Physiological responses to Nordic walking, walking and jogging

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ORIGINAL ARTICLE

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Physiological responses to nordic walking, walking and jogging

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Abstract The goal of this study was to evaluate the physiological responses during incremental field tests (FT) in nordic walking (NW), walking (W) and jogging (J). Fifteen healthy middle-aged women participated in three FT. Heart rate (HR) and oxygen uptake $(\dot{V}O_2)$ were monitored continuously by portable analyzers. Capillary blood lactate (La) was analyzed at rest and after every stage of the FT. The disciplines showed differences during stage 1.8 and 2.1 m s^{-1} for $\dot{V}O_2$ between NW and W ($P < 0.05$). The maximum value was measured at 1.8 m s^{-1} (8%). In accordance with La, $\dot{V}CO_2$ was higher in NW compared with W during all stages ($P < 0.05$) and even higher in NW compared with J during 2.1 and 2.4 m s^{-1}. While there were higher HR for NW and W at 2.4 m s^{-1} than in J ($P < 0.01$), there were increases for HR at fixed values of 2 (La2) and 4 (La4) mmol l^{-1} lactate for J compared with NW and W ($P < 0.01$). Although the speed of NW was slower than that of W at La2 and La4 ($P < 0.05$), there were no differences for the HR and the $\dot{V}O_2$. Our results demonstrate that metabolic responses are a helpful instrument to assess the intensity during bipedal exercise. As NW speed at submaximal lactate levels is lower than in W and J, W and J test measures of HR and $\dot{V}O_2$ are not suitable for NW training recommendations. Additionally, the $\dot{V}O_2$ formed by performing NW is not as high as previously reported.

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Introduction

Physical inactivity is a major factor for developing illness in humans. Regular participation in aerobic endurance sports seems to be an appropriate stimulus to maintain or enhance physical fitness and health. The health benefits gained by practicing endurance sports have been correlated to the caloric expenditure, which is usually measured indirectly by the oxygen consumption (ACSM 1998; Lee and Paffenbarger 1998; Pate et al. 1995). Due to the simplicity of walking (W), the technique is easy to practice even for beginners in endurance sports (Rippe et al. 1988).

An enhanced oxygen consumption $(\dot{V}O_2)$ and a consecutive increase in caloric expenditure for W is reported for the use of hand weights (Graves et al. 1987), incorporated arm exercise (Butts et al. 1995) and the use of walking poles (Church et al. 2002; Porcari et al. 1997; Rodgers et al. 1995). The physiological responses of nordic walking (NW) or similar physical activities were examined on treadmills (Porcari et al. 1997; Rodgers et al. 1995) and in field testing (Church et al. 2002).

Comparative studies between field and treadmill tests have shown higher $\dot{V}O_2$ for running with submaximal intensities on treadmills than during field tests (Jones and Doust 1996; Meyer et al. 2003). The $\dot{V}O_2$ peak and the heart rate (HR) of double poling cross-country skiers were elevated on the treadmill compared with a field test (FT) (Doyon et al. 2001). Major problems, which make it difficult to compare field and treadmill studies are differences in air resistance (Jones and Doust 1996), ground forces and movement patterns (Nigg et al. 1995; Wank et al. 1998). Examinations on treadmills (Porcari et al. 1997; Rodgers et al. 1995) could also have a negative effect on the proper use of NW technique and as a result of this over- or underestimate energy costs and $\dot{V}O_2$ compared with field conditions. In the field study of Church et al. (2002) and the examination by Porcari et al. (1997), the participants chose a self-selected speed, which was carried out for W and NW. Considering that there exist distinct differences for the energetic demands at certain speeds between W and jogging (J) (Greiwe and Kohrt 2000; Margaria et al. 1963; Saibene and Minetti 2002) it is conceivable, that comparable differences between NW and W intensify the previously measured additional energy consumption for NW up to 23% (Church et al. 2002; Porcari et al. 1997).

Measurable parameters for the registration of physiological responses associated with bipedal exercise are besides HR and $\dot{V}O_2$, capillary blood lactate concentrations (La), which are commonly used to evaluate submaximal endurance performance, exercise intensity and to monitor adaptations to endurance training (Heck et al. 1985; Hollmann 1963; Weltman 1995). W and J in contrast to NW are already extensively distinguished with regard to their physiological responses (Greiwe and Kohrt 2000; Saibene and Minetti 2002). A demarcation from NW and J as well as a collection of the metabolic demands from NW do not exist. The aim of the present study is to evaluate the differences of the physiological responses in an incremental field test from NW compared with W and J.

Methods

Subjects

Fifteen healthy middle-aged females participated in this study. The average age, body mass, height and body mass index of the subjects were 44 (6) years, 66 (6) kg, 170 (5) cm and 22.8 (1.8) kg/m^2. All participants performed aerobic endurance training two to three times per week, mainly in the disciplines NW, W and J and occasionally swimming, aerobic dance, tennis or skiing. They were familiar with the use of Exel Nordic Walker poles. All subjects completed medical examination and physical activity questionnaires and signed a consent form prior to commencement of the study. The study was approved by the local Ethics Committee.

Experimental procedure and protocols

Each subject was tested in three randomly ordered field tests—NW, W and J. Testing trials were separated by at least 3 days and took place on a 400-m track at identical daytime. The participants were not allowed to be physically active 1 week before and during the test period. Food intake was standardized 2 days before the tests and the participants were told to be sober 3 h prior to testing. The incremental test protocol required the participation in at least five stages. Tests for NW and W started at 1.2 m s^{-1} und ended not later than 2.4 m s^{-1}. J tests started at 1.8 m s^{-1} and ended with the individual exhaustion. The stages lasted 5:07 min with a range of 1:10 min and were intercepted by a break of 1 min at most. Movement speed increased at 0.3 m s^{-1} with every stage. In order to provide a constant moving speed we used marks, which were placed at every 50 m of the track. An electronic acoustic signal transmitter gave an acoustic signal every 50 m, which was adapted to the required speed.

Measurements and analysis

HR was recorded continuously with Polar Vantage XL (Polar Electro, Kempele, Finnland) devices. La was analyzed from the ear lobe (BIOSEN C line, EKF-diagnostic GmbH, Barleben, Germany). HR and La were measured prior to the test and at the end of every stage. Metabolic gases $(\dot{V}O_2$ and $\dot{V}CO_2)$ were continuously measured with a portable indirect calorimetry system and data from the last 30 s of every stage were analyzed with the corresponding software (K4b^2, Version 7.4b, Cosmed, Rome, Italy). Calibration was executed before each test.

Statistics

According to our test design, we compared NW, W and J at the moving speed 1.8, 2.1 and 2.4 m s^{-1} and NW and W at all stages. Data from HR, $\dot{V}O_2$ and speed were related to the La at the aerobic–anaerobic threshold at 4 mmol l^{-1} La (La4) and at 2 mmol l^{-1} La (La2) by interpolation (Heck et al. 1985). Statistical evaluation was carried out with the program Statistica (Version 6.0, StatSoft, Tulsa, USA). Factorial analysis of variance was used to assess statistical differences with repeated measures (ANOVA, Newman–Keuls). Data is expressed as the mean ± SEM. The significance level for all analyses was set at $P \leq 0.05$.

Results

Significant higher values for $\dot{V}O_2$ (Fig. 1) were measured at 1.8 and 2.1 m s^{-1} with 8 and 7%, respectively for NW compared with W ($P < 0.05$).

La (Fig. 2) was higher for NW compared with W after all stages ($P < 0.05$ at 1.8 m s^{-1} and $P < 0.01$ at 2.1 and 2.4 m s^{-1}). Despite almost identical La for NW and J at the first J stage at 1.8 m s^{-1}, La values differed already at 2.1 m s^{-1} between NW and J ($P < 0.01$) because of the pronounced increase of La for NW during the incremental tests ($P < 0.01$). At 2.4 m s^{-1}, all disciplines showed significantly different La ($P < 0.01$) with highest La for NW (5.65 ± 1.97) and lowest La for J (3.26 ± 2.16).

Carbon dioxide concentrations $(\dot{V}CO_2)$ concentrations changed as expected in accordance with the

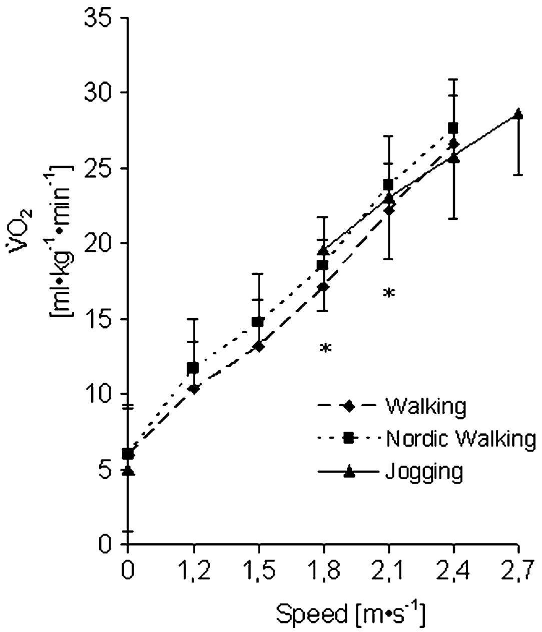

Fig. 1 Relative oxygen consumption (mean ± SEM) during the field tests for walking, nordic walking and jogging. Walking significantly different (*$P < 0.05$) compared with jogging and nordic walking

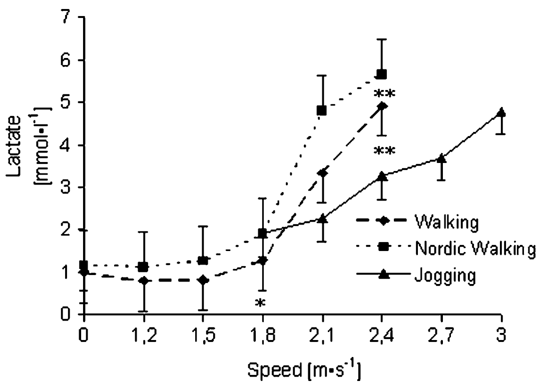

Fig. 2 Capillary blood lactate (mean ± SEM) during the field tests for walking, nordic walking and jogging. Walking significantly decreased (*$P < 0.05$). Significant differences between nordic walking, walking, jogging (**$P < 0.01$)

increased La at 2.1 and 2.4 m s^{-1}. $\dot{V}CO_2$ was higher for NW compared with J and W at 2.1 m s^{-1} ($P < 0.05$) and significant differences occurred between the disciplines at 2.4 m s^{-1} ($P < 0.01$).

HR (Fig. 3) for NW and W were higher than for J at 2.4 m s^{-1} ($P < 0.01$). In spite of highest La and $\dot{V}CO_2$ for NW at 2.4 m s^{-1} there were no differences for HR.

Figure 4 shows the moving speeds at fixed La values. The speed for reaching the La2 and La4 was significantly different for all disciplines, with the slowest speed for NW (1.8 ± 0.2 and 2.1 ± 0.2 m s^{-1} at La2 and La4, respectively) and the highest ($P < 0.01$ compared with W and NW) speed for J (2.3 ± 0.5 and 2.7 ± 0.5 m s^{-1} at La2 and La4, respectively). The speed for W (2 ± 0.2

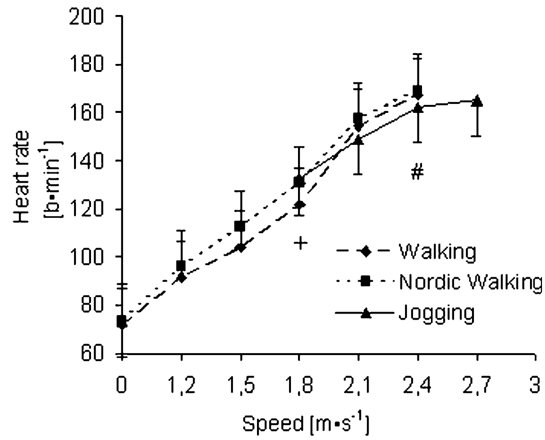

Fig. 3 Heart rate (mean ± SEM) during the field tests for walking, nordic walking and jogging. Walking significantly decreased ($^{+}P < 0.05$). Jogging significantly decreased ($^{\#}P < 0.01$)

and 2.3 ± 0.3 m s^{-1} at La2 and La4, respectively) was higher ($P < 0.05$) than for NW. With the lower speed from W and NW compared with J there were increased HR (Fig. 5) for J at La2 ($P < 0.05$) and La4 ($P < 0.01$). In spite of significant lower W speed for NW compared with W, the HR was the same. At La4, $\dot{V}O_2$ (Fig. 6) for NW was lower than for J ($P < 0.05$).

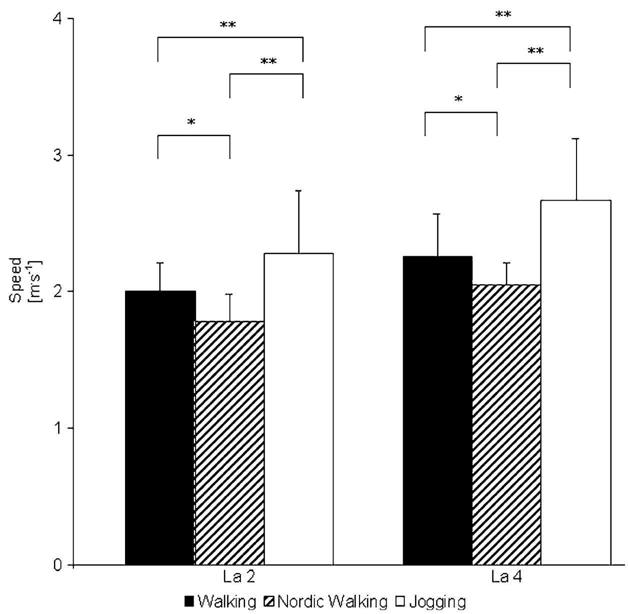

Fig. 4 Running speed (mean ± SEM) at 2 mmol l^{-1} (La2) and at the aerobic–anaerobic threshold (La4) for walking, nordic walking and jogging. Nordic walking significantly decreased (*$P < 0.05$) compared with walking at La2 and at La4. Jogging significantly increased (**$P < 0.01$) compared with walking and nordic walking at La2 and at La4

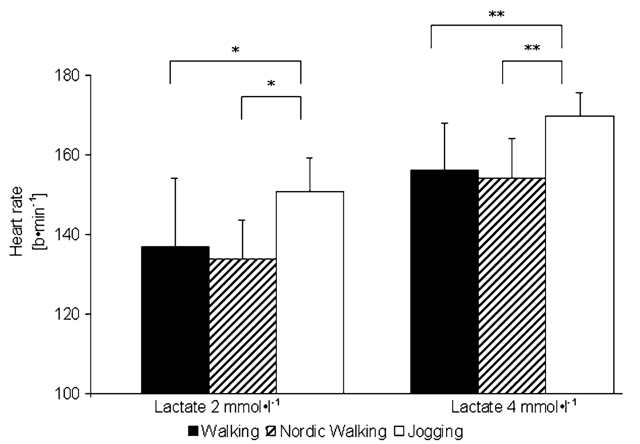

Fig. 5 Heart rate (mean ± SEM) at 2 mmol l^{-1} (La2) and at the aerobic–anaerobic threshold (La4) for walking, nordic walking and jogging. Jogging significantly increased at La2 (*$P < 0.05$) and at La4 (**$P < 0.01$) compared with walking and nordic walking

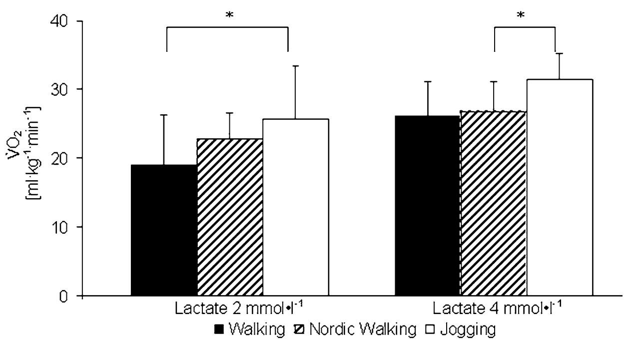

Fig. 6 Relative oxygen consumption (mean ± SEM) at 2 mmol l^{-1} (La2) and at the aerobic–anaerobic threshold (La4) for walking, nordic walking and jogging. Jogging significantly different (*$P < 0.05$) with walking at La2 and with nordic walking at La 4

Discussion

The present study revealed differences in oxygen uptake of up to 8% between NW and W ($P \leq 0.05$) at movement velocities of 1.8 and 2.1 m s^{-1}, respectively during an incremental field test in a group of healthy female subjects. HR for NW and W at 2.4 m s^{-1} were significantly higher ($P \leq 0.05$) compared with J. Capillary La concentration was significantly ($P \leq 0.05$) higher for NW at every stage compared with W and higher at 2.1 and 2.4 m s^{-1}, compared with J. $\dot{V}CO_2$ corresponded to changes in La concentration. With the higher ($P \leq 0.01$) movement speed of J compared with NW and W at La2 and at La4, there were significant higher HR ($P \leq 0.01$) for J at La2 ($P \leq 0.05$) and La4 ($P \leq 0.01$). Despite the slower movement speed for NW compared with W at La2 and La4 ($P \leq 0.05$), $\dot{V}O_2$ as well as HR did not show any differences between these disciplines. At La4, $\dot{V}O_2$ was lower for NW compared with J.

Oxygen uptake and movement speed

Higher oxygen uptake for NW compared with W has already been reported in earlier studies (Church et al. 2002; Porcari et al. 1997; Rodgers et al. 1995); but our data differ considerably. We measured differences of 8% at 1.8 m s^{-1} and 7% at 2.1 m s^{-1}, which roughly correspond to values of 12% at 1.86 m s^{-1} as reported by Rodgers et al. (1995), but differ from those given by Church et al. (2002) and Porcari et al. (1997) who found differences as high as 20.6% (at 1.65 m s^{-1}) and 23% (at 1.69 m s^{-1}), respectively. Because it is known that $\dot{V}O_2$ during endurance tests with (Doyon et al. 2001) and without (Jones and Doust 1996; Meyer et al. 2003) the use of poles is increased on the treadmill compared with FT as well as the fact that running on a treadmill affects the movement patterns compared with running in a natural environment (Nigg et al. 1995; Wank et al. 1998), also the use of a treadmill in the study of Porcari et al. (1997) may have contributed to the differences in $\dot{V}O_2$ values. NW on a treadmill may probably not represent free W with walking poles as optimal pole plant with a fixed ground contact is impaired by the moving walking belt. Thus, for NW typical movement patterns might be influenced negatively and may have affected $\dot{V}O_2$ measures.

Church et al. (2002) assumed that the relatively high NW velocities on the treadmill contribute to inefficient poling technique explaining simultaneously the lower $\dot{V}O_2$ in the study of Rodgers et al. (1995). On the one hand, this assumption might also be true for FT conditions as our data revealed decreasing differences between NW and W with increasing movement speed as far as $\dot{V}O_2$ was concerned. This could be due to a ceiling effect, which means that the range for differences between the disciplines gets smaller when approaching maximal $\dot{V}O_2$. On the other hand, high oxygen consumption at slow speeds as determined by Porcari et al. (1997) cannot be supported by data of the present study.

The major influence on differing $\dot{V}O_2$ oxygen consumption measures can definitely be attributed to the adjustment of movement speed. Rodgers et al. (1995) followed the design given by the incremental test procedure whereas Church et al. (2002) let the subjects freely choose the speed of one locomotive task and asked them to find identical speed in the task compared with the first. Church et al. (2002) randomized this procedure dealing with high interindividual differences in $\dot{V}O_2$ (8–47.6%). Due to the study of Porcari et al. (1997), trial order was conducted randomly for NW and W at a previously determined self-selected W speed. Freely chosen W speed could be shown to correspond to an optimum energy efficiency (Ralston 1958). The metabolic cost distinguishes between J and W due to the predominantly used energetic mechanisms, potential and kinetic energy in W and elastic energy in running (Cavagna et al. 1964; Saibene and Minetti 2002). A speed of about 1.1 m s^{-1} for W was found to be optimal in terms of metabolic efficiency. The transition from W to J occurs at speeds from 1.8 to 2.5 m s^{-1} (Greiwe and Kohrt 2000; Margaria et al. 1963; Saibene and Minetti 2002). As there exist optimal movement speeds for W and J, it is likely that there also exists an optimal movement speed for NW, differing from that of W and J. Thus, it is possible that defining the same movement speeds for W and NW in the studies of Porcari et al. (1997) and Church et al. (2002) could lead to an overestimation of energetic differences. However, the comparison between our study and the data from Church et al. (2002) and Porcari et al. (1997) is limited due to the different study designs. They let their subjects chose their own speed, whereas we predetermined the W speed for every stage.

HR and La accumulation

Our study revealed higher HR for NW than for W up to speed levels of 1.8 m s^{-1} and are in good agreement with other studies (Church et al. 2002; Porcari et al. 1997; Rodgers et al. 1995). At higher speeds, differences in HR and La were no longer found to be significantly different in our study. It is likely that poling techniques did not contribute to forward propulsion. Independent from using poles, W at speeds exceeding the running transition threshold becomes inefficient, which is reflected by significantly higher HR and La at 2.4 m s^{-1} for NW and W compared with J. The additional load distributed to the upper torso musculature in NW is most obviously responsible for the highest La concentrations at every load increment in comparison with W and J. There were no differences between the locomotion modes at 2.4 m s^{-1} as far as $\dot{V}O_2$ is concerned but La concentration for NW was significantly higher. Therefore, we can assume this to be a result of an additional involvement of anaerobic energy metabolisms of the upper torso and arm muscles with predominantly type II muscle-fiber distribution (Johnson et al. 1973; Susheela and Walton 1969). Higher La loads of NW most probably have caused an increase in CO_2 elimination at 2.1 and 2.4 m s^{-1}.

Interpolating the values above and below the aerobic–anaerobic threshold (La4) to evaluate submaximal endurance capacity (Heck et al. 1985) can be used to demonstrate locomotion mode-specific differences between NW, W and J. At a given metabolic load (La2/La4), locomotion speed is considerably lower for NW if compared with W ($P \leq 0.05$) and J ($P \leq 0.01$). W and NW, which are commonly performed in mixed groups, that is, at identical speed levels, are evidently not different as far as HR and $\dot{V}O_2$ are concerned. On the contrary, this means that training recommendations on the basis of HR monitoring and $\dot{V}O_2$-measures derived from W-tests would underestimate specific NW loads. These findings indicate—similar to results from comparisons of more obviously different endurance disciplines (rowing, swimming, running, cycling) (Di Prampero et al. 1978; Strömme et al. 1997)—the necessity of conducting NW-specific performance diagnostics to obtain adequate training recommendations.

In conclusion, the data obtained in the present study indicates higher $\dot{V}O_2$ for NW than in W and J but lower than previously reported; however, the comparability with previous studies is limited because of varying study designs. In this study at comparable speed levels, $\dot{V}O_2$ for NW is as high as for J. Determination of capillary blood La together with $\dot{V}O_2$ and HR are helpful parameters to differentiate between physiological responses of NW, W and J. In order to obtain a particular submaximal La level, NW needs to be performed at lower locomotion speed than W and J. HR and $\dot{V}O_2$ measurements as training recommendations can therefore not be derived from W or running tests.

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