

Research article

LEFT VENTRICULAR SYSTOLIC FUNCTION DURING TREADMILL WALKING WITH LOAD CARRIAGE IN ADOLESCENTS

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ABSTRACT

Backpack carriage occurs in day-to-day tasks and has applications in school, physical training, recreational activities and sports. Using metabolic cart and echocardiograph, this study determined and examined the effects of two different load carriages on left ventricular function during 30 min. of treadmill walking in healthy adolescent male subjects. Seventeen males (13.1 ± 0.5 yrs.) walked on a treadmill at a speed of $4 \text{ km} \cdot \text{h}^{-1}$, each carrying a load relative to his body mass at $333 \text{ gr} \cdot \text{kg}^{-1}$ body weight during one session and without weight during the other session. Significant ($p < 0.05$) differences were noted between the $333 \text{ gr} \cdot \text{kg}^{-1}$ body weight and the no weights with regard to: VO_2 13.6 ± 1.3 and $10.5 \pm 1.1 \text{ ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$; heart rate: 133.2 ± 7.1 and $121.4 \pm 5.6 \text{ beats} \cdot \text{min}^{-1}$; mean arterial blood pressure; 95.4 ± 4.3 and $87.5 \pm 3.8 \text{ mmHg}$ and systolic blood pressure 147.7 ± 7.0 and $129.8 \pm 7.1 \text{ mmHg}$ respectively. No significant differences were noted between the two exercises with regard to left ventricular function variables. This study suggests that in adolescents as in adults, the vasodilatation mechanism dominates during combined dynamic and isometric exercises. Thus, the opposing force to the left ventricular ejection is reduced which in turn does not change the left ventricular global function. In addition, the vasodilatation mechanism enables oxygen supply to the contracting muscles via aerobic energy pathways.

KEY WORDS: Echocardiography, oxygen uptake, systolic function, steady state, vasodilatation.

INTRODUCTION

Combined dynamic and isometric (such as backpack carriage to school) exercise is of great interest in Israel and other countries. Previous studies in normal adults and elderly showed that the effect of isometric stress on dynamic exercise varied widely (Homans et al., 1986; Sagiv et al., 1994; 2002). Isometric maneuver can be very demanding, due to the pressor response (Sagiv et al., 1985), and may increase after-load during backpack carriage which may affect left ventricular global performance

(Miller et al., 1987). These studies confirmed that isometric stress augments heart rate and after-load and changes heart volumes and ejection fraction. This in turn, influences the interplay between stroke volume and heart rate. In addition to the isometric stress imposed during backpack carriage, other potential factors contributing to this variability include walking speed and grade (Sagiv et al., 2000).

The mechanics of ventricular contraction include the concept of the inter-relationship between force, length, velocity and time (Weber and Janicki,

1980). The extent of myocardial fiber shortening is a reflection of interaction between initial fiber stretch (preload), the load opposing shortening (after-load), and intrinsic contractile state (Weber and Janicki, 1980). Based on this relationship, several researches have proposed the end-systolic pressure / volume relationship as a measure of left ventricular contractility, which is independent of preload (Weber and Janicki, 1980; Sagawa, 1981).

Walking and carrying different backpack workloads and the redistribution of body mass during adolescence (Jensen and Nassas, 1988) may influence left ventricular systolic function. This coupled with the increase in metabolic demands on adolescents may impose excessive demands on left ventricular function. We hypothesized that adolescent subjects would not be able to increase left ventricular contractility as much as young adults. Thus, the purpose of the present study was to determine and examine the effects of different loads on left ventricular function in healthy adolescent's male subjects.

METHODS

Subjects

Seventeen healthy adolescent males volunteered for this study. All were judged free of coronary artery disease by clinical history, absence of major risk factors, and graded normal treadmill exercise test up to peak VO_2 , utilizing the Bruce protocol (Bruce et al., 1973). A written informed consent was obtained from each subject's parents, which was approved by the Clinical Science Center Committee on Human Subjects.

Procedure

Each subject reported three times to the laboratory. The first session was devoted to determining peak oxygen uptake, applying the Bruce protocol (Bruce et al., 1973) on a treadmill. The test was terminated by the following criteria: a) levelling of or no further increase in VO_2 with increasing work rate, b) attainment of the age predicted maximum heart rate, c) respiratory exchange ratio > 1.1 , and d) when the subject could not keep up with the load. Values for VO_2 reported were averaged from the last 10 sec of effort. Following 30 min of recovery from the peak oxygen uptake test, the subjects walked on motor-driven treadmill for 10 min at a speed of $4 \text{ km}\cdot\text{h}^{-1}$ while carrying a backpack with a 10 kg load, in order to accustom the adolescents to the study protocol. During the second and third testing sessions following resting measurements, adolescents performed a continuous treadmill walk at a constant speed of $4 \text{ km}\cdot\text{h}^{-1}$ for 30 min. one

session without load carriage and the other session carrying a backpack with load relative to the subject's body mass at $333 \text{ gr}\cdot\text{kg}^{-1}$ body weight at approximately 30% of body weight as suggested earlier (LaFiandra et al., 2003). The order of the different testing loads was balanced over subjects.

Oxygen uptake was measured for 5 min at rest and throughout the 30 min. effort by breath-by-breath open-circuit indirect calorimetry (Medical Graphics St. Paul, MN) metabolic cart. The metabolic cart was calibrated before each test with known primary standard quality gasses. Electrocardiogram and heart rate were continuously monitored during exercise. Blood pressure was monitored using a standard sphygmomanometer cuff and stethoscope. Blood pressure measurements were taken each five minutes throughout the test. The last measurement is the one presented in the table.

Echocardiographic data processing

Two-dimensional echocardiographic and M-mode images were performed at rest and following exercise utilizing Vingmed 725 Sonotron and Sony recorder equipped with 2 and 3 MHz transducers. The diameters of the aorta were determined by two-dimensionally directed M-mode. The left atrium was measured from the parasternal long-axis view. At rest, left ventricular end-diastolic and end-systolic diameters and intraventricular septum and left ventricular posterior wall thicknesses were measured from the parasternal long and short-axis views as well as from 4 and 5 chamber views, just below the mitral valve level, according to the recommendations of the American Society of Echocardiography (Teichholz et al., 1976). Immediately following exercise, due to the short time available, measurements of left ventricular volumes and ejection fraction were determined by Simpson's rule (Van Rossum et al., 1988), from apical 4 chamber view. All echocardiographic studies were performed with the subjects in the standing position at rest, and within 30 s from stopping exercising. The probe was held by hand and directed to a marked point from which resting data were obtained, while the subject was in the standing position without motion.

The beam was directed to the aortic valve outflow tract in the 5-chamber view, or from the supersternal approach for those subjects in whom adequate imaging of 5-chamber or parasternal long axis views was not obtained.

To assess the objectivity of the echocardiographic readings, all recordings were evaluated by two independent experts who were blinded to the load condition. The lowest correlation ($r = 0.89$) was found for inter-observer reliability on

Table 1. Subjects' (n = 17) physical characteristics, echocardiographic and hemodynamic measurements at rest. Data are means (\pm SD).

Variables	
Age (years)	13.0 (1.0)
Weight (kg)	40.3 (4.8)
Height (m)	1.55 (.04)
Aortic valve diameter (cm)	1.72 (.15)
Body surface area (m ²)	1.4 (.2)
Left ventricular posterior wall (mm)	7.0 (.8)
Intraventricular septum thickness (mm)	7.3 (.8)
Left ventricular mass (g)	109.0 (14.7)

end diastolic volume. All other reliability coefficients were higher than 0.92.

Calculations

At rest and during exercise cardiovascular variables were computed as follows:

Stroke volume was the difference of left ventricular end diastolic volume - end systolic volume.

Cardiac output was determined as the product of heart rate and stroke volume.

Total peripheral resistance was calculated as: (mean arterial blood pressure x 80)/cardiac output.

Ejection fraction = [(end diastolic volume - end systolic volume)/ end diastolic volume] x 100%.

End-systolic pressure volume ratio = Cuff-determined systolic blood pressure/left ventricular end-systolic volume.

Mean arterial blood pressure = [(systolic pressure - diastolic pressure)/3 + diastolic pressure].

Statistical analyses

The responses of all the variables during exercise with 333 gr·kg⁻¹ body weight and without weight, were compared with one-way analysis of variance design. A level of P < 0.05 was required for statistical significance. If F ratio was significant, a *post-hoc* Tukey 2 test was used when appropriate to perform single degree of freedom comparisons.

RESULTS

All subjects completed the study without difficulties or abnormal symptoms, dysrhythmias, or electrocardiographic responses. Mean descriptive data for the subjects are presented in Table 1.

Table 2 presents mean values for echocardiography and hemodynamic measurements. From rest to the two different work-loads: without weight and with 333 gr·kg⁻¹ subjects showed significant (p < 0.05) increases in heart rate, cardiac

Table 2. Hemodynamic responses and echocardiographic measurements at rest and at loads of 333 gr·kg⁻¹ and no weights. Data are means (\pm SD).

VARIABLES	REST	333 gr·kg ⁻¹	NO WEIGHTS
HR (beats·min ⁻¹)	85.4 (9.1)	133.2 (7.1) ‡	121.4 (5.6) ‡
SV (ml)	54.2 (6.7)	53.3 (5.8)	56.1 (5.0)
Q (l·min ⁻¹)	4.6 (.4)	7.1 (1.1) ‡	6.8 (1.2) ‡
EDV (ml)	85.6 (4.4)	93.1 (3.2) ‡	95.4 (6.0) ‡
ESV (ml)	31.4 (3.2)	39.8 (3.2) ‡	39.3 (2.8) ‡
EF (%)	63.3 (5.0)	57.3 (5.1) ‡	58.8 (5.2) ‡
P/V (ratio)	3.3 (.6)	3.7 (.8)	3.3 (.7)
SBP (mmHg)	102.1 (7.0)	147.7 (7.0) ‡	129.8 (7.1) *‡
DBP (mmHg)	66.4 (6.0)	69.3 (3.1)	66.4 (3.7)
MABP (mmHg)	78.3 (4.0)	95.4 (4.3) ‡	87.5 (3.8) *‡
TPR (dynes·s ⁻¹ ·cm ⁻⁵)	1362 (102)	1075 (99) ‡	1030 (76) ‡
VO ₂ (ml·kg ⁻¹ ·min ⁻¹)	3.1 (.6)	13.6 (1.3) ‡	10.5 (1.1) *‡
VO ₂ (% of VO _{2max})	.07 (.01)	31.4 (5.7) ‡	24.2 (4.7) *‡

Abbreviations: HR = Heart Rate, SV= Stroke Volume, Q = Cardiac output, EDV = End Diastolic Volume, ESV = End Systolic Volume, EF = Ejection Fraction, P/V = SBP/ESV, SBP = Systolic Blood Pressure, DBP = Diastolic Blood Pressure, MABP = Mean Arterial Blood Pressure, TPR = Total Peripheral Resistance, VO₂ = Oxygen uptake.

* denotes p < 0.05 between work-loads.

‡ denotes p < 0.05 compared with rest.

Table 3. Subjects' echocardiographic and hemodynamic measurements at peak exercise. Data are means (\pm SD).

Variables	
Heart Rate (beats \cdot min ⁻¹)	198(6)
Stroke Volume (ml)	78.3 (4.4)
Cardiac output (l \cdot min ⁻¹)	15.5 (1.2)
End Diastolic Volume (ml)	108.4(6.0)
End Systolic Volume (ml)	30.2 (3.8)
Ejection Fraction (%)	72.2 (5.2)
SBP/ESV (ratio)	6.0 (.7)
Systolic Blood Pressure (mmHg)	180.4 (7.1)
Diastolic Blood Pressure (mmHg)	64.2 (7.7)
Mean Arterial Blood Pressure (mmHg)	102.9 (10.8)
TPR (dynes \cdot s ⁻¹ \cdot cm ⁻⁵)	527 (76)
VO ₂ (ml \cdot kg ⁻¹ \cdot min ⁻¹)	43.2 (4.0)
RER (ratio)	1.09 (.08)
LA (mM \cdot l ⁻¹)	10.7 (1.6)
ML (watts)	125.0 (10.6)

Abbreviation: SBP/ESV = Systolic Blood Pressure / End Systolic Volume.

output, left ventricular end diastolic volume, systolic and mean blood pressures and oxygen uptake, while ejection fraction and total peripheral resistance were significantly ($p < 0.05$) reduced. End-systolic pressure volume ratio, stroke volume, and diastolic blood pressure did not differ significantly across conditions, with and without weights. Significant differences ($p < 0.05$) were noted between the two exercises with regard to: heart rate, systolic blood pressure, mean arterial blood pressure and oxygen uptake. No significant differences were noted between the two exercises with regard to left ventricular function. Table 3 describes the subjects' values of echocardiographic and hemodynamic measurements at peak exercise (mean \pm S.D). Table 3 reveals that values of oxygen consumption are those attained at peak exercise. Since subjects could not keep up with the load none of the subjects complied with the other criteria set for the termination of the test.

DISCUSSION

This study suggests that healthy adolescents responding to backpack load up to 333 gr \cdot kg⁻¹ body weight and no weights did not manifest an increase in left ventricular contractility, namely end-systolic pressure volume ratio and ejection fraction, consequent to a minor increase in after-load.

The oxygen consumption values as a percentage of VO_{2peak} were: 31.4% during the bout with weights and 24.2% during the exercise without weights. However, this does not reflect the real workload percentage. The approach of calculating percentage of submaximal effort while carrying a load used in another study (Epstein et al., 1988) was

incorrect. In that study the VO₂ achieved during submaximal isometric exercise was divided by values of VO_{2max} achieved during dynamic exercise without load, leading to a wrong conclusion as to what percentage of true work the subjects were performing. Thus, in the present study workloads expressed by VO₂ do not represent the real load performed by our subjects.

Stroke volume values were alike since left ventricular volumes were similar during the exercise with the 333 gr \cdot kg⁻¹ load and without the load carriage. This response can be attributed to the vasodilatation mechanism which kept left ventricular volumes and stroke volume during both exercise conditions at a low level with nearly the same values as at rest. The stroke volume response in the present study is in agreement to those reported previously, in which the lower cardiovascular responses to exercise in children may be attributed to their smaller heart size (Vinet et al., 2002; Turley and Wilmore, 1997).

Although the metabolic cost differed between the two exercises, the observed similarity in left ventricular volumes during both exercise conditions is due, at least partially, to the minor differences in diastolic, systolic and mean arterial blood pressures between conditions. In addition, the interaction of the opposing physiological influences of dynamic exercise (vasodilatation) and isometric exercise (vasoconstriction) resulted in lower values of total peripheral resistance compared to the resting and no weight bout values. This reduced total peripheral resistance, although not at the level of dynamic exercise, is in the same direction seen during dynamic exercise, thus, facilitating ejection. This response suggests that during isodynamic maneuver,

the physiological responses of the dynamic component mimic those of the isometric maneuver (Jackson et al., 1973).

Left ventricular contractility did not increase during both exercises from resting values. It seems that the minor increase in after-load did not force the left ventricle to augment contractility. This may be due to the force-length relation during the isovolumic phase. In that phase, for any given contractile state the ejecting ventricle contracts within the confines of its isovolumetric developed force-length relation. Therefore, the extent of shortening and end-systolic length is determined by the instantaneous course of systolic force and length and is quite independent of initial length and time of contraction (Weber and Janicki, 1980; Sagawa, 1981).

CONCLUSION

This study suggests that in well-trained adolescents, as in adults, the influence of the vasodilatation mechanism dominates during combined dynamic and isometric exercises, thus reducing the opposing force to the left ventricular ejection which in turn leaves the left ventricular global function unchanged. In addition, the vasodilatation mechanism enables oxygen supply to the contracting muscles via aerobic energy pathways. This has implications in sports and day-to-day tasks such as carriage of school backpack, training adolescents at a higher target training heart rate and thus increasing efficacy of overall functional capacity.

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KEY POINTS

- This study suggests that in adolescents as in adults, the vasodilatation mechanism dominates during combined dynamic and isometric exercises.
- Thus, the opposing force to the left ventricular ejection is reduced which in turn does not change the left ventricular global function.
- In addition, the vasodilatation mechanism enables oxygen supply to the contracting muscles via aerobic energy pathways.

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