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GAIT PARAMETERS, POSTURE, AND MUSCLE ACTIVITY DURING NORDIC WALKING AND NORMAL WALKING

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ABSTRACT

Nordic walking (NW), which involves walking with specially designed poles, has attracted attention as a means of enhancing physical activity across diverse populations. While NW is known to increase energy expenditure and upper limb muscle activity compared to conventional walking (W), its biomechanical characteristics—particularly those involving joint kinematics and lower limb muscle activity—have not been fully clarified. The purpose of this study was to compare gait parameters, joint kinematics, and muscle activity between NW and W, and to elucidate their kinematic characteristics.

Nineteen healthy male participants (mean age: 26.3 ± 2.4 years) performed 10-m walking trials at a self-selected comfortable speed under both W and NW conditions. A 1-hour NW training session was conducted prior to testing. Gait parameters were measured using a pressure-sensitive walkway, joint kinematics were obtained using an IMU-based three-dimensional motion analysis system, and muscle activity was assessed using surface electromyography.

Compared with W, NW significantly increased stride length, step length, and walking speed. In terms of joint kinematics, NW resulted in increased hip extension, knee flexion during the stance phase, and ankle plantarflexion, along with greater trunk and cervical rotation. Muscle activity in the posterior deltoid, erector spinae, rectus abdominis, gluteus maximus, rectus femoris, and tibialis anterior was significantly higher during NW, whereas no significant difference was observed in gastrocnemius activity.

A novel aspect of this study is the integrated analysis of trunk motion, lower limb joint kinematics, gait parameters, and muscle activity. These findings suggest that NW induces changes in joint kinematics through pole use, thereby influencing gait parameters and muscle activity. Despite limitations related to the homogeneous participant group, lack of speed control, and short experimental duration, NW may be an effective strategy for enhancing lower limb muscle activity and joint mobility, with potential applications in rehabilitation settings.

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INTRODUCTION

One of the primary objectives in global public health promotion is to establish effective strategies that encourage physical activity and reduce sedentary behavior, with the aim of improving overall population health and mitigating the incidence of numerous preventable diseases and functional impairments (World Health Organization, 2010). Evidence on poor health and health behaviors in people with disabilities reveals that promotion of physical activity and significant reductions in sedentary behaviors are an important focus for eliminating health disparities (Emerson & Baines,

2011). Walking (W) is one of the most effective forms of physical activity and is commonly chosen as the initial mode of exercise by many individuals (Williams et al., 2012). W is a widely practiced form of exercise due to its ease of implementation, regardless of time or location, and its accessibility across all age groups.

Furthermore, walking requires no specialized equipment and is considered one of the most feasible and sustainable physical activities, making it a key component in public health recommendations (World Health Organization, 2020).

A variation of walking that involves the use of specially designed poles held in both hands is known as Nordic Walking (NW). Originating in Finland, NW is now practiced globally as a safe and accessible form of physical activity, suitable for individuals across a broad range of ages and physical conditions. The NW technique is characterized as follows: the poles are planted diagonally on the ground in coordination with the heel strike of the opposite leg during gait. According to the International Nordic Walking Association (INWA), NW produces higher heart rates, greater energy expenditure, and reduced stress on the ankle and knee joints compared to W at the same exercise intensity. Physiologically, NW performed at a self-selected pace has been shown to elicit higher oxygen consumption, energy expenditure, and heart rate than W (International Nordic Walking Association, 2016). Furthermore, previous studies have reported that although Nordic walking markedly increases whole-body metabolic demand, it does not necessarily increase perceived exertion. In addition, the use of poles may improve frontal plane stability and reduce the risk of lower limb injuries (Saller et al., 2023).

In the field of biomechanics, several studies have compared NW and W by analyzing ground reaction forces and gait parameters. Results indicate that NW reduced the vertical ground reaction force during the single-limb support phase and increased cadence and stride length (Park et al., 2015). In healthy adults, NW has also been reported to result in increased walking speed and stride length compared to W (Willson et al., 2001). Recent studies have also reported that Nordic walking may alter spinal kinematics, suggesting that trunk movement is also influenced during gait (Ivanov et al., 2025). These findings collectively suggest that NW contributes to improved gait patterns. Regarding muscle activation, many studies comparing NW and W have reported increased activity in upper limb muscles during NW, with no significant differences observed in the lower limbs (Shim et al., 2013; Pellegrini et al., 2015). However, other studies have found increased lower limb muscle activation as well (Psurny et al., 2018), indicating inconsistency in findings and highlighting the need for further investigation into the effects of NW on lower limb muscle activity.

NW has been incorporated into physical therapy programs for individuals with conditions such as diabetes, cardiovascular disease, respiratory disorders, peripheral vascular disease, chronic low back pain, and Parkinson's disease, with generally positive outcomes reported (Tschentscher et al., 2013).

In intervention studies involving healthy individuals, participation in a 12-week NW program has been associated with improvements in balance (Kocur et al., 2015), as well as dynamic balance and gait patterns (Nakashima et al., 2013). In addition, a 12-week Nordic walking intervention has been reported to improve upper body muscle strength, cardiovascular endurance, and flexibility (Takeshima et al., 2013). Conversely, a study comparing the effects of 13 weeks of NW and W in middle-aged and older adults found no significant differences in upper and lower limb muscle strength between groups. Additionally, some studies have report-

ed inconclusive results regarding the effects of NW on pain, muscle strength, flexibility, fatigue, and gait parameters (Kukkonen-Harjula et al., 2007). Although numerous studies have demonstrated the physiological and biomechanical benefits of NW, few studies have comprehensively evaluated joint kinematics together with trunk motion, gait parameters, and muscle activity between NW and W.

Previous studies have compared Nordic walking and conventional walking in terms of gait parameters and muscle activity, and some have examined joint kinematics. However, studies that comprehensively evaluate trunk motion together with lower limb joint kinematics, in combination with gait parameters and muscle activity, remain limited. Therefore, the present study aims to provide a more integrated biomechanical analysis of Nordic walking. The purpose of this study is to compare and analyze gait parameters, joint angles of the upper and lower limbs, and muscle activity during NW and W.

METHODS

Participants

Nineteen healthy male participants (mean age: 26.3 ± 2.4 years) were recruited for this study. Exclusion criteria included the presence of acute illness or any difficulty in walking; however, none of the participants met these criteria.

Measurements

Participants performed a 10-meter comfortable walking test under two conditions: W and NW. Gait parameters were recorded using a sheet-type foot pressure contact measurement system (WalkWayMW-1000, Anima Corporation). Joint angles and acceleration were captured using an inertial measurement unit (IMU)-based portable three-dimensional motion analysis system (myoMOTION, Sakai Medical Corporation). Muscle activity was measured via a wireless electromyography system (Ultium EMG, Sakai Medical Corporation). A single gait cycle - from initial contact (IC) of the stance leg to the subsequent IC of the same leg - was extracted using foot acceleration data. IC timing was identified from anteroposterior impact acceleration along the X-axis, while foot lift-off was estimated from vertical acceleration along the Z-axis. The gait cycle was segmented into five phases - IC, Loading Response (LR), Midstance (MSt), Terminal Stance (TSt), and Pre-Swing (PSw) - according to the Rancho Los Amigos Hospital method, following the gait phase definitions established by Perry (1992).

The total length of the walking path was 16 meters. A 2.4-meter WalkWay system was placed at the center of the walkway and defined as the measurement zone, and only data from this section were used for analysis. Participants were instructed to walk barefoot at a self-selected, comfortable pace to reflect natural gait characteristics. Each condition was measured four times. The average of all valid data points recorded during the measurement phase across the four trials was used for analysis. The measurement procedure was as follows: first, data were collected under the W condition. This was followed by a 1-hour NW training session, which included 20 minutes of NW practice on a treadmill. The treadmill speed was set to match the participant's comfortable walking speed determined during the W condition. Sufficient rest was provided between measurements to minimize the influence of fatigue on the results.

Gait parameters

Gait parameters were measured using the WalkWay system, which was installed at the center of the walking path. This system comprises eight sheet-type foot pressure measurement units connected to an analysis computer. As participants walked across the sheets, the

coordinates of foot contact points were recorded and displayed in real time. Temporal and spatial gait parameters were automatically calculated based on the relative positions of the foot contacts. The sensor resolution was 10 mm × 10 mm, and measurements were captured using 14,000 pressure sensors. All detectable gait cycles within the measurement section across the four trials were analyzed, and the mean values were used for statistical analysis. The following parameters were included: stride length (cm), step length (cm), walking speed (cm/s), cadence (steps/min), and gait cycle time (s).

Joint angles

The joint angles were measured using the myoMOTION system (Sakai Medical Corporation), a portable three-dimensional motion analysis device based on inertial sensors. Each sensor (W100 mm × L108 mm × H19 mm) includes a gyroscope, magnetometer and accelerometer.

Sensors were securely attached to ten landmarks: the occiput, C7 and T12 spinous processes, sacrum, superior borders of both patellae, anterior aspects of both lower legs, and dorsum of both feet. Elastic straps and surgical tape were used to ensure sensor stability during movement. Joint calibration was performed in a neutral standing position, with the participant leaning lightly against a wall to maintain mid-range joint alignment. The sampling frequency was set to 100 Hz. Measured variables included anatomical angles of cervical, thoracic, and lumbar rotation, pelvic anterior tilt, posterior tilt, and rotation, hip flexion and extension, knee flexion and extension, ankle dorsiflexion and plantarflexion, and segmental acceleration at sensor sites. From these data, the total range of motion (ROM) during a single gait cycle was calculated for each joint based on maximum flexion/extension, tilt, dorsiflexion/plantarflexion, and rotation values. Additionally, for the knee joint, maximum flexion angles during both stance and swing phases were computed. As with gait parameters, all detectable gait cycles from the four trials were analyzed, and mean values were used for subsequent analysis.

Muscle activities

Muscle activity was assessed using a wireless surface electromyography (EMG) system (Ultium EMG, Sakai Medical Corporation). The sensors are compact (W25 mm × L36.6 mm × H17.5 mm) and lightweight (14 g), minimizing interference with natural movement. The sampling frequency was set to 2,000 Hz. The following muscles were monitored on the stance leg side: posterior deltoid, lumbar erector spinae, rectus abdominis, gluteus maximus, rectus femoris, biceps femoris, tibialis anterior, and medial gastrocnemius. Prior to electrode placement, hair and surface keratin were removed to reduce skin-electrode impedance, and skin preparation was conducted using Skin-Pure (YZ-0019, Nihon Kohden Corporation). Muscle activity data were normalized to each participant's maximum voluntary contraction (MVC) and expressed as a percentage of MVC (%MVC). All valid gait cycles from the four trials were included in the analysis, and mean values were used for statistical evaluation.

NW intervention

A NW intervention was conducted by a certified activity leader accredited by the Japan Nordic Walking Association (JNWA). The intervention consisted of a one-hour individual NW training session. The training followed the JNWA-certified activity leader curriculum and included the following core instructions:

1) Plant the pole held in the hand opposite to the stepping foot while maintaining elbow extension.
2) Push against the ground with the planted pole to propel the body forward, ensuring

that the shoulders remain relaxed.

3) Release the grip on the pole as the push-off phase begins.

Each training session was conducted on an individual basis to ensure proper technique acquisition and personalized instruction. Pole length was determined according to the JNWA guideline, calculated as 0.68 times the participant's height (in cm).

Analysis Methods

Joint angles, muscle activities, and gait parameters were compared before and after the intervention within the same participants. Normality of all variables was assessed using the Shapiro–Wilk test. For variables with a normal distribution, paired t-tests were used; for non-normally distributed variables, the Wilcoxon signed-rank test was applied. Statistical analyses were performed using SPSS Statistics version 25 (IBM Corp., Armonk, NY, USA), with the significant level set at $p < .05$.

Ethical Consideration

This study was conducted in accordance with the Declaration of Helsinki and the Ethical Guidelines for Medical and Health Research Involving Human Subjects. Informed consent was obtained from all participants after providing a comprehensive explanation of the following; (1) purpose, methods, and procedures of the study, (2) privacy protection, (3) potential benefits and risks of participants, (4) right to withdraw at any time, (5) financial considerations, (6) dissemination of research findings, (7) handling and disposal of materials and data after the study, (8) infection prevention measures. The study protocol was approved by the Ethics Committee of Takasaki University of Health and Welfare (Approval No. 2055).

RESULTS

Gait Parameters

In terms of gait parameters, stride length (W: 114 ± 11.6 cm; NW: 131 ± 21.0 cm; effect size [ES]=0.73), step length (W: 63.3 ± 5.91 cm; NW: 70.1 ± 8.21 cm; ES = 0.71), and walking speed (W: 105 ± 16.4 cm/s; NW: 130 ± 19.7 cm/s; ES = 0.81) were significantly greater during NW compared to W. In contrast, cadence was significantly higher during NW (W: 106 [99.0–113] steps/min; NW: 116 [109–120] steps/min; ES = 0.66). No significant difference was observed in the duration of a single gait cycle between the two walking conditions.

Table 1. *Gait Parameters*

	Walking (*M*±*SD*)	Nordic Walking (*M*±*SD*)	*p*-value	ES (d)
Stride (cm)	114 ± 11.6	131 ± 21.0	.021*	0.73
Step length (cm)	63.3 ± 5.91	70.1 ± 8.21	.034*	0.71
Walking speed (cm/s)	105 ± 16.4	130 ± 19.7	.016*	0.81
Cadence (steps/min)	106 (99.0, 113)	116 (109, 120)	.008*	0.66
Gait cycle time (s)	1.04 ± 0.06	1.02 ± 0.10	.073	0.43

Note. Values are presented as mean ± standard deviation or median (IQR). * indicates a statistically significant difference ($p < .05$).

Joint angles

Regarding joint angles, significant differences were observed between the two walking conditions. NW resulted in greater: hip extension (W: 18.6 [16.9–23.2]°; NW: 23.5 [20.9–25.9]°; ES=0.78), knee flexion during the stance phase (W: 17.2 ± 2.33°; NW: 22.1 ± 3.94°; ES = 0.71), knee extension (W: –4.09 [–5.12 to

–3.48]°; NW: –5.51 [–6.23 to –4.23]°; ES = 0.55), ankle dorsiflexion (W: 9.62 ± 2.83°; NW: 10.7 ± 3.18°; ES = 0.36), ankle plantarflexion (W: 17.2 ± 3.91°; NW: 21.2 ± 4.76°; ES = 0.81), cervical rotation (W: 3.97 ± 0.86°; NW: 4.81 ± 1.48°; ES = 0.53), and lumbar rotation (W: 6.51 ± 4.25°; NW: 7.96 ± 7.85°; ES = 0.84). In contrast, thoracic rotation was significantly lower during NW (W: 4.62 [3.58–7.22]°; NW: 4.15 [2.59–5.70]°; ES = 0.57), NW demonstrated greater angles in hip extension, knee flexion during the stance phase, knee extension, ankle dorsiflexion, ankle plantarflexion, cervical rotation, and lumbar rotation compared to W, whereas thoracic rotation was lower during NW.

Table 2. *Joint Angles*

	Walking (*M*±*SD*)	**Nordic Walking (*M*±*SD*)**	***p*-value**	**ES (d)**
Hip flexion	25.1 ± 5.21	29.2 ± 5.82	.252	0.53
Hip Extension	18.6 (16.9, 23.2)	23.5 (20.9, 25.9)	.001*	0.71
Knee flexion stance phase	17.2 ± 2.33	22.1 ± 3.94	.003*	0.78
Knee flexion swing phase	55.1 (52.3, 58.2)	60.2 (52.1, 65.2)	.258	0.64
Knee extension	-4.09 (-5.12, -3.48)	-5.51 (-6.23, -4.23)	.034*	0.55
Ankle dorsiflexion	9.62 ± 2.83	10.7 ± 3.18	.041*	0.36
Ankle plantarflexion	17.2 ± 3.91	21.2 ± 4.76	.005*	0.81
Cervical rotation	3.97 ± 0.86	4.81 ± 1.48	.032*	0.53
Thoracic rotation	4.62 (3.58, 7.22)	4.15 (2.59, 5.70)	.035*	0.57
lumbar spine rotation	6.51 ± 4.25	7.96 ± 7.85	.011*	0.84
Pelvis rotation	11.9 (10.3, 15.1)	12.5 (10.7, 15.5)	.089	0.42

Note. Values are presented as mean ± standard deviation or median (IQR). $p < .05$ indicates a statistically significant difference. All values are expressed in degrees (°).

Muscle activities

Regarding muscle activity, significant increases were observed in the posterior deltoid across all gait phases. During the IC to LR phase, activity increased from 0.65 [0.38–1.14]% in the W condition to 1.27 [0.79–2.31]% in the NW condition (effect size [ES] = 0.61). In the MSt to TSt phase, activity increased on both the stance side (W: 1.41 [0.74–2.35]%; NW: 2.60 [1.38–5.02]%; ES = 0.78) and the swing side (W: 1.99 [0.55–2.58]%; NW: 5.89 [2.61–13.2]%; ES = 0.80). During the PSw phase, activity increased substantially (W: 2.62 [1.46–5.46]%; NW: 22.3 [12.6–26.8]%; ES = 0.85).

The erector spinae also demonstrated significant increases in muscle activity across all phases. During the IC to LR phase, activity rose from 6.89 ± 5.32% (W) to 20.1 ± 17.6% (NW; ES = 0.81). In the MSt to TSt phase, increases were seen on both the stance side (W: 7.77 [3.12–9.30] %; NW: 12.8 [11.7–22.1] %; ES = 0.81) and the swing side (W: 7.59 [3.63–10.4] %; NW: 13.5 [5.39–25.1] %; ES = 0.68). In the PSw phase, activity increased from 6.41 ± 4.93% to 23.4 ± 19.1% (ES = 0.69).

Similarly, rectus abdominis activity was significantly elevated across all phases: IC to LR phase (W: 3.72 ± 2.76%; NW: 7.12 ± 4.27%; ES = 0.75), MSt to TSt phase (stance side) (W: 3.10 [2.35–4.16]%; NW: 7.64 [3.61–9.12]%; ES = 0.66), MSt to TSt phase (swing side) (W: 2.43 [2.06–3.62]%; NW: 6.64 [3.41–9.62]%; ES = 0.71), and PSw phase (W: 4.18 ± 2.93%; NW: 7.45 ± 4.10%; ES = 0.65). The gluteus maximus showed significant increases in the IC to LR phase (W: 6.51 [3.47–8.21]%; NW: 12.8 [2.92–25.9]%; ES = 0.53) and MSt to TSt phase (W: 2.20 [1.63–4.36]%; NW: 6.81

[3.62–9.72]%; ES = 0.79). Rectus femoris significantly increased during the IC to LR phase (W: 5.89 ± 3.76%; NW: 8.81 ± 6.83%; ES = 0.54), MSt to TSt (W: 4.14 [1.26–6.21]%; NW: 6.35 [2.85–16.4]%; ES = 0.56), and PSw phase (W: 2.28 [0.92–12.1]%; NW: 3.38 [2.72–6.16]%; ES = 0.58). The biceps femoris exhibited a significant increase in the MSt to TSt phase (W: 3.26 [1.08–6.16]%; NW: 7.09 [3.07–13.0]%; ES = 0.71). The tibialis anterior also showed significantly greater activity during the MSt to TSt (W: 8.12 ± 5.46%; NW: 12.1 ± 6.59%; ES = 0.56) and PSw phase (W: 6.11 [3.15–10.8]%; NW: 8.14 [4.98–15.2]%; ES = 0.76). In contrast, no significant differences were observed in the activity of the medial gastrocnemius across all phases.

Table 3. *Upper Limb and Trunk Muscle Activities*

			Walking (*M*±*SD*)	Nordic Walking (*M*±*SD*)	*p*-value	ES (d)
Posterior deltoid	IC - LR		0.65 (0.38, 1.14)	1.27 (0.79, 2.31)	.023*	0.61
	MSt - TSt	Stance side	1.41 (0.74, 2.35)	2.60 (1.38, 5.02)	.006*	0.78
		Swing side	1.99 (0.55, 2.58)	5.89 (2.61, 13.2)	.022*	0.80
	PSw		2.62 (1.46, 5.46)	22.3 (12.6, 26.8)	.002*	0.85
Erector spinae	IC - LR		6.89 ± 5.32	20.1 ± 17.6	.004*	0.81
	MSt - TSt	Stance side	7.77 (3.12, 9.30)	12.8 (11.7, 22.1)	.003*	0.81
		Swing side	7.59 (2.63, 10.4)	13.5 (5.39, 25.1)	.013*	0.68
	PSw		6.41 ± 4.93	23.4 ± 19.1	.007*	0.69
Rectus abdominis	IC - LR		3.72 ± 2.76	7.12 ± 4.27	.005*	0.75
	MSt - TSt	Stance side	3.10 (2.35, 4.16)	7.64 (3.61, 9.12)	.018*	0.66
		Swing side	2.43 (2.06, 3.62)	6.64 (3.41, 9.62)	.006*	0.71
	PSw		4.18 ± 2.93	7.45 ± 4.10	.008*	0.65

Note. Values are presented as mean ± standard deviation or median (IQR). * indicates a statistically significant difference ($p < .05$). All values are expressed as percentages (%).

Table 4. *Lower Limb Muscle Activity*

		Walking (*M*±*SD*)	Nordic Walking (*M*±*SD*)	*p*-value	ES (d)
Gluteus maximus	IC - LR	6.51 (3.47, 8.21)	12.8 (2.92, 25.9)	.042*	0.53
	MSt - TSt	2.20 (1.63, 4.36)	6.81 (3.62, 9.72)	.006*	0.79
	PSw	1.83 (0.95, 4.16)	2.34 (1.17, 4.38)	.475	0.21
Rectus femoris	IC - LR	5.89 ± 3.76	8.81 ± 6.83	.041*	0.54
	MSt - TSt	4.14 (1.26, 6.21)	6.35 (2.85, 16.4)	.033*	0.56
	PSw	2.28 (0.91, 4.50)	3.38 (2.72, 6.16)	.035*	0.58
Biceps femoris	IC - LR	5.93 (2.85, 12.4)	7.54 (5.23, 21.1)	.397	0.23
	MSt - TSt	3.26 (1.08, 6.16)	7.09 (3.07, 13.0)	.004*	0.71
	PSw	1.87 (0.92, 12.1)	3.75 (2.02, 16.3)	.397	0.23
Tibialis anterior	IC - LR	12.0 (6.54, 17.2)	16.2 (9.80, 26.2)	.177	0.36
	MSt - TSt	8.12 ± 5.46	12.1 ± 6.59	.036*	0.56
	PSw	6.11 (3.15, 10.8)	8.14 (4.98, 15.2)	.047*	0.76
Gastrocnemius	IC - LR	4.50 (2.02, 57.6)	14.1 (5.52, 22.3)	.683	0.11
	MSt - TSt	17.3 (9.86, 36.2)	20.1 (16.2, 42.1)	.472	0.19
	PSw	8.21 (3.06, 18.5)	9.38 (3.14, 28.1)	.272	0.29

Note. Values are presented as mean ± standard deviation or median (IQR). * indicates a statistically significant difference ($p < .05$). All values are expressed as percentages (%).

DISCUSSION

This study compared gait parameters, joint angles, and muscle activity between NW and W. The findings revealed that NW led to increases in walking speed, stride length, joint ROM, and muscle activity across the upper extremities, trunk, and lower extremities. Among these, the significant increase in walking speed during NW appears to be a key contributing factor to the observed changes. An increase in walking speed is known to result in greater stride length, enhanced joint movement, and elevated muscle activity (Den Otter, et al., 2004). Consistent with previous findings, the present study confirmed that NW promotes a faster walking speed compared to W, which likely underlies the increased activation observed in lower limb muscles. Additionally, the use of poles, a defining feature of NW, appears to influence joint kinematics and muscle activation patterns. Specifically, NW produced notable changes in lower limb joint angles and trunk rotation.

In particular, NW was characterized by significant increases in both maximum knee flexion and extension during the stance phase. The timing of peak knee flexion, occurring shortly after initial contact (IC), suggests an enhanced shock absorption in response to increased walking speed. This biomechanical adaptation is typically associated with a greater knee flexion moment, which necessitates increased activation of the rectus femoris and biceps femoris to control knee motion and prevent excessive flexion. Furthermore, during the midstance to terminal stance (MSt–TSt) phases, the knee and hip joints remained in a flexed position as the center of gravity moved forward in the sagittal plane, supporting dynamic forward propulsion.

This hip flexion generates a flexion moment at the hip joint, necessitating increased activity from the gluteus maximus, erector spinae, and rectus abdominis to stabilize the trunk and prevent excessive anterior flexion. In summary, the findings of this study suggest that in NW, the increase in walking speed induces changes in joint kinematics, leading to a distinct muscle activation pattern compared to W.

The findings of the present study suggest that Nordic walking may represent an effective exercise modality, despite being a simple modification of conventional walking through the use of poles.

Previous studies have indicated that walking alone has limited effects on improving lower limb muscle strength. In contrast, the present study demonstrated significantly increased lower limb muscle activity during Nordic walking. These results may indicate a potential increase in muscle loading with long-term intervention.

In addition, the observed increases in the range of motion at the knee and hip joints suggest that Nordic walking may contribute to improvements in joint flexibility. Taken together, these findings suggest that Nordic walking may enhance physical activity by promoting greater muscle engagement and joint mobility, which could have positive implications for functional capacity and overall well-being.

Additionally, NW resulted in increased activity of trunk muscles, with increased activity in the erector spinae and rectus abdominis. This suggests potential applicability of NW in rehabilitation programs aimed at improving trunk stability and overall physical function.

However, several limitations of this study should be acknowledged.

First, the study population consisted exclusively of healthy young adult males, which limits the generalizability of the findings to females, older adults, and individuals with clinical conditions. In addition, the sample size was relatively small, which may reduce the statistical power and the robustness of the findings.

Second, although participants underwent a 1-hour Nordic walking training session that included treadmill-based practice, all measurements were conducted during overground walking. This difference in experimental environment may have influenced gait patterns. However, this does not invalidate the present findings, as the training session was intended to familiarize participants with the Nordic walking technique prior to data collection.

Third, walking speed was not controlled in this study. As a result, it is difficult to distinguish the specific effects of pole use from those associated with increased walking speed. Future studies should consider controlling walking speed to better isolate these factors.

Fourth, the duration of the intervention was relatively short, and therefore may not adequately capture long-term biomechanical adaptations to Nordic walking.

Finally, the present study did not include detailed kinematic analysis of the upper limbs, despite their important role in Nordic walking. Future studies incorporating upper limb kinematics may provide a more comprehensive understanding of the movement characteristics of Nordic walking.

CONCLUSIONS

The present study demonstrated that NW offers advantages over conventional W in terms of gait parameters, joint range of motion, and muscle activity. A novel aspect of this study is the comprehensive evaluation of trunk motion and lower limb joint kinematics in combination with gait parameters and muscle activity. This approach provides new insights into the biomechanical characteristics of NW that have not been fully clarified in previous studies.

These findings suggest that NW is not merely an aerobic exercise, but also a movement that enhances lower limb and trunk muscle activity as well as joint mobility. Therefore, NW may serve as an effective intervention in both exercise and rehabilitation settings.

However, the results should be interpreted with caution due to several limitations, including the homogeneity of the study population, the lack of walking speed control, and the short duration of the intervention. Future studies are needed to examine the long-term effects of NW under controlled conditions and in more diverse populations.

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