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Biomechanical parameters in lower limbs during natural walking and Nordic walking at different speeds

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Purpose: Nordic Walking (NW) is a sport that has a number of benefits as a rehabilitation method. It is performed with specially designed poles and has been often recommended as a physical activity that helps reduce the load to limbs. However, some studies have suggested that these findings might be erroneous. Study aim. The aim of this paper was to compare the kinematic, kinetic and dynamic parameters of lower limbs between Natural Walking (W) and Nordic Walking (NW) at both low and high walking speeds. Methods: The study used a registration system, BTS Smart software and Kistler platform. Eleven subjects walked along a 15-metre path at low (below 2 $m \cdot s^{-1}$) and high (over 2 $m \cdot s^{-1}$) walking speeds. The Davis model was employed for calculations of kinematic, kinetic and dynamic parameters of lower limbs. Results: With constant speed, the support given by Nordic Walking poles does not make the stroke longer and there is no change in pelvic rotation either. The only change observed was much bigger pelvic anteversion in the sagittal plane during fast NW. There were no changes in forces, power and muscle torques in lower limbs. Conclusions: The study found no differences in kinematic, kinetic and dynamic parameters between Natural Walking (W) and Nordic Walking (NW). Higher speeds generate greater ground reaction forces and muscle torques in lower limbs. Gait parameters depend on walking speed rather than on walking style.

Key words: *walking, kinematics analysis, Nordic Walking*

1. Introduction

Nordic Walking (NW), which is understood to mean walking with specially designed walking poles, has been gaining in popularity in recent years and has now become a very attractive form of both recreation and rehabilitation. The publications on NW movement usually concern energy expenditure and metabolic cost [10], [12], [14], [15] and changes in body fat, body composition and metabolic rate [8], [9]. The Internet websites often contain unverified reports which claim that NW contributes to increased energy consumption (by over 40%), higher efficiency and higher heart rate compared to ordinary walking [11], and even that NW reduces the load to lower limbs [13]. However, the results presented are contradictory. There have been reports that demonstrated the beneficial effect of NW on hip, knee and ankle joints through reduced load to these points. On the other hand, there are studies which have shown that the use of poles does not change the load to the lower limbs [11]. Verification of information about actual reduction of load to the lower limbs during NW is essential for Nordic walkers with obesity, the elderly, and those with knee joint pain or osteoarthritis (OA).

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NW has many characteristics that are similar to cross country skiing [19]: similar temporal and spatial profile of body part movements [17], similar development of the major motor skills and involvement of the same muscle groups. Both sports activate muscles of the upper body [18] and both offer plenty of opportunities for practice regardless of age or level of physical fitness. Differences lie in the use of skis in skiing technique, which are not used in NW, and that NW can be practised during all seasons of the year. The aim of this study is to compare kinematic, kinetic and dynamic parameters, with particular focus on the load to the hip, knee and ankle joints present at different speeds between Natural Walking (W) and Nordic Walking (NW). Studies of the kinematics and dynamics gait parameters are widely described in the literature [2], [5]–[7], [20].

2. Material and methods

Walking tests were carried out in the Biomechanical Laboratory (with PN-EN ISO 9001:2009 Quality Management System certification). Research Ethics Committee has approved the research study. Guardians were informed about the procedures and expressed their consent. To analyze human motion in sport video [1] or infrared cameras are used. Furthermore, we used BTS Smart software, 6 infrared cameras, Davis model [20] and 2 Kistler force platforms. We employed a field study design and examined ground reaction forces and kinematic and dynamic parameters between Nordic Walking (NW) and Natural Walking without poles (W) at 2 different walking speeds in eleven male subjects ($x \pm s$; age: 40.1 ± 4.9 yr; weight: 74.5 ± 18.1 kg). Participants, who were experienced NW coaches, walked along a 15-m path with and without walking poles, which in total made 10 to 12 full walking cycles. This length of the testing path ensured acceleration to the most comfortable speed and braking. The person studied walked along the testing path at least 10 times. The walking speed of the first part of the test was low (below 2 $m \cdot s^{-1}$) whilst it was higher during the second trial (over 2 $m \cdot s^{-1}$). At least 6 properly recorded walks were used during analysis, of which each walk comprised 8 to 12 correct gait cycles. A gait cycle encompassed the time from the very first contact of the right foot with the ground until the next contact of the same foot with the ground. All the cycles were averaged and normalized with respect to body mass.

This study adopted the premiss that the joint angles in the anatomical position are 0°. The foot–ground angle α_s, is the angle between the foot line (toe-heel) and the ground level. A value of 0° means that the whole foot lies flat on the ground.

3. Results

The following types of gait were analysed: Natural Walking (W_{slow}, below 2 $m \cdot s^{-1}$) and fast Natural Walking (W_{fast}, over 2 $m \cdot s^{-1}$) as well as slow Nordic Walking (NW_{slow} below 2 $m \cdot s^{-1}$) and fast Nordic Walking (NW_{fast}, over 2 $m \cdot s^{-1}$).

BTS Smart software was used to calculate the following mean kinematic parameters (with standard deviations): stride length (left and right step in total), walking speed (Table 1), instantaneous angular displacements in hip, knee and ankle joints and pelvis with respect to three planes (Fig. 1), kinetic parameters: muscle torques and power generated in the above joints in the sagittal plane (Fig. 2) and dynamic parameters: vertical and horizontal ground reaction forces during the support phase (Fig. 3).

4. Discussion

Analysis of the results obtained during the study showed no reduction in the load to lower limbs or changes in biomechanical parameters during Nordic

Table 1. Mean kinematic parameters recorded in the subjects studied

	W_{slow}	NW_{slow}	W_{fast}	NW_{slow}
L [m]	1.47 ± 0.08	1.58 ± 0.08	1.82 ± 0.08	1.89 ± 0.08
v [$m \cdot s^{-1}$]	1.38 ± 0.08	1.48 ± 0.11	2.16 ± 0.12	2.25 ± 0.15

W_{fast} – fast walking without poles, NW_{fast} – fast Nordic Walking, W_{slow} – slow walking without poles, NW_{slow} – slow Nordic Walking, L – mean stride length, v – mean speed, s – standard deviation

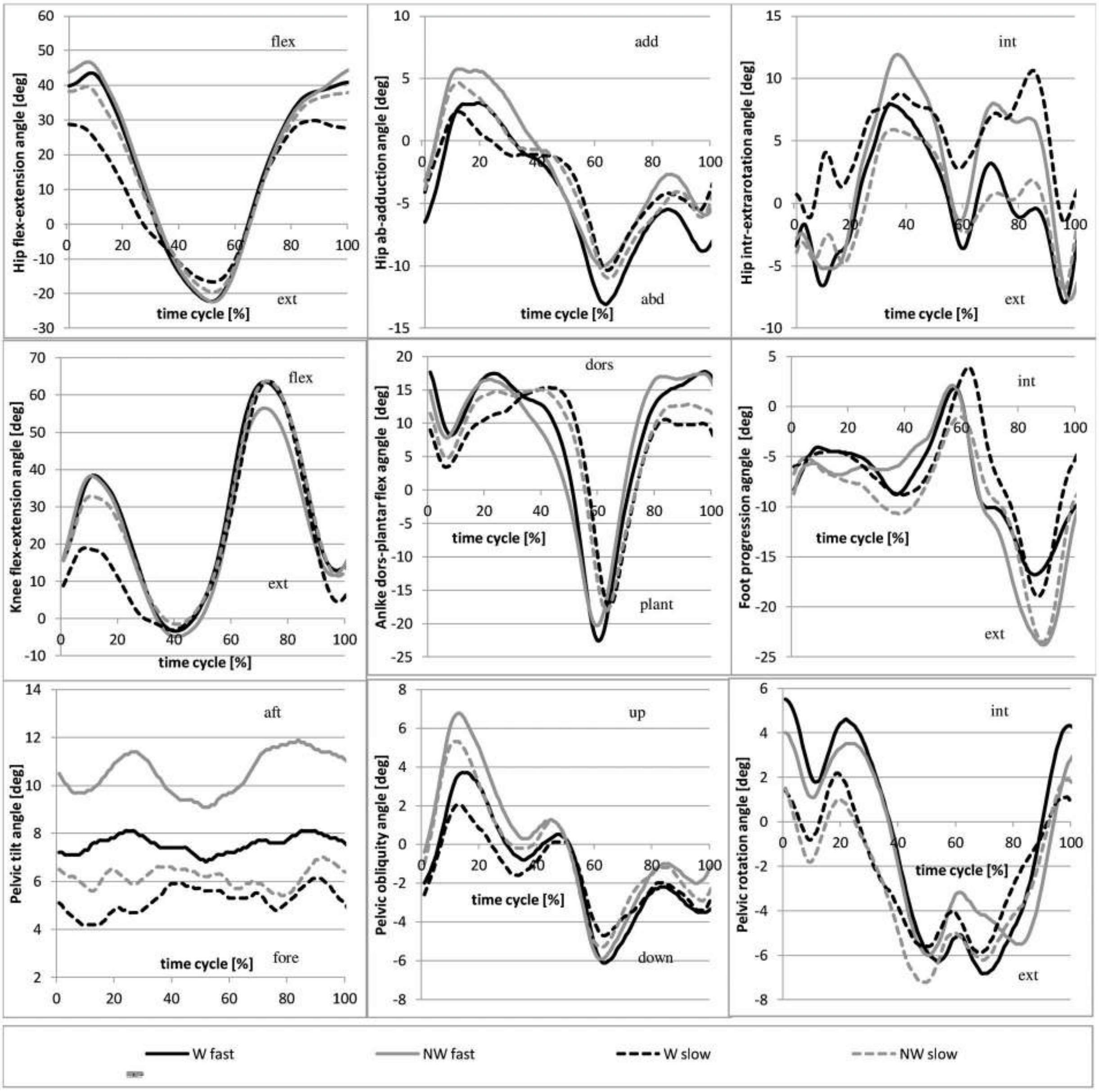

Fig. 1. Kinematic parameters: angular displacements in hip, knee and ankle joints and pelvis in three planes.
W_{fast} – fast walking without poles, NW_{fast} – fast Nordic Walking,
W_{slow} – slow walking without poles, NW_{slow} – slow Nordic Walking

Walking compared to the Natural Walking. All the Pearson's correlation coefficients between the parameters and the instantaneous profiles were statistically significant ($0.87 < r < 0.99$) at the level of significance set at $p \leq 0.01$.

Angular displacements

Angular displacements in the hip, knee and ankle joint and pelvis have similar instantaneous values and a similar profile of the cycle (Fig. 1). Increasing the walking speed causes an insignificant rise in the displacement range. However, the shape of the curve remains unchanged. The only change observed was pelvic anteversion increased in the sagittal plane in NW_{fast} by 6°.

We found no significant differences between NW and W in instantaneous angular displacements.

Kinetic parameters

Similar to kinematic parameters, Nordic Walking does not cause changes in the profiles and instantaneous values of muscle torques and powers generated in the analysed joints (Fig. 2). Changes in muscle torque and power are correlated with walking speed. Increased walking speed causes a rise in muscle torque and power at the specific points of the gait cycle.

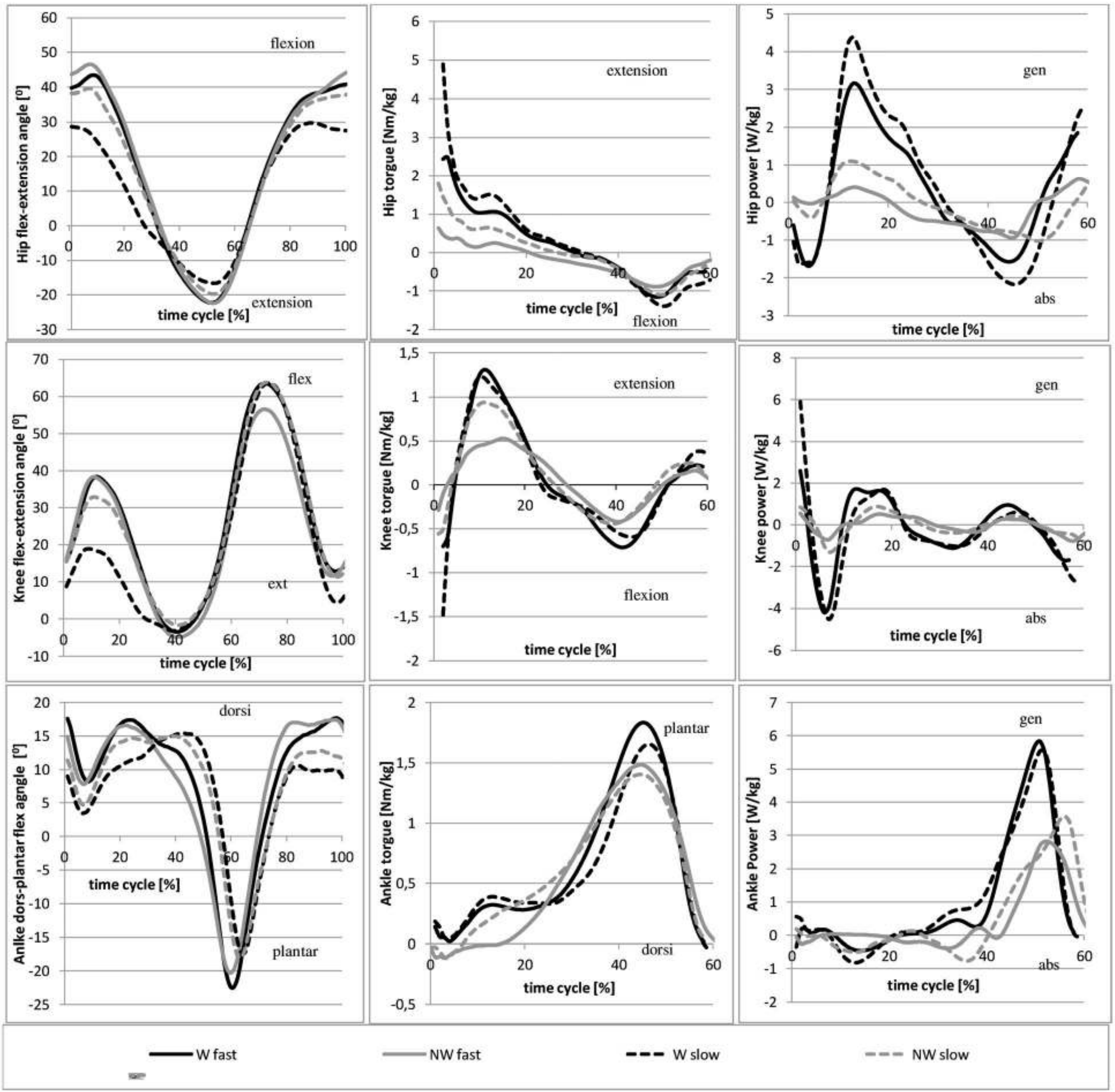

Fig. 2. Kinetic parameters: muscle torques, power generated and angular displacements in hip, knee and ankle joints in the sagittal plane; W_{fast} – fast walking without poles, NW_{fast} – fast Nordic Walking, W_{slow} – slow walking without poles, NW_{slow} – slow Nordic Walking

We found no significant difference between NW and W in muscle torque and power.

Dynamic parameters

Instantaneous values of ground reaction forces (GRF) in fast Natural Walking (W_{fast}) and fast Nordic Walking (NW_{fast}) show a similar profile (Fig. 3). However, these values are higher than the values of ground reaction forces in slow walking of both types (W_{slow} and NW_{slow}). With regard to slow walking, the vertical and anterior-posterior components of ground reaction forces show slight differences. Nordic Walking causes an increase in the vertical component by 20% in the first phase (foot contact) and a reduction in 20% in the second phase (swing of the other foot), and an increase in anterior-posterior component by 10% in the first phase (foot contact) and the third phase (foot take-off), compared to Natural Walking at the same speed.

No significant differences in GRF were found between NW and W in our study.

The popular magazines, the Internet website and advertisements often emphasize the alleged benefits of Nordic Walking. They mainly refer to the reduction of lower limbs in Nordic Walking [21]. The findings of the present study are not consistent with

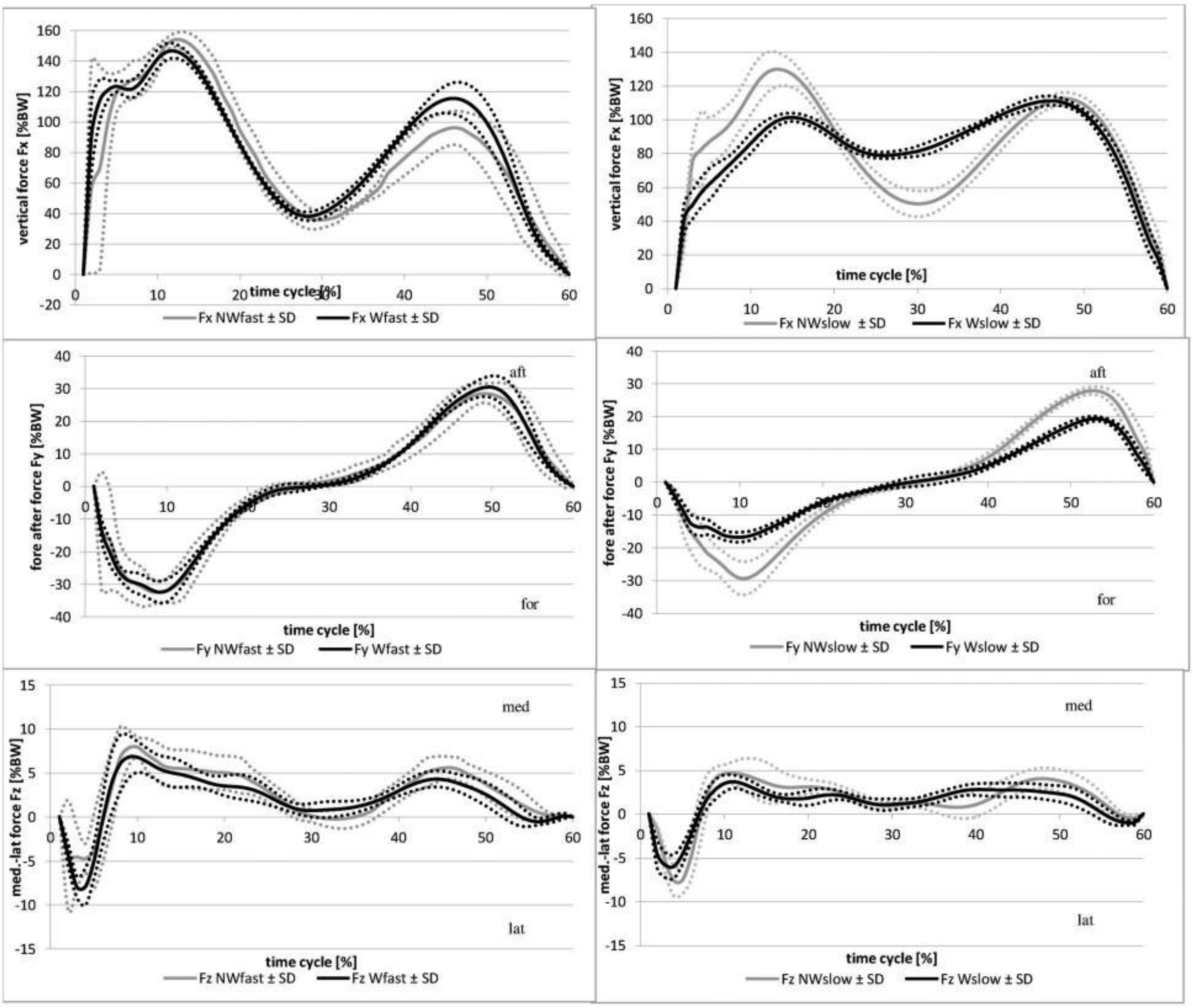

Fig. 3. Dynamic parameters: ground reaction forces expressed in percentage body mass for a subject; W_{fast} – fast walking without poles, NW_{fast} – fast Nordic Walking, W_{slow} – slow walking without poles, NW_{slow} – slow Nordic Walking

these reports. Lack of changes in the load was also found by Hansen et al. [11]. The difference between the results obtained in our study and that obtained by Wilson et al. [14] might be attributable to the Nordic Walking experience of the subjects participating in the experiment. Wilson et al. [21] examined subjects who had never been involved in Nordic Walking. We examined certified NW coaches, similar to a study presented by Hansen et al. [11]. The selection of the people who were well-trained and used a similar technique ensured homogeneity of the data and validity of the test. Good technique and improvement of the skills under the supervision of a professional coach helps avoid overload to joints and allows one to perform the NW activity in full awareness.

Proper verification of the load during NW is especially critical for obese and elderly people, who are advised not to overload the lower limbs. The overload to the knee joint might intensify knee joint pain or osteoarthritis (OA) [16]. Therefore, frequent NW activity among the elderly should, due to the risk of knee joint injuries, require prior consultation with a physician.

The lower limb joints are loaded to a different degree when comparing walking on a flat surface with walking in mountainous terrain. Bohne and Abendroth-Smith [3] analysed the experiences of NW coaches during walking in the mountains with various additional loads. Unlike the results presented in this study, Bohne and Abendroth-Smith [3] found insignificant reduction in the vertical ground reaction forces, muscle torque and power generated in the joints of the lower limbs. Daviaux Hintzy, Samozino and Horvais [4] noticed that using pools induces a decrease in plantar pressure intensity in running with pools, but the localization and the magnitude of this decrease depends on the slope situation.

NW walking is much more similar to cross-country skiing [18]. The similarities concern the use and function of poles and their effect on the skeletal system during cross-country skiing motion [19] and involvement of the upper body parts (upper limbs and upper trunk) [17]. This paper did not examine the effect of involvement of the upper body part in NW compared to the Natural Walking (W). Indeed, such an effect has been demonstrated and represents the beneficial aspect of using poles, provided that there are no contraindications connected with age, obesity or joint pathologies.

Apart from the effect of forces, muscle torque, power generated in the joints of the lower limbs and improved involvement of the upper body during NW, there are other benefits that should be highlighted. Easley et al. [8] found no significant differences in the loss of body mass between natural walkers and Nordic walkers. After a 16-week training regimen, Easley et al. [9] observed small but statistically significant improvements in body composition and metabolic rate in previously sedentary subjects. Despite walking less than 20 minutes a week, Nordic walkers showed similar metabolic improvements to people who did not use poles.

It was found that the type of walking does not cause changes in parameters, which are similar in both Natural Walking and Nordic Walking. However, they are affected by the walking speed. It was expected that, at a constant walking speed V [m/s], the support with poles would elongate the stride length L [m] and increase pelvis rotation. However, those changes were not observed. The noticeable change is pelvic anteversion in the sagittal plane during fast Nordic Walking (Fig. 1). Furthermore, no changes were found in muscle torque and power generated in the joints studied (Fig. 2) and the ground reaction forces (Fig. 3). Walking at higher speeds causes muscle torque, power generated and ground reaction forces to be higher. In conclusion, these parameters depend on walking speed rather than walking style.

5. Conclusion

Our study found no differences in kinematic, kinetic and dynamic parameters in the hip, knee and ankle joints between natural and Nordic Walking. Changes in the above parameters were correlated only to the walking speed. Higher pelvic tilt was observed in the sagittal plane during fast walking. The scientific investigations of the parameters that differentiate between the Natural Walking and Nordic Walking (NW) are valuable. However, it can be unequivocally stated that NW generates a load in the lower limbs, which is similar to the natural gait, provided that proper NW technique is learnt. Similar to cross-country skiing, Nordic Walking activates the upper part of the body. The main benefit of NW is its popularity as a form of physical activity. If this was to be the only reason to spend some time outdoors, one should not hesitate to take up the poles themselves.

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