MODELA DIMENSIONLESS NUMBER AND THE WALK-TO-RUN TRANSITION IN HUMANS

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INTRODUCTION

Originally used in the fluid mechanics field, the concept of dynamic similarity enables two different-sized systems to be considered as scaled models. This concept was applied to terrestrial locomotion, and states that while travelling at different absolute speeds, different-sized animals may still move in a remarkably similar manner [1]. Dynamic similarity between two systems is possible only in particular circumstances. Equal values of N_{Fr} (N_{Fr}=v²/gl) have been shown to ensure dynamic similarity between different-sized subjects during walking [2]. N_{Fr} is a dimensionless number and corresponds to the ratio of centripetal force (Fc=mv²/l) to gravitational force (P=mg) acting at the center of gravity during walking. Dynamic similarity during walking has been used to predict locomotor parameters of extinct species, to quantify the impact of pathology, or to explore different gravitational fields.

No dimensionless number was known to ensure dynamic similarity during bouncing gaits like running. We previously highlighted a new dimensionless number (N_{Modela}) from mechanical energy transfer occurring at the center of gravity during running [3]. Equivalent experimental conditions, or equivalent events such as the walk-to-run transition should be met for different-sized subjects when moving with equal values of N_{Modela}.

This study aimed to test whether different-sized subjects switch from a walk to a run at equal values of N_{Modela}.

METHODS

Thirteen healthy male subjects (mean height 1.78±0.07m) volunteered to take part in the study. The running test was designed in order to study the mechanical energy exchange occurring at the center of gravity (Cg) of subjects walking and running at various speeds. Speeds ranging from 80 to 280%, by incremental steps of 20%, of the spontaneous walking speed were randomly imposed to subjects. The stride frequency was freely chosen by the subject during the protocol. Subjects walked or ran on a 15-meter long runway equipped with flush-to-the-floor mounted Kistler force plates, and covered by Ethylene Vinyl Acetate (EVA) foam. Kinematic data were recorded using a Vicon Peak Motus® motion system analysis. Fourteen skin markers were disposed on the subjects' bony landmarks according to the Winter's body mod in order to compute the Cg position. Filtered kinetic and kinematic data enabled us to compute the potential gravitational energy E_P=mgh, kinetic energy E_K=0.5mv², potential elastic energy E_E=0.5kΔl², N_{Fr}=v²/gl, Str=f.Δl/v at the Cg of the subject at each instant of the stance phase (with m: body mass, g: gravitational acceleration, h: vertical position of the center of gravity, v: speed at the center of gravity, k: virtual leg-spring stiffness, Δl: variation in virtual leg length, f: natural frequency). We then computed the energies ratio ER=(E_P+E_K)/E_E, and N_{Modela}= (1/Str²)((2/N_{Fr})+1) at each instant of the stance phase. The aim of the analysis was to compare $N_{Mo\text{-}Dela}$ variability and mean value of the population at the same relative speed. A variance ratio F-test and a repeated-measures analysis of variance (ANOVA) were used (p<0.05).

PRELIMINARY RESULTS AND DISCUSSION

Mean spontaneous walking speed was 1.22±0.12m.s^{-1}. Mean±sd values of N_{Modela} are presented for each relative speed (Figure 1).

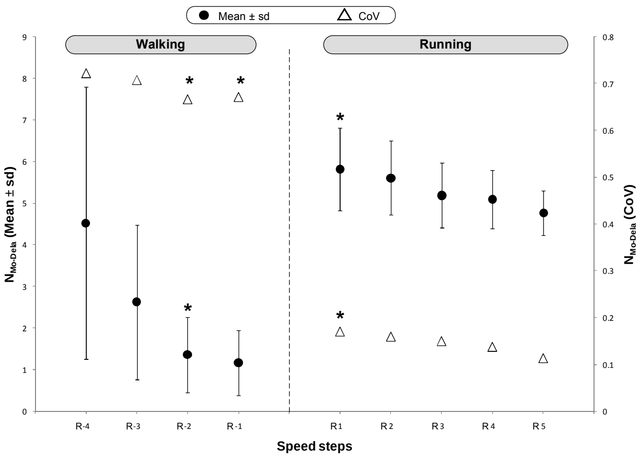

Figure 1: Mean (±sd) values and coefficient of variation (CoV) of $N_{Mo\text{-}Dela}$ at each speed. *: significantly different from previous step.

R-4 to R5 represents speed relative to gait transition. The figure shows a significant abrupt change in mean values of $N_{Mo\text{-}Dela}$, from 1.16 before gait transition (R-1) to 5.82 at the first running step (R1). Inter-subject standard deviation significantly decreased while approaching gait transition (from 3.27 in R-4 to 0.78 in R-1), and was stabilized over the running steps. The coefficients of variation were particularly affected by gait transition, decreasing from about 0.7 (70%) during walking to 0.15 (15%) during running. Our results show that subjects switched from walking to running at relatively close values of $N_{Mo\text{-}Dela}$. More generally, equal values of $N_{Mo\text{-}Dela}$ reveal equivalent conditions between different-sized bouncing systems. The approach of making different-sized subjects run with equal values of $N_{Mo\text{-}Dela}$, should enable the equivalent mechanical energy exchange to be imposed on them. In this case, subjects would be in similar dynamic conditions during running. This has to be confirmed through the analysis of the inter-subject scale factors for the biomechanical parameters during walking and running.

REFERENCES

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