Nordic Walking does not reduce the loading of the knee joint

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The use of Nordic Walking (NW) as a rehabilitation modality has increased considerably. NW (walking with poles) is advocated as a healthy physical activity that reduces the load on the knees. Few studies using the techniques of NW exist, and the findings are contradictory. The aim of this study was to investigate whether NW reduces the loadings upon the knee joint compared with walking without poles (NP). Seven experienced female NW instructors volunteered. Three-dimensional gait analyses were performed. Internal flexor and extensor joint moments were calculated using an inverse dynamics approach and the knee joint compressive forces were calculated. No differences in compression or shear forces between NW and NP were found. The peak knee flexion angles were larger during NW (-32.5 ± 6.0°) compared with NP (-28.2 ± 4.2°). The hip range of motion (ROM) was significantly increased during NW (64.4 ± 10.2°) compared with NP (57.8 ± 9.7°); no differences in the knee and ankle joint ROM were observed. The changes in the joint angles were not followed by changes in the joint dynamics. The present study does not support the statement that NW reduces the load on the knees.

Walking for fitness purposes is a health-promoting activity; thus, walking in a moderate amount at a brisk pace minimizes the risk for lower extremity injuries, while it adheres to adequate physical activity according to national recommendations for health activity (Hootman et al., 2002). The use of Nordic Walking (NW) as a rehabilitation modality has increased considerably in the last few years. NW is fitness walking with specially designed Nordic Walker poles that also engage the upper body during walking. NW has found its way into the fitness market and in rehabilitation programs with an increasing number of users. Walking poles are advertised as a product that turns walking into an effective total body exercise with benefits similar to cross-country skiing (www.excrstrider.com, 2006). In the popular literature such as health magazines and in web pages, it is often stated that the general benefits of NW are an increase in energy consumption (as much as 46%), higher efficiency and higher heart rate compared with ordinary walking. Furthermore, it is stated as a health fact “that NW does not aggravate the joints of the lower extremity and that it reduces the load on especially the knee joints” (e.g. Kreuzriegl et al., 2002; Gerg et al., 2005; www.nordicwalking.com, 2006). Only very few studies using walking poles and the techniques of NW exist, and according to loading of the joints the findings range from a small reduction (Willson et al., 2001) to an increased load Kleindienst et al., 2006. The knee joint is the largest joint in the human body and it is involved in all kinds of human locomotion. Knee joint pain or osteoarthritis (OA) of the knee is the most common joint disease, especially among older people (Verbrugge, 1995), and the single greatest cause of chronic functional impairment. Females have a higher prevalence than males (11.4% vs 6.8%) and the prevalence of OA is expected to increase dramatically during the next 20 years as the population ages (Felson et al., 1987). Especially, knee OA is a major cause of disability and dysfunction, causing joint pain and gait disturbances such as reduced walking velocity and reduced knee range of motion (ROM) (Messier, 1994). Therefore, rehabilitation strategies that aim at increasing the functional capacity without potentially detrimental mechanical joint loadings would be beneficial in the rehabilitation of patients with joint diseases. It has been argued that individuals whose intensity of activity is limited by lower extremity orthopedic problems might benefit from the increased stability provided by use of poles (Rodgers et al., 1995). Accordingly, the purpose of this study was to investigate whether NW reduces the loadings upon the knee as well as the hip and ankle joints compared with walking with No Poles (NP). As the mechanical load can be expressed as
internal compression and shear forces for the joints and external ground reaction forces (GRF), both parameters were measured and quantified in the present study. To ensure the use of a correct and standardized NW technique, and to increase the homogeneity of the data according to gait pattern, only very experienced NW instructors were included as subjects.

Materials and methods

Subjects

Seven experienced female instructors in NW were recruited: mean age 51 years (range: 42–58), height 167 cm (range: 158–174) and weight 63.1 kg (range: 56–76). They were all healthy and non-obese. Informed written consent was obtained.

Gait analysis

The subjects walked across two force platforms (AMTI, OR6-5-1 Advanced Mechanical Technology, Inc, Watertown, MA, USA) placed on a 6 m walking ramp. All subjects were instructed to walk as they would during their normal practice. They were all using the NW technique according to the guidelines of the International Nordic Walking Association (INWA) with the poles in a diagonal position (www.inwa.nordic-walking.com). The subjects practiced walking on the ramp several times until they were able to walk at their normal speed for NW. During data recordings, the subjects walked 10 times with the poles (NW) in a row and 10 times without poles (NP). The order of walking with or without poles was randomized. The subjects were instructed to walk at their normal speed for NW under both conditions. The walking speed was measured by photocells placed before and after the force platforms, which made it possible to ensure that the speed was identical during NW and NP walking. A variation of ± 10% of normal speed for NW during a trial was accepted. If the walking speed exceeded this limit, the trial was discarded.

Fifteen small, reflecting spherical markers (12 mm diameter) were placed on the subjects according to the marker setup described by Vaughan et al. (1992). The markers were placed on the head of the fifth metatarsal, the heel, the lateral malleolus, the tibial tuberosity, the lateral femoral epicondy, the greater trochanter, the anterior superior iliac spine and the sacrum. All subjects wore their own walking shoes. Five video cameras (Canon MV 600, digital video, Computer City, Copenhagen, Denmark) operating at 50 Hz were used to record the movements. Synchronization between the video signals and the force plate signals was obtained by an audio signal that was transmitted to all five video cameras. The signal was stored on the audio track of the audio and video- interleaved (AVI) file formats and used to synchronize the video signals. Additionally, the signal triggered the recordings of the force platforms, which ensured synchrony between the video and force signals. The video sequences were digitized and stored on a computer. Sixteen non-co-planar points on a standard calibration frame (Peak Performance 5) were digitized to calibrate each of the video sequences. The calibration frame was placed in the middle of the walkway and covered both force plates. Three-dimensional (3D) coordinates were then reconstructed by direct linear transformation using the Ariel Performance Analysis System (APAS). Before the calculations, the position data were digitally low-pass filtered by a fourth-order Butterworth filter with a cut-off frequency of 6 Hz, and the 1000 Hz force plate signals were downsampled to 50 Hz to fit the video signals.

Calculations

The angular position of the ankle, knee and hip joints was calculated to describe the movements in the sagittal plane. Zero degrees defined the anatomical position (foot at 90° to leg) and positive values reflected knee hyperextension, hip flexion and ankle dors flexion. Internal flexor and extensor joint moments about the ankle, knee and hip were calculated using a 3D inverse dynamics approach described by Vaughan et al. (1992). The joint moments were expressed in an anatomically based reference system. The anatomical axes for the flexor and extensor moments of the ankle, knee and hip joint were the medio-lateral axes of the segment reference frames of the shank, the thigh and the pelvis, respectively. Ankle dors flexor, knee extensor and hip flexor joint moments were considered to be positive, while ankle plantar flexor, knee flexor and hip extensor joint moments were considered to be negative. MATLAB was used for all calculations. To assess the knee joint compressive forces, a statically determinate muscle model was applied (Schipplein & Andriacchi, 1991). The model assesses whether the overall knee compression forces are sufficient to balance the net frontal plane moments, thereby keeping the joint closed laterally. The medio-lateral position of the tibio-femoral contact point is fixed at 25%, of the knee medio-lateral joint diameter from the knee joint center, whereas the antero-posterior contact point changes with flexion. As long as the overall knee compression forces acting over the contact point resist the frontal plane moments, no tension in lateral soft tissue is required; otherwise, appropriate lateral tissue tension is introduced to avoid lateral joint opening. Lateral soft tissue tension indicates that all joint forces are supported by the medial joint compartment and more than the estimated muscle force is needed to avoid lateral opening of the joint. The overall knee compression force was calculated as the vector sum of (a) the intersegmental reaction forces resolved along the long axes of the tibia, (b) the compression components of the active muscle group forces and (c) the axial component of the cruciate ligament tension. The muscles included the hamstrings, gastrocnemius and quadriceps muscles. The hamstring and gastrocnemius complex constituted a flexor muscle group active when the net sagittal knee joint moment favored the flexor (i.e. negative) and the quadriceps muscle represented an extensor muscle group active when the net moment favored extensors (positive). The muscle forces were calculated by combining the net sagittal plane joint moments with the muscle moment arms derived from a third-order polynomial relating the knee joint angle to the muscle moment arms (Draganich et al., 1987). The axial cruciate ligament forces were estimated under the assumption that the cruciates only resist antero-posterior shear forces. The antero-posterior shear forces were calculated as the vector sum of (a) the intersegmental reaction forces resolved along the antero-posterior axis of the tibial plateau and (b) the antero- posterior components of the active muscle group forces. The model differed from the one published previously by (Schipplein and Andriacchi, 1991), in that the knee joint diameter was obtained from each subject and used to calculate the position of the tibio-femoral contact point. In the original model, the knee joint diameter was fixed at 80 mm for all subjects. The predicted values are presented as a proportion of body weight.

Normalization and data reduction

Data obtained from the left leg with the poles (NW) and without the poles were analyzed. Three gait cycles were time-normalized and averaged for each subject. Normalization was performed in MATLAB by interpolating data points to form 100 samples for each gait cycle. Only the stance phase was analyzed. The joint moments were normalized to body weight. The peak values of the knee and hip joint moments and knee joint angles in the first half of the stance phase were calculated.
Table 1. Average (SD) peak knee joint compression and shear forces during Nordic Walking (NW) and during Walking without poles (NP)

<table>
<thead>
<tr>
<th></th>
<th>NW Mean (SD)</th>
<th>NP Mean (SD)</th>
<th>Mean (SD)</th>
<th>Difference 95% CI</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall compression (bw)</td>
<td>3.65 (0.6)</td>
<td>3.56 (0.5)</td>
<td>0.08 (0.6)</td>
<td>[−0.38;0.55]</td>
<td>0.74</td>
</tr>
<tr>
<td>Medial compartment compression (bw)</td>
<td>3.17 (0.4)</td>
<td>2.66 (0.6)</td>
<td>2.22 (0.5)</td>
<td>[−0.23;0.67]</td>
<td>0.37</td>
</tr>
<tr>
<td>Lateral compartment compression (bw)</td>
<td>0.92 (0.4)</td>
<td>1.16 (0.4)</td>
<td>0.26 (0.5)</td>
<td>[−0.21;0.08]</td>
<td>0.19</td>
</tr>
<tr>
<td>Anterior shear force (bw)</td>
<td>0.78 (0.2)</td>
<td>0.74 (0.2)</td>
<td>0.04 (0.3)</td>
<td>[−0.22;0.15]</td>
<td>0.72</td>
</tr>
<tr>
<td>Posterior shear force (bw)</td>
<td>−0.06 (0.1)</td>
<td>−0.03 (0.1)</td>
<td>0.03 (0.1)</td>
<td>[−0.08;0.02]</td>
<td>0.27</td>
</tr>
</tbody>
</table>

Values are in times bodyweight (bw). 95% CI and P-values from paired t-tests of the differences are presented.

for each subject. The peak value of the ankle plantar flexor moment and values of the ankle and hip joint angles at peak knee flexion were also calculated. The individual peak values were then used as input parameters to the statistical analyses.

Statistics

Student’s t-test for paired data was used to identify differences between NW and NP. The level of significance was set at 5%.

Results

Data for the knee joint compression and shear forces are presented in Table 1. We found no difference for either compression or shear forces between NW and NP (P > 0.19). The time-course patterns of the ankle joint angle during NW and NP were very similar and no significant differences were observed in this parameter (Fig. 1). In contrast, the peak knee flexion in the first half of the stance phase was significantly larger during NW (−32.5 ± 6.0°) compared with NP (−28.2 ± 4.2°) (P = 0.02). There was no significant difference in the peak hip flexion, although it approached significance (NW: −34.6 ± 8.8°; NP: −30.0 ± 7.3°, P = 0.06). The hip ROM was significantly increased during NW (64.4° ± 10.2°) compared with NP (57.8 ± 9.7°) (P = 0.01), while no differences in the knee and ankle joint ROM were observed (Fig. 1). The differences in the angular positions were not followed by an increase in the dynamics results as can be seen from the joint moment curves in Fig. 2. However, an increased ankle moment for the first 25% of the stance phase was found for NW. No significant difference was found for GRF (Fig. 2). There was no significant difference in walking speed between NW (5.4 km/h; SD 0.3, range: 5.05−5.83 km/h) and NP (5.6 km/h; SD 0.3, range: 5.18−5.86 km/h). There was a small but significant (P = 0.003) difference in stride length: NW: 0.95 m (SD 0.15) and NP: 0.89 m (SD 0.13).

Discussion

The main finding of this study was that no decrease in loadings of the knee joint was observed during NW compared with walking without poles. There was no difference in compression and shear forces for the knee joint. Additionally, no difference in hip and knee extensor moments during NW was observed when compared with walking without poles. However, a small but significant increase in joint angular movements was found for NW, suggesting a more “bouncy” walk compared with nor-
Mechanical loads of Nordic walking

Fig. 2. Joint moments and ground reaction forces.

Oriental walking. This may explain the increased ankle plantar flexor moment and the increased stride length during Nordic walking.

Inspired by the use of hiking poles and poles for skiing, NW poles are recommended for recreational walkers and people with joint problems such as overweight people. In advertisements for NW, it is stated that there is scientific evidence for the benefits of NW and that these benefits include reductions in the load on the knee as well as increased energy consumption (http://research.imw.berkhopolku.com, 2006). In downhill walking overuse injuries occur in the lower extremity, particularly in the foot, ankle and knee (Blake & Ferguson, 1993). It has been found that the use of hiking poles in downhill walking reduces the GRF significantly for knee joint moment (12–18%), and tibio-femoral compressive and shear forces (12–25%) (Schwamberger et al., 1999). However, NW is not introduced for hill walking but rather for level walking and thus the loadings on the joints are different. NW, it thought to optimize normal (brisk) walking in order to increase the benefits and minimize the loads upon the joints and it includes a special technique that has to be learned. Some of the scientific studies had used novices in NW introducing the poles and the technique on the day of the investigation, which very likely may bias the results. In the present study, the subjects were all experienced instructors in NW and the walking velocity was the same for both conditions (5.4–5.5 km/h). As the subjects were experienced NW instructors, they were very much aware of the use of a proper technique. Their speed for NW was self-selected and they were able to reproduce the same speed without poles. It is important to use the same speed when loadings are to be compared because a difference in walking speed would confound the results of GRF as increases in walking speeds per se will result in increased knee joint extensor moments and flexion angles (Kirtley et al., 1985).

Willson et al. (2001) suggested that walking with poles could potentially result in a load reduction of the lower extremities. The subjects in that particular study were all novices in NW (8M, 5F). In contrast to the findings of the present study, Wilson et al. found a general decrease in knee angle ROM of when using poles compared with NP. They used both a self-selected speed to compare walking with and without poles with a difference in speed of 3.3% (NW 5.7 km/h; NP 5.3 km/h) and a controlled speed to compare three different techniques of walking with poles. They found a reduction of stresses on the lower extremities, expressed as an average decrease in the vertical GRF of 3.3% during walking with poles than walking without poles for two of the conditions and an increase of 4.4% for the third condition, which is similar to the technique used in NW (www.nordicwalking.com). Willson et al. (2001) indicate that there is a potential benefit of poles use for exercise. Brunelle and Miller (1998) reported that walking poles appear to absorb shock during the mid-stance phase but at heel strike, the poles aided in increasing the vertical GRF (Fv). The Fv from the walking pole accounted for 25.7% of the total body weight. In the anterior–posterior direction (Fh), the forces were 5.8% of the total body weight, thus indicating a forward thrust component while using the walking poles. They suggested that persons with lower extremity injuries should use the poles with caution because of the increased Fh at heel strike. More recently, Kleindienst et al. (2006) investigated experienced Nordic Walkers and showed higher vertical and horizontal GRFs during landing for NW compared with normal walking. They concluded that “none of the kinematic parameters suggest a physiological benefit of NW compared to walking.” In our study, no significant difference between NW and NP in GRF was found.
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Our study sample comprised women aged between 42 and 58 years, which presumably is a pre-OA age. However, the prevalence of lower extremity joint diseases increases with age, and especially prevalent knee OA is higher among women aged >55 years (Srikanth et al., 2005). As indicated in the study by Willson et al. (2001), familiarity with the NW technique is important for the knee joint load magnitude, and therefore caution should be exercised if NW is recommended to elderly persons who are novice in NW. This is supported by an indication of physical activity being a significant risk factor for incidence of knee OA (Felson et al., 1997).

The GRF represents the external forces of the mechanical loads; in the present study, we additionally quantified the internal loads from compression and shear forces for the knee joint. It is important to minimize the loadings upon the knee joint as excessive knee joint loadings are believed to contribute to the development and progression of knee OA (Sharma et al., 1998; Miyazaki et al., 2002) and increased adduction moments are determinants of loads in the medial compartment of the knee (Schippelein & Andricchi, 1991). An increased adduction moment is associated with increased risks of losing joint space width (Miyazaki et al., 2002). The present results showed that the compression force (tibio-femoral bone-on-bone force) was approximately three times the body weight. Previous reports of tibio-femoral joint loadings during normal walking in healthy subjects range from 2.4 to six times the body weight (Morrison, 1968, 1970; Kusner et al., 1997; Costigan et al., 2002; Taylor et al., 2004; Thambyah et al., 2005; Henriksen et al., 2006; Shelburne et al., 2006), and the results of the present study are within this range. No reduction in the compression loads of the knee joint during walking with the support of poles (NW) was observed. The shear forces represent a reaction force in the internal stabilizing structures necessary to prevent sliding of the femur on the tibia and to balance external forces in co-action with the compression forces. No reduction in shear forces was found for NW in the present study.

The generalization of the present results to relevant patient groups is uncertain, because we have estimated joint loads in a healthy sample. It would have been favorable to investigate this in a patient population. However, we chose experienced NW instructors as our study group to ensure that a correct and standardized NW technique was used by the participants. Furthermore, this also ensured homogeneity of the data, which increase the internal validity of the study. By including patients, unwanted variability in the dependent variables (joint loads, etc.) caused by factors unrelated to the independent variable (such as malalignment, pain, etc.) could be introduced. In the case of knee OA, attenuated knee extensor moments during the loading response have been reported, which is believed to be a compensation adopted in order to reduce the joint loading and thereby avoid pain (Kaufman et al., 2001). While attenuating the extensor moments may be favorable in terms of joint loads and/or instability, it may induce knee joint instability because the knee extensor moment has been shown to have a significant role in stabilizing the knee against valgus/varus deformation (Olmstead et al., 1986). While the present study does not provide an insight into whether NW would be beneficial to knee joints with pathology in terms of joint loads and/or instability, the overall time-course patterns of joint kinematics and kinetics during NW resemble those of normal walking, and, provided that the correct NW technique is used, it is questionable whether patients would exhibit joint loads different from those reported in the present study.

The cardiovascular benefits of NW were not investigated in this study, but results from the literature have shown that a small, but significantly higher oxygen consumption and energy expenditure occurs when for walking with poles (WP) compared with walking without poles (NP). Rodgers et al. (1995) observed a small increase in HR and VO2 in 10 moderately active females. Forcari et al. (1997) found a higher VO2 (23%), caloric expenditure (22%) and HR (16%) for NW compared with NP. Church et al. (2002) found an increase of similar magnitude as Forcari et al. (1997) under field conditions. However, the number of investigations and number of subjects investigated are limited.

In summary, the present results indicate that NW does not reduce the loadings upon the joints. We suggest that NW as a rehabilitation modality for people with joint diseases or overweight be used with caution, considering that it does not reduce the loadings of the joints compared with normal walking. However, individuals who are not susceptible to lower extremity joint injuries or degeneration and are otherwise non-active might benefit from the small but significant increase in energy consumption from Nordic Walking.

Conclusion and perspectives

The present study does not support the statement that NW reduces the load on especially the knees joints compared with walking without poles. Further studies on patient populations are needed before it is safe to recommend NW as a rehabilitation modality for obese people and for people with musculo-skeletal problems of the lower limb.

Physical activity is an important factor with respect to public health. One of the major goals of the World Health Organization (WHO) is to improve the global public health through physical activity. Nordic
walking has become a popular fitness activity, which is positive from a public health viewpoint. However, when fitness instructors, physical therapists and clinicians have to decide whether NW is to be recommended as a beneficial physical activity to obese patients, the arguments for these recommendations have to be based on scientific evidence. The current study showed that Nordic walking per se does not contribute to an unloading of the major joints in the lower extremities, which contradicts with the general arguments for NW. Thus, it is important to further investigate whether it is safe to recommend NW as a rehabilitation modality for e.g. obese people or for people with musculo-skeletal diseases or injuries of the lower limb.

Key words: walking poles, compressive forces, ground reaction forces, walking, inverse dynamics, fitness.

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