JOINT LOADING OF LOWER EXTREMITIES DURING NORDIC WALKING COMPARED TO WALKING BASED ON KINETIC AND KINEMATIC DATA

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Based on a higher cardio-pulmonary and cardio-vascular benefit and a promised reduction of mechanical load of the musculoskeletal system Nordic Walking (NW) shows an increased market potential. The present study should investigate whether there are differences in joint loading of lower extremities using an inverse dynamics approach between NW and Walking. In this experiment 15 subjects participated, who were already experienced with the NW technique. Kinematic data were collected using a 6-camera 3-dimensional Vicon System. Kinetic data were recorded using a Kistler force plate. Based on the findings it is to summarize, that the use of the poles during NW, performing the diagonal technique, do not lead to a reduction of joint loading of the lower extremities compared to Walking in general. Moreover for NW a higher knee joint loading during landing could be observed which is caused by the specific NW technique.

KEY WORDS: nordic walking, kinetics, kinematics, joint loading, lower extremity

INTRODUCTION: Several market studies confirm for Nordic Walking (NW) a steady rate of economic growth and still a high market potential. Based on GfK-numbers the NW/Walking shoe market was growing 68% in the first quarter of 2005 compared to the year before (Burger, 2005).

These facts are supported by a lot of scientific studies, which revealed a higher cardio-pulmonary and cardio-vascular benefit (10-30%) for NW compared to Walking (Rodgers, Vanheest & Schachter, 1995). Moreover, the popular literature and the media promise, that NW leads to a reduction of mechanical load of the musculoskeletal system (~30%) based on the use of poles compared to Walking (Strunz, 2004; Pramann, 2005).
In the scientific literature only a few serious biomechanical research studies could be found, which investigated the differences between NW and Walking. Schwameder and co-workers (1999) could prove by means of an inverse dynamics approach, that down hill walking with hiking poles ("double-pole-technique") leads compared to down hill walking without hiking poles to significant load reductions of vertical ground reaction forces, knee joint moments (sagittal plane) and tibiofemoral compressive and shear forces (12-25%). However, it is to emphasize, that the trials with poles were performed using the 3-by-1 simultaneous pole technique ("double-pole-technique"), where the touch-down of both poles occurred simultaneously and not in the "diagonal technique", which is applied to 90% during NW (Hoffmann, 2004). In this context Brunelle & Miller (1998) could figure out, that the vertical ground reaction forces during landing are higher for NW (performing the "diagonal technique") compared to Walking. This result is supported by a study of Rist, Kälin & Hofer (2004). Besides, they could analyze, that the vertical ground reaction forces for NW are lower during push off compared to (power) Walking. However, not one study could prove a reduction of mechanical load of the musculoskeletal system of ~30% regarding NW using the "diagonal technique" compared to Walking.
Therefore the present study should investigate whether NW in the "diagonal technique" leads to a reduction of joint loading of the lower extremities compared to Walking.

METHODS: On the study participated 15 male subjects (age: Ø 31 years; body height: Ø 177cm; body mass Ø 77kg) who were already experienced with the NW-technique for Ø 2 years. Even 10 out of the 15 subjects were educated NW-instructors.

Kinematic data (200Hz) were collected using a 6-camera 3-dimensional Vicon System (Vicon, Oxford Metrics, Oxford, UK). Reflective markers were placed on the pelvis, upper leg,

lower leg, rearfoot and forefoot (3 per segment). Kinetic data (1000Hz) were collected using a Kistler force plate (Kistler, Zurich, Switzerland). A lower body model (Michel, Kleindienst & Krabbe, 2004) was applied to determine joint centers and angles between segments.
Subjects walked across the force plate in the middle of a 25m runway at a controlled velocity of 2.0 ± 0.2ms^{-1} with a conventional running shoe (adidas® adistar trail) regarding both NW and Walking. Kinematic and kinetic data were collected for 5 valid trials for each subject and movement condition. The NW-trials were executed in the diagonal technique with the same NW-pole type (exel®). The pole length was adapted for each subject based on body height.
Three-dimensional knee and ankle joint moments were calculated during the stance phase using an inverse dynamics approach. Moreover the metatarsophalangeal (MTP) joint moments in the sagittal plane during stance phase were determined. In this context the midpoint between the 1. and 5. MTP marker, which were placed slightly distally of these joint cavities, was chosen to represent the MTP center of rotation. The MTP moment was considered to be zero until the ground reaction forces acted distal to the joint (Stefanyshyn & Nigg, 1997). This method is based on the assumption that the inertial forces acting on the phalanges can be neglected.
Selected values were determined from each curve and averaged for each condition and subject. Significant differences between the movement conditions were detected using non-parametrical tests ($p \leq 0.05$).

RESULTS AND DISCUSSION: The analysis of the knee extension moment (Tab. 1) shows a higher moment for NW compared to Walking (Ø7%). However, it indicates not a significant difference. The max. knee extension moment occurs during landing phase (21% of stance phase) and based on the NW-diagonal-technique, a reduction of joint loading (through the pole use) was not expected. Only in the push off phase it comes to an active use of the poles.

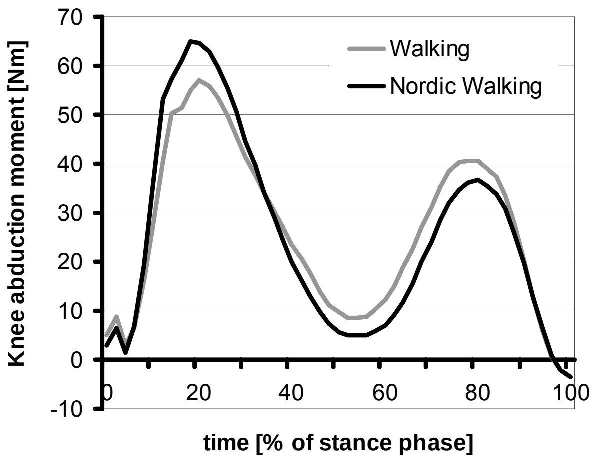

Figure 1: Knee abduction moments (n = 15)

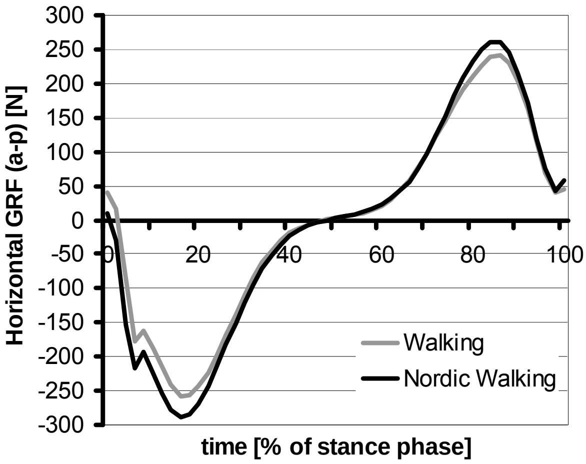

Figure 2: Horizontal GRF, a-p-direction (n = 15)

The knee joint moments in the frontal plane (Fig. 1, Tab. 1) reveal a sig. higher max. abduction moment during landing for NW compared to Walking (Ø13%). In contrast to this, during push off a sig. lower max. knee abduction moment (Ø12%) for NW is to note (Fig.1), which can be explained by the use of the pole. The sig. higher max. abduction moment during landing is caused by the longer step length in NW (Rist, Kälin & Hofer, 2004) and the resultant change of kinetic and kinematic parameter during landing compared to Walking. The max. knee external rotation moment, which occurs in the push off phase, is sig. higher in NW and can be explained by the higher max. internal rotation angle during NW (Tab. 1).
The analysis of the ankle joint moments do not indicate sig. differences between NW and Walking (Tab. 1). That is also true for the MTP plantarflexion moment (Tab. 1). Consequently, the specific NW-technique as well as the pole use do not effect joint loading in the ankle joint complex and MTP region as well.

Table 1: Kinetic and kinematic data (n = 15)
(gcs → segment movement with reference to the global coordinate system)

Parameter	Plane/ direction	Nordic Walking		Walking		P - level
		mean	± SD	mean	± SD	
Knee joint moment – max. extension [Nm]	sagittal	94	27	87	27	n.s.
Knee joint moment – max. abduction (landing) [Nm]	frontal	68	14	59	14	***
Knee joint moment – max. abduction (push off) [Nm]	frontal	38	11	42	8	*
Knee joint moment – max. external rotation [Nm]	transverse	13	2	11	3	**
Ankle joint moment – max. plantarflexion [Nm]	sagittal	130	24	134	16	n.s.
Ankle joint moment – max. inversion [Nm]	frontal	6	3	6	4	n.s.
Ankle joint moment – max. abduction [Nm]	transverse	-16	6	-15	5	n.s.
MTP joint moment – max. plantarflexion [Nm]	sagittal	78	12	78	9	n.s.
1. max. force peak (landing) [N]	vertical	1144	109	1144	131	n.s.
2. max. force peak (push off) [N]	vertical	811	148	865	106	*
Loading rate (landing) [Ns^{-1}]	vertical	35146	9844	32381	5361	n.s.
1. max. force peak (braking, a-p) [N]	horizontal	-293	53	-262	45	*
2. max. force peak (acceleration, a-p) [N]	horizontal	263	49	242	36	0.10
Loading rate (braking, a-p) [Ns^{-1}]	horizontal	12161	3544	11201	2252	n.s.
Knee joint angle – max. flexion [°]	sagittal	22.0	8	18.5	8	***
Knee joint angle – max. adduction [°]	frontal	13.1	6	8.6	5	***
Knee joint angle – max. internal rotation [°]	transverse	17.6	12	14.6	8	n.s
Ankle joint angle – max. dorsiflexion [°]	sagittal	5.4	4	5.7	4	n.s.
Ankle joint angle – max. eversion ($\beta_{max.}$) [°]	frontal	4.8	3	3.6	3	***
Ankle joint angle – max. adduction [°]	transverse	-4.7	6	-5.2	7	n.s.
MTP joint angle – max. dorsiflexion [°]	sagittal	-26.8	4	-26.1	4	n.s.
Touch down angle - γ_0 [°] (gcs)	frontal	3.3	2	2.3	2	0.10
Max. eversion angle - $\gamma_{max.}$ [°] (gcs)	frontal	-1.6	1	-0.9	1	*
Max. eversion velocity - γ_v [°/s] (gcs)	frontal	63	22	70	36	n.s.
Path of Motion γ_{POM}[°] (gcs)	frontal	5.0	2	3.8	2	*
Sole angle - δ_0 [°] (gcs)	sagittal	-37.1	4	-35.0	3	*
Max. sole angle velocity - δ_v [°/s] (gcs)	sagittal	549	81	521	54	*

The vertical ground reaction forces reveal no differences regarding the first force peak (landing), whereas the second force peak (push off) is sig. lower during NW (Tab. 1). This result is supported by Rist, Kälin & Hofer (2004) and be due to the pole use. Moreover, Rist, Kälin & Hofer (2004) and Brunelle & Miller (1998) could observe a sig. higher first force peak during NW. The horizontal ground reaction forces indicate a sig. higher first force peak (braking) during NW and even higher forces during acceleration (second peak) compared to Walking (Fig. 2, Tab. 1). The vertical as well as the horizontal loading rate are higher in NW than in Walking (Tab. 1). However, these results are not significantly.
All three knee joint angles show higher values for NW and consequently, these angles and the time of their occurrence contribute to the explanation of the higher knee joint moments during NW compared to Walking (Tab. 1). With exception of the max. eversion angle ($\beta_{max.}$) none of the ankle joint angles reveal sig. differences. Also the MTP dorsiflexion angle does not exhibit a sig. difference between NW and Walking (Tab. 1).
Similar to the max. eversion ankle angle (calcaneus with reference to shank; $\beta_{max.}$) the max. eversion angle (calcaneus with reference to gcs; $\gamma_{max.}$) demonstrates a sig. higher eversion movement of the calcaneus during NW compared to Walking (Tab. 1). The sig. higher eversion angle contributes to the sig. higher POM in NW. The sig. higher sole angle in NW

leads to a sig. higher sole angle velocity during NW compared to Walking (Tab. 1). Also Rist, Kälin & Hofer (2004) could observe a sig. higher sole angle in NW compared to Walking and suppose a relationship to the higher vertical ground reaction forces during landing. Besides, the sig. higher sole angle at touch down contributes to the explanation of the higher max. knee extension, max. knee abduction moment, higher max. horizontal force peak during braking as well as vertical and horizontal loading rate. All these parameters occur during landing/braking and hence they can be caused by the sig. higher sole angle. In this context it is to note, that all knee joint and ankle joint angles at touch down (t_0) do not reveal sig. differences between NW and Walking. Exclusively the sole angle at touch down indicates a sig. difference of the calcaneus with reference to the global coordinate system between NW and Walking. The touch down angle (frontal pane; γ_0) only exhibits a statistical trend (p = 0.10). These findings lead to the consideration, that the longer step length during NW, which belongs to the specific NW-technique, changes the kinematics of the foot placement with reference to the space (gcs) at and/or prior touch down and initiates the changes in kinetics and kinematics during landing.

CONCLUSION: Based on the findings of the present study it is to summarize, that the use of the poles during NW performing the diagonal technique does not lead to a reduction of joint loading of the lower extremities compared to Walking based on kinetic and kinematic data in general. This is contrary to the popular literature and the media which promises, that NW leads to a reduction of mechanical load of the musculoskeletal system (~30%) based on the use of poles compared to Walking (Strunz, 2004; Pramann, 2005). Exclusively the max. knee abduction moment during push off points at a reduction of joint loading caused by the pole use. However, the sig. higher max. knee external rotation moment counteracts this effect. Moreover, for NW a higher knee joint loading during landing could be observed which is caused by the specific NW-technique. Regarding running it is well known, that increased knee moments are directly linked to the incidence of PFPS (Stefanyshyn et al., 2001). It is only to speculate, that such a correlation is valid for NW and Walking as well. Therefore it is necessary to conduct prospective epidemiological laboratory and field studies in order to investigate the influence of joint moments on the incidence of sport specific injuries and complaints.

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