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Original article

Relationship between limbs anthropometrical characteristics and energy expenditure during arm cranking and leg cycling unloaded exercises

Existe-il des relations entre la dépense énergétique lors d'exercices de pédalage sans charge des membres inférieurs et supérieurs et les caractéristiques anthropométriques de ces membres ?

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Abstract

Purpose. – The purpose of this study was to examine the relationships of VO_2 during unloaded arm cranking and leg cycling exercises to respectively relevant upper and lower limbs anthropometrical characteristics.

Method. – Fifteen males completed a 5-min unloaded bout on an arm crank ergometer (60 rpm) and a cycle ergometer (90 rpm). VO_2 corresponding to each unloaded exercise (VO_2 unload), body mass, lengths, and circumferences of upper and lower limbs were measured.

Results. – Upper limbs cranking showed a significantly lower ($P < 0.001$) VO_2 unload than lower limbs cycling (499.0 ± 56.5 and $981.6 \pm 126.0 \text{ ml min}^{-1}$). Moreover, upper and lower limbs VO_2 unload values were significantly and positively correlated with circumferences, and length of upper and lower limbs, respectively, with highest correlations obtained between circumferences and VO_2 unload. The amount of VO_2 unload is then principally dependent (i) on the inertia of the limbs, which increased with the circumference of the limb and (ii) on the arm level, which increased with the length of the limb. On the other hand, body mass was not or less correlated with VO_2 unload. This result could be explained by the specificity of the unloaded exercise since only the limb muscles were activated, the entire body mass not being representative of the muscle mass activated.

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Résumé

Objectifs. – Le but de cette expérimentation était d'étudier les relations entre la dépense énergétique lors d'exercices de pédalage des membres supérieurs et inférieurs et les caractéristiques anthropométriques de ces membres.

Méthodes. – Quinze hommes ont réalisé cinq minutes de pédalage à vide sur un ergomètre à bras (60 rpm) et un cyclo-ergomètre (90 rpm). Ont été mesurées la consommation d'oxygène au cours des deux exercices ($\text{VO}_{2\text{sanscharge}}$), la masse corporelle et les longueurs et circonférences des membres supérieurs et inférieurs.

Résultats. – $\text{VO}_{2\text{sanscharge}}$ était significativement plus faible lors du pédalage membres supérieurs versus inférieurs ($499,0 \pm 56,5$ et $981,6 \pm 126,0 \text{ ml min}^{-1}$). De plus, les $\text{VO}_{2\text{sanscharge}}$ obtenues avec membres inférieurs et supérieurs étaient significativement et positivement corrélées respectivement avec la circonférence et la longueur des membres inférieurs et supérieurs, les meilleures corrélations étant entre circonférences et $\text{VO}_{2\text{sanscharge}}$. $\text{VO}_{2\text{sanscharge}}$ est donc principalement dépendant (i) de l'inertie des membres qui augmente avec leur circonférence et (ii) du bras de levier qui augmente avec leur longueur. En revanche, la masse corporelle n'est peu ou pas corrélée avec $\text{VO}_{2\text{sanscharge}}$. Ce résultat peut s'expliquer

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par la spécificité de l'exercice de pédalage sans charge puisque seuls les membres sont activés sans besoin d'aide supplémentaire du reste du corps.

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Keywords: Internal work; Upper limbs; Lower limbs; Length; Circumference

Mots clés : Travail interne ; Membres supérieurs ; Membres inférieurs ; Longueur ; Circonférence

1. Introduction

The oxygen consumption (VO_2) is dependent on the body mass of the subject during field cycling [11] and during cycle ergometer exercise (e.g. [2,7]). In field cycling, the subject's VO_2 is related to two principal forces: air resistance when travelling on flat terrain, and gravity when travelling uphill. So small cyclists have an advantage in climbing since the force necessary to put up gravity was reduced [11]. Significant positive and linear VO_2 –body mass relationships were also found during moderate cycle ergometer exercise in women [2] and in mixed women and men [7]. The amount of VO_2 during cycle ergometer exercise is dependent upon the load on the muscle and then on the mass of muscle at work [1]. Berry et al. [2] have explained the increases in VO_2 with body mass by an elevation in internal work during moderate cycle ergometer exercise. Internal work is defined as the amount of VO_2 required to simply rotate the limb at a given cadence without load, that is $\text{VO}_{2\text{unload}}$ [4]. So internal work induced an amount of VO_2 , which is added to the oxygen consumption to produce the external work. For healthy subjects, the heavier the subject, the higher the muscle mass, the higher the inertia of the limbs and then the higher the internal work [4]. This explanation was confirmed by Kamon et al. [6], who found that external loading added to the ankles during cycling increased the VO_2 . Specific relationships between $\text{VO}_{2\text{unload}}$ and some anthropometrical characteristics were established by two studies. They found linear, significant and positive relationships between $\text{VO}_{2\text{unload}}$ and thigh volume [2] or lower limb mass [4]. But the effects of body mass, length and circumferences of lower limbs on $\text{VO}_{2\text{unload}}$ were never established during cycling exercise. And upper limbs cycling movements were never related to specific upper limb anthropometrical characteristics. The scope of the present experimental study was therefore (i) to measure the VO_2 during unloaded cycling exercises realised by upper (UL) or lower (LL) limbs and (ii) to relate $\text{VO}_{2\text{unload}}$ with relevant global, UL or LL anthropometrical characteristics. These results would help us to determine which anthropometrical characteristics most affected $\text{VO}_{2\text{unload}}$ during cycling and why?

2. Method

2.1. Subjects

Fifteen healthy male volunteers not trained in UL and LL cycling exercises participated in this study. The mean values of age, height and body mass were 23.1 (standard deviation (S.D.) = 1.7) years, 179.5 (S.D. = 4.0) cm, and 74.9 (S.D. = 4.9) kg, respectively. The local ethics committee approved the experiment and the subjects gave their written consent.

2.2. Experimental protocol

Subjects completed a 5-min test in unloaded condition (i.e. without flywheel brake resistance) on each ergometer, separated by 10 min at least. Test order was randomised. Spontaneously freely chosen rates reported during arm cranking (60 rpm [10]) and leg cycling (90 rpm [9]) exercises were imposed and regulated by auditory pacing from a metronome.

2.3. Material and measurements

The leg cycling was conducted on a standard friction-loaded cycle ergometer (Monark 818E, Stockholm, Sweden) with the subject seated on the saddle. The saddle height was adjusted so that there was a slight bend of the knee joint when the pedal was at its lowest point.

The arm cranking was conducted with a standard friction-loaded arm cranking ergometer (Monark 881E, Stockholm, Sweden), with the subject seated on a chair. The ergometer was fixed to a table in front of the subject and adjusted in such a way that the crank axle was at shoulder level and the elbow was slight bending when the arm was fully extended on the arm crank [10].

VO_2 (ml min^{-1}) was measured from data obtained by a breath-by-breath automated metabolic system (Medical Graphics type CPX/D, St Paul, WI, USA) and averaged during the last minute of each unloaded exercise ($\text{VO}_{2\text{unload}}$). Prior to and after each experimental trial, the gas analysers were calibrated with known reference gas mixtures.

Measures of length (L, cm) and circumference (C, cm) of LL (thigh, calf) and UL (arm, forearm) were realised on the right side of the subject by the same investigator, using the anthropometric standardization reference manual [8]. Thigh (L_{thigh}) and calf (L_{calf}) lengths were determined from the midpoint of the inguinal ligament to the proximal edge of the patella and from the proximal end of the medial border of the tibia to the distal tip of the medial malleolus, respectively. Arm (L_{arm}) and forearm (L_{forearm}) lengths were determined from the superolateral aspect of the acromion to the posterior surface of the olecranon process of the ulna and from the most posterior point overlying the acromion to the most distal palpable point of the styloid process of the radius, with elbow flexed. LL (L_{LL}) and UL (L_{UL}) lengths were the sum of $L_{\text{thigh}} + L_{\text{calf}}$ and the sum of $L_{\text{arm}} + L_{\text{forearm}}$, respectively. Thigh (C_{thigh}), calf (C_{calf}), arm (C_{arm}) and forearm (C_{forearm}) circumferences were located to the midpoint of the thigh (midway between the midpoint of the inguinal crease and the proximal border of the patella), to the maximum circumference of the calf, to the midpoint of the arm (midway between the lateral projection of the acromion process of the scapula and the inferior margin of the olecranon process of the ulna) and to the maximum circumference of the forearm, respectively. What-

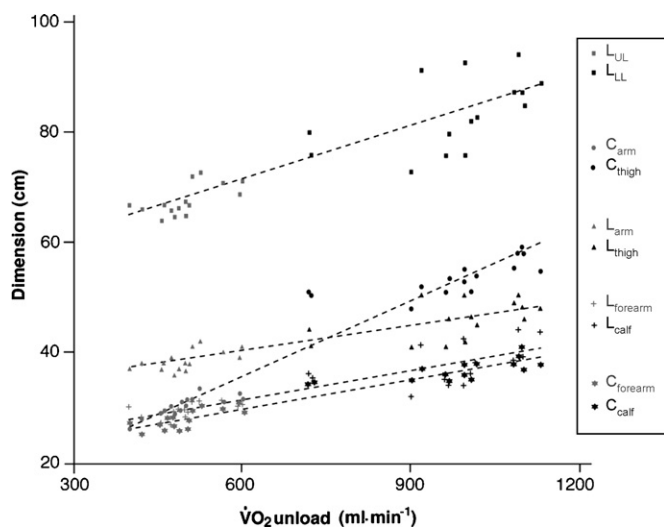


Fig. 1. Linear relationships between the oxygen consumption ($VO_{2\text{unload}}$) measured during unloaded arm cranking and leg cycling exercises and the mixed values of specific anthropometrical characteristics of upper and lower limbs (lengths of upper and lower limbs (L_{UL} and L_{LL}), circumferences of arm and thigh (C_{arm} and C_{thigh}), lengths of arm and thigh (L_{arm} and L_{thigh}), lengths of forearm and calf ($L_{forearm}$ and L_{calf}), circumferences of forearm and calf ($C_{forearm}$ and C_{calf}).

ever the measure, the tape was passed horizontally around the limb.

2.4. Statistics

Results are presented as mean \pm S.D. values. Correlations and simple linear regressions analyses were realised to examine all measured parameter relationships. And the significance of differences between measured parameters were tested with paired student's *t*-tests. Significance was set at the 0.05 level.

3. Results

LL and UL anthropometric data were presented in Table 1. All LL anthropometric values were significantly higher ($P < 0.001$) than UL anthropometric values (L_{LL} versus L_{UL} ; L_{thigh} versus L_{arm} ; L_{calf} versus $L_{forearm}$; C_{thigh} versus C_{arm} ; C_{calf} versus $C_{forearm}$).

Table 1
Subject's anthropometrical characteristics (mean, S.D.)

Upper	L_{arm} (cm)	$L_{forearm}$ (cm)	L_{UL} (cm)	C_{arm} (cm)	$C_{forearm}$ (cm)
Mean	38.5	29.3	67.8	29.7	27.7
S.D.	1.8	1.3	2.8	2.3	1.7
Lower	L_{thigh} (cm)	L_{calf} (cm)	L_{LL} (cm)	C_{thigh} (cm)	C_{calf} (cm)
Mean	46.0	37.9	83.7	53.6	36.6
S.D.	3.5	3.7	6.8	3.8	1.5

L_{UL} : length of upper limb; L_{LL} : length of lower limb; C_{arm} : circumference of arm; C_{thigh} : circumference of thigh; L_{arm} : length of arm; L_{thigh} : length of thigh; $L_{forearm}$: length of forearm; L_{calf} : length of calf; $C_{forearm}$: circumference of forearm; C_{calf} : circumference of calf.

Table 2

Correlation coefficients (r^2) between anthropometric variables and oxygen consumption during upper and lower limbs unloaded exercise (UL $VO_{2\text{unload}}$ and LL $VO_{2\text{unload}}$)

	Correlation coefficient	
	UL $VO_{2\text{unload}}$	LL $VO_{2\text{unload}}$
Body mass	0.2848 *	0.1727
L_{thigh}		0.286 *
L_{calf}		0.275 *
L_{LL}		0.2841 *
C_{thigh}		0.5371 **
C_{calf}		0.6399 ***
L_{arm}	0.359 *	
$L_{forearm}$	0.2833 *	
L_{UL}	0.4002 *	
C_{arm}	0.4663 ***	
$C_{forearm}$	0.5669 ***	

L_{UL} : length of upper limb; L_{LL} : length of lower limb; C_{arm} : circumference of arm; C_{thigh} : circumference of thigh; L_{arm} : length of arm; L_{thigh} : length of thigh; $L_{forearm}$: length of forearm; L_{calf} : length of calf; $C_{forearm}$: circumference of forearm; C_{calf} : circumference of calf. * Correlation is significant at $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$.

$VO_{2\text{unload}}$ were $499.0 \text{ ml min}^{-1}$ (S.D. = 56.5) and $981.6 \text{ ml min}^{-1}$ (S.D. = 126.0) during respectively UL and LL cycling. LL was found to elicit a significantly higher $VO_{2\text{unload}}$ ($P < 0.001$) than UL cycling.

UL $VO_{2\text{unload}}$ increased linearly and positively with $L_{forearm}$, L_{arm} , L_{UL} , C_{arm} , $C_{forearm}$, body mass. LL $VO_{2\text{unload}}$ increased also linearly and positively with L_{calf} , L_{LL} , L_{thigh} , C_{thigh} , C_{calf} while body mass were not correlated (Table 2, Fig. 1).

4. Discussion

Present $VO_{2\text{unload}}$ LL data were in accordance with the literature using an actual measurement of VO_2 during an unloaded pedalling exercise at high pedalling rate as 90 rpm [4,5]. On the other hand, $VO_{2\text{unload}}$ UL data were, at our knowledge, determined for the first time. $VO_{2\text{unload}}$ were significantly lower when the exercise was realised with the upper than the lower limbs. And in the same sense, all anthropometrical parameters of the upper limbs were significantly lower than those of the lower limbs. These results suggested that the anthropometrical characteristics of the moving limbs influenced the VO_2 during both arm cranking and leg cycling unloaded exercises. Present significant linear positive relationships between specific UL or LL anthropometrical characteristics and UL or LL $VO_{2\text{unload}}$ confirmed these results. But correlation coefficients were different according to the anthropometrical parameters.

The highest correlation between $VO_{2\text{unload}}$ values and anthropometrical characteristics was obtained with circumference parameters, these parameters best representing the mass of the limbs. The energy required for unloaded exercise, that is for the internal work, is only used for the movement of the limbs without resistance and not for external power output developed by the muscle of the limbs [4]. Thus, the amount of $VO_{2\text{unload}}$ is principally dependent on the inertia of the limb and then on

the mass of the limb. As a consequence, UL VO_2 unload was significantly lower (-49%) than LL VO_2 unload since UL circumference was significantly lower (-24 to -44%) than LL circumference. The circumference of distal segments seem to be the major factor influencing both UL and LL VO_2 unload since C_{forearm} and C_{calf} were very well correlated with respectively LL and UL VO_2 unload. This result confirmed the influence of the inertia on VO_2 unload since these distal segments were placed far from the axis of rotation and then have an important influence on the inertia.

Concerning the length's parameters, their significant positive influences on both UL and LL VO_2 unload are, to our knowledge, described for the first time. This could be explained by the specificity of the unloaded exercise since only the internal work influenced VO_2 . The internal work was positively influenced by the arm level of the limbs during cycling movement [12]. And these arm level increased positively with the length of the limb [3]. The energy dissipated against the internal work during both UL and LL cycling increases then linearly with UL lengths (arm, forearm) and with LL lengths (thigh, calf), respectively.

Even when all studies showed that VO_2 is dependent on body mass during submaximal cycling (e.g. [7,11]), present study found no (LL) or very low (UL) correlations between VO_2 unload and body mass. This result could also be explained by the specificity of the unloaded exercise. During LL unloaded cycling, only the LL muscles were activated in order to simply rotate the pedals. As a consequence, the mass of the entire body was not representative of the muscle mass activated. Concerning the UL unloaded cycling, the UL muscles were not the single muscles involved since the UL cycling movement necessitates the utilisation of back, shoulders and chest muscles [10]. The low but significant relationship between body mass and UL VO_2 unload

values illustrated the influence of some muscles not taking into account on the UL measurements.

To summarise, our results demonstrated that specific anthropometrical characteristics of the limbs recruited during unloaded cycling affected considerably the VO_2 , in contrast to the regular utilisation of the entire body anthropometrical characteristics.

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