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Short communication

Evaluation of the kinetic energy of the torso by magneto-inertial measurement unit during the sit-to-stand movement

Kevin Lepetit [a], Khalil Ben Mansour [a], Sofiane Boudaoud [a], Kiyoka Kinugawa-Bourron [b], Frédéric Marin [a,*]

[a] UMR CNRS 7338 Biomechanics and Bioengineering, University of Technology of Compiègne, Sorbonne University, Research Center, Dr Schweitzer Street, 60200 Compiègne, France
[b] Pitié-Salpêtrière Hospital – Charles Foix Hospital (AP-HP), Avenue de la République, 94200 Ivry-sur-Seine, France

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ABSTRACT

Sit-to-stand tests are used in geriatrics as a qualitative issue in order to evaluate motor control and stability. In terms of measured indicators, it is traditionally the duration of the task that is reported, however it appears that the use of the kinetic energy as a new quantitative criterion allows getting a better understanding of musculoskeletal deficits of elderly subjects. The aim of this study was to determine the feasibility to obtain the measure of kinetic energy using magneto-inertial measurement units (MIMU) during sit-to-stand movements at various paces. 26 healthy subjects contributed to this investigation. Measured results were compared to a marker-based motion capture using the correlation coefficient and the normalized root mean square error (nRMSE). nRMSE were below 10% and correlation coefficients were over 0.97. In addition, errors on the mean kinetic energy were also investigated using Bland-Altman 95% limits of agreement (0.63 J–0.77 J), RMSE (0.29 J–0.38 J) and correlation coefficient (0.96–0.98). The results obtained highlighted that the method based on MIMU data could be an alternative to optoelectronic data acquisition to assess the kinetic energy of the torso during the sit-to-stand test, suggesting this method as being a promising alternative to determine kinetic energy during the sit-to-stand movement.

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1. Introduction‘

Currently, several geriatric tests are proposed to follow-up the well-being of elderly subjects. They are particularly used to prevent fall risks and musculoskeletal deficits (Beauchet et al., 2011; Greene et al., 2010). Falls are one of most common causes of loss of independence which significantly increase the mortality rate of senior citizens (American Geriatrics Society,British Geriatrics Society and American Academy of Orthopaedic Surgeons Panel on Falls, 2001). Among these tests, it appears that the timed up-and-go (TUG) and in particular its most difficult phase, the sit-to-stand (STS) phase, is the most frequently used to evaluate musculoskeletal deficits (Beauchet et al., 2011; Mathias et al., 1986; Podsiadlo & Richardson, 1991; Wall et al., 2000). In practice, only task duration using a chronometer would be quantified during these tests (Beauchet et al., 2011). However, the link between TUG and fall risks has been called into question (Barry et al., 2014; Thrane et al., 2007). Consequently, authors recommended to use it with caution and concluded on the necessity to develop better tools to indicate balance deficits in seniors. The quantification of mechanical energy has been suggested as an alternative to investigate the motion strategy (Latash et al., 2016), for example by estimating the average of the vertical kinetic energy during STS tasks (Cameron et al., 2003). However, results did not necessarily allow conclusions on fall risks because the investigation of motion strategies and muscle contributions requires the instantaneous energy (Latash & Zatsiorsky, 2001).

During the STS task, the torso is the most dynamic and the heaviest segment (Dumas et al., 2007). Hence, most of the kinetic energy of the body can be measured at the level of the torso. To estimate this instantaneous kinetic energy of the torso, inertial and kinematic parameters have to be specifically identified (Gordon E Robertson et al., 2004) and a quantitative analysis of the movement is required. In the context of clinical routine investigations, wearable magneto-inertial measurement units (MIMUs) appear to be more adapted than optoelectronic devices (Steffen et al. (2013)).

The purpose of this work was twofold: one aim was to determine if the rotational component of the kinetic energy of the torso can be neglected during the STS, the second one was to evaluate if a

* Corresponding author.
E-mail address: frederic.marin@utc.fr (F. Marin).

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MIMU is sufficiently accurate to replace optoelectronic devices to compute kinetic energy of the torso during STS.

2. Materials and methods

Twenty-six healthy subjects were included in this study: fourteen males (29 ± 4yo, 74 ± 12 kg, 175 ± 7 cm) and twelve females (23 ± 3yo, 58 ± 8 kg, 165 ± 7 cm). All volunteers gave their free and informed consent for the experiments.

Participants were instrumented with a MIMU (APDM, Opal, Portland, USA) fixed on the chest approximately at two-thirds of the breastbone with an elastic strap and 17 reflective markers fixed on anatomical landmarks (Fig. 1). Thirty-six cameras (Vicon motion systems Inc., Oxford, UK) were focused to track the position of the markers. The height of the chair was standard (45 cm). The signals of the MIMU and of the optoelectronic device were sampled at 80 Hz and 100 Hz, respectively.

Each participant performed three sessions composed of five STS trials. To record spontaneous pace, subjects were asked to perform movements without instruction during the first session. For the second session, they were requested to stand up as fast as possible and during the last one, to stand up slowly, as if they were tired. After the sessions, the mass of each subject was measured using a weighing scale.

Assuming the torso as a rigid body, the center of mass (CoM) of the torso G_T is fixed in the body frame of the torso and the inertial matrix of the torso is invariant in time. Based on rigid body mechanics theory, the kinetic energy E_k of the torso in the inertial reference frame, at each time t, is defined by its translational and rotational components:

$$E_k = \frac{1}{2} m_T v_{G_T}^2 + \frac{1}{2} \boldsymbol{\omega_T} [\mathcal{J}_{G_T}^T] \boldsymbol{\omega_T} \quad (1)$$

where m_T is the mass of the torso, v_{G_T} is, at the time t, the velocity of the CoM of the torso G_T, $[\mathcal{J}_{G_T}^T]$ is the inertial matrix of the torso expressed at G_T and $\boldsymbol{\omega_T}$ is the angular velocity of the torso at time t.

2.1. E_k computed by the optoelectronic data

The lumbar joint center (LJC) was computed as the barycenter of MPSIS (Midpoint between the Postero-Superior Iliac Spines), RASIS and LASIS (Right and Left Antero-Superior Iliac Spines) and the cervical joint center (CJC) as the midpoint between C7 (7th cervical) and SUP (suprasternal) (Fig. 1).

Then, the torso coordinate frame and the position of the torso CoM were assessed according to an anthropometric model (Dumas et al., 2007).

The velocity of G_T during the STS was computed by Newton's difference quotient of G_T positions. The angular velocity of the torso was computed in the torso coordinate frame (Hamano, 2013).

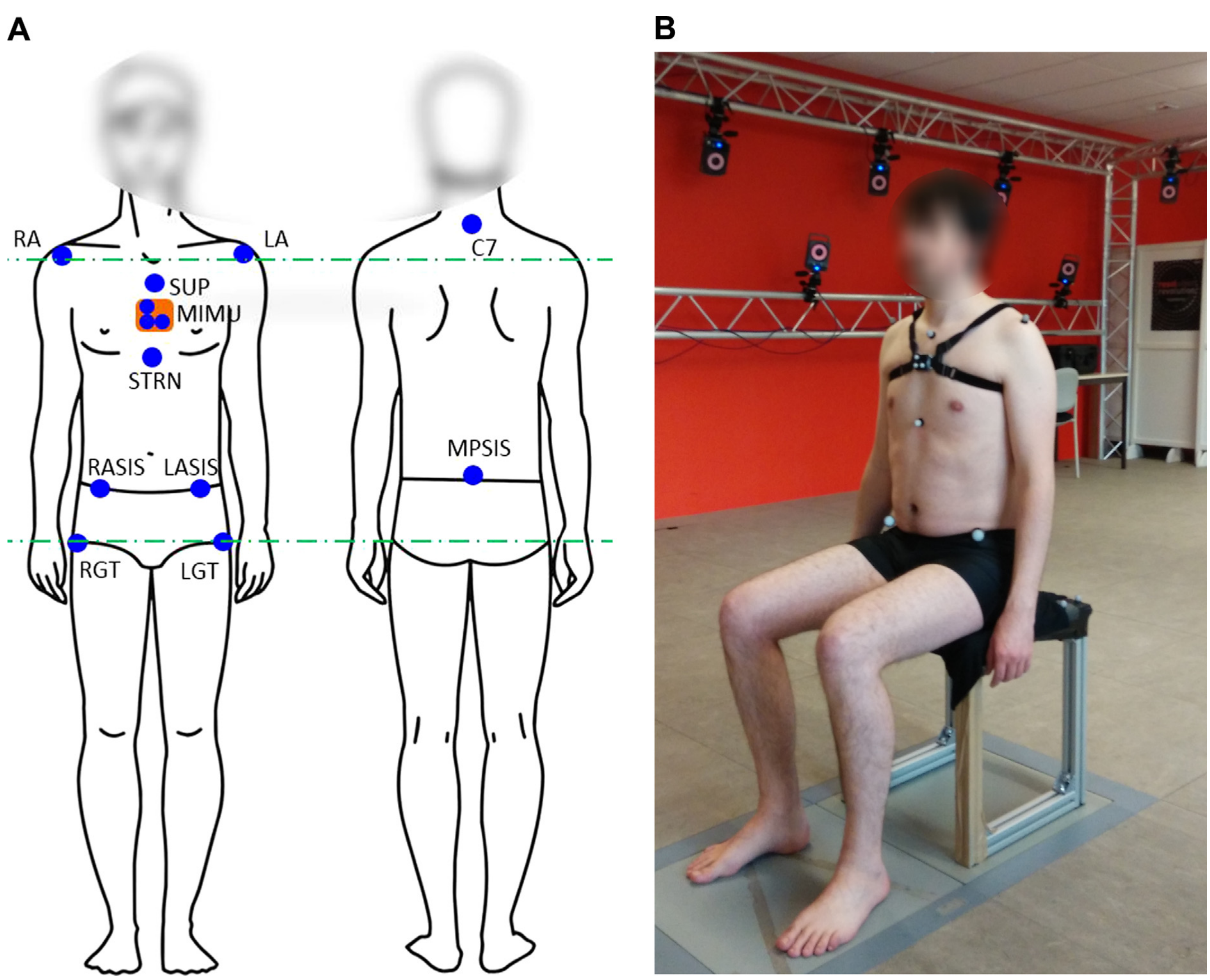

Fig. 1. Markers placed on anatomical landmarks and on the MIMU (fixed on the chest with an elastic strap).

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