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Comparison of Cardio-Pulmonary Responses to Forward and Backward Walking and Running

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ABSTRACT: Backward running has long been used in sports conditioning programs and has recently been incorporated into rehabilitative setting as a method of increasing quadriceps strength while decreasing the joint compressive forces about the knee. Although backward locomotion has been studied kinetically, the metabolic cost of backward walking or and/or running has not to my knowledge been previously characterized. O_2 consumption and other cardiopulmonary variables were measured under constant speed exercise during backward and forward walking at 107. 2m min^{-1} and during backward and forward running at 160.8m min^{-1} peak O_2 consumption (VO_2 peak) was also measured during maximal incremental backward and forward running VO_2, HR and blood lactate were significantly higher P< 0.001) during backward walking and running than during forward walking and running. During backward walking, and backward running, subjects exercised at 60% and 84% of their forward VO_2 peak, respectively. In conclusion, for a given speed, backward locomotion elicits a greater metabolic demand and cardiopulmonary response than forward locomotion. In general, these data suggest that while undergoing rehabilitation an injured athlete may continue to exercise using backward walking/running at an intensity sufficient enough to maintain cardiovascular fitness levels.

KEY WORDS: *Exercise, cardiovascular, pulmonary, backward walking, running*

INTRODUCTION

In the quest to enjoy the benefits of aerobic conditioning, individuals engaged in running often suffer over-use type injuries at the patellofemoral joint (PEJ) and surrounding structures. (James, Bates and Osterning , 1978) Rehabilitation specialists treating runners with these conditions face the challenge of developing quadriceps strengthening programs which reduce tendon tensile and patellofemoral joint compressive forces.

Backward running, a training technique prevalent in football, basketball, and tennis, has recently gained popularity as a method for treating patella-femoral pain syndrome (PFPS) (Flynn, Soutas – Little, 1993; Flynn Soutas – Little, 1991). A number of investigators have studied the biomechanics of backward locomotion (Bates, Morson and Hamill, 1984; Devita de stripping, 1991; Flynn and Soutas – Little, 1991, Kramer and reid, 1981; Moler, Michelson and Scott, 1978, Thorstenson, 1986; Threshold, Horn and Worrowics, Roonery and Ghelsem, 1989). Kinetic analysis of backward running suggests that compressive forces at the patellofemoral joint are lower when compared with forward running (Flynn and Soutas Little, 1991). Additionally, training program using this technique increase quadriceps power and strength (Mackie and Dean, 1984; Threshold, Horn, Wo, towicz, Rooney, and Shapiro, 1987), yet the total lower extremity muscle work is similar in both modes (Devita and Striplings, 1991). Although backward running may seem a reasonable alternative which meets Patellofermal pain syndrome rehabilitation goals little is known about the metabolic cost of and cardiopulmonary response to this mode of locomotion. In my rehabilitative setting, clinical observations, revealed increased respiration, qaudricep fatigue, and rapid exhaustion in injured

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athletes walking and running backward as compared with forward running and walking on a treadmill. I suspected that backward locomotion was associated with increased metabolic and cardiopulmonary responses.

Knowledge about cardiopulmonary response to backward running is necessary if runners using this technique for Patellofemoral pain syndrome rehabilitation strive to maintain aerobic conditioning levels. To my knowledge, there have been no previous studies that have examined the aerobic responses to backward locomotion. The present study was designed to define the metabolic cost and cardiopulmonary responses during backward walking and running and to compare them with their forward equivalent at the same power and at maximal exercise. This information will allow the physical therapist and athletic trainer to apply backward locomotion in injury rehabilitation in a fashion that will maintain or enhance aerobic fitness. In addition, Coaches and athletes using backward walking and running for lower extremity strengthening and injury prevention can use this data to assist in training program development

METHODS

Subjects:

Ten healthy, physically active, men volunteered for this investigation. All maintained a good level of cardio respiratory and motor fitness and were able to run 2 miles in under 15minutes. Four subjects were well – trained runners, but no subject regularly ran backward. They were (mean $\pm$ SEM) 24$\pm$ 1.2 yr old, 178 $\pm$ 1.6cm in height, and weighed 75$\pm$ 2.2 kg. all acknowledged voluntary participation in this study through written informed consent.

Testing procedures: All testing was conducted in the Human performance Laboratory of the department of Education for the Physically and health impaired, school of special Education, Federal College of Education (special) Oyo. The mean barometric pressure and laboratory temperature were 656 mm Hg and 24^0c, respectively. All subjects were first required to undergo at least two 15 minute familiarization sessions on a treadmill, which was sufficient to provide reasonable competency in backward locomotion. Additional sessions were performed if an individual was not judged to be proficient enough in backward walking and running to undergo testing.

Subjects were tested forward and backward on a treadmill on two separate days with at least 24 hours between testing periods. All forward tests were performed on the first day and backward tests were performed on a subsequent day. Forward testing was performed first to more fully familiarize subjects with treadmill running while wearing head gear and mouth pieces for gas exchange analysis. Three tests were conducted for both forward and backward modes (total of six test conditions). The first consisted of a 3 minutes resting period followed by 6 minutes of constant speed exercise at 107.2m.min^{-1} (walking 4 mph) with a $1^0/_0$ grade to simulate the additional demands of outdoor (field) walking and running (i.e., wind resistance) (Fohenbach, Mader and Holloman, 1987; Heck, Mader, Hess, Muller and Holoman, 1985). Although some subjects felt more comfortable running backward at the 107.2m.min^{-1} speed (4MPH), all were required to walk to allow comparisons in the walking mode. The second test was identical, except that a speed of 160.8m.min^{-1} (running 6mph) was used as the constant speed intensity. The final test was a maximal incremental exercise test. Similar protocols were used for both forward (F_{max}) and backward (B_{max}), maximal incremental exercise testing, consisting of a 3-min resting period followed by 1- min stages at a constant running speed of 120. 6m.min^{-1} (4.5 mph) for B_{max} and 160.8m.min^{-1}(6mph) for F_{max} with a 2^0/0 elevation increase each minute until volitional exhaustion.

There was a 30-45 min rest period between the test conditions, including a 5-10 min period of a active recovery (walking 53. 6-80.4m.min^{-1}) (2-3 mph)to allow blood lactate to return to baseline. The testing order (4mph, 6 mph, max) was held constant on each day. Test order was not randomized for logistical reasons, such as: time duration required for subject testing (equipment set up for randomization would have been exceedingly time consuming to ensure quality data), increasing metabolic demand of each stage, and to allow for more complete familiarization with activity before maximal testing.

Cardiopulmonary measurements: The subjects breathed through a two-way nonrebreathing valve (Hans Rudolph 2400) while exercising. Expiratory gases were measured at the mouth using a mass spectrometer (per kin Elmer, M G A 1100) ventilation was measured with a pneumotachometer. An on-line computer (Medical Graphics Corp, 2001) performed breath –by- breath calculation of oxygen consumption (VO_2), Carbon dioxide production (VCO_2), minute ventilation (VE), and other cardiopulmonary measurements. Twelve – lead ECG (Quinton instruments, Q 4000) was continuously monitored during all testing and heart rates were measured from a three-lead rhythm strip taken at the end of every minute during each condition. Anaerobic threshold (AT) determinations were made using ventilatory parameters as defined by Wasserman (1984) and were agreed upon by three independent, experienced observers.

Blood Sampling Technique: Immediately before and after all exercise testing conditions, blood was drawn from an antecubital in-dwelling venous catheter that was kept patent by periodic infusion of 1-2 ml of heparin lock flush (10 USP Units. ml^{-1}). Blood samples of 0.2 ml were immediately placed in a centrifuge tube (Y51 2372 preservative tubes) that contained a buffer combined with a lysing agent (Samples were stored at room temperature and were analyzed within 2 hours of collection. Samples were analyzed for L lactate (Y51, 1500 Sport Lactate Analyzer) under stable laboratory conditions (mean temp 24^0C). Total whole blood lactate values were determined in duplicate with the average value reported.

RESULTS

Cardiopulmonary Responses: Minute ventilation, oxygen consumption, RER, and HR were significantly higher during the backward walking and running conditions than during forward walking and running at comparable speed (Table 1). Equipment error resulted in the loss of one subject's forward walking data. During backward walking, V_E, VO_2, and HR were approximately 112%, 78%, and 47% higher, respectively, than during forward walking. All subjects reported local muscular quadriceps fatigue and an increasing difficulty in maintaining backward walking as more significantly limiting than breathlessness or overall fatigue, but all were able to complete this walking speed. The metabolic cost of backward running was also higher than during walking conditions. V_E, VO_2, and HR were 88%, 31% and 15% higher, respectively, during backward running than during forward running. Four of the 10 subjects were not able to complete the entire backward running 6-min constant speed exercise. These subjects were unable to continue because of thigh fatigue and a sudden "loss of coordination" in the last 3 min of the backward running test (Table 1).

The metabolic cost of the backward walking mode was similar to the forward running mode in terms of VO_2, expressed as a percentage of forward peak VO_2 (VO_2 peak) achieved during F_{max} (Fig. 1). At the same VO_2 (Table 1), HR response was not significantly different between forward and backward locomotion, but VE and RER were higher during backward walking than during forward running. All cardiopulmonary variables measured were significantly greater during F_{max} than during B_{max} (Table 2). In general, the subjects were not able to achieve the same peak oxygen consumptions backward as they did forward with the protocol employed. Anaerobic thresholds differed between the exercise modes, with higher AT achieved during F_{max} (2.761 min^{-1}) than during B_{max} (2.041 min^{-1}).

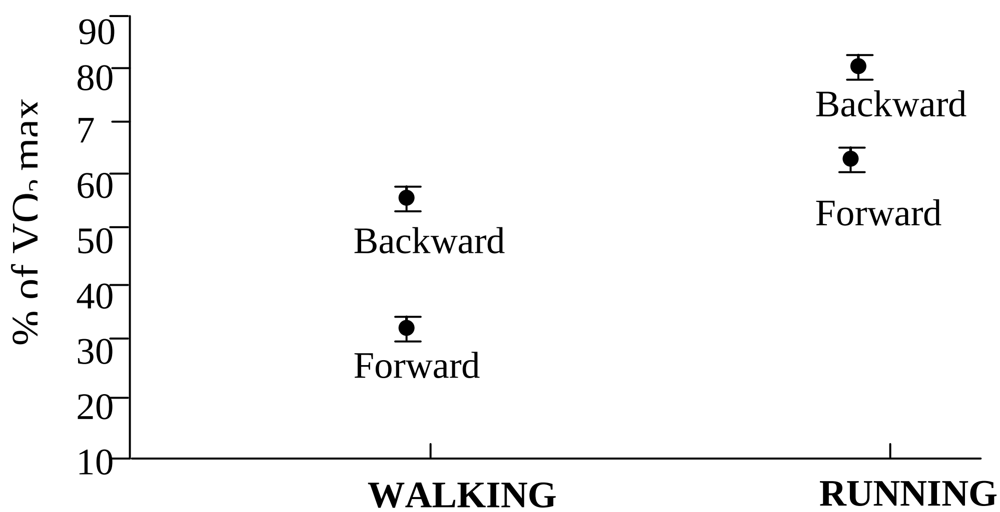

Figure 1:
Relative oxygen consumption ($ml.kg^{-1}. min^{-1}$) during each constant speed condition expressed as a percentage of the maximum forward VO_2 (mean ± SEM).

Table 1:
Comparison Of Cardiopulmonary Variables Measured At Constant Speed During Walking and Running

	WALKING (107.2m.min^{-1})		**RUNNING (160.8m.min-1)**	
	Forward (N=9)	Backward (N = 10)	Forward (N = 10)	Backward N = 6
VE, l.min^{-1}	36.9 ± 1.2	78.1 ± 4.2*, +	68.0 ± 2.8+	128.1 ± 8.6*
VO_2, l.min^{-1}	1.40 ± 0.04	2.49 ± 0.09	2.61 ± 0.08	3.41 ± 0.10*
VO_2, ml.kg^{-1}min^{-1}	18.7 ± 0.4	33.3 ±1.25*	34.8 ± 0.87	46.7 ± 2.36*
RER	0.88 ± 0.01	1.03 ± 0.02*, +	0.92 ± 0.01+	1.09 ± 0.03*
HR, beats min^{-1}	106 ± 5*	156 ±6	151 ± 6*	174 ± 7*
Lactate Pre, mmol.l^{-1}	0.9 ±0.08	1.0 ± 0.10	1.0 ± 0.10	1.3 ± 0.38
Lactate Post mmol.l^{-1}	1.3 ± 0.28	4.4 ± 0.55*, +	1.8 ± 0.27+	7.9 ± 0.76*

* $P<0.001$ for backward vs forward walking and backward vs forward running
+ $P< 0.001$ for backward walking vs forward running.

Table 2:
Comparison of Cardiopulmonary Variables Measured during forward and backward maximal incremental treadmill testing (Mean ± SEM)

	Forward (N = 10)	Backward (N = 10)
VE, l.min^{-1}	164.9 ± 5.5	138.3 ± 5.4*
VO_2, l.min^{-1}	4.14 ± 0.13	3.35 ± 0.11*
VO_2, ml.kg^{-1}min^{-1}	55.4 ± 1.99	44.9 ± 1.81*
AT, l.min^{-1}	2.76 ± 0.10	2.04 ± 0.09*
RER	1.25 ± 0.02	1.20 ± 0.01*
HR, beats. Min^{-1}	193 ± 3	186 ±4*
Lactate Pre, mmol.l^{-1}	1.0 ± 0.08	1.4 ± 0.20+
Lactate post, mmol.l.$^{-1}$	12.1 ± 0.87	8.5 ± 0.63*

* $P<0.01$ from forward running
+ $P< 0.05$from forward running

Table 3:
Comparison Of Stride Length And Frequency At Constant Speed During Walking And Running

	SRIDE FREQUENCY STEPS. MIN-^{1} (N=6)	SRIDE LENGTH M(N=6)
Walking (107.2m.min^{-1}; 4mph)		
Forward	126 ± 3	0.85 ± 0.03
Backward	145 ± 3*	0.74 ± 0.04*
Running (160.8m.min^{-1} ; 6mph)		
Forward	158 ± 2	1.0 ± 0.02
Backward	190 ± 5*	0.85 ± 0.04*

* $P< 0.05$ from forward locomotion

Blood Lactate: In both constant speed walking and running conditions, blood lactate concentration [La$^-$] was higher after the backward mode than after the forward mode. Expressing blood lactate value as delta lactate values (post-exercise lactate minus pre-exercise lactate), the change in backward walking lactate was 3.00 mmol higher than forward walking, and backward running lactate change was 5.75 mmol higher than in the forward running condition. In addition, the lactate concentration during backward walking was significantly higher than during forward running. In contrast, B_{max} blood lactate levels did not reach those attained at F_{max}.

Stride Length and Frequency: Kinematic data on stride length and frequency are presented in Table 3. Backward walking and backward running resulted in significantly shorter stride length and significantly greater stride frequently than the forward walking and forward running counterparts.

DISCUSSION

The present study characterizes the metabolic and cardiopulmonary response to backward walking and backward ruining compared with forward walking and forward ruining respectively. The results clearly demonstrate an increased metabolic cost and cardiopulmonary demand during constant speed backward walking and backward running when compared with forward walking and forward ruining respectively, confirming my clinical suspicions. It was also noted that despite similar VO^2 (backward walking Vs forward ruining), V_E , and RER were increased during backward walking this rise cowed be explained by the earlier production of lactate noted during backward walking (4.4 mm01.1^{-1}) than seen during forward ruining (1.8 mm01.1^{-1}). It appears that the peripheral muscle requirements in backward locomotion are different. However, Devita and stribling (1991) reported the total lower extremity muscle work to be similar during forward ruining and backward ruining at the same speed despite a significant change in the muscle power and work output. They estimated a 1.00 J.kg^{-1} increase in work of the knee extensors during the stance phase of backward ruining when compared with the forward running condition. Kramer and Reid (1981) also noted a similar difference in knee extensor muscle work during backward walking and reported that the lower extremity muscle were active for a greater sustained period of time than during forward walking, with quadriceps action in backward walking of a concentric and isometric nature. Flynn and Soutas- Little (1993) reported that lower extremity muscle were active for a longer proportion of stance during backward ruining than forward ruining. These investigators determine that two knee extensor muscles (vastus medialis and vastus lateralis) produced primarily isometric and concentric contractions. This contrasts with the predominately eccentric action of the knee extensors during forward walking and forward ruining (Williams, 1985). Therefore it appears that the total muscle work of the lower extremity is similar between forward and backward conditions but is produced by different muscle action (concentric vs eccentric) and joint power output.

The increased cardiopulmonary demand during constant speed backward walking and backward ruining as compared with the forward counter parts, could be due to this different action of the quadriceps group, which is primarily a decelerator during forward locomotion and an accelerator during backward locomotion (Devita and stribling, 1991; and Flynn and soutas- little, 1993). Indeed, all subjects in the present study reported quadriceps fatigue during backward walking and backward running.

A number of investigators have reported an increased metabolic cost of concentric vs eccentric muscle contractions. Abbot, Bigland and Ritchie (1952) reported a dramatically higher energy cost for performing concentric cycle ergometry than when resisting eccentrically. An explanation for the phenomenon of increased energy cost during positive work was offered by white (1977). He postulated that during concentric contractions when the muscle fiber cross-bridge has completed its power stroke and produced shortening, ATP is required for the detachment and reset of the cross bridge conversely, during eccentric contractions the cross-bridge is forcibly detached and reattached without further ATP splitting.

The increased metabolic cost during backward locomotion may also be explained in part by the subjects' lack of training in backward walking and running. Economy of motion in a novel activity may require increasingly greater motor unit recruitment in order to complete the task (Schwane, Waltrous, Johnson and Armstrong, 1983). Indeed backward walking and backgward running require greater sustained Electromyographic activity of the quadriceps than forward walking and forward running (Flynn and soutas-Little, 1993; Kramer and Reid, 1981). Consequently, greater motor unit recruitment may increase oxygen demand to the point that the muscle contractile output requires greater support through anaerobic pathways. The high levels of blood lactate measured in this study during backward as compared with forward locomotion at the same speed suggest that backward locomotion modes rely on a higher percentage of anaerobic metabolism than their forward counterparts.

Greater variability in our measures for backward compared with forward locomotion suggests that a wider range of economies were present in the backward conditions. The fact that 4 of the 10 subjects were not able to complete the constant speed backward running because of loss of coordination suggests that local muscle conditions such as unfamiliar patterns of recruitment and high lactate accumulation resulted in muscle fatigue and exercise termination, indicating that the cardio pulmonary system was not the limiting factor. Furthermore, two of the subjects who were not able to complete the constant speed backward running had $VO_{2\ max}$ values >60 ml. kg^{-1}. min $^{-1}$, while other subjects with significantly lower maximal oxygen consumptions were able to complete the entire 6 min of backward running. While some subjects showed a significantly lower metabolic cost (lower VO_2) during backward running than other subjects, none could have continued at this running speed for an extended period of time, as reflected by the high blood lactate values which were fourfold higher than during forward running (7.9 $mm01.1^{-1}$ backward running vs 1.8 $mm01.1^{-1}$ forward running)

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