



Locomotor pattern and mechanical exchanges during collective load transport

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ABSTRACT

While the locomotor behavior of humans walking alone, loaded or unloaded, has been extensively studied, the locomotor behavior of humans transporting a load collectively is very poorly documented in the biomechanics literature. Yet, collective carriage is a task commonly performed in sport (CrossFit), military and health care (carriage of an injured person) activities and is a task that raises growing interest in robotics (Cobots). The primary aim of our research was to test the hypothesis that the mechanical cost of locomotion is comparable when two individuals are transporting an object collectively and when they are walking alone. To test this, the movements of ten pairs of individuals walking side by side, separately or while transporting collectively an object, were recorded with a three-dimensional motion analysis system (Vicon®). Our results show a similar pattern in the periodic displacement of the center of mass and in mechanical costs, between individuals walking alone and individuals carrying a load collectively. Moreover, a better pendulum-like behavior was found in the sagittal plane and in 3D for the pairs of individuals carrying an object, which suggests that the saving in mechanical exchanges is higher when two individuals are carrying an object collectively than when they are walking alone. The values of the parameters measured in our experiment could be used as a benchmark for the implementation of collective carriage tasks in robotics.

1. Introduction

Load carriage is part of the routine of everyday life in humans and the effect of load carriage (load on top of the head: [Heglund, Willems, Penta, & Cavagna, 1995](#); on the shoulders: [Castillo, Lieberman, McCarty, & Lieberman, 2014](#); on the back: [Ackerman & Seipel, 2014](#); [Bastien, Willems, Schepens, & Heglund, 2016](#)) on the locomotor behavior of single individuals is relatively well documented in the literature. However, humans are also endowed with the capacity to transport objects collectively and hitherto there are to our knowledge no studies on the biomechanics of individual locomotion during collective transport in humans. Our study fills this gap with an analysis of individual locomotor pattern and mechanical exchanges during a collective transport task. This task is part of our everyday life experience, e.g. when we move a heavy or voluminous object with the help of another person. It is also a task that is performed routinely by humans working in factories when they have to move heavy loads together or in clinical environments when caretakers have to move a patient. Therefore, a better understanding of the biomechanics of collective load carriage could have potential applications in the field of ergonomics. Finally, collective load carriage is one of the exercises regularly performed by athletes in sports. For example, the CrossFit program (i.e. CrossFit daily training or CrossFit events, [Feito, Burrows, & Tabb, 2018](#))

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needs to move loads by team regularly.

Cavagna, Saibene, & Margaria (1963), Cavagna, Heglund, & Taylor (1977) were the first to propose the Inverted Pendulum System (IPS) model to explain the economy of gait in humans. In this model the oscillations of the center of mass of the body (CoM) during stable walking in the sagittal plane is represented as a wave with constant amplitude and period (Cavagna et al., 1977; Kuo, 2007). For an ideal pendulum this undulation can be represented by a sine wave as a function of time. It has been shown that the displacement of the CoM in humans is not an ideal sine function but is very close to it (Ackerman & Seipel, 2014; Saunders, Inman, & Eberhart, 1953). The oscillations of the CoM allow the transfer of potential energy into kinetic energy and *vice versa* on each gait cycle, explaining the major part of the mechanical economy of walking (Cavagna, Willems, & Heglund, 2000; Lee & Farley, 1998). Although there are also during walking some oscillations of the CoM in the frontal plane due to the movement of the pelvis (Blickhan et al., 2007; Kuo, 1999; Mahaudens, Banse, & Detrembleur, 2008) and the stabilization of lateral motion (Kuo, 1999), they actually contribute for a very weak part of the overall changes in mechanical energy (Cavagna et al., 1963; Tesio & Detrembleur, 1998). The question we ask in this paper is whether individuals are able to walk as economically when they are transporting collectively an object as when they are walking alone and unloaded.

Representing the body by its CoM allows to understand a good part of the biomechanics of locomotion. However, it neglects some important information, namely the variations of kinetic energies at the level of each body segment. Yet, the study of the mechanical exchanges due to the body segments during collective carriage could complement the global analysis of the CoM and highlight the regulation of walking economy. High resolution 3D tracking and reconstruction techniques (Tesio & Detrembleur, 1998) allow to take this into account by using a Poly-Articulated Model (PAM) (Moretto, Villeger, Costes, & Watier, 2016; Zatsiorsky & Seluyanov, 1983), i.e. a poly-articulated system of multiple rigid segments, where each segment i is characterized by a center of mass CoM_i and a mass m_i . In this paper, we used this method to test the general hypothesis that when two individuals are transporting an object collectively their locomotor pattern (i.e. amplitude and pendulum-like behavior of the CoM displacement) and their mechanical exchanges (i.e. percentage of energy recovered, internal, external and total works), are similar to that of an unloaded individual walking alone.

2. Materials & methods

2.1. Participants

Ten pairs of healthy male volunteers, whose characteristics are presented in Table 1, took part in the experiment.

The volunteers had no orthopedic disabilities, no dysfunctions of the locomotor system, no neurological or vestibular diseases, no visual deficits and no proprioceptive disorders or dementia. Informed consent was obtained from all participants. The research was non-invasive and respected a level of activity practiced daily by the individuals, in accordance with the definition of a non-interventional study given by the CNRS bioethical office.

2.2. Procedures

The volunteers were tested successively in two experimental conditions: one in which they walked by pairs but separately (condition Walking Separately: WS) and the other in which they walked with a box they carry together by two lateral handles (condition Collective Transport: CT). The mass of the box was 13.41 kg and its size was 0.40x0.40x0.28 m (Length × Width × Height). A single trial was performed in the WS condition and three trials in the CT condition (i.e. CT1, CT2, CT3). During each trial, the volunteers had to walk at spontaneous speed along a 13 m-long walkway.

2.3. Data acquisition

Thirteen optoelectronic (11 MX3 and 2 TS40) video cameras (Vicon®, Oxford) were used to acquire the kinematic data. Forty-two markers were placed on bony landmarks and on the navel of each volunteer, according to Wu et al. (2002, 2005). Following Ackerman and Seipel (2014), in order to compare the locomotor pattern of individuals walking loaded and unloaded, we analyzed the kinematic data of the two individuals and the load separately, i.e. we considered three separate systems. The calibrated volume (30 m³) was set in the middle of the walkway in order to record the walking patterns at a stable state walking (i.e. to exclude the acceleration and deceleration phases at the beginning and at the end of each trial). To allow the kinematic analysis, the volunteers and the box were reconstructed with the software Nexus© 1.8.5 (Fig. 1).

Table 1
Characteristics of the subjects: mean (standard deviation).

	Age (yr)	Size (m)	Mass (kg)
Subject 1 (S1)	25.40 (4.72)	1.77 (0.07)	74.78 (9.00)
Subject 2 (S2)	25.30 (2.71)	1.77 (0.05)	74.54 (12.38)

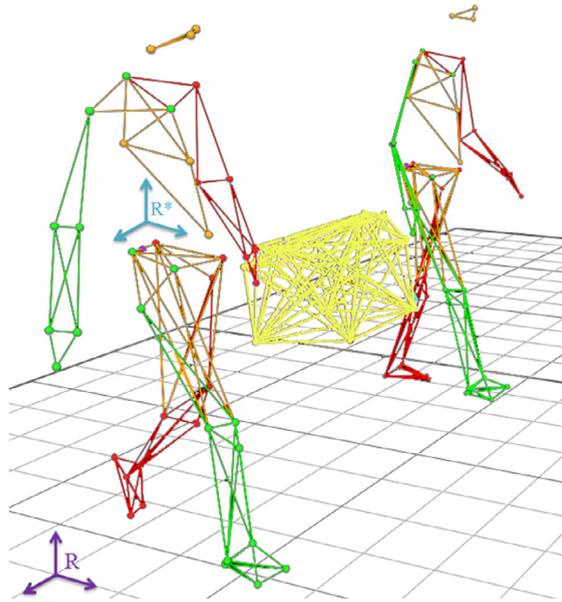


Fig. 1. Example of a reconstruction of the participants and the box they carry on Nexus. The sampling frequency was set at 200 Hz (filtered by a 4th order Butterworth filter and a 5 Hz cut frequency). The precision of the optoelectronic system was 1 mm for 1 m. The points correspond to the locations of the markers placed on the body according to De Leva’s model (De Leva, 1996). The R* referential (segments coordinate system) is represented in blue and the R referential (external coordinate system) in purple. The left side of the body is represented in red, the right side in green, the head, trunk and pelvis in orange and the box in yellow. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

2.4. Computed parameters

2.4.1. Inverted Pendulum System and external work

The Inverted Pendulum System (IPS) model allows us to evaluate the pendulum-like behavior of the CoM of each volunteer in the WS and CT conditions. The De Leva’s anthropometric tables (1996) allowed us to estimate the mass, the center of mass position CoM_i and the radius of gyration of each segment. The global CoM of each volunteer was then computed from the CoM_i of their segments.

Sine wave: To record at least one gait cycle for each individual, a walking cycle was defined as the interval between two heel strikes of the same leg. One gait cycle thus consisted of two steps. Following Ackerman and Seipel (2014), we modeled the vertical motion of the CoM along time in the sagittal plane as a sine function.

The amplitude ($A = \frac{Z_{max} - Z_{min}}{2}$; in meter), angular frequency ($\omega = \frac{2\pi}{T}$ in $rad.s^{-1}$, with T the period) and phase shift ($\varphi = \tau * \frac{2\pi}{T}$ in radian, with τ the time shift) of the vertical displacement of the CoM allowed us to determine the function (see Castillo et al., 2014):

$$Z(t) = A \sin(\omega t + \varphi) \tag{1}$$

The difference between the vertical displacement of the CoM and the adjusted sinusoidal function was assessed by the Root Mean Square Error (RMSE). The RMSE was normalized by the amplitude (RMSE/A), so that we only considered the error due to the alterations of the periodic signal.

External work: We computed the kinetic and potential energies, as well as the external works on the antero-posterior, medio-lateral and vertical axis.

W_{kf} is the positive work to accelerate the CoM forwards, calculated as the sum of the increments of the forward kinetic energy (E_{kf} , computed on the antero-posterior axis) along the time curve with:

$$E_{kf} = \frac{1}{2} m \vec{V}_f(t)_{/R}^2 \tag{2}$$

where m is the mass of the individual and $\vec{V}_f(t)_{/R}$ is the linear forward velocity of the CoM in the Galilean reference frame (R).

W_{kh} is the positive work to accelerate the CoM on the medio-lateral and antero-posterior axis, calculated as the sum of the increments of the horizontal kinetic energy (i.e. the medio-lateral kinetic energy E_{kml} , computed on the medio-lateral axis, plus the forward kinetic energy E_{kf} .) along the time curve with:

$$E_{kml} = \frac{1}{2} m \vec{V}_{ml}(t)_{/R}^2 \tag{3}$$

where $\vec{V}_{ml}(t)_{/R}$ is the linear medio-lateral velocity of the CoM in the Galilean reference frame (R).

W_v is the positive work to move the CoM against gravity, calculated as the sum of the increments of the vertical kinetic energy

(E_{kv} , computed on the vertical axis) plus the potential energy (E_{pot} , computed on the vertical axis) along the time curve with:

$$E_{kv} = \frac{1}{2} m \vec{V}_v(t)^2 / R \quad (4)$$

and

$$E_{pot} = mgh/R \quad (5)$$

where $\vec{V}_v(t)_{/R}$ is the linear vertical velocity of the CoM in R, $g = 9.81 \text{ m.s}^{-2}$ the module of the acceleration vector due to gravity and $h_{/R}$ the vertical height of the CoM position in R.

$W_{ext(sagittal)}$ and $W_{ext(3D)}$ are the positive external work to raise and accelerate the CoM in the sagittal plane and in the three directions of the space (i.e. mediolateral, anteroposterior and vertical axis), respectively. They are computed as the sum of the increments of the external mechanical energy ($E_{ext(sagittal)}$ and $E_{ext(3D)}$) along the time curve (Bastien et al., 2016; Burdett, Skrinar, & Simon, 1983) with:

$$E_{ext(sagittal)} = E_{pot} + E_{kv} + E_{kf} \quad (6)$$

$$E_{ext(3D)} = E_{ext(sagittal)} + E_{kml} \quad (7)$$

We also computed the energy recovered through the pendulum-like oscillations of the CoM (RR, called recovery rate in Fumery, Claverie, Fourcassié, & Moretto, 2018). This metric has been proposed by Cavagna, Thys, and Zamboni (1976) as an indicator of the amount of energy transferred between the potential and the kinetic energy of the CoM due to its pendulum-like behavior: the closer the value of RR to 100%, the more consistent the locomotor pattern is with the IPS model (Bastien et al., 2016; Cavagna et al., 1963; Fumery et al., 2018; Gomenuka, Bona, da Rosa, & Peyré-Tartaruga, 2014; Willems, Cavagna, & Heglund, 1995).

For the sake of comparison with the data of the literature, we first computed a value of the energy recovered for the sagittal plane only (RRs, Eq. (8)) and then, since we had the positions of the markers in 3D, for the three dimensions of the space (RR3D, Eq. (9)).

$$RRs = 100 \frac{W_{kf} + W_v - W_{ext(sagittal)}}{W_{kf} + W_v} \quad (8)$$

$$RR3D = 100 \frac{W_{kh} + W_v - W_{ext(3D)}}{W_{kh} + W_v} \quad (9)$$

Here, we assumed that the friction forces at the joints and at the ground contacts can be neglected. In this condition, the system is submitted only to conservative forces and thus the variation of the external mechanical energy is null and the system is conservative. In this case, the system could have a 100% recovery and all potential energy would be converted into kinetic energy.

2.4.2. Internal work

In order to take into account the coordination between all body segments we determined the internal work by considering each individual as a poly-articulated system consisting of 16 segments.

Following the assumption of a conservative PAM, the internal work (W_{int}) was computed in 3D as the sum of the increments of the $E_{int,k}$ along the time curve with:

$$E_{int,k} = \frac{1}{2} \sum_{i=1}^{16} (m_i \vec{V}_i(t)^2 / R * + m_i K_i \times 2 \vec{\omega}_i^2 / R *) \quad (10)$$

where m_i is the mass of the i^{th} segment, $\vec{V}_i(t)_{/R^*}$ the linear velocity of this i^{th} segment CoM in the barycentric reference frame (R^* , Fig. 1), K_i the radius of gyration around this i^{th} segment CoM and $\vec{\omega}_i^2_{/R^*}$ its angular velocity in the R^* reference frame (Duboy, Junqua, & Lacouture, 1994).

2.4.3. Total work

The total mechanical energy of the PAM (E_{tot}) was computed as follows in 3D in the R reference frame (Leboeuf & Lacouture, 2008; Moretto et al., 2016).

$$E_{tot} = E_{pot} + E_{kv} + E_{kf} + E_{kml} + E_{int,k} \quad (11)$$

Finally, since the cycle duration was longer in the CT than in the WS condition, in order to compare the two conditions we assessed the quantity of energy expanded by the volunteers and we normalized it per unit of distance. Each work (internal, external and total) was thus divided by the distance walked by the volunteers during one gait cycle.

2.5. Data analysis

The data were analyzed with Matlab R2016b© and R 3.4.3©. After checking for normality, a paired Student *t*-test was used to compare the parameters assessed in the WS condition and in the first trial of the CT condition. The changes in the three successive trials in the CT conditions (CT1, CT2 and CT3) were tested with a linear mixed model (GLMM) with trial number entered as a fixed factor and volunteer identity as a random variable. The threshold of statistical significance was set at 0.05.

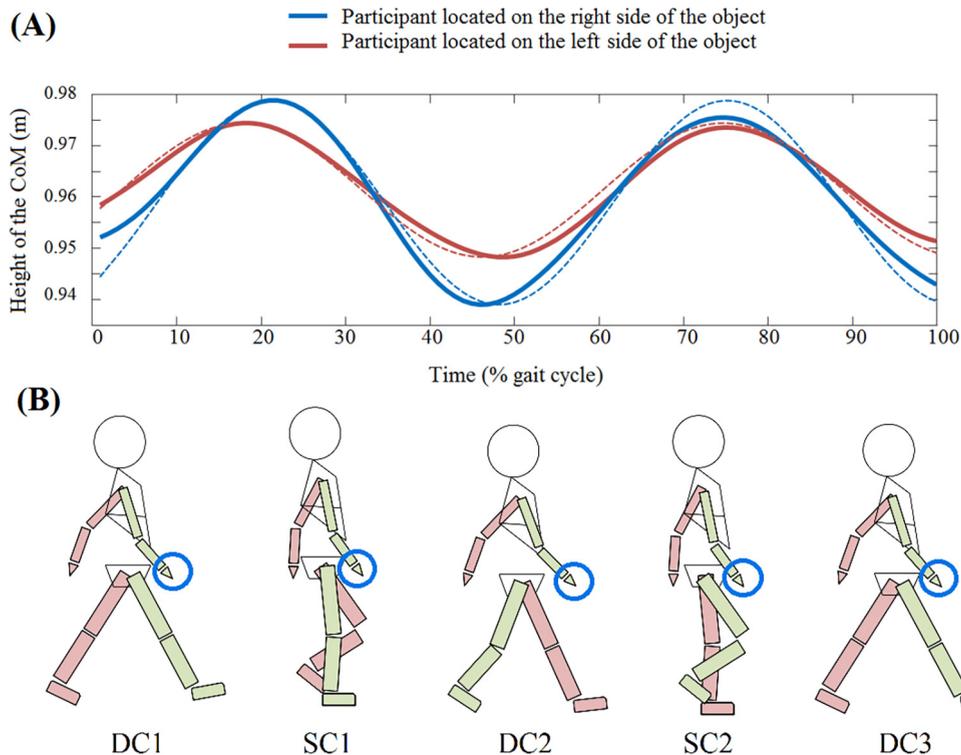


Fig. 2. (A) Example of the vertical displacement of the CoM over a walking cycle for a pair of participants carrying a box of 13.41 kg while walking at a speed of $1.29 \text{ m}\cdot\text{s}^{-1}$. The continuous lines correspond to the experimental results and the dashed lines to the fitted sinusoidal function. (B) An example of the PAM organization over the different phases (DC: double contact and SC: single contact) of the walking cycle in the WS condition. The carrier hand of the participant located on the right side of the object is circled in blue. The time cycle was normalized by considering the duration of the gait cycle of each participant.

3. Results

3.1. Center of mass trajectory

The CoM velocity (mean \pm s.d.) was $1.25 \pm 0.12 \text{ m}\cdot\text{s}^{-1}$ in the WS condition and 1.28 ± 0.17 , 1.36 ± 0.13 and $1.40 \pm 0.14 \text{ m}\cdot\text{s}^{-1}$ (CT1, CT2 and CT3 respectively) in the CT condition. There was no significant difference between WS and CT1 (Student t test: $t = -1.15$, $p = 0.26$). However, the CoM velocity was significantly different between the three trials in the CT condition (GLMM: $F_{2,40} = 29.27$, $p < 0.01$). It increased by 6.25% between CT1 and CT2 ($t = 5.03$, $p < 0.01$), by 9.38% between CT1 and CT3 ($t = 7.51$, $p < 0.01$) and by 2.94% between CT2 and CT3 ($t = 2.47$, $p = 0.02$).

Whether in the WS or CT condition, the vertical displacement of the CoM of the two individuals was sinusoidal (Fig. 2).

The amplitude of the CoM increased by 9.12% between the trial in the WS condition and the first trial in the CT condition (Fig. 3A, Student t test: $t = 2.07$, $p = 0.05$). Overall there was a significant increase of the amplitude of the CoM over the three trials in the CT condition (GLMM: $F_{2,40} = 4.20$, $p = 0.02$). The amplitude increased by 9.16% between CT1 and CT2 ($t = 2.82$, $p < 0.01$), but did not differ significantly between CT1 and CT3 ($t = 1.99$, $p = 0.05$), and CT2 and CT3 ($t = -0.83$, $p = 0.41$).

The RMSE was not significantly different between the trial in the WS condition and the first trial in the CT condition (Fig. 3B, Student t test: $t = -0.43$, $p = 0.67$). However, it was significantly different between the three trials in the CT condition (GLMM: $F_{2,40} = 6.57$, $p < 0.01$). The RMSE first increased by 63.5% between CT1 and CT2 ($t = 3.48$, $p < 0.01$) and then decreased by 29.2% between CT2 and CT3 ($t = -2.61$, $p = 0.01$). No significant difference in the RMSE was found between CT1 and CT3 ($t = 0.87$, $p = 0.39$).

3.2. Inverted Pendulum System

The energy recovered in the sagittal plane (RRs: Fig. 3C) increased from 58.74% in WS to 65.95% in CT1 (Student t test: $t = 2.44$, $p = 0.02$). However, there was no significant difference between the three trials in the CT condition (GLMM: $F_{2,40} = 1.99$, $p = 0.15$).

The energy recovered in 3D (RR_{3D}: Fig. 3D) also increased and raised from 58.45% in WS to 65.91% in CT1 (Student t test: $t = 2.50$, $p = 0.02$). In the same way as the RRs, there was no significant difference in the RR_{3D} between the three trials in the CT condition (GLMM: $F_{2,40} = 1.83$, $p = 0.17$).

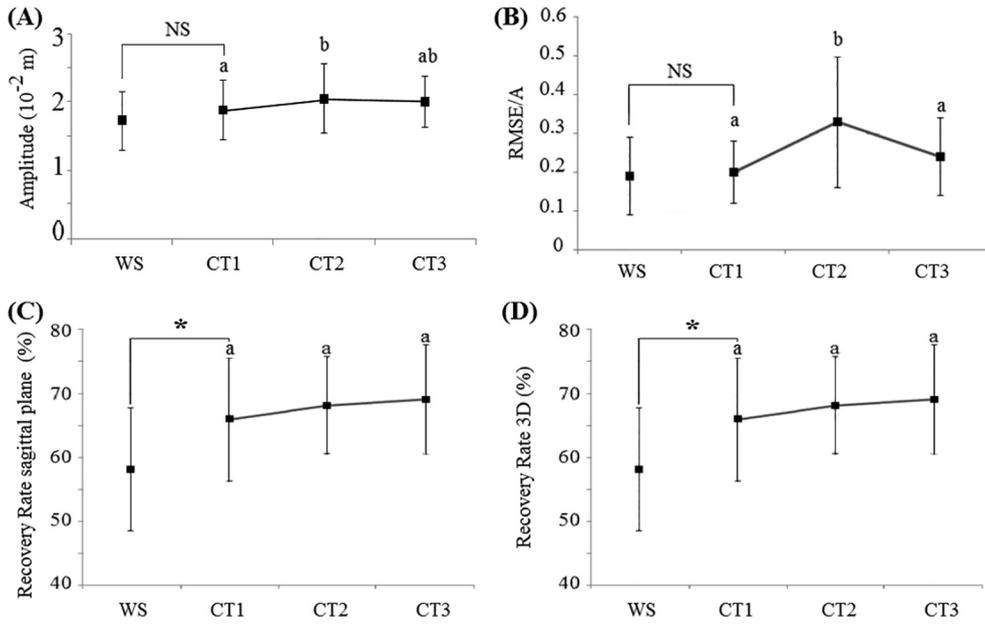


Fig. 3. Mean \pm s.d. of (A) the amplitude of the vertical displacement of the CoM, (B) of the dimensionless RMSE (RMSE normalized by the amplitude of the vertical displacement of the CoM), (C) of the recovery rate in the sagittal plane and (D) of the recovery rate in 3D, for the trial in the WS condition and for the three trials in the CT condition ($N = 20$ in all trials). For the CT condition the values of the bars bearing the same letter (a, b) are not significantly different (GLMM). NS = no significant difference and * = significant difference (paired t -test, $p < 0.05$).

3.3. Total mechanical work

The internal, external and total mechanical work, computed for the two poly-articulated systems, were not different between WS and CT1 (Fig. 4, Student t test: $t = -1.81$, $t = 1.09$ and $t = 0.42$ for W_{int} , W_{ext} and $W_{mechaTot}$, respectively, $p > 0.05$ in all cases). Overall, there was also no significant difference between the three trials in the CT condition for W_{int} (GLMM: $F_{1,40} = 1.07$, $p = 0.31$), W_{ext} (GLMM: $F_{1,60} = 0.24$, $p = 0.63$), and W_{Tot} (GLMM: $F_{1,40} = 0.01$, $p = 0.91$).

4. Discussion

The aim of our study was to test the hypothesis that the locomotor pattern of an individual walking while carrying a load with another individual remains as pendular and economical as when he is walking alone. This hypothesis was tested by using the IPS model associated with a PAM to assess the economy of the locomotor pattern. The IPS represents the ideal situation of a pendulum displacement of the CoM and is considered as a model of energy saving during walking (Donelan, Kram, & Kuo, 2002). The PAM

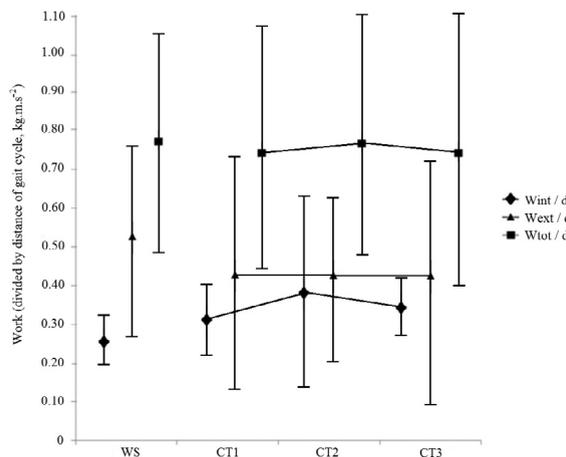


Fig. 4. Mean \pm s.d. of the total, internal and external mechanical work divided by the distance of the gait cycle for the trial in the WS condition and for the three trials in the CT condition ($N = 20$ in all trials).

allowed us to compute the position of the CoM and to take into account the internal work (Moretto et al., 2016; Zatsiorsky & Seluyanov, 1983). To our knowledge, it is the first time that the economy of gait during collective load carriage in humans is investigated. Our work explores first the immediate adaptation of the individuals to load transport (WS vs CT1), then the adaptation to the task due to its repetition (CT1, CT2 and CT3).

When the RMSE and the amplitude of the vertical displacement of the CoM were compared between WS and CT1, no significant differences were found. The vertical displacement of the CoM of the individuals as a function of time in the two conditions thus followed the same sinusoidal pattern. These results are consistent with those of Holt, Wagenaar, Lafiandra, Kubo, and Obusek (2003) who found no significant difference in the amplitude of the CoM displacement for isolated individuals walking loaded (wearing a backpack) or unloaded.

To assess the consistency of the walking pattern with the IPS model, we computed the energy recovered according to Cavagna et al. (1977), i.e. in the sagittal plane only, and the energy recovered in the three dimensions of the space, RR_{3D} , to take into account the fact that the potential energy can be transferred in forward as well as in transverse kinetic energy.

The value of RR s we found in the WS condition (59%) is close to that found by Bastien et al. (2016) in unloaded Nepalese porters and untrained individuals, i.e. 61% for individuals walking at $1.4 \text{ m}\cdot\text{s}^{-1}$. Because the value of RR s increases in the CT condition compared to the trial in the WS condition, one can say that the walking pattern of the individuals was closer to a pendulum-like behavior when they were performing the collective load transport task than when they were walking separately. This result can be compared to that found by Heglund et al. (1995) in African women of the Luo tribe carrying loads on top of their heads. These authors found a RR s of 65% for unloaded women and a RR s of 68% for women carrying a load representing 10% of their body-mass (BM).

The values of RR_{3D} we found are very close to that found for RR s. Thus, one can conclude that the pendular behavior of the CoM is low in the frontal plane. Since this is observed in both the WS and CT conditions, one can assume that the walking pattern is not disturbed by the collective transport task, despite the physical link established between the two individuals. Finally, one should note that both RR s and RR_{3D} increase between WS and CT1, suggesting an adjustment of the individuals to the load carriage task. Thus, it seems that the additional efforts linked to the coordination between individuals in the frontal plane do not disturb the energy recovered by each individual.

When the individuals are considered as a poly-articulated system and the contribution of each body segment can be assessed, the total mechanical work can be computed. Our results show that the mechanical work (whether internal, external or total) did not change in CT1 compared to WS. Although Heglund et al. (1995) calculated mechanical work only in the sagittal plane, the values they found are comparable to ours for African women carrying loads of up to 20% of their body mass on top of their head. Our results are also close to those of Bastien et al. (2016) on individual Nepalese porters in which the changes in mechanical energy due to the lateral movements of the CoM were also neglected. In agreement with our findings these authors found that for individuals walking at a speed of $1.1 \text{ m}\cdot\text{s}^{-1}$ the mass-specific total work is independent of the load carried, although it decreases with increasing loads for higher speeds (W_{ext} is stable but W_{int} decreases) (Bastien et al., 2016).

When comparing the three successive trials in the CT condition we observed an increase in the speed of the CoM, which could be considered a result of immediate adaptation to the collective task. Indeed, this could correspond to a better motor control of the task, i.e. for the same economy in mechanical output, individuals performed the carriage task faster during the first ones trials of collective carriage. As in Holt et al. (2003), this increase was accompanied by an increase of the CoM amplitude. There was also a trend to increase for both the RR s and RR_{3D} (Fig. 3). The movements of the lower limbs could contribute to increase the pendulum like behavior of the overall CoM, and thus lead to a higher economy level.

Our study shows that the displacement of the CoM of an individual during the collective transport of an object follows the same sinusoidal pattern as that of an individual walking alone and unloaded. Moreover, during collective transport the pendular behavior of the CoM of the individuals increases, so that their locomotor pattern was more consistent with the IPS model. In parallel, we noted an increase in the speed and in the CoM amplitude during successive trials, which seems an immediate adaptation to the collective transport situation. It could be also interesting to complete this analyze with more trials, to observe a possible effect of training. Finally, when the external and internal work are considered in 3D, we found that, despite the physical link between individuals, the total mechanical cost of locomotion did not change when walking alone and when walking while transporting an object with another individual. Our results are in accordance with the literature on load transport by single individuals and demonstrate the stability and economy of the locomotor pattern during load transport in general. As a caveat however, one should note that the object carried by the individuals in our experiment was relatively light and that one does not know whether the same results would be observed with heavier objects. In addition, a study of the metabolic cost and efficiency (Minetti, Formenti, & Ardigo, 2006) associated with collective load carriage could be helpful to complement the mechanical analysis presented here.

Today, carriage tasks are increasingly appearing as training exercises to improve physical capacities, e.g. in CrossFit training by team. Our study provides a better understanding of the effects of collective load carriage between two humans on locomotion and could be useful for improving the design of this type of training exercises. Our results could also be used for the conception of robots especially designed to assist humans (Cobot) in achieving difficult and strenuous tasks.

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Declaration of Competing Interest

The authors do not have to disclose any financial or personal relationships with other people or organizations that could inappropriately influence (bias) their work.

Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.humov.2019.05.012>.

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