Original Article

Effect of Nordic walking on the range of motion of the trunk and upper extremities at different walking speeds and ground slope

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Abstract

Nordic Walking (NW) is an increasingly popular physical activity with beneficial health effects. Therefore, it is necessary to consider the effect of different factors that may influence its performance. The aim of this study was to compare the range of motion of the trunk and upper extremities during NW with conventional walking (W) at different walking speeds and ground slope. 16 healthy men participated in the survey (age 22.7 ± 1.3 years, weight 75.5 ± 5.3 kg, height 180 ± 5.0 cm), who performed NW and W treadmill trials on inclines of 0% and 8%. The treadmill speed was self-selected for each subject at start for NW and then increased by 10 and 20%. VICON MX system was applied for 3D kinematic analysis. During NW, the range of motion of the pelvis in sagittal plane significantly increased compared to W ($p = 0.002$). During NW on flat ground at speed increased by 10 and 20% respectively, the range of motion at the shoulder joint in sagittal plane was considerably smaller ($p = 0.010$ and $p = 0.035$ resp.) than during W. The range of motion at the elbow joint was significantly higher during NW at self-selected speed and on 8% incline ($p = 0.003$) when compared to W. The same applies for speed increase by 10% ($p = 0.011$).

Key Words: kinematics, Nordic walking, pelvis, shoulder, healthy men

Introduction

Recently, NW has been attracting considerable interest. Due to the popularity and attractiveness of NW, the possibility of using it as a form of exercise in various areas of sport, recreation, tourism and rehabilitation is becoming increasingly popular (Morgulec-Adamowicz, Marszałek, & Jagustyn, 2011). NW is known to bestow beneficial effects on the resting heart rate, blood pressure, exercise capacity, maximal oxygen consumption, and quality of life in patients with various diseases and can thus be recommended to a wide range of people as primary and secondary prevention (Tschentscher, Niederseer, & Niebauer, 2013).

Furthermore, NW improved the stride length, gait variability based on stride length, maximal walking speed, exercise capacity at submaximal level and postural stability in patients with Parkinson's disease (Reuter et al., 2011). NW can also improve exercise capacity, lower body endurance and coordination of movements in patients with good exercise tolerance participating in early, short-term rehabilitation after an acute coronary syndrome (Kocur, Deskur-Śmielecka, Wilk, & Dylewicz, 2009). In comparison with W, NW has two major differences that bring benefits (Kocur & Wilk, 2006). Firstly is the increase in oxygen uptake that leads to higher energy expenditure without increasing the perceived exertion (Church, Earnest, & Morss, 2002). The second difference is the decrease of load on lower extremities when part of the body mass is carried by the upper extremities (Kocur & Wilk, 2006). According to the study of Sugiyama, Kawamura, Tomita, and Katamoto (2013), the use of poles in NW attenuates muscle activity in lower extremities during the stance and push-off phases with concomitant decrease for the lower extremities, and increased energy expenditure through the upper body and the respiratory system at certain walking speeds. Currently, the reduction in loading of the lower extremities is questioned by many studies (Dziuba, Żurek, Garrard, & Wierzbicka-Damska, 2015; Hansen, Henriksen, Larsen, & Alkjaer, 2008; Stief et al., 2008). Additionally, the recommendation of NW as a rehabilitation training concept for overweight people and orthopedic patients with existing musculoskeletal problems of the lower extremities compared with W has to be reconsidered (Stief et al., 2008). In NW, the reaction forces on lower extremities during heel-strike increase in contrast to W and decrease during the push-off phase (Hagen, Hennig, & Stieldorf, 2011; Kleindienst, Michel, Schwarz, & Krabbe, 2006; Stief et al., 2008). Walking up a slope of increasing inclination requires change(s) to the walking pattern and an important one concerns the leading foot that does not land with an almost straight knee joint as seen in horizontal walking. Here, extra concentric contraction of the hip flexors is needed requiring additional effort and energy expenditure. Following lead-foot landing, work is done concentrically by the hip and knee extensors to raise the center of mass and increase potential energy (Chapman, 2008).

The aim of this study was to compare the range of motion of the trunk and upper extremities during NW with W at different walking speeds and ground slope (inclines).

Methods

Subjects

The experimental group consisted of 16 healthy men (age 22.7 ± 1.3 years, weight 75.5 ± 5.3 kg, height 180 ± 5.0 cm), who had no experience with NW prior to commencing the survey. In the pre-research phase, all subjects were fully informed about the procedure of measurements, they were duly acquainted with all possible risks related to the research, and they provided their written consent. The study was approved by the Ethics Committee of the Faculty of Physical Culture at Palacký University Olomouc.

Procedure and Protocol

Prior to commencing the measurements, the subjects were familiarised with the basic principles of NW. They were given two one-hour training lectures by an experienced NW lecturer. The length of poles of each subject were set at 68% of the total body height (Hansen & Smith, 2009). With respect to individual locomotion performance of each person, the self-selected NW speed was measured for each subject at the beginning of the research on a 40m track by means of photocells FiTROLight Gates (FiTRONiC s.r.o., Bratislava, Slovak Republic). The photocells were located 20 and 30 metres from the starting point of the track at shoulder level. Self-selected NW speed was calculated as the average value from two attempts. All participants were familiarised with walking and NW on a treadmill. The protocol consisted of three walking speeds (self-selected speed, self-selected speed increased by 10% and self-selected speed increased by 20%) and two slopes (flat surface and 8% inclination). The sequence of conditions was random for each protocol to avoid the effect of adaptation of walking performance and fatigue. Two individual protocols were made out for each subject. One of these was for NW and the second for W. The order of these protocols was random as well. A sufficient break time of at least 30 min was set between both protocols. The entire protocol lasted for 7 min. Each protocol started with a warm-up phase (30s), which was followed by 3 minutes of measurement during which the walking speed changed every minute (3 different conditions). The warm-up phase condition corresponded to the first condition of the protocol (first minute of measurement). In the next 30s, the ground slope was changed and the whole measurement was repeated, again with random sequence of walking speed. The first 30s in each minute of the measurement served for adapting to the new condition, 3D analysis was done for 30s during the second half of each condition. 5 walking cycles were used for processing data. The measurement was performed in relatively standard laboratory conditions (temperature $20\text{--}24^\circ\text{C}$, relative humidity $40\text{--}60\%$) maintained by air-conditioning and humidifier.

Instruments

The measurement was performed on LODE Valiant treadmill (Lode, B. V. Medical Technology, Groningen, Holland) with a 2-m wide belt enabling NW without any limitations to movement. The VICON MX system (Oxford Metrics Group, Oxford, Great Britain) was used for 3D kinematic analysis. The system consisted of 7 infra-red cameras of type T10 with 200 Hz (shot) frequency and 1 Mpx resolution. 35 markers were placed on the subject's body according to the Plug-in gait full body model by an experienced assistant.

The range of motion at the pelvis was assessed in three basic planes: sagittal, frontal and transversal (rotation). The range of motion of the trunk was assessed in the sagittal and frontal planes and at the shoulder joint in the sagittal and transversal planes. The range of motion at the elbow joint was assessed only in the sagittal plane.

Data processing and statistical analysis

Recorded data was assessed in Vicon Nexus and Vicon Polygon (Oxford Metrics Group, Oxford, United Kingdom) programmes. Statistical data processing was performed in Statistica (Version 12, StatSoft, Inc., Tulsa, OK, USA). Multi-factor analysis of variance (ANOVA) was used to make a comparison between the measured parameters during NW and W, at different speeds and inclination. The differences were tested by Fischer's LSD test. The level of statistical significance was set at $\alpha = 0.05$.

Results

The assessment of angular parameters in different walking conditions is shown in Table 1.

Table 1. Observed kinematic parameters of the assessed body segments in different walking conditions

	Walking on the flat ground		Uphill walking (8%)		ANOVA (<i>p</i>)	Fisher's LSD test (<i>p</i>)	
	Regular walking	Nordic walking	Regular walking	Nordic walking		W0 vs NW0	W8 vs NW8
Pelvis S							
v0	4.3±1.7	5.0±1.6	4.8±2.1	6.3±3.5	0.002	0.453	0.099
v10	4.3±1.3	5.4±1.9	4.7±0.7	6.2±2.6		0.222	0.097
v20	5.4±1.2	5.8±1.0	5.9±2.2	7.5±3.4		0.615	0.087
Pelvis F							
v0	10.7±2.6	12.0±2.3	12.2±2.8	10.9±3.1	0.753	0.390	0.487
v10	11.5±3.7	11.7±2.6	11.8±4.8	13.0±3.4		0.887	0.414
v20	12.5±4.1	13.0±2.4	14.3±3.6	13.6±3.9		0.749	0.686

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Pelvis T							
v0	14.1±4.5	15.6±3.3	12.6±4.0	15.0±5.7	0.076	0.477	0.328
v10	16.3±4.3	15.8±3.9	12.8±3.9	16.2±5.3		0.796	0.101
v20	18.4±4.8	19.0±5.0	16.2±5.1	18.4±7.5		0.769	0.360
Trunk S							
v0	4.6±1.4	4.9±3.2	4.9±1.5	4.7±1.3	0.224	0.680	0.765
v10	4.4±1.5	5.0±2.3	4.6±2.2	5.2±2.3		0.473	0.498
v20	4.8±1.2	5.7±3.0	5.3±1.9	5.7±2.4		0.284	0.606
Trunk F							
v0	6.3±1.3	7.4±3.9	6.7±2.3	7.2±3.5	0.557	0.249	0.674
v10	6.9±1.5	6.9±2.9	6.9±1.6	5.9±1.6		0.965	0.338
v20	7.9±2.7	6.5±1.4	7.3±2.4	6.6±1.5		0.143	0.504
Shoulder rotation							
v0	9.5±4.4	11.5±5.1	10.9±2.4	9.7±4.8	0.717	0.214	0.490
v10	9.3±3.8	9.7±4.8	10.8±3.2	9.1±3.4		0.783	0.345
v20	8.9±2.8	9.2±4.7	10.8±4.0	9.4±4.0		0.864	0.438
Shoulder S							
v0	30.6±9.2	24.9±9.0	29.2±10.0	22.5±6.8	< 0.001	0.083	0.078
v10	32.3±8.0	23.9±7.0	29.8±9.4	23.4±8.1		0.010	0.076
v20	32.4±8.8	25.5±8.7	32.5±10.4	26.6±8.8		0.035	0.102
Elbow S							
v0	44.7±11.3	49.1±14.4	43.7±13.4	60.8±12.0	0.001	0.355	0.003
v10	51.3±11.9	53.5±9.6	44.9±15.5	58.9±10.2		0.644	0.011
v20	52.8±10.5	49.0±15.0	48.7±14.1	56.8±13.9		0.429	0.132
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Note. *M* – mean, *SD* – standard deviation, *v0* – walking at self-selected speed, *v10* – walking at self-selected speed increased by 10%, *v20* – walking at self-selected speed increased by 20%, *Pelvis S* – range of motion of pelvis in the sagittal plane, *Pelvis F* – range of motion of pelvis in the frontal plane, *Pelvis T* – range of motion of pelvis in the transversal plane, *Trunk S* – range of motion of trunk in the sagittal plane, *Trunk F* – range of motion of trunk in the frontal plane, *Shoulder S* – range of motion of shoulder joint in the sagittal plane, *Elbow S* – range of motion of elbow joint in the sagittal plane, *ANOVA* – multi-factor analysis of variance assessing effect size through all experiments of a given parameter, *W0 vs NW0* – comparison of regular walking and Nordic Walking on the flat ground, *W8 vs NW8* – comparison of regular walking and Nordic Walking during uphill walking, *p* – value of statistical significance, values of all parameters are given in degrees.

From the results of analysis of variance follows that the range of motion of the pelvis in sagittal plane was significantly increased during NW compared to W ($p = 0.002$). There is significant difference in the range of motion at the shoulder joint in sagittal plane between W and NW ($p < 0.001$). During NW on flat ground at speed increased by 10%, the range of motion was significantly smaller ($p = 0.010$) than during W. The same applies to walking on a flat ground at speed increased by 20% ($p = 0.035$).

The range of motion at the elbow joint in sagittal plane differs significantly between W and NW ($p = 0.001$). The range of motion during NW up the hill at self-selected speed was significantly higher ($p = 0.003$) compared to W. The same applies to NW at speed increased by 10% ($p = 0.011$).

No statistically significant difference was found for different conditions in other measured parameters between W and NW.

Discussion

A number of studies deal with the analysis of metabolic demands during NW and loading of the lower extremities. However, only a limited number of studies address the topic of kinematic analysis of NW. To the best of our knowledge, no study focusing on kinematics of the trunk and upper extremities exists in available literature. The purpose of this study was, therefore, to compare the range of motion of the trunk and upper extremities during NW and W at different walking speeds and inclination.

The results of the study of Morgulec-Adamowicz et al. (2011) show that NW leads to significant increase in hip joints movement in the sagittal plane. Stief et al. (2008) [ENREF 21](#) came to the conclusion that NW increases the step length in contrast to W. From the results of our study it follows that during NW there is significant increase in the range of motion at the pelvis in sagittal plane compared to W. It can, therefore, be assumed that the increase in step length during NW is associated with not only by increase in the range of motion at the hip joint in sagittal plane but also with increase in the range of motion at the pelvis in the same plane.

According to Chapman (2008), walking up an incline of a rising gradient requires change(s) to the walking pattern. All normal subjects used the same kinematic and motor strategies to adapt to uphill walking (Leroux, Fung, & Barbeau, 1999). The hip joint movement patterns showed significant differences from the patterns

observed during walking on flat ground. During uphill walking, the hip extensor movement increases. The main kinematic change is in the requirement to lift the lower limb and the centre of mass in vertical direction (Hong et al., 2014; Lay, Hass, & Gregor, 2006). Increased ground inclination induced a flexed posture of the hip, knee and ankle during initial contact. This adaptation process actually began in the mid-swing with graded increase in hip flexion and ankle dorsiflexion as well as gradual decrease in knee extension (Leroux et al., 1999). Based on the mentioned information we assume that the difference in the range of motion at the pelvis in sagittal plane between NW and W is empowered by increased demands on the range of motion at the hip joint; thus, the range of motion at the pelvis in sagittal plane is higher during uphill walking rather than when walking on flat ground.

During W, the thorax rotates around the longitudinal axis in direction opposite to the pelvic movement, which is a response to maximal anterior tilt of the pelvis occurring during heel-strike (Swinnen et al., 2013).

During lower speeds, the thorax and pelvis tend to rotate in the same direction, which means an in-phase pattern although a particular anti-phase coordination (moving in opposite directions) always appears during the movement (Dedieu & Zanone, 2012; Huang et al., 2010). The shift in pelvis-thorax coordination from in-phase to anti-phase with increasing velocity was found to depend on the pelvis beginning to move in-phase with the femur, while the thorax continued to counter rotate with respect to the femur (Bruijn, Meijer, Van Dieen, Kingma, & Larnoth, 2008; Huang et al., 2010; Lamothe, Beek, & Meijer, 2002). In our study, we assessed trunk (shoulders) rotation and pelvis rotation separately. We did not find any significant differences for these parameters between both walking performances. The question is, however, if the same phase shift occurs between pelvic rotation and trunk rotation during NW, as it is in the case of W. The different step length and upper extremities movement occurring in NW could influence the phase shift between pelvic rotation and trunk rotation as well. For this reason, further research on the topic would be useful.

The range of motion at the shoulder joint in sagittal plane in healthy men was assessed during W (conventional walking) in the study by Carmo, Kleiner, da Costa, and Barros (2012). The value was $20.1 \pm 8.2^\circ$. In the case of elbow joint, this range of motion was $12.0 \pm 4.3^\circ$. The average speed of walking was $3.0 \pm 0.6 \text{ km} \cdot \text{h}^{-1}$. Our study, in contrast, produced higher measured values. We assume this to be due to higher speed of walking, which was $6.2 \pm 0.3 \text{ km} \cdot \text{h}^{-1}$. This fact is in accordance with the study conducted by Hejrati, Chesebrough, Foreman, Abbott, and Merryweather (2016), who confirmed the increase in range of motion with increasing walking speed.

The range of motion at the shoulder joint in sagittal plane was significantly smaller at higher speeds during NW on flat ground. The studies by Pellegrini et al. (2015) and Shim, Kwon, Kim, Kim, and Jung (2013) describe the increase in muscle activity in the area of shoulder joint and upper limbs during NW compared to W. It concerns, apart from increase in activity of m. biceps brachii and m. triceps brachii, also increased use of m. latissimus dorsi responsible for extension of the shoulder joint during the poling phase and also m. deltoideus that is responsible for stabilisation of the shoulder joint. We assume that if the movement of upper limbs during poling came prevalingly from the shoulder joint, the propulsion force exerted on the pole would be very strong. This may be the reason why in NW there is reduction in the range of motion at the shoulder joint in sagittal plane compared to W. The range of motion at the elbow joint in sagittal area was significantly higher for NW during uphill walking at self-selected speed and at speed increased by 10%. According to [ENREF 20](#) Nottingham and Jurasin (2010), the pole tip should make contact with the ground somewhere between the opposite heel and the middle of the stride distance between the feet. We assumed that it is necessary to lift the pole higher during increasing ground inclination at the moment of pole contact with the ground. With regard to the fact that it comes to significant decrease in the range of motion at the shoulder joint in sagittal plane, the lifting of the pole higher during uphill NW is performed by higher flexion at the elbow joint.

Study limitations

The experimental group was quite homogenous. It comprised young healthy men. Although we assume that the conclusions of this study could be applied also on women and other age categories, it is necessary to make other measurements with concrete groups including patients who were prescribed NW as part of their rehabilitation. Walking on a treadmill differs in some parameters from walking in the terrain. Currently, it is impossible to realize this study with similar methods in the terrain. During 3D kinematic analysis, there is always the risk that the markers could move from the original position on the skin. This is nevertheless a common problem that concerns the majority of studies dealing with 3D kinematic analysis. Moreover, it is possible to minimise potential mistakes by means of a suitable filter during data processing.

Conclusion

The focus of this study was to compare the trunk and upper extremities movement during NW and W performed at different walking speed and ground slope. No differences were found for the range of motion of the trunk and pelvis during walking on flat ground. The range of motion of the pelvis in sagittal plane increases during uphill NW compared to W. The NW influences lowering the range of motion at the shoulder joint in sagittal plane. The smaller range of motion at the shoulder joint during uphill NW is accompanied by increased range of motion at the elbow joint in sagittal plane.

It is necessary to take into account the different positions of the upper extremities and the subsequent possible differences in their loading when considering the use of this way of locomotion, for example in rehabilitation.

In the next phase of the research, it is necessary to concentrate on the comparison of kinematics of the trunk and upper extremities between NW and W during downhill walking.

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Conflicts of interest

None declared.

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