Center of Mass behavior during forward and backward walking

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1. Introduction

Backward Walking (BW) or retro locomotion is a natural form of human locomotion with an expected form based on Forward Walking (FW) (Thorstensson 1986; van Deursen et al. 1998). It is used as an alternative exercise for sports training, orthopedics and neurological rehabilitation (Balasukumaran et al. 2019) because BW walking offers benefits beyond those offered by FW walking. Indeed, BW walking enhances lower muscles strength and balance, improves proprioception and, intralimb coordination (van Deursen et al. 1998; Alghadir et al. 2019; Shen et al. 2021).

Most of studies focused on (1) the energetic cost, showing higher metabolic cost (2), the kinetic and kinematic modification showing similarities by a simple time-reversal of FW walking and, (3) the muscle activity, revealing a dissimilar pattern of muscle activity (Thorstensson 1986; Winter et al. 1989; Grasso et al. 1998).

In this research, we looked forward to study the Center of Mass (CoM) vertical behaviour and, the energy recovered during a Backward Walking (BW) and to compare it to the evolution to of the one of a Forward Walking (FW). These results will be used to feed 'CoBot' Collaborative Robot database. Indeed, BW walking is used during collective load transport; where two participants associate a FW and BW walking to transport an object (i.e. stretchers). In this study, we recorded and computed the CoM of twenty-four participants performing a BW and FW walking. We hypothesized that performing a BW walking modified the CoM vertical behaviour and hence the Energy Recovered (ER).

2. Methods

2.1. Experiments

Twenty-four participants fourteen women and ten men (mean ± s.d.: age = 24,66 ± 2,49 year; height = 1,70m ± 0,08m; mass = 64,49 kg ±7,55kg) were recruited for this experiments. Each one was equipped of 42 reflective spherical markers placed at anatomical landmarks. The 3-D kinematics of the upper limb, lower limb, and the trunk was then recorded by 19 cameras Vicon Motion Systems Ltd sampled at 200 Hz. We instructed the participants to perform two distinct conditions: the first one consisted in a spontaneous forward walking (FW), and the second one in a spontaneous backward walking (BW). For each condition we recorded 3 trials per participants.

2.2. CoM evolution

The De Leva Anthropometric tables (de Leva 1996) was used to estimate the mass m_i and the CoM of each segment i (CoM_i). The participant CoM location has been then computed in the global frame reference R(0, *x*, *y*, *z*) as follows (M, Participant Mass):

$$\overrightarrow{OCoM} = \frac{1}{M}\sum_{i=1}^{n=16} m_i \overrightarrow{OG_i}$$

2.3. Energy recovered

The forward kinetic (W_{kf}), the vertical (W_v) and external work (W_{ext}) of the CoM_t were computed according to the method of Bastien et al. 2016. Then based on the external work, the percentage of energy recovered of the CoM in the sagittal plane was computed as follow:

$$ER(\%) = \frac{W_{kf} + W_v - W_{ext}}{W_{kf} + W_v}$$

2.4. Statistical analysis

In order to compare vertical CoM excursion, we computed, for each participant, the mean amplitude relative to standard anotomic position, mean width signal, mean angular frequency and period of their displacement for a gait cycle. A Shapiro-Wilk test was performed to check the normality distribution of the data. Then, a parametric test: student-t test (Normally distributed data) and a non-parametric test: Wilcoxon test (Non normally distributed data) were performed to compare results obtained for the FW and BW. For the ER, we also checked the normality data distribution with a Shapiro-Wilk test and then, performed a Wilcoxon test. The significance threshold was set to 0,05.

3. Results and discussion

The mean amplitude of the CoM vertical excursion was 17,3% lower during BW compared to FW ($t = 4{,}1616$; df = 23; $p = 3{,}76.10^{-4}$). Regarding width ($t = 0{,}4096$; df = 23; $p = 0{,}6859$), angular frequency ($w = 0{,}1259$; $p = 0{,}8998$), and, period ($t = -0{,}6626$; df = 23; $p = 0{,}5142$) of the signals we did not find any significant differences across the two conditions.

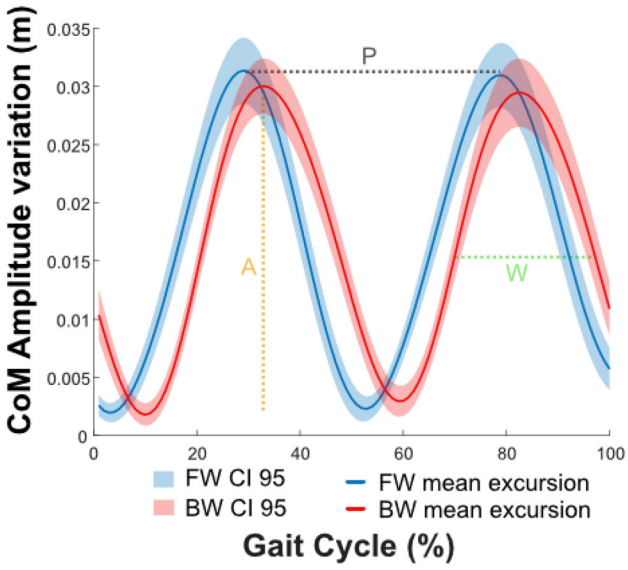

Figure 1. CoM trajectories in the sagittal plan to percentage of the gait cycle during a backward (BW) and forward (FW) gait cycle; with A: Amplitude, P: Period and, W: Width.

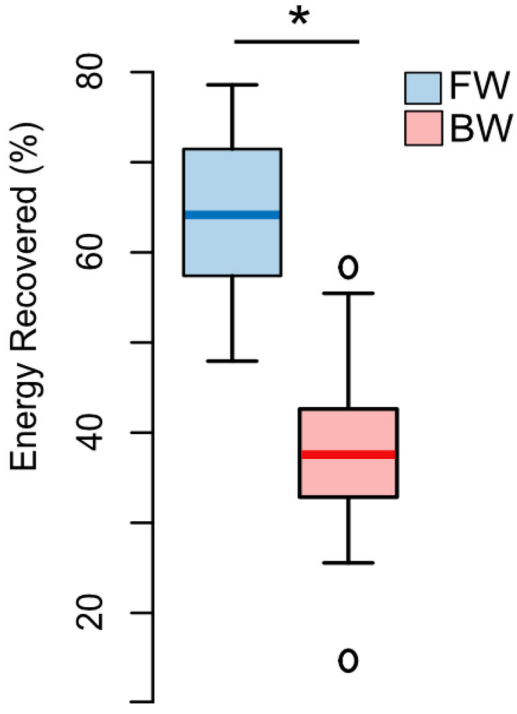

Figure 2. Boxplot of the Energy Recovered during the FW and BW conditions.

In fact, during a Backward walking there is no visual feedback which leads to smaller temporal gait parameters. We showed that these changes induced a modification of the CoM behaviour by deacresing its amplitude. However, they did not impacted the width, the angular frequency and, the period of the signal. Our results can explain those found in the literature, where they consider backward walking as a simple time-reversal of a FW walking pattern (Figure 1).

Energy Recovered 'ER' was 37,94% lower during BW compared to FW ($w = 5{,}8869$; $p = 3{,}9348.10^{-4}$ – Figure 2), showing an altered pendulum-like behavior of the CoM during Backward walking. These results are consistent with previous results of Minetti and Ardigò (2001) and, allow us to validate the protocol used for this study.

4. Conclusions

The purpose of this research was to study the behavior of the Center of Mass (CoM) and, the energy recovered during Backward and Forward walking. The results showed a decrease of the CoM vertical excursion amplitude for a Backward gait cycle. However, no differences were found for the width, angular frequency and, period of the CoM vertical displacement, thereby explaining the time-reversal aspect of a FW walking found in the literature. Moreover, the Energy Recovered decreased during BW walking showing the alteration of the CoM pendulum-like behaviour. Future research should focus on the modification of these results when two participants performing a FW and BW walking are associated thus replicating a collective load transport situation. We expect that this association induces an alteration of the pendulum-like CoM behavior of the system formed by the carriers and the load carried.

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