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Determination of Cardiovascular Responses of Children to Maximal Treadmill Exercise with Bruce Treadmill Protocol

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ABSTRACT

This study aimed to determine the cardiovascular responses of children to maximal treadmill exercise with Bruce Treadmill Protocol and to compare these responses between girls and boys. A total number of 20 subjects with age ranging from 5-11 years were included in the study. Subjects were separated to two groups i.e. group A, group B on the basis of their gender. Group A comprised of 10 girls, while 10 boys made up Group B. The treadmill is started at Stage-1 which has a speed of 2.7 km/hr and an incline of 10%, after 3 minutes both speed and incline is increased to 4.0 km/hr and 12% respectively to Stage 2. Blood pressure was recorded in supine position immediately after completion of exercise and at 1,2,3,4,5,6,7,8,9 and 10 minutes of recovery.Heart rates was recorded at each minute of the recovery, till it became stable.Recorded data show that there is no significant, difference in both the vascular variables of Heart rate and Blood pressure in response TST both during Exercise and during Recovery Levels of circulating hormones especially around the period of puberty, help to explain some of the sex differences in anaerobic fitness but the evidence is equivocal and current data suggest that sexual maturity does not exert any independent effect on anaerobic fitness once age, body mass, body composition are concurrently controlled for., Improvements in neural adaptations with age, complete myelination of nerve fibres, improved muscle coordination during multi-joint exercise and an improved capability to recruit motor units or more fully activate muscles help to explain age-related improvements in anaerobic fitness.

INTRODUCTION

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concurrently controlled for. Improvements in neural adaptations with age, complete myelination of nerve fibres, improved muscle coordination during multi-joint exercise and an improved capability to recruit motor units or more fully activate muscles help to explain age-related improvements in anaerobic fitness.

Exercise testing is integral to the evaluation of children and adolescents with symptoms associated with exercise suspected to be cardiac in origin and remains the most objective method to assess physical fitness and endurance[1]. An increasing emphasis has been placed on physical fitness in the media during the last 2 decades. However, during that same time period, physical education programs have decreased in school[2].Exercise testing provides information on exercise capacity and facilitates assessment of pathophysiologic characteristics, effectiveness of medication, and risk of potential disease[3].

The treadmill test does not require prior experience or practice and is thus suitable for children.Treadmill Stress Test (TST) is a diagnostic method with a number of indications for children and adolescents. The risk posed by TST in children and adolescents is very low when compared to adults.An increasing number of tests have been designed for children in the past 20 years, mainly to evaluate cardiopulmonary fitness or arrhythmia, and also to assess exercise-induced changes in airway resistance [1].

An often used protocol is the Bruce treadmill protocol, which was originally designed for adults but is now also applied worldwide for children from the age of 4 years.For accurate exercise results, it is extremely important to avoid any interruption during stress testing, owing to the striking immediate changes following cessation of exercise which have been noted in continuous recordings[4].

The knowledge of the physiological and biological processes taking place during maturation is essential to understand the etiopathogenesis of hypertension and of other risk factors associated with major cardiovascular events[5].

Also, the measurement of maximal oxygen uptake (VO2 max), Heart rate and blood pressure recorded at this point of maximal oxygen uptake is widely used as the standard of cardiopulmonary functional reserve in children and adolescents[6].

But since Cumming et al.reported a strong correlation between the maximal endurance time and maximal oxygen uptake, endurance time is therefore a good alternative for testing young children in the clinical setting[7].

The cardiac events that occur from the beginning of one heartbeat to the beginning of the next are called Cardiac Cycle. The Cardiac cycle consists of a period of relaxation called Diastole, during which the heart fills with blood followed by a period of contraction called Systole and Heart Rate may be defined as 'number of heart beats per minute .Normal values for Resting Heart (HR) rates are 70-80 bpm in adults and upto 100 bpm in children[8].

Blood Pressure (BP) means the force exerted by the blood against any unit area of the vessel wall. The effect of pressure on blood flow is greater than one would expect, reason being - that an increase in arterial pressure not only increases the force that pushes the blood through, the vessels also distend the walls at the same time which decreases vascular resistance[9].

The heart pumps blood into the aorta, the mean blood pressure in the aorta is high, averaging about 100mm Hg. Also because heart pumping is pulsatile, the arterial pressure alternates between systolic pressure level of 120mm Hg and a diastolic pressure level of 80mm Hg at normal resting state in adults [10].

For each heartbeat, BP varies between systolic and diastolic pressures. Systolic pressure is peak pressure in the arteries, which occurs near the end of the cardiac cycle when the ventricles are contracting. Diastolic pressure is minimum pressure in the arteries, which occurs near the beginning of the cardiac cycle when the ventricles are filled with blood .Digital Blood Pressure Sphygmomanometer are much easier to use and accurate compared to the traditional mercury manometer.[11]

It has been reported that both boys and girls have a lower cardiac output (Q) than adults at a given absolute submaximal rate of work or O_2 uptake (VO_2). This lower Q at a given submaximal to maximal rate of work is attributed to a lower stroke volume (SV), which is only partially compensated for by a higher heart rate –HR[12].

A number of epidemiological studies have established normal blood pressure values as well as the effect of exercise on these variables of blood pressure, heart and endurance time in children of different populations but few are from India. To my knowledge, there are even fewer data available for endurance testing of Indian children and comparing the differences between the two sexes. The objective of this research is to analyse the difference between the fitness levels of girls and boys (age 5-11 years) in the Urban Indian set up[13].

MATERIALS AND METHOD

A total number of 20 subjects with age ranging from 5-11 years were included in the study. Subjects were separated to two groups i.e. group A, group B on the basis of their gender. Group A comprised of 10 girls, while 10 boys made up Group B. The subject's recruited were children of AIIMS Para-Medical team living in AyurVigyan Nagar.

Subjects were were asked to follow the Bruce Treadmill Protocol. The Bruce Protocol is a maximal exercise test where the subject works to the point of complete exhaustion as the treadmill speed and incline is increased every three minute.

The treadmill is started at Stage-1 which has a speed of 2.7 km/hr and an incline of 10%, after 3 minutes both speed and incline is increased to 4.0 km/hr and 12% respectively to Stage 2 .

1. Subjects were invited to participate in the study. The purpose and goal of the study was explained both to the subjects and their parents. Those willing to participate were then screened as per the inclusion criteria and exclusion criteria mention above. An informed consent was taken from both the subjects as well as parents of the eligible subjects.

2. These subjects were then taken to the exercise department.A detailed verbal discription explaining the procedure was given to the subject. A manual demonstration on how to perform exercise on the treadmill and how to use the safety valve was given. They were encouraged to ask questions pertain the safety and working of the treadmill to avoid apprehenshion on the part of the young subjects.When the subjects agreed that they understood the intervention, he/she underwent the following procedure

A complete evaluation of the subject was done and demographic data such as age,weight and height were also obtained. Subject was then made to lie down supine on the exercise plinth for 10 minutes, during which the baseline values for heart rate(HR) and blood pressure (BP) were obtained and recordedwith appropriately sized cuff.

The subject was then instructed to perform graded exercise testing to exhaustion on the treadmill with the standard Bruce Protocol.Unlike the original Bruce Protocol, keeping the age and safety factor in mind the subjects were permitted to hold the handlebar of thetreadmill during the study.They were vigorously encouraged to reach a level of maximal exercise. The test was terminated when the subject refused to continue despite strong verbalencouragement. This endurance time was recorded.The subject was placed in supine position immediately after exercise. Heart rates were monitored and recorded every minute during the exercise and also at the time of termination. The heart rate recorded at the time of termination was labeled as Maximal Heart Rate.

Blood pressure was recorded in supine position immediately after completion of exercise and at 1,2,3,4,5,6,7,8,9 and 10 minutes of recovery.Heart rates was recorded at each minute of the recovery, till it became stable.

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RESULTS

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significant difference in the resting heart rate between sexes of the older age. The mean maximal heart rates for all subjects were virtually identical, 197 ± 9 beats/min for girls and 199 ± 5 beats/min for boys, with no significant difference with respect to age or sex. During recovery an abrupt decline in heart rate occurred in all age groups during the first minute after exercise to an average of 148 ± 9 beats/min for girls and 157 ± 4 beats/min for boys. Heart rates at the end of recovery were 6% to 18 % above resting heart rates.The mean endurance time for all age groups for boys was 10:00 ± 00:01 minutes and for girls were 8:57 ± 00:01 minutes.

The resting systolic BP and diastolic BP increased with advancing age for boys and girls. No significant difference was found in resting SBP in boys versus girls. In response to exercise, maximum SBPs were similar for boys and girls.

DISCUSSION

Despite the low prevalence of cardiopathies among children and adolescents, in addition out heart diseases and checking functional capability, Treadmill Stress Test (TST) helps to assistant doctors to more confidently allow ordinary physical activities or sports practice to ruling those with exercise-related symptoms[14] Regular TST may give parents more confidence as well to allow their children - whether they have a condition or not - to lead their lives as normally as possible, without the many times unnecessary constraints on their physical activities[15].The Bruce Treadmill Protocol is the most widely used standard treadmill exercise test; the progressive increase in grade and speed allows reproducible evaluation of subjects of all ages and levels of fitness[16] . We slightly modified the test procedure by permitting the children to hold the guardrails (handle bars). In our experience, walking on treadmill with increments of speed and inclination till maximal performance without rail holding is too difficult for many children aged 5-11 years. This is why; we preferred the safety of holding the rail in these young children. This strategy enabled more young children to perform this maximal exercise test. Rail holding, however, is known to increase endurance time and reduce physiological strain (e.g. HR, VO_2) during sub maximal exercise .Tolerance level to exercise in children may be the result of emotional factors rather than real fatigue. These conditions may justify the lower exercise time length and lower maximum HR reached by the younger ones.

Formulas used to calculate maximum HR expected in adults do not apply for maximum HR expected in pediatric populations. Children's physiologic response to exercise is similar to that of adults, with progressive increase proportional to exertion increase, but differs in the maximum values reached and in lowest correlation between HR and age range[17]. Normal children in different age ranges reach HR max above 180 bpm. Values above 200 bpm are commonly found. Children with HR max < 180 bpm have either not been properly exercised or present chronotropic deficit. In the present series, irrespective of gender, HR max was >180 bpm, which suggests all adolescents have been exercised properly.Near identical maximal heart rates in response to exercise suggest that endurance times can be compared between boys and girls as a measure of performance. Endurance times were slightly lower for girls than for boys at all age groups[18]. Thus the mean endurance time for girls was lower compared to boys, even though the difference between the endurance times of both the sexes was not significant (40.3 seconds). Although endurance times increased with age for both sexes. My findings suggest that cardiovascular conditioning is slightly reduced for females than for males.

Heart rate increases in parallel with increasing exercise intensity. Heart rate is stimulated to increase through the activation of mechano-, chemo- and baroreceptors sending afferent signals to the cardiovascular control centre in the brain. This in turn adjusts sympathovagal balance to the SA node bringing about a change in HR[19]. At the onset of exercise, there is a rapid increase in HR. Due to its speed of response; this is suggested to arise through a withdrawal of parasympathetic modulation which enables the HR to increase up to the intrinsic rate of approximately 100 beats/min. Thereafter, any increase in HR is stimulated through an increased sympathetic modulation. Increased sympathetic cardiac modulation is evident from approximately 25% peak VO_2 onwards and by the time exercise reaches an intensity of 50–60% of peak VO_2, data suggest that vagal modulation disappears all together. Very few studies have reported the dynamics of autonomic control of HR during exercise in children[20].

The recovery of power is faster in children than in adults during repeated brief maximal intensity exercises that are separated by short rest intervals. For instance, Hebestainreported that prepubertal boys recovered faster than adult men despite having similar body-mass-related peak VO_2.Percentage recovery in Peak Power (PP) was significantly higher than recovery in Total Mechanical Work (TMW) in boys and men. The authors suggested that the faster power recovery in boys compared to men could be partially explained by the lower PP, TMW and percent fatigue in boys, the lower post-exercise blood lactate concentration in boys, and faster removal of post-exercise metabolites in boys compared to men. Despite the range of research protocols used in different laboratories, the results consistently suggest that boys and girls recover more quickly than men and women, respectively, during a series of repeated maximal intensity sprints of short duration separated by short rest periods[21]. The quicker recovery of power output in young people can, at least in part, be attributed to the faster time constant for phosphocreatine resynthesis in children and adolescents compared to adults [22]

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In order to interpret these cardiovascular variables, we need to understand the role of cardiovascular system in children.Without an efficiently functioning pump and blood distribution network the exercising muscle would not receive the necessary oxygenated blood and nutrients to allow exercise to continue for more than a minute or so. Additionally, the by-products of oxidative and anaerobic metabolism could not be removed nor would the heat generated by muscular activity be adequately dissipated, all potentially limiting the ability of an individual to exercise.

Although we have a relatively complete understanding of how an adult's cardiovascular system responds to exercise, the practical, technological and ethical limitations in assessing cardiovascular function in the exercising child mean that our knowledge of children's responses is only slowly taking shape[23]. There is also the added challenge of interpreting these responses in relation to growth and maturation, so that fair comparison can be made with the responses of adults. It is important to understand the factors that interact to regulate cardiac output (Q). We know that cardiac output is the product of heart rate (HR) and stroke volume (SV) and changes in either or both of these variables will affect Q. Stroke volume refers to the amount of blood expelled by the heart in each beat and is measured in millilitres (ml). It represents the difference between the volume of blood in the ventricles before contraction (preload) and that remaining in the ventricles after the heart has contracted (afterload). Preload is influenced by the capacity of the ventricles, how much they distend as they fill with blood and most importantly venous return. The heart can only pump out the amount of blood it receives back from the systemic circulation; therefore venous return is critical in determining SV. Muscular, thoracic and ventricular 'pumps' all aid venous return. Afterload is determined by the strength with which the heart muscle contracts to eject the blood contained within the ventricles and by the systemic vascular resistance. Systemic vascular resistance refers to the resistance to flow provided by the vascular network. If systemic vascular resistance is low, afterload will be reduced and SV will increase[24].

Contractility is influenced firstly by preload – the stretching of the myocardial fibres through the volume of blood filling the ventricles promotes the Frank–Starling mechanism that in turn aids contractility. Secondly, contractility is related to the size and thickness of the myocardial mass – an increased cardiac muscle mass produces more force facilitating ejection of blood from the ventricles[25]. Stroke volume increases with increasing body size. An autopsy study with children indicated that heart weight and ventricular wall thickness also increased relative to body mass, stature and BSA Finally, the ratio of heart volume to body mass stays constant through 8–18 years; hence it is clear that heart size increases in direct proportion with body size[26]

Finally, the myocardial auto-rhythmic cells have the attribute of being able to generate innate action potentials and thus safeguard a basic HR. The sympathetic nervous system innervates the SA node, the atrioventricular (AV) node, the atria and the ventricles of the heart, and its regulation of HR occurs through a combination of both neural and hormonal pathways. The ionotropic effects of catecholamine's noradrenaline and adrenaline released by the sympathetic nervous system and adrenaline secreted by the adrenal glands both act to increase contractility, serving to increase HR. Conversely the parasympathetic nervous system, through the release of its neurotransmitter acetylcholine (A.Ch), reduces HR. However, the net effect of sympathetic and parasympathetic autonomic modulation is to increase and decrease heart rate, respectively[27].

During exercise Stroke volume increases progressively up to moderate submaximal intensities (approximately 40–50% peak VO_2) and then plateaus until termination of exercise. This response is, however, dependent on body position. In the upright body position at the commencement of exercise there is a rapid increase in SV. Stroke volume increases approximately 30–40%, soon attaining its maximal level even during submaximal exercise. This increase in SV reflects the combined effects of vasoconstriction and the action of the skeletal muscle pump in redistributing the blood that had been naturally residing in the lower extremities at rest[28]. It has been suggested that there is a small (<5%) increase in SV reflecting an enhanced contractility, in the supine as well as the upright body positions, but this is not always demonstrated.

With increasing exercise intensities venous return continues to rise but due to a reduced filling time caused by the increasing HR, end diastolic diameter (EDD) stays stable. However, towards maximal exercise the rapidity of the HR can outpace venous return, such that ventricular filling is reduced slightly, reflected in a slight decline in EDD. Left ventricular end systolic diameter (ESD) reduces with increasing exercise intensity, representing an enhancement in myocardial contractility with exercise[29].

During submaximal exercise, children typically have a lower absolute SV than adults at all levels of submaximal exercise or when working at a given VO_2. This is characterized by a smaller SV and a higher HR to deliver the same Q. Indeed, adults nearly double SV from rest to maximal exercise[30]

There is speculation that hormonal factors, especially around the period of puberty, may account for some of the characteristic observations in maximal intensity exercise performance. Hormones have both primary and secondary effects. For example, concentrations of circulating growth hormone and testosterone in males and oestradiol in females are markedly increased during puberty. More so in boys, there is a substantial gain in lean body mass during puberty. Muscle mass, estimated by creatinine excretion, accounts for as much as 42% of the total body composition in boys at the age of 5 years and increases to approximately 54% by the age of 17 years. Whereas in girls, the muscle mass increases from 40 to 45% of the total body mass. The advantages of having greater active muscle mass to recruit during exercise, is potentially useful in providing an enhanced functional capacity and metabolic rate in the exercise performance of post pubertal or adolescent boys compared with girls [31]Alterations in muscle mass, muscle fibre type or muscle fibre diameter during growth and maturation help to explain some but not all the age- and sex-related changes in anaerobic fitness. Genetics exert a significant influence on anaerobic fitness. A greater preponderance of type II muscle fibres in adolescence and adulthood than in childhood helps to explain the increase in anaerobic fitness with age. Differences in muscle metabolism between children and adults in their responses to maximal intensity exercise suggest a reduced reliance on anaerobic metabolism during childhood[32]. Levels of circulating hormones, especially around the period of puberty, help to explain some of the sex differences in anaerobic fitness but the evidence is equivocal and current data suggest that sexual maturity does not exert any independent effect on anaerobic fitness, once age, body mass, body composition are concurrently controlled for[33]. Improvements in neural adaptations with age, complete myelination of nerve fibres, improved muscle coordination during multi-joint exercise and an improved capability to recruit motor units or more fully activate muscles help to explain age-related improvements in anaerobic fitness[34]. However, a full understanding of the development of anaerobic fitness awaits further research.

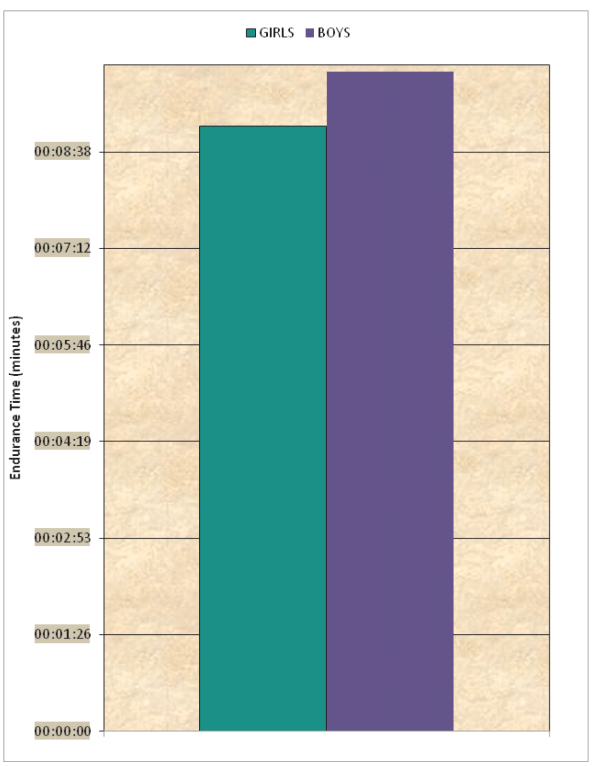
CONCLUSION

Based on the results of the present study, in which we assessed the cardiovascular response to the treadmill stress test in normal 5 to 11yearold Urban Indian children and found that both girls and boys in the prepubertal stages had similar cardiopulmonary endurance times. Also recorded data show that there is no significant difference in both the vascular variables of Heart rate and

Table 1: Comparison of Pre and Post Treadmill Stress Test (TST)

VARIABLES	GIRLS		BOYS	
	MEAN	S.D.	MEAN	S.D.
Resting/Baseline Heart Rate (in beats/min)	97.9	8.3	96.1	10.8
Maximal HR After TST	197.2	9.4	199.0	5.2
Heart Rate Recovery time (in minute)	49:54	0:00	57:06	0:00
TST Endurance time (in minute)	9:08	1:25	10:00	1:15

Graph Showing Comparison Of Mean Endurance Time Of Girls And Boys



Comparison Of Both Baseline Diastolic Blood Pressure And Its Decline From Maximal Value During Recovery In Boys And Girls

Blood pressure in response TST both during Exercise and during Recovery.

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