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Comparison of cardiovascular responses following self-selected maximal effort in forward, backward and sideways walking

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ABSTRACT

Humans learned to walk forward in the course of evolution, while sideways and backward walking are considered to be novel tasks. This study compared the cardiovascular parameters during forward, backward and sideways walking of students in a Nigerian University. Fifty apparently healthy young adult students (25.6±2.0 years) were purposively recruited to participate in the study. Participants had their anthropometric characteristics (weight and height) and cardiovascular parameters (heart rate [HR], systolic blood pressure [SBP], diastolic blood pressure [DBP], mean arterial pressure [MAP], pulse pressure (PP) and rate pressure product (RPP), and rate of perceived exertion [RPE]) determined at baseline. Participants' HR, SBP, DBP, MAP and RPE responses after a 100 meter walk at the subject's self-selected maximum speed during the different modes of walking were compared using multiple analysis of variance. Significantly higher DBP, MAP (P<0.05) and RPE (P<0.01) for sideways walking compared to backward walking, higher (P<0.01) HR, SBP and RPE for both sideways walking and backward walking compared to forward walking, and higher (P<0.01) HR, SBP, DBP, MAP and RPE for sideways walking compared to forward walking were found. We also found higher (P<0.01) HR, SBP and RPE for backward walking compared to the corresponding values during forward walking. Overall, findings of heightened cardiovascular responses suggest higher energy expenditure in sideways walking compared to forward and backward walking. We hypothesize that the differential plane of motion and the more prevalent static muscle work in sideways walking may be responsible for the apparently more strenuous nature of sideways walking compared to the other modes.

KEY WORDS: ***Cardiovascular; Energy expenditure; Ambulation; Walking; Motor pattern***

INTRODUCTION

Walking is a human locomotion activity that involves the coordination of numerous muscles to produce a progressive change in body position while maintaining balance and limiting energy expenditure[1,2]. Recent focus on the health benefits of physical activity has increased the interest in walking as an easily employable and popular mode of moderate level of physical activity, making it the preferred mode over others such as bicycling, swimming, and rope skipping[3–5]. Brisk walking for a minimum period of thirty to sixty minutes a day, five days a week, is known to reduce the risks of cancer, type 2 diabetes, heart disease, anxiety and depression and also improve the life expectancy of individuals suffering from obesity or high blood pressure[6] just as more vigorous physical activity and exercise such as jogging[4].

Humans generally perform locomotion in a forward direction, and walking sideways or backward could be considered novel tasks with joint kinematic patterns that are different from that of forward walking[7]. Forward walking at a constant speed is accomplished by bursts of concentric and eccentric muscle work[8]. During both phases of human locomotion, the gluteus maximus and medius, tensor fascia lata, adductor magnus, iliopsoas, adductor longus, quadriceps, hamstrings, tibialis anterior and gastrocnemius muscles are all involved and activated concentrically and/or eccentrically. Backward walking is a movement trajectory that is practically a mirror image of forward walking[9], with toes touching the ground first, before the heels, but in similar order. Thus, a muscle group that contracts concentrically in forward walking during a specific phase or sub-phase of the gait cycle could be expected to contract eccentrically in the corresponding phase during backward walking.

However, sideways walking has a different trajectory of movement compared to forward or backward walking, with abduction and adduction of the hip as the principal components of movement in this mode. The pattern of hip movement and power patterns (kinetic variables) during sideways walking are entirely different from those of forward and backward walking due to distinct variations in the groups of muscles activated during this walking mode[10,11]. Forward and backward walking show the same groups of muscle activated, with variation only in the sequence and degree of muscle activation. For example, in a study[12] of muscle activity of healthy adults, the activity in the rectus femoris muscle and tibialis anterior muscle was found to be more when walking backward than forward.

Investigations show that while kinematic variables such as the relative stance or swing time have been shown to be similar when running forward or backward[13], other variables such as stride length and stride frequency have been shown to differ considerably between forward and backward running[14,15]. Patterns of muscle activation during each of the two phases of the gait cycle (stance and swing phase) have also been explored with divergent findings among researchers[10,16]. There is, however, a consensus on which muscles are activated and the sequences of activation of these muscles in gait[17].

It has been hypothesized that an individual may not be able to walk as fast backward or sideways as walking forward due to certain anatomical constraints that limit the flexion-extension movements of the hip and knee joints when walking sideways or backward compared to when walking forward[18]. It has also been speculated that the energy that may be expended in the three walking patterns (i.e. walking forward, backward and sideways) can be substantially different from each other. This conjecture is supported by Flynn *et al*[19] who reported an increased VO_2 maximum and heart rate of 78% and 48% respectively in backward walking when compared with forward walking.

Backward and sideways walking are often performed in short bursts as part of various sports, or as a procedural intervention in rehabilitation as in the management of conditions such as patellofemoral pain syndrome[20,21]. Backward and sideways walking activities have been shown to contribute to improvement in stability during normal forward walking[13]. Presently, there is paucity of data on the cardiovascular responses and the extent of body exertion involved in sideways and backward walking on any populations in sub-Saharan Africa. The present study aimed to compare the cardiovascular parameters and the perceived exertion experienced by young adult Nigerians university students during forward, backward and sideways walking.

METHODOLOGY

Participants

The participants for this quasi-experimental study were 50 (32 males and 18 females) apparently healthy students of the College of Medical Sciences, University of Maiduguri, Nigeria, that were non-smokers and free from any cardiovascular diseases and musculoskeletal injuries or physical disability. The study was undertaken at the College of Medical Sciences football field (120 x 100m) between 7:00 to 9:00 Hours in the months of May and June 2012.

Procedure

The Institutional Research and Ethical Committee of the University of Maiduguri Teaching Hospital approved the study and a sample of apparently healthy young adult students of the University was purposively recruited to participate in the study. The aim and objectives, procedure and possible risk to which the participants could be exposed in the course of the study were explained to the prospective participants and their written informed consents were obtained. A week to the testing date, a preliminary exercise testing was done to determine the suitability of the participants for the study. Prospective participants were advised to limit themselves to light breakfast taken at least 3 hours before the visit. Light breakfast advised was not more than a cup of tea and two slices of bread or a fruit, or a cup of cereal. Enrolees were also advised to avoid any caffeine drink, alcohol and vigorous physical activity 24 hrs before the test, as advised by Pérusse-Lachance *et al*[22].

On the day of the test, each participant was assigned a serial number for the purpose of identification for data management and was provided with a chair with backrest near the starting point of the 100m marked section on the field. The height and weight of the participants were measured using a Height meter (Stadiometer) and bathroom weighing scale, respectively. Resting Heart Rate (HR) and blood pressure of the participants were also measured using a digital sphygmomanometer (OMRON M2 Basic CE0197, Japan) and a rating of perceived exertion (RPE) score was determined using the Borg Scale immediately before each trial. The Borg RPE is a subjective way of measuring physical activity intensity level and is based on the physical sensations a person experiences during physical activity, including increased heart rate, increased respiration or breathing rate, increased sweating, and muscle fatigue[23]. A printed 16 point graded category scale (6-20) of perceived exertion[23] mounted on a cardboard background was exhibited to subjects, for which they were instructed to point to the number on the scale that most accurately corresponded to their overall sense of exertion (from 6=No exertion at all to 20=Maximal exertion).

Participants then performed each of the three walking activities in random order on separate days, at least 24 hours apart. In the first trial, participants were asked to walk forward, sideways or backward as fast as they could for the marked distance (100m), and the time it took for the participant to complete the distance was recorded using a stopwatch. Immediately after completing a walk, the Systolic Blood Pressure (SBP), Diastolic Blood Pressure (DBP) and HR of the participants were measured and RPE was also obtained. In the subsequent trials, the same procedure was repeated for the other patterns of walking. Derived indices such as pulse pressure (PP), Mean Arterial Pressure (MAP), Rate Pressure Product (RPP), Body Mass Index (BMI), speed and energy costs of walking and Metabolic Equivalent of Task (MET) were computed. RPP is an index of myocardial oxygen uptake and is indication of how hard the heart is working to maintain optimum circulation[24]. MAP is the average pressure during the cardiac cycle and is an indication of tissue perfusion and pulse pressure is a correlate of stroke volume[24]. MET is a physiological measure expressing the energy cost (or calories) of physical activities, and one MET is the energy cost expended by an individual while seated at rest[24].

Data Analysis

The data collected were entered into the computer and analysed using Statistical Package for the Social Science (SPSS), version 16.0 for windows (SPSS Inc., Chicago, Illinois, USA). Derived indices including PP, MAP, RPP, and MET were also computed and entered. Descriptive statistics of mean, and standard deviation were used to describe data obtained. Multiple analysis of variance (MANOVA), was used to explore differences in the cardiovascular parameters, RPE and MET between the different walking modes, at a level of significance set at < 0.05.

RESULTS

Physical characteristics of the participants

The mean age and BMI of the participants were 25.6±2.0 years and 21.8±3.6 kg/m^2 respectively. The mean speed (meter per second) for forward walking, sideways walking and backward walking were 1.8±0.3, 1.0±0.3 and 1.3±0.3, respectively and their respective mean energy cost (units) were 230.6±45.2, 424.2±115.2 and 325.3±98.3 respectively. Other physical characteristics of the participants are shown on **table 1**.

Table 1: Physical Characteristics of the Participants

Variable	Mean (SD)
Age	25.6±2.0
Weight	63.8±11.8
Height	1.71±0.073
BMI	21.8±3.6
Speed (m/sec.)	
• Forward Walking	1.8±0.3
• Sideways Walking	1.0±0.3
• Backward Walking	1.3±0.3
Energy Cost (Kcal/min)	
• Forward Walking	3.84±0.75
• Sideways Walking	7.02±1.92
• Backward Walking	5.42±1.64

Cardiovascular parameters at baseline and responses during walking activities

The mean baseline HR for the participants before walking forward, sideways and backward were 79.5±10.1, 78.4±11.1 and 77.9±11.2 respectively. The mean baseline cardiovascular parameters for walking forward, backward and sideways, respectively for SBP were 115.1±8.7, 114.9±2.7, and 114.5±7.7, for DBP were 70.9±6.4, 70.7±5.1 and 68.9±7.7, and for RPE were 6.9 ± 1.5, 6.9 ± 1.4 and 6.6±1.2. The mean cardiovascular responses following self-selected maximal effort during walking forward, backward and sideways were 82.0±12.6, 86.4±15.5, and 86.0±14.2 for HR, 125.5±10.2, 132.4±14.4 and 131.6±13.1 for SBP, 72.0±7.3, 75.9±9.5 and 72.0±9.6 for DBP. The mean RPE were

10.9±1.0, 16.9±1.8 and 15.9±1.3 during walking forward, backward and sideways respectively. Other cardiovascular parameters are shown in **table 2**.

Comparison of baseline cardiovascular parameters and rate of perceived exertion values

Table 2 shows comparison of baseline cardiovascular parameters of participants before walking. There was no significant difference (P>0.05) in the baseline RPE before forward, backward or sideways walking. No significant difference (P>0.05) was found in the baseline SBP, DBP, MAP, PP, RRP before any of the walking type. There was an overall significant difference (P<0.001) in cardiovascular responses during each of the walking activities compared to baseline values. The results also show higher values (P<0.001) for RPE immediately following the walking activities compared to the baseline values.

Table 2: Comparison of cardiovascular parameters at baseline and after walking activities

Variable	fwb vs fwx	swb vs swx	bwb vs bwx
Heart Rate	79.5±10.1 vs 82.0±12.6[a]	78.4±11.1 vs 86.4±15.5[a]	77.9±11.2 vs 86.0±14.2[a]
Systolic Blood Pressure	115.1±8.7 vs 125.5±10.2[a]	114.9±2.7 vs 132.4±14.4[a]	114.5±7.7 vs 131.6±13.1[a]
Diastolic blood pressure	70.9±6.4 vs 72.0±7.3[a]	70.7±5.1 vs 75.9±9.5[a]	68.9±7.7 vs 72.0±9.6[a]
Mean arterial pressure	84.2±6.8 vs 89.9±7.1[a]	85.4±4.7 vs 94.8±9.7[a]	84.2±6.8 vs 92.0±8.0[a]
Pulse pressure	45.0±10.2 vs 53.5±9.3[a]	85.4±4.7 vs 56.2±12.3[a]	43.1±17.2 vs 59.6±11.9[a]
Rate pressure product	90.9±15.1 vs 10.3±18.3[a]	90.0±13.6 vs 11.1±34.4[a]	88.7±12.9 vs 10.9±31[a]
Rate of perceived exertion	6.9±1.5 vs 10.9±1.0[a]	6.9±1.5 vs 16.9±1.8[a]	6.6±1.2 vs 15.9±1.3[a]

fwb=forward walking baseline values; swb=sideways walking baseline values; bwb= backward walking baseline values; fwx=forward walking exercise values; swx=sideways walking exercise values; bwx=backward walking exercise values; Superscript a indicating significant differences at p<0.01; Superscript b indicating significant differences at p<0.05; Rate pressure product values are 102

Comparison of cardiovascular responses between walking pattern

Table 3 shows the comparison of cardiovascular responses following self-selected maximal effort following different walking activities. Significantly higher (P<0.01) HR, SBP, DBP, MAP, PP and RPE responses were observed following sideways walking compared to forward walking. Significantly higher (P<0.05) HR, SBP and RPE were also observed following backward walking compared to forward walking. Significantly higher (P<0.01) DBP, PP and RPE were observed following sideways walking compared to backward walking, while significantly higher (P<0.05) MAP was observed following backward walking compared to sideways walking.

No significant difference (P>0.05) in DBP, MAP and RPP was observed following backward walking compared to forward walking, and no significant difference (P>0.05) in PP and RPP was observed following forward walking compared to sideways walking. The result also showed no significant difference (P>0.05) in HR, SBP and RPP following sideways walking compared to backward walking.

Table 3: Comparison of cardiovascular responses at different walking modes

Variable	fwx v swx	fwx vs bwx	swx vs bwx
Heart Rate	82.0±12.6 vs 86.4±15.5[a]	82.0±12.6 vs 86.0±14.2[a]	86.4±15.5 vs 86.0±14.2
Systolic Blood Pressure	125.5±10.2 vs 132.4±14.4[a]	125.5±10.2 vs 131.6±13.1[a]	132.4±14.4 vs 131.6±13.1
Diastolic blood pressure	72.0±7.3 vs 75.9±9.5[a]	72.0±7.3 vs 72.0±9.6	75.9±9.5 vs72.0±9.6[b]
Mean arterial pressure	89.9±7.1 vs 94.8±9.7[a]	89.9±7.1 vs 92.0±8.0	94.8±9.7 vs 92.0±8.0[b]
Pulse pressure	53.5±9.3 vs 56.2±12.3	53.5±9.3 vs 59.6±11.9	56.2±12.3 vs 59.6±11.9
Rate pressure product	10.3±18.3 vs 11.1±34.4	10.±18.3 vs 10.9±31. 4	11.1±34.4 vs 10.9±31.4
Rate of perceived exertion	10.9±1.0 vs 16.9±1.8[a]	10.9±1.0 vs 15.9±1.3[a]	16.9±1.8 vs 15.9±1.3[a]

fwx=forward walking exercise values; swx= sideward walking exercise values; bwx= backward walking exercise values; Superscript a indicating significant differences at p<0.01; Superscript b indicating significant differences at p<0.05; Rate pressure products values are 102

DISCUSSION

Characteristics of the participants

The age and BMI of the participants in this study were 25.6±2.0 years and 21.8±3.6 kg/m^2 respectively, similar to the values (25.1±2.2 years and 21.5±3.4 kg/m^2) reported in another study[25] among Nigerian undergraduate students. The BMI score of participants in the present study is also comparable to that (24.1±0.1) obtained from a study[26] among urban Cameroonian subjects of similar age, suggesting that our participants' demographic characteristics may be similar to that of similar population

Cardiovascular responses following self-selected maximal effort walking forward, backward and sideways

Significantly higher HR and SBP responses were observed following sideways and backward walking when compared to forward walking. This finding is similar to that of a previous study[27], which showed that the HR and SBP responses were higher while walking backward in water than when walking forward in the same medium. It is also similar to that of another study by Chaloupka *et al*[28], which reported higher HR and SBP during backward walking when compared to forward walking.

The higher SBP during backward and sideways walking when compared with the values during forward walking may be attributed to the unusual nature of the backward and sideways walking activity as man is not accustomed to these walking patterns in the course of evolution. It has also been suggested that backward walking and more especially sideways walking evoke more muscle activity in the lower extremities when compared to forward walking[2,11], thereby causing intra-muscular pressure to increase, leading to occlusion of local blood flow, increased peripheral resistance and increased systolic pressure. The present study found no significant difference in both DBP and MAP following forward walking compared to backward walking. This is consistent with a previous study[28], which reported no significant differences in diastolic blood pressure between backward and forward walking in an open field.

The reason for the non-significant increase in RPP in the present study remains unclear. The non-significant increase in the PP can be attributed to the fact that PP is only affected by the blood vessels compliance. Moreover, during exercise an increase in cardiac output as a result of stimulation by the inotropic competence and an increase systemic vascular resistance changes the MAP and not the PP by maintaining the compliance of the vessels. However, no constant aortic compliance value exists because the relationship between volume and pressure is not linear. At higher volumes and pressures, the slope of the relationship decreases and compliance decreases[24].

Speed, RPE and sideways and backward walking

The self-selected walking speed during forward walking and backward walking were 1.8±0.3m/s and 1.3±0.3 respectively in the present study. While the value for forward walking is comparable to the speed reported in a study by Hreljac *et al*[29] who reported a speed of 1.99±0.20 m·s-1, it is lower than the value for backward walking in the same study in which the subjects recorded 1.63±0.11 m/s for backward walking among young healthy college students.

Lowest speed was observed for sideways walking compared to the speed walking backward, while walking forward generated the highest speed. This may be due to the kinematic differences characterized by increased stride frequency and decreased stride length in forward walking when compared to backward walking[19]. This alteration in stride pattern could possibly be responsible for the higher RPE recorded for sideways walking than backward walking. In a previous study[30], evidence of increased oxygen requirement was found for sideways walking.

The high-energy cost associated with sideways and backward walking, which is in direct correlation of the self-selected maximal speed, is not surprising. This is because it has been hypothesized that during novel walking, the relatively new motor task might increase motor unit recruitment, leading to increased metabolic cost of the activity[31]. The peripheral muscle requirements of forward walking, sideways walking and backward walking are different[10,16].

Why sideways walking elicits higher responses than backward and forward walking even when undertaken with reduced speed is unclear. More especially, given that much more muscles are potentially activated in this walking mode than in the other mode. One possible reason for the heightened response or relatively higher response in sideways walking could be that the locomotor muscles in both forward and backward walking are involved in concentric and/or eccentric contraction, whereas these muscles are involved in static contraction in sideways walking. Static contraction is believed to elicit greater muscle work than concentric and eccentric muscle work. Moreover, because of the evolutionary fixation of motion along the coronal axis and sagittal plane, sideways locomotion takes place along the sagittal axis and coronal planes for which the body is not developmentally suited in the course of evolution. However, given that the effort required for maintaining balance in walking sideways is more than in walking backwards and much more than in forward walking, RPE and energy cost are expected to be heightened during sideways walking.

The small sample size and the non-probability sampling technique utilized are limitations of this study. Although, the demographics of the sample seem to be comparable to those of similar samples in previous studies[25,26], it is not known if the participants in the present study are representative of the population from which they were drawn. However, the study has some implications for practice.

Practical and Clinical Implications

The findings of the present study have important practical applications for exercise and sports specialists or other professionals who are involved in the analyses of movement patterns for training and rehabilitation. Walking is a mode of exercise usually recommended as a health enhancing physical activity because it requires no training and carries little or no risk of injury when compared with other modes such as jogging. Increasing the duration and intensity of exercise is a necessary progression when exercise is geared towards aerobic fitness in health promotion and in the third phase of cardiac rehabilitation program following a cardiac interventional procedure or cardiothoracic surgery. Walking backward or sideways at self-selected speed can be employed as a progression from normal walking as a means of increasing exercise intensity, because just as in normal walking, no training is required.

Also, walking backward and sideways could be utilized to build variety into exercise programs and to improve adherence. Walking backward can be used to strengthen hip extensors and promote stability in a backward direction, while walking sideways can strengthen hip abductors and adductors to promote lateral stability. These muscles contribute to lumbo-pelvic stability needed for good posture, and prevent pelvic drop and excessive trunk lateral sway respectively, during gait[32]. Therefore sideways walking can be used to address deficit as in Trendelenburg gait or gluteus medius lurch, while backward walking can useful in addressing pelvic tilt dysfunction and enhance good posture in standing and during gait.

CONCLUSION

This study shows that heart rate, systolic blood pressure and RPE responses were significantly increased following backward and sideways walking at self-selected maximal walking speeds, compared to the responses obtained following forward walking. While the diastolic blood pressure responses were not significantly different for forward and backward walking, the responses were higher following sideways walking than for the other patterns of walking. Although the self-selected maximum walking speed was higher for sideways and backward walking (in decreasing order of magnitude) than the value for forward walking pattern, the metabolic cost as indicated by the RPE was lower in reverse order with absolute but insignificantly higher rate pressure product (an index of myocardial oxygen uptake) for the sideways, backward and forward walking. The study suggests that backward and sideways walking at self-selected maximum walking speed can be used to increase the intensity of exercise as a means to improving aerobic fitness or exercise capacity in health and diseases.

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