Indian J Physiol Pharmacol 2013; 57(2) : 169–176

COMPARISON OF CARDIORESPIRATORY RESPONSES BETWEEN SURYA NAMASKAR AND BICYCLE EXERCISE AT SIMILAR ENERGY EXPENDITURE LEVEL

BISWAJIT SINHA*, TULIKA DASGUPTA SINHA, ANJANA PATHAK AND O.S. TOMER

Department of Physiology,
Defence Institute of Physiology and Allied Sciences (DIPAS),
DRDO, Ministry of Defence,
Delhi – 110 054

(Received on October 30, 2012)

Abstract : Surya Namaskar (SN), a popular traditional Indian yogic practice called "Sun Salutations", includes practice of twelve physical postures involving alternate backward bending and forward bending postures. The practice of twelve postures in succession makes one round of its practice. Many people practise it as part of their daily physical fitness regimen. No study is available to compare cardiorespiratory responses of SN with bicycle exercise (BE). 20 healthy Yoga instructors practicing various Yogic practices including SN since last 7-8 years participated in the study. They performed SN in the laboratory according to their customary daily practice routine. The subject also performed incremental load bicycle exercise test till exhaustion on their second visit for measuring their $\dot{V}O_2$ max. SN and BE were compared at three similar exercise intensity levels in terms of % of $\dot{V}O_2$ max. The exercise intensities were light (10-20% $\dot{V}O_2$ max), moderate (21-40% $\dot{V}O_2$ max) and high intensities (41-50% $\dot{V}O_2$ max). Heart rate at high work intensity was significantly higher in BE than SN (P<.001). Ventilation and carbon dioxide output were significantly higher in BE than SN at high exercise intensity (P<0.001). Overall, cardiorespiratory stress is less in SN than BE at similar work intensities.

Key words : surya namaskar, yogic practice, cardiorespiratory parameters, bicycle exercise

INTRODUCTION

Surya Namaskar (SN), a traditional Indian Yogic practice, involves performing twelve physical postures with alternate forward and backward bending (1). Practicing twelve physical postures of SN constitute one round of its practice. Each forward bending posture is practiced with exhalation to residual volume and backward bending

*Corresponding author : Dr. Biswajit Sinha, Scientist 'D' and Associate Professor, Department of Physiology, Institute of Aerospace Medicine, Indian Air Force, Old Airport Road, PIN: 560017, Mob: 0091-9342347428; Fax No. 0091-8025224659; Email: bsinha2001@yahoo.co.in

posture with inhalation to total lung capacity (TLC). The practice of SN has become very popular amongst people since its practice gives the benefit of aerobic exercise along with stretching of muscles. The deep breathing performed with each posture also renders some benefits of breathing exercise.

Bicycle exercise (BE), a very popular form of aerobic exercise and people practice in gym or at home. It is a dynamic exercise involving mostly the lower limb muscles unlike SN where almost all muscles of the body get involved. The SN is having both the static and dynamic components of the exercise; the variation of these components depends on the pace it is practiced. Slower practice will bring in more isometric component whereas faster practice will cause preponderance of dynamic components.

The energy cost and cardiorespiratory changes during the practice of SN in yoga trainees was reported first by the author (2). In another study, the author reported cardiorespiratory responses and energy cost of practicing two consecutive rounds of SN at slow and fast pace and also studied how much time is normally taken by Yoga Instructors when they performed SN at slow and fast pace (3). Mody Found out average work intensity for practicing one round of SN was 7.67 kcal/min during performance of 04 rounds of SN in 30 min, in trainees who underwent training in SN for 2 years. He observed that regular practice of SN may maintain or improve cardiorespiratory fitness as well as promote weight management (4). Bhavanani et al studied the comparative differential effects of six months of slow and fast SN training on cardiorespiratory parameters and muscle endurance in 42 school children aged 12-16 years. They concluded that the effects of fast SN training are similar to those of physical aerobic exercise with increased muscular endurance and power, whereas the effects of slow SN training are similar to those of Yoga training with fall in cardiovascular parameters toward lower normal values (5). Sasi et al reported increase of systolic blood pressure, peak expiratory flow rate, forced vital capacity and reduction of respiratory rate, heart rate and diastolic blood pressure in 115 school children aged 10-14 years after practice of 30-40 minutes of daily SN for 45 days (6). Hagins et al reported that yoga practice incorporating SN for more than 10 minutes may constitute some portion of sufficient intense physical activity and can improve cardiorespiratory fitness in unfit or sedentary individuals (7). Bhutkar et al evaluated the effects of regular practice of sun salutation on muscle strength, general body endurance and body composition (8). In another study, Bhutkar et al observed that regular SN practice improved cardiopulmonary efficiency in healthy adolescents and was beneficial for both males and females (9).

The exercise intensity of BE and other dynamic and static exercises of varying work intensity are well reported in the literature (10-13). It was hypothesized that cardiorespiratory responses of SN may be lesser as compared to BE at similar work intensity level. The reason for this premise was based on an earlier study by the author where they observed that oxygen demand of SN was increased by 10% from 1st round to 2nd round of practice and heart rate reserve by 2-10% from 1st round to 2nd round (3). Whereas in BE, the exercise intensity at a particular level of work intensity is exerted immediately unlike SN where the intensity of the exercise increases progressively from 1^{st} round to successive rounds. Further, isometric component is comparatively higher in SN than BE where there is preponderance of dynamic component. The cardiorespiratory responses to isometric and dynamic exercise vary in great deal. Muscle metaboreflex, central command and type of muscle contraction, size of the muscle mass involved and contraction intensity affect the cardiorespiratory changes during exercise. No scientific study is available where BE had been compared with SN at similar energy expenditure level. The present study was carried out with an aim to compare cardiorespiratory responses of SN with BE at three levels of work intensities in terms of percentage of $\dot{V}O_2$ max.

METHODS

Twenty young, clinically healthy male volunteers from various yoga centers located in and around Delhi, India participated in the present study. They were aged between 20-26 years and belong to the same ethnic group. Their height was 170.2±4.93 cm and body weight was 62.2±3.76 kg.

The participants were non-smokers, vegetarian and non-alcoholic. They were practicing 3 rounds of SN along with other Yogic practices 1 hour daily for last 7-8 years. The duration of performing 1 round of SN practice was 3 min and 40 s.

Participants gave their voluntary informed consent to participate in the study and undertake physiological monitoring on them during actual performance of SN in the laboratory. They were being familiarized with experimental set up and protocol before carrying out any physiological recording on them. The Institute Ethical Committee approved the protocol of the study.

The participants performed SN in a dimly lit, sound attenuated and thermoneutral room in the laboratory along with other yogic practices. It was ensured to provide adequate rest period in between two yogic practices by monitoring their cardio-respiratory parameters till it returned to the pre-yoga baseline values. They performed only one round of SN in the laboratory. The $\dot{V}O_2$ max of the subjects was measured on their second visit to the laboratory by an incremental load bicycle exercise test till exhaustion. The subjects first warmed up in bicycle at a workload of 25 watt for 3 min. This was followed by rest for 2 min and followed by exercise at an incremental workload starting from 25 watt till exhaustion. The subjects performed exercise at each workload for 3 min.

The ventilatory parameters recorded during SN and BE were oxygen consumption ($\dot{V}O_2$ in $L.min^{-1}$), carbon dioxide output ($\dot{V}CO_2$ in $L.min^{-1}$), minute ventilation ($\dot{V}_E$ in $L.min^{-1}$), tidal volume (V_T in $L.breath^{-1}$), breathing rate (f_R in $breaths.min^{-1}$). Exercise test assembly, Jaeger Oxycon Champion (Erich Jaeger, Germany), was used for measuring ventilatory parameters. Heart rate (HR- in beats per minute) was measured by using single lead ECG by putting three electrodes on anterior surface of the chest. Derived parameters like ventilatory equivalent for oxygen (EQO_2), ventilatory equivalent for carbon dioxide ($EQCO_2$) and oxygen pulse (O_2P) were calculated from the main parameters.

The oxygen consumption and other cardiorespiratory parameters during actual practice of SN and BE were measured in the laboratory. $\dot{V}O_2$ during SN practice was found to vary from as low as 0.420 $L.min^{-1}$ to 1.22 $L.min^{-1}$. The $\dot{V}O_2$ max of the subjects was 3.0±0.48 $L.min^{-1}$. Three exercise intensities of SN equivalent to an energy expenditure of 10-20% $\dot{V}O_2$ max, 21-40% $\dot{V}O_2$ max, 41-50% $\dot{V}O_2$ max % of $\dot{V}O_2$ max were worked out. These exercise intensities were described as light, moderate and high exercise intensity. The cardiorespiratory parameters at an energy expenditure of 10-20% O_2 max, 21-40% $\dot{V}O_2$ max, 41-50% $\dot{V}O_2$ max % of $\dot{V}O_2$ max during SN were found out. The cardiorespiratory parameters of BE equivalent to 10-20% $\dot{V}O_2$ max, 21-40% $\dot{V}O_2$ max, 41-50% $\dot{V}O_2$ max exercise intensities were also found out. SN and BE were then compared keeping energy expenditure or oxygen uptake level as constant.

The data was analyzed by using a statistical software package Statistica 8.0. First, data was checked for normality by Shapiro Wilks 'W' statistic. A repeated measure ANOVA with two factors was applied to analyze the data. First factor was exercise intensity which had three different levels like light intensity (10-20% $\dot{V}O_2$ max), moderate intensity (21-30% $\dot{V}O_2$ max) and high intensity (40-50% $\dot{V}O_2$ max). The other factor was type of exercise which again had two levels i.e. SN and BE. Posthoc analysis was done by applying Tukey HSD for intragroup and intergroup comparison.

RESULTS

The cardiorespiratory responses during SN and BE at similar low, moderate and high exercise intensities were shown in Table I. At high exercise intensity, HR was significantly higher ($P<0.001$) in BE than SN.

TABLE I: Comparison of cardiorespiratory parameters of SN and BE at low (10-20% $\dot{V}O_2$max), moderate (21-40% $\dot{V}O_2$max) and high (41-50% $\dot{V}O_2$max) exercise intensity.

Parameters	*10-20% $\dot{V}O_2max$*		*21-40% $\dot{V}O_2max$*		*41-50% $\dot{V}O_2max$*	
	SN (I)	*BE (II)*	*SN (III)*	*BE (IV)*	*SN (V)*	*BE (VI)*
HR	84.0±11.17	78.4±12.16	94.5±15.66^{a3,b3}	89.5±13.17^{b3}	96.6±13.39^{a3,b3}	108.6±11.96^{a3,b3,c3,d3,e3}
O_2P	5.38±2.53	5.49±1.73	7.84±2.12^{a3,b3,e3}	8.06±1.63^{a3,b3,e3}	13.04±3.79^{a3,b3,c3,d3}	11.40±2.77^{a3,b3,c3,d3,e3}
$\dot{V}CO_2$	0.350±0.93	0.359±0.11	0.600±0.15^{a3,b3,e3,f3}	0.577±0.12^{a3,b3,e3,f3}	0.900±0.17^{a3,b3,c3,d3}	0.999±0.26^{a3,b3,c3,d3,e3}
$\dot{V}_E$	12.57±3.86	14.59±3.24	18.87±5.41$_{a3,b3}$	19.76±3.15^{a3,b3}	25.52±4.63^{a3,b3,c3,d3}	28.74±6.01^{a3,b3,c3,d3,e3}
f_R	17.62±3.70	18.04±4.23	18.52±7.14	22.14±4.03^{a3,b3,c2}	23.23±4.29^{a3,b3,c3}	24.36±3.47^{a3,b3,c3}
$\dot{V}_T$	0.746±0.32	0.849±0.26^{a1}	1.093±0.33^{a3,b2}	0.921±0.24	1.129±0.26^{a3,b3,d1}	1.195±0.27^{a3,b3,d2}
EQO_2	29.78±6.03	35.43±6.09^{a3}	24.46±4.45^{a3,b3}	28.98±4.85^{b3,c3}	21.38±3.93^{a3,b3,c2,d3}	23.63±2.13^{a3,b3,d3}
$EQCO_2$	35.21±4.71	42.08±7.99^{a3}	30.84±3.07^{a3,b3}	35.87±6.56^{b3,c3}	28.03±2.11^{a3,b3,d3}	29.01±2.25^{a3,b3,d3}

Data presented are mean±SD. Analysis of data was done by two factors repeated measure ANOVA. Post-hoc analysis was done by Tukey HSD test for intragroup and intergroup comparison of SN and BE.
a- significantly different from SN (I) group
b- significantly different from SN (II) group
c- significantly different from SN (III) group
d- significantly different from SN (IV) group
e- significantly different from SN (v) group
The numbers 1, 2 and 3 denotes the level of significance at $P<0.05$, $P<0.01$ and $P<0.001$ respectively.

O_2P was significantly higher in SN than BE at high exercise intensity (P<0.001). At high exercise intensity $\dot{V}CO_2$ was significantly higher (P<0.001) in BE than SN.

Overall respiratory stress was found to be higher in BE than SN. At low and moderate exercise intensities $\dot{V}_E$ was not though significantly higher in BE as compared to SN, but it was significantly higher in BE than SN (P<0.001) at higher work intensity. f_R was found to be higher in BE than SN at three levels of work intensities but it showed significantly higher value in BE than SN at moderate work intensity only. At low exercise intensity, V_T was significantly lower in SN than BE (P<0.05). EQO_2, an estimate of required amount of pulmonary ventilation for 1 L of oxygen consumption, was significantly higher in BE than SN at low and moderate exercise intensities (P<0.001 in both cases). $EQCO_2$ measures the volume of air flowing in the lungs for removal of 1 L of CO_2 from it in a minute and it was significantly higher in BE than SN at both low and moderate intensity (P<0.001 in both the cases).

DISCUSSION

Cardiovascular response to exercise depends on various factors namely the type of exercise performed i.e. isometric or isotonic, size of the active muscle mass involved, intensity of the muscle contraction and duration of the exercise (13-15). Various investigators have shown that isometric muscular contraction induced increase in heart rate is dependent upon the level of force generated in the muscle during isometric contraction (16-17). Afferent nerves from working muscles are important in determining the heart rate and blood pressure responses to brief maximal static exercise (18). However, others have reported that cardiovascular response to static contraction is directly proportional to the size of the active muscle mass involved (19-20).

Yogic Asanas are characterized by presence of slow, static isometric component (21). The practice of SN involves both the static and dynamic components of the exercise. At lower exercise intensity, the higher HR in SN might have been due to an additional static exercise input over and above its dynamic component.

It is reported that imposition of a static exercise component on dynamic exercise increases submaximal heart rate response (22). At higher exercise intensity (41-50% $\dot{V}O_2$ max), HR was seen to be higher in BE than SN. HR regulating mechanisms are different during dynamic exercise from static exercise, with a predominant role of reflex drive from muscles (‘muscle metaboreflex’) in the former and of ‘central command’ in the latter. Activation of central neuronal circuits that occur during static or dynamic exercise or even before the start of the exercise is known as ‘central command’. Central command controls parasympathetic and sympathetic efferent activity that determines the cardiovascular responses during exercise. ‘Muscle metaboreflex’ drive arises from the muscle as a result of accumulation of local metabolites within the contracting muscles during exercise. This reflex is known as ‘exercise pressor reflex’ or ‘muscle metaboreflex’. During static exercise, the rise in arterial blood pressure occurs mainly via an increase in sympathetic activity to blood vessels due to 'muscle metaboreflex' activation, whereas the increase in HR occurs mainly through a decrease in parasympathetic activity to the sinus node due to 'central command (23). However, at variance, the other study pointed out that 'muscle metaboreflex' contributes to HR regulation during static exercise via sympathetic activation (24). Cardiovascular responses to moderate intensities of static contraction can be produced primarily by motor command, but both the motor command and muscle chemoreflexes contribute to cardiovascular responses at higher intensities of static exercise (25).

SN practice is not a sustained heavy intensity isometric muscle contraction to fatigue; it is a moderate intensity static contraction. The practitioners hold a particular posture for an average of 15-20 sec followed by transitioning into next posture by dynamic action of the muscles, thus causing cessation of isometric contraction phase. Muscle metaboreflex during SN is not powerful enough to cause an increase in heart rate either by increased sympathetic activity or reduced parasysmpathetic activity. Lower HR in BE as compared to SN at low and moderate exercise intensities might be attributable to strong metaboreflex drive from muscles as static contraction of muscles during SN is primarily responsible for autonomic control of HR than central command mediated increase in HR during dynamic exercise. In light static exercise, the heart rate increases much more than during dynamic exercise at the same oxygen uptake level (26).When exercise intensity has progressed into higher side, HR in BE has become more than SN. The higher HR at BE at high exercise intensity might have been resulted from increased central command resulting in higher sympathetic drive. This has surpassed the muscle metaboreflex mediated sympathetic or parasympathetic action of HR increase as seen in SN.

O_2P indicates the myocardial oxygen transport (14, 27). It was found to remain almost similar at 10-20% and 21-40% of the $\dot{V}O_2$ max. At 41-50% $\dot{V}O_2$max, comparatively higher O_2P in SN indicate better oxygen transport in it than BE. Higher O_2P in SN was attributable to comparatively lower HR during SN at this work intensity because O_2P is the ratio of O_2 consumption to HR. The increase in $\dot{V}_E$ during exercise is partly due to the proprioceptive afferent impulses from the muscles and joints and partly due to stimulatory collateral impulses from the higher centres of the brain (motor cortex) to the respiratory centre (28). During exercise, muscle contraction takes place because of the same stimulatory motor impulses from the higher centres of the brain. Thus, the brain tells the muscle what and how much work to do and informs the supporting cardiovascular and respiratory systems of their task (28). In the present study, the work intensity in SN as well as in BE may be considered as moderate level of exercise. Relatively higher value of $\dot{V}_E$ in BE at higher work intensity may be due to more proprioceptive impulses from the muscles, joints, and tendons concerned or may be due to strong motor impulses from the higher centres of the brain commensurate with the nature and frequency of the muscle contraction of BE. $\dot{V}CO_2$ depends on the metabolic activity of the cell that is further dependent upon the intensity of the exercise. In the present study, the amount of carbon dioxide produced in BE exceeded than that produced in SN at higher level of work intensity (41-50% of the $\dot{V}O_2$max). Though, SN is dynamic in nature amongst other yogic asanas, it is executed slowly unlike BE that is performed at a fixed pace (55-60 revolutions per minute). At similar level of energy demand (41-50% of $\dot{V}O_2$max), the greater carbon dioxide output in BE might be due to strong ventilatory drive probably resulting from higher PCO_2 in the blood produced during BE.

During the practice of SN, load is distributed amongst various groups of muscles in the body unlike BE where load is exerted constantly and exclusively on lower limb muscles. The metabolic stress appeared to be more in BE than SN at similar level of energy demand (41-50% of $\dot{V}O_2$max).

Ventilatory equivalent for oxygen (EQO_2) at 10-20% and 21-40% of the $\dot{V}O_2$max intensity was always significantly higher in BE. This indicates that SN practitioners had more efficient breathing patterns during its practice at similar level of work intensity. Ventilatory equivalent for carbon dioxide also showed significantly higher value in BE at 10-20% and 21-40% of the $\dot{V}O_2$max. Work intensity suggesting that SN practitioners may have a lower metabolic load than bicyclist.

Conclusion

Cardiorespiratory responses during SN and BE were compared at three exercise intensities in the present study. Overall, cardiorespiratory stress in SN was found out to be lesser than BE.

However, more in depth research is needed to explore the relative contribution of 'muscle metaboreflex' and 'central command' during BE and SN with the help of muscle sympathetic nerve activity, heart rate variability and other autonomic neural investigations.

ACKNOWLEDGMENTS

The authors put on record the sincere thanks to the subjects who voluntarily participated in the study. The authors express their sincere thanks to Dr. US Ray, Scientist 'F' (Retd.) for his support, inspiration and valuable advice during the study. The authors also express their sincere gratitude to Dr. W Selvamurthy, CCR&D (LS and IC), DRDO for his continuous support and Dr. Shashibala Singh, Director, DIPAS for her timely help.

REFERENCES

1. Singh K, Bal BS, Vaz W. The effect of Suryanamaskar Yogasana on muscular endurance and flexibility among Intercollege Yoginis. *J Physical Education and Sport* 2010; 27(2): 61–67.
2. Sinha B, Ray US, Pathak A, Selvamurthy W. Energy cost and cardiorespiratory changes during the practice of Surya Namaskar. *Indian J Physiol Pharmacol* 2004; 48(2): 184–190.
3. Sinha B, Ray US, Dasgupta Sinha T. Physiological study of Surya Namaskar, a yogic practice (research letter). *Alternative therapies in Health and Medicine* 2011; 17(3): 62–64.
4. Mody BS. Acute effects of Surya Namaskar on the cardiovascular & metabolic system. *J Body Mov Ther* 2011 Jul; 15(3): 343–347.
5. Bhavanani AB, Udupa K, Madanmohan and

Ravindra PN. A comparative study of slow and fast suryanamaskar on physiological function. *Int J Yoga 2011*; 4(2): 71–76.

6. Sasi AK, Sivapriya DV, Thirumeni S. Effects of Surya Namaskar on cardiovascular and respiratory parameters in school students. *Recent Res in Sci and Tech* 2011; 3(10): 19–24.
7. Hagins M, Moore W, Rundle A. Does practicing hatha yoga satisfy recommendations for intensity of physical activity which improves maintains health and cardiovascular fitness? *BMC Complement Altern Med* 2007 Nov; 30(7): 40.
8. Bhutkar MV, Bhutkar PM, Taware GB and Surdi AD. How effective is Sun Salutation in improving muscle strength, general body endurance and body composition. *Asian J Sports Med* 2011; 2(4): 259–266.
9. Bhutkar PM, Bhutkar MV, Taware GB, Vinayak D and Doddamani BR. Effect of Suryanamaskar Practice on Cardio-respiratory Fitness Parameters: A Pilot Study. *Al Ameen J Med Sci* 2008; 1(2): 126–129.
10. Mc Ardle WD, Katch FI, Katch VL. Energy expenditure in Household, Occupational, recreational and sports Activities. In: Exercise Physiology, 4th ed. USA, Lippincott, Williams & Wilkins 1996; 769–781.
11. Mc Ardle WD, Katch FI, Katch VL. Human energy expenditure during rest and physical activity. In: Exercise Physiology, 6th ed. USA, Lippincott, Williams & Wilkins; 2000; 195–208.
12. Astrand PO, Rodahl K, Dahl HA, Strome SB. Body fluids, blood and circulation. In: Textbook of Work Physiology, Physiological Bases of Exercise. 4th ed; Champaign, Ill, Human Kinetics 2003; 127–176.
13. Plowman SA, Smith DL. Exercise Physiology for Health, Fitness and Performance. 2nd ed; Philadelphia, PA: Lippincott Williams and Wilkins 2008; 351–379.
14. Franklin BA. Cardiovascular responses to exercise and training. In: Garrett Jr. WE, Kirkendall DT, eds. Exercise and Sport Science. Philadelphia, PA: Lippincott Williams and Wilkins 2000; 107–116.
15. Barett K, Brooks H, Boitano S, et al. Ganong's Review of Medical Physiology. 23rd ed; Delhi; India, Tata McGraw Hill 2010; 507–520.
16. Galvez JM, Alonso JP, Sangrador LA, Navarro G. Effect of muscle mass and intensity of isometric contraction on heart rate. *J Appl physiol* 2000; 88: 487–492.
17. Seals DR. Influence of force on muscle and skin sympathetic nerve activity during sustained isometric contractions in humans. *J Physiol* 1993; 462: 147–159.
18. Lassen, A, Mitchell JH, Reeves DR, Rogers HB, Secher NH. Cardiovascular responses to brief static contractions in man with topical nervous blockade. *J. Physiol* (Lond.) 1989; 409: 333–341.
19. Lewis SF, Snell PG, Taylor WF, et al. Role of muscle mass and mode of contraction in circulatory responses to exercise. *J Appl Physiol* 1985; 58: 146–151.
20. Mitchell JH, Payne FC, Saltin B, Schibye B. The role or muscle mass in the cardiovascular response to static contraction. *J Physiol* 1980; 309: 45–54.
21. Ray US, Mukhopadhyay S, Tomer OS, et al. Physiological responses during the practice of individual yogic exercises (Asanas), yogic breathing (Pranayama) and Meditation in yoga trainees and proficients. Ministry of Defence Report No.: DIPAS/13/2000. New Delhi: 2000; 27–28, 50.
22. Petrofsky JS and Phillips CA. The Physiology of static exercise. *Exerc Sport Sci Rev* 1986; 14: 1–44.
23. Iellamo F, Pizzinelli P, Massaro M, Raimondi G, Peruzzi G, Legramante JM. Muscle metaboreflex contribution to sinus node regulation during static exercise, Insights from spectral analysis of heart rate variability. *Circulation* 1999; 100: 27–32.
24. Maciel BC, Gallo L Jr, Marin Neto JA, Martins LEB. Autonomic nervous control of the heart rate during isometric exercise in normal man. *Pflugers Arch* 1987; 408: 173–177.
25. Gandevia SC and Hobbs SF. Cardiovascular responses to static exercise in man; central and reflex contributions. *J Physiol* 1990; 430: 105–117.
26. Hietanen E. Cardiovascular responses to static exercise. *Scand J Work Environ Health* 1984 Dec; 10(6 Spec No): 397–402.
27. Rowland TW. Developmental Exercise Physiology. 3rd ed; USA, Human Kinetics 1996; 29.
28. Guyton AC, Hall JE. Regulation of respiration. In: Text Book of Medical physiology. 11th ed; Philadelphia; USA, Elsevier Saunders 2001; 514–533.