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Abstract

HUMAN LOCOMOTION: CENTRE OF MASS AND SYMMETRY

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In both research laboratory and sport/clinical settings, it becomes very important to develop a ‘multilateral approach’ (qualitative and quantitative) to fully describe the individual behaviour of the centre of mass of the human body (BCOM) (i.e. the imaginary specific point at which the body behaves as if its masses were concentrated) over time and space.

Consequently, the aim of this doctorate is to describe kinematic variables of the BCOM in varying locomotion conditions. This purpose, focusing on the BCOM as the investigation object fulfilling such a need, has been achieved through a different use of classic biomechanical procedures.

In effect, two different studies were carried out.

The **first project** sought: a) to develop a mathematical method (Fourier Series) which could describe and graphically represent each individual (subject or population) gait signature (i.e. Digital Locomotory Signature, a global index of the BCOM dynamics) during locomotion on a treadmill; b) to assess the symmetry (i.e. Symmetry Index) in each movement direction, along the BCOM trajectory, between the two stride phases; finally, c) to build up an initial comprehensive *database* of ‘healthy values’ (equation coefficients) in a set of different conditions considering gender (males *versus* females), age (from 6 to 65 years), gait (walking *versus* running), speed and gradient (level, uphill and downhill).

Although only slight gender differences were found, human 'healthy' gait is rather asymmetrical. To be precise: 1) the lowest speeds have the most peculiar signature independently of age and gradient: indeed, these speeds are not so completely natural and common. However, if speed increases, the BCOM raises in such a way that its corresponding 3D *contour* becomes more regular; 2) right and left sides of the stride are quite asymmetrical (i.e. in the forward direction). Globally, this asymmetry is probably related both to anatomy (i.e. leg length) and which hand you use (i.e. right-handedness); 3) on average, the symmetry pattern is slightly lower in running gaits; and as expected, 4) young children and elderly adults are the most asymmetrical subjects, independently of testing conditions: while, during the early stages of life, this global asymmetry could be ascribed to the process of gait development, old age asymmetries are probably due to structural wearing down of the musculoskeletal system.

Importantly, the mathematical methodology used here, by analysing even subtle changes in the 3D BCOM trajectory: a) characterizes its displacements over both time and space; b) quantitatively describes the individual gait signature; and c) represents the basis for the evaluation of gait anomaly/pathology (e.g. children with cerebral palsy, obese people and amputees).

Finally, knowing the main biomechanical variables becomes fundamental both to fully describe the mechanics of walking and running and to extract and characterize the individual gait signature. In effect, our measurements (discrete method *versus* continuous mathematical function, and direct *versus* indirect measurement) of both simple and complex variables wholly confirm, complete and amplify previous literature data.

Similarly to what previously demonstrated in horse performances, the **second project** tried: a) to verify both static anatomical and kinematic functional symmetries as important and relevant indicators of running economy (i.e. the reciprocal of metabolic cost) in humans featuring different running levels (i.e. occasional, skilled and top runners categorized primarily upon their best marathon time); b) to develop imaging based bi- and three-dimensional methods to analyse static symmetries recorded by Magnetic Resonance Imaging (lower limbs and pelvic area); c) to describe the kinematic symmetries defining both the Digital Locomotory Signature and the Symmetry Index; finally, d) to investigate running economy as a performance determinant.

In effect, both the 2D/3D analysis of static symmetries highlight very few differences among runners; however, a strong relationship between ankle and knee areas has been underlined in all runners. Furthermore, independently of training ability: as expected, 1) the BCOM raises and lifts slightly as a function of running speed; 2) right and left steps are mostly asymmetrical in the forward direction and symmetrical in the vertical direction (i.e. combined action of gravity and ground reaction force); 3) differently to what was expected, slight differences have been found among runners. On the whole, the asymmetry is probably related both to anatomy and handedness. Other than that, no running economy differences were found.

In conclusion, while a relationship between symmetries and running economy has not been found, significant results have however been underlined in each trial (static and dynamic symmetries).

Finally, the deep investigation of both bioenergetics (treadmill *versus* over-ground) and biomechanics (simple/complex variables and spatial/temporal variability of the BCOM) of running has highlights only little (significant) differences among groups.