Branko Škof*
Radoje Milić

STROKE VOLUME DYNAMICS IN MALE SUBJECTS OF DIFFERENT FITNESS LEVELS

DINAMIKA UTRIPNEGA VOLUMNA SRCA PRI MOŠKIH RAZLIČNE TELESNE PRIPRAVLJENOSTI

ABSTRACT

Stroke volume (SV) is well known as a routine clinical cardiodynamic measure. It represents the amount of blood ejected by the left ventricle in one beat. There is a certain lack of data describing SV dynamics in both sedentary people and recreational runners. Our aim in the present study was to evaluate both the stroke volume dynamics in males of different fitness levels and the relationship between the maximal SV value measured during graded exercise testing (GXT) on a treadmill and the SV value at $VO_{2\,max}$.

A sample of 100 healthy males voluntary participated in this study. According to the participants' different tested fitness levels (VO_{2max}) 57 individuals were selected and divided into two groups: (a) individuals with VO_{2max} values above 50 ml $O_2 \cdot min^{-1} \cdot kg^{-1}$ - (N = 33; High Group); and (b) individuals with VO_{2max} values less than 40 ml $O_2 \cdot min^{-1} \cdot kg^{-1}$ (N = 24; Low Group). All of the tests were performed in the Exercise Physiology Laboratory (University of Ljubljana, Faculty of Sport) with the Cosmed $K4b^2$ portable "breath by breath" system for spiroergometry on a Woodway EG6 motor-driven treadmill. The special GXT protocol for recreational runners was used. The Student t-test and χ^2 was used to evaluate possible differences between the two groups. The most important findings of the study showed that experienced recreational runners have a significantly higher Q: 26.1 ± 2.5 vs. 20.7 ± 4.1 l $\cdot$ min^{-1} ($p \leq 0.001$), a bigger SV: 173.8 ± 22.4 vs. 141.9 ± 24.1 ml $\cdot$ beat $^{-1}$ ($p \leq 0.001$), a higher SI: 88.9 ± 9.3 vs. 67.9 ± 7.2 ml beat $^{-1}$ m^{-2} ($p \leq 0.001$) than sedentary persons or less trained recreational runners. There are no differences in types of SV responses among subjects of different fitness levels.

Both groups reached the maximal SV at a practically identical level of test (57.4 ± 16.1% vs. 59.8 ± 14.2% VO_{2max}). Further, the patterns of the fall in SV according to VO_{2max} in both groups tested were similar (14.7 ± 5.7%

IZVLEČEK

Utripni volumen srca (SV) je rutinska klinična kardiodinamska mera. Podatki, ki opisujejo dinamiko utripnega volumna srca (SV) med obremenitvijo, so pomanjkljivi tako za neaktivno populacijo kot za rekreativne tekače. Namen pričujoče raziskave je bil oceniti dinamiko utripnega volumna srca pri moških z različnimi telesnimi sposobnostmi in odnos med maksimalnim utripnim volumnom, izmerjenim med stopnjevanim testom na tekoči preprogi (GXT), in njegovo vrednostjo na točki maksimalne porabe kisika ($VO_{2\,max}$).

V raziskavi je prostovoljno sodelovalo 100 zdravih nekadilcev. Glede na aerobno sposobnost (VO_{2max}) smo jih za potrebe te študije izbrali 57 in jih razdelili v dve skupini: (a) posamezniki z vrednostjo VO_{2max} > 50 ml O2 $\cdot$ $min^{-1} \cdot kg^{-1}$ - izkušeni rekreativni tekači (skupina HIGH) in (b) posamezniki z vrednostjo VO_{2max} < 40 ml O2 $\cdot$ $min^{-1} \cdot kg^{-1}$ - netrenirani oz slabo trenirani rekreativni tekači (LOW skupina). Vsi testi so bili opravljeni v Laboratoriju za fiziologijo športa (Univerze v Ljubljani, Fakultete za šport) na Woodway EG6 tekoči preprogi z uporabo prenosnega sistema za spiroergometrijo Cosmed $K4b^2$. Uporabili smo GXT protokol za rekreativne tekače.

Student t-test smo uporabili za ugotavljanje možnih razlik med skupinama. Statistično značilnost razlik smo sprejeli z napako α manjšo od 0.05.

Rezultati raziskave kažejo da se aerobno bolj sposobni rekreativci značilno razlikujejo od manj sposobnih. Imajo večji minutni volumen srca (Q): 26.1 ± 2.5 proti 20.7 ± 4.1 l $\cdot$ min^{-1} ($p \leq 0.001$); večji utripni volumen (SV): 173.8 ± 22.4 proti 141.9 ± 24.1 ml $\cdot$ utrip $^{-1}$ ($p \leq 0.001$) in višji indeks utripnega volumna (SI): 88.9 ± 9.2 proti 67.9 ± 7.2 ml $\cdot$ $utrip^{-1} \cdot m^{-2}$ ($p \leq 0.001$). Med posamezniki različne telesne pripravljenosti, ki so bili vključeni v našo raziskavo, ni razlik v dinamiki SV in tipu odziva SV na telesno obremenitev.

vs. 13.4 ± 5.9%). One may conclude that recreational running training has not reached the threshold (scope and/or intensity) at which qualitative changes in the cardiac function's effectiveness take place like they do with highly trained endurance athletes.

Key words: stroke volume, cardiac output, recreational runners, plateau

University of Ljubljana, Faculty of Sport, Gortanova 22, 1000 Ljubljana, Slovenia

Corresponding author:
Branko Škof, PhD
University of Ljubljana
Faculty of Sport
Gortanova 22
1000 Ljubljana
Slovenia
Tel.: + 386 1 520 77 00
E-mail: branko.skof@fsp.uni-lj.si

Obe skupini sta dosegli maksimalni utripni volumen na skoraj enaki stopnji testne obremenitve: 57.4 ± 16.1% proti 59.8 ± 14.2% VO_{2max}. Prav tako je zmanjšanje utripnega volumna (SV) glede na njegovo vrednost doseženo na točki največje porabe kisika, enak: 14.7 ± 5.7% proti 13.4 ± 5.9%.
Trening rekreativnih tekačev ni dovolj obsežen in intenziven, da bi vzpodbudil tudi kvalitativne adaptacije srčne funkcije, ki so značilne za mlade vrhunsko trenirane vzdržljivostne športnike.

Ključne besede: utripni volumen srca, minutni volumen srca, rekreativni tekači, plato

INTRODUCTION

Stroke volume (SV) is a well-known routine clinical cardio dynamic measurement. It represents the amount of blood ejected by the left ventricle in one beat. In a normal subject, SV at rest can be predicted by a model including variables such as ventricular end-diastolic dimension, ventricular contractility, afterload and preload (Robergs & Roberts, 1996).

Studies agree that highly trained endurance athletes are characterised by their superior cardiac functional capacity, i.e. a higher maximal stroke volume and cardiac output, compared with non-athletes (Rowland & Roti, 2004), but disagree over the findings on the dynamics or the type of change in stroke volume (SV) in people of different fitness levels.

Four main types of stroke volume responses to exercise have been reported in the literature: i) *plateau;* ii) *plateau with a drop;* iii) *plateau with a secondary increase;* and iv) *progressive increase* (Astrand, Cuddy, Saltin, & Stenberg, 1964; Higginbotham et al., 1986; Proctor et al., 1998; Rivera et al., 1989; Spina et al., 1993; Ferguson, Gledhill, Jamnik, Wiebe, & Payne, 2001; Ogawa et al., 1992; Ekblom & Hermansen, 1968; Gledhill, Cox, & Jamnik, 1994; Krip, Gledhill, Jamnik, & Warburton, 1997; Martino, Gledhill, & Jamnik, 2002; Warburton, Gledhill, Jamnik, Krip, & Card, 1999; Zhou et al., 2001).

Some studies show that during an acute bout of progressive upright exercise in a healthy adult person SV typically rises at low work intensities, then changes little ("plateaus" – types i and ii) to the point of maximum intensities – at subject exhaustion (Rowland, 2005; Astrand, Cuddy, Saltin, & Stenberg, 1964). The concept of a plateau in SV has mainly been attributed to a decrease in the diastolic filling time, as well as the systolic ejection time that occurs during exercise of increasing intensity (Higginbotham et al., 1986).

More recent investigations have reported that SV progressively increases to VO_{2max} (type iv) in certain highly trained athletes (Gledhill et al., 1994; Krip et al., 1997; Martino et al., 2002). The physiological mechanisms involved in an enhanced SV during exercise include enhanced diastolic filling due to increases in blood volume, left ventricular diameter, and ventricular compliance, enhanced systolic emptying due to increases in myocardial contractility and decreases in ventricular afterload (Vella & Robergs, 2004).

In most studies authors compare the SV dynamics in highly trained endurance athletes and *physically inactive individuals,* but little is known about whether regular recreational exercises, particularly those involving running, are sufficient to increase the efficiency of the cardiac function. Our aim in the present study was to evaluate:

i) The stroke volume dynamics in male subjects of different fitness levels (experienced recreational runners and beginners) and the relationship between the maximal SV value measured during graded exercise testing (GXT) on a treadmill and $VO_{2\,max}$.
ii) Types of stroke volume responses to exercise in male subjects of different fitness levels.

METHODS

Subject sample

The subjects were selected from recreational running groups that exercised under the expert guidance of qualified coaches and the auspices of the newspaper publisher Delo – Polet from

2005–2007). One hundred healthy and non-smoker volunteer male runners performed the initial testing which included a graded exercise test – GXT protocol (see below). Based on the VO2max consumption during the initial GXT protocol only 57 subjects were selected for further statistical analysis. They were divided into two groups based on their VO2max consumption value, i.e.: (i) subjects with less than 40 ml O2 · min-1 · kg-1 were included in the Low Group (n=24); and (ii) subjects with values above 50 ml O2 · min-1 · kg-1 were included in the High Group (n=33). Their basic characteristics are presented in Table 1. In the High Group the 31 subjects were regularly trained recreational runners with at least three years' running experience (6.4 ± 3.9 years on average). They had regularly participated in recreational running events for at least two years. They had joined the exercise group with the desire to improve their running form. On average, they were actively involved in sport 3.8 ± 2.1 hours/week and ran 38.5 ± 15.2 km/week. Conversely, subjects from the Low Group were inactive individuals who were included in organised training in order to change their »inactive/sedentary lifestyle« and improve their poor physical condition. Most of them were unable to run a few hundred metres without stopping.

Table 1: Basic information on the subjects; expressed in mean (± SD)

	High Group (n = 33)	Low Group (n = 24)
Age (year)	40.4 (8.9)	44.7 (9.1)
Body height (cm)	174.6 (8.3)	177.9 (7.7)
Body weight (kg)	72.2 (15.0)	87.9 (17.9)
BMI (weight / height^2)	23.6 (3.1)	27.8 (4.4)
BSA (m^2)	1.95 (0.13)	2.08 (0.15)
peak VO_2 (ml $\cdot$ kg^{-1} $\cdot$ min^{-1})	54.1 (3.8)	36.8 (3.3)

Legend: BMI = body mass index, BSA = body surface area

Measurement instruments

All exercise *(spiroergometry)* tests were conducted in the Exercise Physiology Laboratory (University of Ljubljana, Faculty of Sport) using a Cosmed K4b^2 portable "breath by breath" system and a Woodway EG6 motorised treadmill. A special GXT (graded exercise test) protocol for recreational runners was used. Maximal oxygen uptake ($VO_{2\,max}$) is widely recognised as the best single measure of aerobic fitness (Wasserman et al., 2005).

GTX Protocol:

All of the subjects performed an exercise stress test according to the Nowacki protocol. This is a graded treadmill exercise test for evaluating the *maximal oxygen consumption* or maximal *capacity of an individual* to perform *aerobic* work. The test with *direct ergospirometry* was performed using the *Cosmed K4B2* portable *breath-by-breath* analyser. We used a Hans Rudolph mask, telemetry, Woodway ELG 6 treadmill, Lifepack ECG monitor, and Polar S810 heart rate monitor. The test started with a 3 minute warm-up at a running speed of 5 km/h on a treadmill at a 0% incline for the inactive subjects and a speed of 7 km/h, on a treadmill at a 0% incline for the active subjects. We continued with a 3 minute run at a speed of 6 km/h for the inactive and 8 km/h for the active subjects on a treadmill on the same incline. After 3 minutes we increased the treadmill incline to 2% and then left it unchanged. After the minute had elapsed at the third level (a speed of 6 or 8 km/h, a 2% incline) the running speed increased by 1 km/h every two minutes. The test was performed without interruption until the appearance of objective or subjective reasons for the interruption thereof. The end of the test was followed by a further 5 minute walk at a speed of 2 km/h and a 0% incline during which we monitored the decline in oxygen consumption, ventilation and heart rate.

Cardiac output (Q) was calculated according to the method previously described by Stringer and co-authors (Stringer, Hansen, & Wasserman, 1997):

(1) $Q = VO_{2\ uptake} / [5.721 + (0.1047 \times \%\ VO_{2max})]$

Stroke volume (SV: ml · heart rate^{-1}) and *stroke volume index* (SI: ml · heart rate^{-1} · m^{-2}) were calculated according to the formulas below:

(2) SV = Q / HR (heart rate; beats · min^{-1})

(3) SI = SV / BSA (body surface area; m^2)

Stroke volume dynamics were recorded during each test and analysed according to previously published recommendations (Rowland, 2009).

In order to avoid fatigue-related effects on the test performance, we allowed no strenuous physical activity for 48 hours prior to the testing. We informed the participants about the procedures involved and the associated risks. Subsequently, the participants completed a routine health questionnaire and gave their written informed consent. The experimental protocol was approved by the Ethics Committee (University of Ljubljana, Faculty of Sport) and performed in accordance with ethical principles concerning human experimentation laid down in the Declaration of Helsinki.

Statistical methods

Statistical calculations were performed using SPSS Statistics 17.0. The results are presented as mean ± SD. The Student t-test and χ^2 test were used to evaluate any differences between the two groups. Probabilities of less than 0.05 were accepted as significant.

RESULTS

During the incremental running test subjects in the High Group achieved a running speed of 14.9 km · h^{-1} and 54.1 ml · kg^{-1} · min^{-1}, while subjects in the Low Group achieved a running speed of 11.7 km/h and an average of 36.8 ml · kg^{-1} · min^{-1} ($p \leq 0.001$). Their running speed at a measured VO_{2max} was 14.6 km · h^{-1} or 11.2 km · h^{-1} ($p \leq 0.001$), whilst the subjects in both groups achieved the same SVmax at almost identical heart rates – of 118 or 120 beat · min^{-1}. The running speed at SVmax did not differ between the groups (7.20 km · h^{-1} vs. 6.40 km · h^{-1}; $p \geq 0.05$).

Types of SV responses to exercise in male subjects of different fitness levels: Several types of SV responses are almost identical between both groups ($\chi^2 = 0.456$) (Table 2). Five well-trained recreational runners (15%) showed a significant exercise-induced decrease in their stroke volume value (SV) during the later phase of the test protocol (Δ SVmax – SV at $VO_{2max} \geq 20\%$).

Table 2: Types of SV responses (number and %) in male subjects of different fitness levels

Types of SV responses	High Group (n = 33)	Low Group (n = 24)
1 - plateau	6 (18.2%)	5 (20.8%)
2 - plateau with a drop (up to 20%)	21 (63.5%)	18 (75%)
3 - plateau with a secondary increase	0	0
4 - progressive increase	1 (3%)	1 (4.2%)
5 - plateau with a large drop (more than 20%)	5 (15%)	0

SV dynamics in male subjects of different fitness levels: These were manifested differently in the experienced recreational runners than in the sedentary people or less trained recreational runners. Well-trained runners have a higher Q: 26.1 ± 2.5 vs. 20.7 $l \cdot min^{-1}$ ($p \leq 0.001$), a greater SV: 173.8 ± 22.4 vs. 141.9 ± 24.1 $ml \cdot beat^{-1}$ ($p \leq 0.001$), a higher SI: 88.9 ± 9.3 vs. 67.9 ± 7.2 $ml \cdot beat^{-1} \cdot m^{-2}$ ($p \leq 0.001$) (Table 3).

Both groups reached the maximum SV at an almost identical level of individually measured values of $VO_{2\,max}$ (57.4 ± 16.1% vs. 59.8 ± 14.2% $VO_{2\,max}$; $p \geq 0.05$). In addition, the drop in SV (reached at $VO_{2\,max}$) was similar in both groups in view of the maximal SV value reached during the test (14.7 ± 5.7% vs. 13.4 ± 5.9%; $p \geq 0.05$) (Table 3).

Table 3: Stroke volume dynamics in male subjects of different fitness levels; mean (± SD)

	High Group (n = 33)	Low Group (n = 24)
HR_{max} ($beat \cdot min^{-1}$)	180.5 (8.6)	174.5 (7.5)**
VO_{2max} ($ml \cdot kg^{-1} \cdot min^{-1}$)	54.1 (3.8)	39.1 (3.8)***
Q_max ($L \cdot min^{-1}$)	26.1 (2.5)	20.7 (4.1)***
QI_max ($L \cdot min^{-1}$)	13.4 (0.8)	9.9 (1.1)***
SV_max ($ml \cdot beat^{-1}$)	173.8 (22.4)	141.9 (24.1)***
SI_max ($ml \cdot beat^{-1}$)	88.9 (9.3)	67.9 (7.2)***
SV at VO2max ($ml \cdot beat^{-1}$)	147.5 (15.2)	122.7 (21.9)***
SI at VO2max ($ml \cdot beat^{-1}$)	75.5 (6.9)	62.1 (5.8)***
HR at SVmax ($beat \cdot min^{-1}$)	118.3 (23.1)	120.0 (17.9)
% HRmax at SVmax (%)	65.5 (12.2)	68.9 (10.2)
% VO2max at SVmax (%)	57.4 (16.1)	59.8 (14.2)
Δ (SVmax – SV at VO2max) (%)	-14.7 (5.7)	- 13.4 (5.9)
% SVmax at VO2max (%)	85.3 (5.8)	86.5 (9.4)

Legend: HR = heart rate, Q = cardiac output, SV = stroke volume, SI = stroke volume index
The asterisks indicate significant differences between group values (*$P \leq 0.05$: **$P \leq 0.01$; ***$P \leq 0.001$)

DISCUSSION

The main findings of the study are:

a) Values of cardiac output (Q), stroke volume (SV) and stroke volume index (SI) in the experienced recreational runners are significantly higher than in their less active counterparts.

b) Regardless of fitness level, both subject groups showed a plateau in SV at the same intensity level – at the same % $VO_{2max.}$
c) The decrease in SV from the plateau value to the VO_{2max} value is the same in both subject groups and does not depend on an individual's fitness.
d) The predominant type of SV response is a plateau with a drop.

In the present study we compared Q and the SV response to incremental exercise to maximum in a group of well-trained, middle-aged recreational runners and a group of untrained or low-trained individuals. The results regarding the effectiveness of the cardiac function fully confirmed the findings of previous studies which indicate that highly trained endurance athletes are characterised by their superior cardiac functional capacity – a higher maximal stroke volume (SV) and cardiac output (Q) compared with non-athletes (Rowland, 2009).

The 20.7% higher Q_{max} and 18.5% higher SV_{max} in the experienced recreational runners in relation to the values for the second group of subjects is the consequence of a greater final value of left *ventricular volume* (LVED). Enhanced diastolic filling and subsequent enhanced contractility are responsible for the increased stroke volume in trained subjects (Gledhill, et al., 1994). It is important to recognise that the augmentation of cardiac output is extremely dependent upon preload reserve (Vella & Robergs, 2005). Differences in blood plasma volume and the extent of bradycardia in physically active vs. inactive individuals lead to a higher SV and Q, and subsequently enhanced aerobic power (VO_{2max}) and running efficiency.

It is generally accepted that during a gradual increase in training intensity the SV in untrained individuals steadily increases and reaches a plateau at 40 to 50% VO_{2max} (Astrand et al., 1964; Vella & Robergs, 2004), while in well-trained endurance athletes the SV keeps increasing until the progressive exercise workload ceases – or that the types of SV responses depend on an individual's *training* experience and/or physical *fitness level* (Gledhill et al., 1994; Krip et al., 1997; Martino et al., 2002; Zhou et al., 2001).

In the present study, the SV increased gradually in both groups and reached a plateau in SV_{max} at 57.4% or 59.8% VO_{2max}, at 118/120 beat · min^{-1} and between 48 and 55% of their maximum running speed while stress testing. There were no differences in the SV dynamics and type of SV response to exercise among the individuals with different fitness levels included in our study.

It is obvious that a progressive increase in SV to the maximal capacity can only be achieved by some highly trained athletes and that regular recreational exercise does not lead to similar qualitative changes in the efficiency of the cardiac function. This assumption has been partially confirmed by the results of a research study conducted by the authors to compare the SV response among groups of untrained young adults (VO_{2max} = 48.9 ml · kg^{-1} · min^{-1}), well-trained (VO_{2max} = 72.1 ml · kg^{-1} · min^{-1}) and elite runners (VO_{2max} = 84.1 ml · kg^{-1} · min^{-1}). They found that untrained individuals and well-trained runners reached a plateau in SV at around 40% VO_{2max}, whereas in elite runners it continues to increase until the maximum workload is reached (Zhou et al., 2001).

In the literature we find descriptions of four types of SV responses to a gradually increasing workload. Type 2 – a plateau with a drop is the predominant type of SV response to a gradually increasing workload (Ogawa et al., 1992; Proctor et al., 1998; Spina et al., 1993; Spina et al., 1992). According to those authors, a plateau with a drop is when the SV reaches its peak (maximum) value, followed by a slight decrease to within 20% (Figure 1).

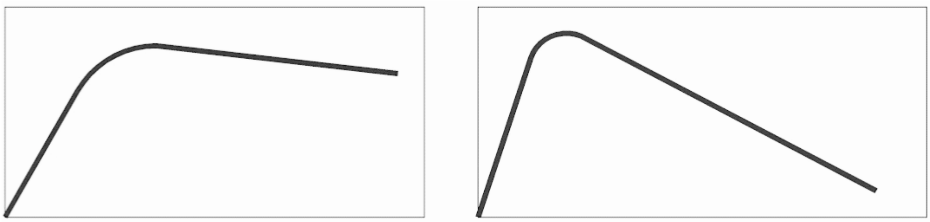

Figure 1: Two types of stroke volume responses to exercise: (left) Plateau and (right) Plateau with a significant drop.

The results of our study show that for some experienced adult recreational runners (in 15% of cases) after experiencing a plateau in SV a considerable decrease (more than 20%) from its maximum value to the point of an organism's maximal aerobic power (VO_{2max}) can be observed. This type of SV response could be renamed »Plateau with a significant drop«.

CONCLUSION

The results show that alongside quantitative differences (well-trained recreational runners have a greater SV, SI and Q than untrained individuals) there are no qualitative differences in the SV response to a gradually increasing workload between regularly training recreational runners and untrained adult individuals. One can conclude that recreational running training has not reached the threshold (scope and/or intensity) at which qualitative changes in the effectiveness of the cardiac function also take place.

More research may be needed to answer the question of what scope, intensity and type of training is required to increase SV during exercise at a gradually increasing intensity. It is also important to determine whether age *per se* affects the SV response to a gradually increasing workload.

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