 and 32 %, respectively), suggesting the presence of a remarkable exchange between potential and kinetic energies.
The evolution of mechanical paradigms, underlying the 4 modes of progression, incorporated strategies as: a) the suspension of (most of) the body mass by using the saddle, in order to limit the potential energy fluctuations (HH, MB (Minetti et al. 2001)), b) the conversion of some potential energy into kinetic energy (HH (Minetti et al. 2001), MS), and c) the uncoupling of limb movement from the ground movement (IS, MB), which both reduces the internal work (due to the lower speed of the limbs with respect to the body centre of mass) and optimize the propelling muscle function (better operative range in the efficiency/velocity diagram). Obviously, the multiple combination of the more effective strategies, like a and c in MB, results in the most economic and fast modes of progression.

REFERENCES

- Rollerblade website: www.rollerblade.com/skate/work_it/calorie_usage/calorie_usage.html