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The vertical excursion of the body visceral mass during vertical jumps is affected by specific respiratory maneuver

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ABSTRACT

Most of the inverse modeling of body dynamics in sports assumes that every segment is ‘rigid’ and moves ‘as a whole’, although we know that uncontrolled wobbling masses exist and in specific condition their motion should be optimized, both in engineering and biology. The visceral mass movement within the trunk segment potentially interferes with respiration and motion acts such as locomotion or jumping. The aim of this paper is to refine and expand a previously published methodology to estimate that relative motion by testing its ability to detect the reduced vertical viscera excursion within the trunk. In fact, a respiratory-assisted jumping strategy is expected to limit viscera motion stiffening the abdominal content of the bouncing body. Six subjects were analyzed, by using inverse dynamics incorporating wobbling masses, during repeated vertical jumps performed before and after a specific respiratory training period. The viscera excursion, which showed consistent intra-individual time courses, decreased by about 30% when the subjects had become familiarized with the trunk-stiffening maneuver. We conclude that: (1) present methodology proved to detect subtle visceral mass movement within the trunk during repetitive motor acts and, particularly, (2) a newly proposed respiratory maneuver/training devoted to stiffening the trunk segment can reduce viscera vertical displacement.

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1. Introduction

In biomechanical studies of human and animal motion and locomotion, the body is often simplified as composed by a number of rigid segments. From the location of those segments in 3D space, many important variables such as the body center of mass (BCoM), the related internal and external mechanical work (Willems, Cavagna, & Heglund, 1995) are calculated to infer the characteristic dynamics of movement (Minetti, Cisotti, & Mian, 2011; Saibene & Minetti, 2003). Also, rotational parameters such as joint net moments and segments inertial characteristics are based on the same "rigid body model". Unfortunately, such assumption can lead to experimental inaccuracies (Gao & Zheng, 2008; Leardini, Chiari, Della Croce, & Cappozzo, 2005). For this reason specific wobbling mass models have been proposed (Gruber, Ruder, Denoth, & Schneider, 1998; Yue & Mester, 2002) to improve and to refine experimental results especially during impacts (Gunther, Sholukha, Kessler, Wank, & Blickhan, 2003; Pain & Challis, 2004), in an attempt to enhance the description of the complex mechanical behavior of the human body by including the contribution of soft parts. This approach allows quantification of the soft tissue deformation and displacement as a consequence of the impact forces transmission along the body (Challis & Pain, 2008; Wakeling & Nigg, 2001) during walking (Chen, Mukul, & Chou, 2011), running (Boyer & Nigg, 2007) and jumping (Gittoes, Brewin, & Kerwin, 2006; Mills, Scurr, & Wood, 2011). Soft tissue and viscera motion can also affect the external work of level and gradient walking (DeVita, Helseth, & Hortobagyi, 2007; Zelik & Kuo, 2010) and of running economy and stability (Daley & Usherwood, 2010). It was even proposed that a suitable muscle-tuned control of that collateral effect could minimize the overall energy dissipation (Friesenbichler, Stirling, Federolf, & Nigg, 2011).

Thus, soft tissue and viscera movement has to be considered as a non-negligible factor in modeling optimization strategies and in experimental methodology, also in relation to the potential mechanical interaction with the rest of the body. For example, several authors have pointed out the role of the visceral mass movement (within the trunk) in the locomotor–respiratory coupling during trotting and galloping in quadrupeds (Alexander, 1993; Bramble & Carrier, 1983; Simons, 1999). A similar condition occurs in humans, where some locomotor–respiratory coupling in running (McDermott, Van Emmerik, & Hamill, 2003) and walking (Rassler & Kohl, 1996) reflects the influence on the diaphragm function of the transient axial acceleration of abdominal viscera (Brown, Lee, & Loring, 2004; Loring, Lee, & Butler, 2001; Wilson & Liu, 1994). A very simple experiment illustrates this point: whoever tries to breath out-of-phase with respect to the spontaneous pattern during repeatedly jumping in place feels a great discomfort in achieving such a goal, mainly because respiratory muscles have to fight against the volume changes imposed by the jump-induced vertical accelerations of the visceral piston within its container.

In addition to the coupling between a cyclic activity as locomotion and respiration, there are other movements where the visceral mass displacement can play a role. In sport activities as volleyball, basketball or athletics, where jumping efficacy or horizontal-to-vertical velocity conversion is crucial (Yu & Hay, 1996), it is conceivable that controlling the wobbling mass could potentially avoid discomfort and energy dissipation associated with adverse oscillations, by also lowering workload perception (Bonsignore, Morici, Abate, Romano, & Bonsignore, 1998) or enhancing the jump performance. In this respect training techniques have been suggested to reduce the amplitude of that movement (Caufriez, 2005; Kapandji, 1977; Lumb, 2005) or even to obtain a beneficial influence on BCoM trajectory during the motion cycle.

A few years ago, an inverse dynamic method incorporating visceral wobbling mass was proposed to infer the movement of the visceral mass during cyclic motor acts (Minetti & Belli, 1994). In short, by comparing the movement of the container (i.e. the rigid, multi-segment body) assessed by motion analysis, to the displacement of the 'true' BCoM, evaluated by double integration of the net vertical ground reaction force, it was possible to quantify the relative motion of the visceral mass within the trunk.

The aim of this paper was to apply that method to test whether a novel jumping technique, based on stiffening both chest and abdominal walls by means of a particular respiratory maneuver, was associated with the expected reduction in the visceral mass vertical displacement within the trunk.