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THE VERTICAL EXCURSION OF THE BODY VISCERAL MASS DURING VERTICAL JUMPS IS AFFECTED BY SPECIFIC RESPIRATORY MANOEUVRE

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SUMMARY
A few years ago, a methodology using both 3D motion capture and platform dynamometry was proposed to infer the movement of the visceral mass during cyclic motor acts [11]. Here we apply that method proving how a novel jumping technique, based on stiffening both chest and abdominal wall by means of a particular respiratory manoeuvre, is limiting visceral mass' vertical displacement (within the trunk) in vertical jumps. The resulting reduction of viscera motion by about 30% represents the first experimental evidence that the effects of a voluntary pattern of respiratory muscles activation during jumping can be accurately measured with a non-invasive approach.

INTRODUCTION
In biomechanical studies of human motion and locomotion, the body is often simplified as composed by a number of rigid segments. Alas, soft parts and viscera motion has to be included to avoid experimental inaccuracies [7] and specific wobbling mass models were proposed [12] to improve experimental results especially during impacts [11]. Besides several authors pointed out visceral mass contribution in the locomotor-respiratory coupling in quadrupeds [1] and in human, whose diaphragm function influences abdominal viscera's axial acceleration [8]. Thus, assessment of soft tissue and viscera movement is functional in modelling optimization strategies and in experimental methodology, also in relation to the potential mechanical interaction with the rest of the body. For example visceral mass could be "controlled" by a respiration technique [4] which improves abdominal belt stiffness: a 'low' diaphragmatic respiration increasingly compacts viscera towards the pelvis and a proper contraction activity of the abdominal wall/pelvic floor muscles avoids the forward displacement of the compressed viscera.

The aim of this work was to (i) quantify the relative motion (within the trunk) of visceral mass during vertical jumps executed employing the "controlled" respiratory/stiffening manoeuvre, and to (ii) check method accuracy in detecting 'controlled' technique effect on viscera kinematics.

METHODS
Six subjects (age 23.3 ± 2.5, weight 659.4 ± 53.0 N) were selected to jump in two different sessions (5 trials of 15 consecutive jumps per session) on a force platform (1200 Hz - Kistler, CH) measuring the vertical GRF synchronized with a six-camera motion capture system (400 Hz - Vicon MX, Oxford Metrics, UK). The human body was modelled as a series of 14 linked rigid body segments [10], and 4 'technical-markers' were placed on the estimated centre of mass position of pectoral muscles, and right and left abdomen surface.

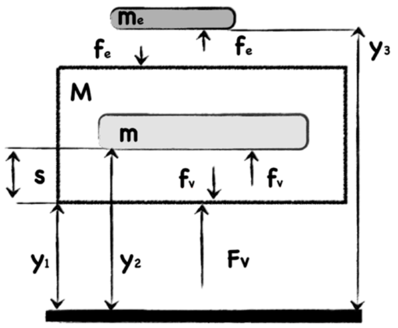

Figure 1: Model for the estimation of visceral mass displacement 's': M is the container mass, m and m_e represent respectively the internal visceral mass and the external mass, y_1, y_2 and y_3 are distances from ground level while $s=y_2-y_1$. The whole system oscillates vertically and exerts a vertical ground reaction force F_v, while internal and external mass exerts a force f_v and f_e respectively on the container.

During the first session, subjects jumped barefoot, with the hand on their hips, without any advice. The second experimental session took place according to the same protocol after a training period of one month in which the subjects followed a specific learning progression devoted to jump in the "controlled" way. Before the second session, respiration technique and muscle contraction skills were tested on every subject: airflow was measured with a heated Fleisch pneumotachograph (HS Electronics, March-Hugstetten, Germany) and a differential pressure transducer (Validyne MP45, Northridge, CA). The activity of rectus and obliquus abdominis muscles was recorded via surface EMG (model ICP511, Grass Technologies, US). Volume changes were obtained by numerical integration of the digitized airflow signal, after calibration of the measuring apparatus by means of a graded cylinder and a metronome.

The viscera motion was measured applying a refined version of the method proposed by Minetti and Belli in 1994 [10]. In line with the original paper, we considered just vertical motion but included an 'external' wobbling mass (m_e, mainly pectoral muscles and abdominal wall) as part of the container of mass M (Figure 1). The relative visceral mass displacement 's' was calculated solving the model's equation of motion: the movement of the container (i.e. the rigid, multi-segment body) and external mass assessed by motion analysis, and the displacement of the 'true' body centre of mass (CoM), were the input variables of the model.

RESULTS AND DISCUSSION

The visceral mass (VMD), pectoral and abdomen external mass displacements (EMD) are represented as relative to the CoM. The VMD, for all the subjects, measured during normal jumps (0.069 ± 0.020 m), is significantly higher ($p < 0.05$, paired t-test), than in controlled jumps (0.053 ± 0.018 m). For all the subjects, VMD shows a different pattern with respect to container displacement both in normal and in controlled jumps (Figure 2), with a detectable time shift between the curves. The pectoral (normal 0.037 ± 0.09 m – contr 0.032 ± 0.09 m) and abdominal (normal 0.023 ± 0.011 m – contr 0.020 ± 0.010 m) EMD values are comparable between jumping techniques (paired t-test), while pectoral EMD is significantly larger ($p<0.05$, paired t-test) than abdomen EMD in both techniques. The volume of expired air during controlled jump sequence (0.16 ± 0.03 l/jump), is comparable with normal jump sessions (0.19 ± 0.04 l/jump), despite of a higher activation of expiratory muscles (normal 50 ± 7 % max activation - contr 15 ± 1 % max activation), proving that diaphragm applies an opposite force to contrast the rising viscera.

The VMD mean value found in this work is comparable with the literature: few quantitative analyses were conducted mostly anatomically or in slow-dynamic condition [6], where vertical viscera motion was found to range between 0.03 m and 0.07 m. Only Minetti & Belli [10] reported a value related to submaximal repeated jumps (0.08 m).

Our results show that muscles not directly involved in jumping could affect body dynamics, and stress the potential interaction between respiration and movement.

From the energetic point of view, the time delay between CoM and VMD could generate energy losses resulting in some extra-mechanical work done by muscles in different movement types. The 'economy' of walking [13] and bouncing locomotion, such as running or skipping, could be influenced and the mechanical external work calculated from kinematically measured CoM displacement could be refined by adding viscera contribution [5]. While this is supposed to be a small adjustment in normal subjects, any deviation from a mesomorphic body such as obese patients with relevant internal and external wobbling masses would involve a more substantial correction of the inverse dynamics approach. In this way the proposed respiratory strategy could give potential benefits in terms of movement performance and the non-invasive method described could be easily adopted.

Finally, it should be noticed that the method still suffers of inaccuracies due to: 1) skin marker and soft tissue motion artefact [3,7], and 2) muscle tuning effect [2].

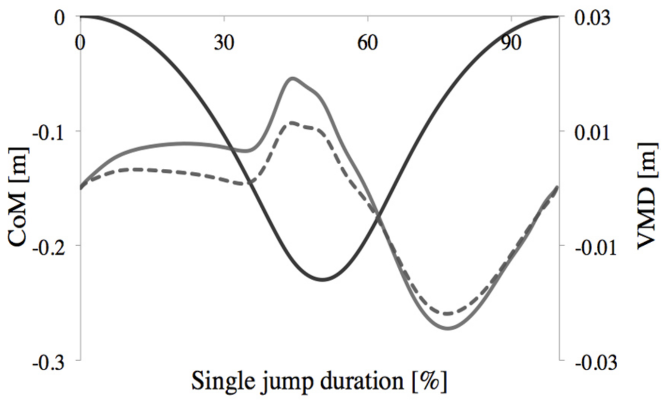

Figure 2: The overall mean curve of VMD in normal (grey solid line) and controlled (grey dashed line) jumps, and overall mean curve (controlled and normal) of body CoM (black solid line) are shown. All the curves are time-normalized with single jump duration (0-100%).

CONCLUSIONS

In conclusion, the combination of the inverse/direct dynamics method to measure viscera motion and a novel respiration assisted jumping technique reveals that the vertical displacement of the abdominal wobbling mass can be modulated also in dynamic condition. Moreover, it has been demonstrated that the accuracy of this refined method is adequate to detect, with a non invasive approach, the effects of internal forces on the kinematic of the visceral mass and could be adopted to evaluate those their impact in sport biomechanics and locomotion energetics.

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