EFFECTS OF A NORDIC WALKING INTERVENTION ON WALKING IN NORMAL ADULTS

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ABSTRACT

The purpose of this study was to compare and examine gait parameters, hip joint angle, and lower extremity muscle activity during normal walking before and after Nordic walking (NW) intervention.

Nineteen healthy male participants (age 26.3 ± 2.4 years) were included in the study. During walking, we measured gait parameters using the foot-print-measuring gait analysis system. Angular changes of the hip joint were measured with an IMU-type portable three-dimensional motion analyzer and the EMG activity of each muscle. The measurements above were performed before and after a one-hour NW training course. The hip joint angle, muscle activity, and gait parameters were compared before and after the intervention with the same participants.

In gait parameters, the stride length and walking speed were significantly greater after the intervention, while the cadence decreased significantly. Both hip flexion and extension angles were significantly greater after the intervention. In terms of muscle activity, the rectus abdominis, the tibialis anterior, and the gastrocnemius were very different after the intervention.

According to previous reports, employing a large stride length during NW would affect the normal gait after the training. The use of the Nordic pole may have stimulated a substantial forward movement in the lower extremities using the large range of motion of the hip joints. The benefits of NW include enhanced forward propulsion during gait and additional stability during the stance phase due to the greater support surface provided by the poles.

Keywords: *three-dimensional motion, muscle activity, gait parameter, hip joint angle, motion analysis*

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INTRODUCTION

Walking is the most common activity among the elderly due to its low economic costs and ease of incorporation into daily life (DiPietro, 2001; Pelssers et al., 2013). It is becoming increasingly popular among the elderly in Japan (Tsuji, 2019). Numerous intervention studies on the benefits of walking programs for the elderly have been reported. These walking programs not only focused on increasing the amount of walking (Rosenberg et al., 2012 and Cheng et al., 2009), improving motor function, mental health (Cheng et al., 2009), and cognitive function (Rosenberg et al., 2012), but also on the positive effect on depression and a higher subjective sense of health in the elderly, especially among women (Tsuji, 2019).

Nordic walking (NW) is a sport that originated in Finland and has spread throughout the world as a form of exercise that can be easily performed by anyone, as per their goals, regardless of age, gender, or physical ability. There are estimated to be over 40,000 NW participants in Japan and more than 6 million in over 50 countries worldwide (Tetsu et al., 2016). The International Nordic Walking Association has shown that NW boosts heart rate, increases energy expenditure, and reduces stress on the ankle and knee joints compared to walking at the same intensity (International Nordic Walking Association, 2016). In terms of physiological effects, NW, which is performed at a subjectively increased walking speed, has been reported to increase oxygen consumption, energy expenditure, and heart rate compared to normal walking (Pérez-Soriano et al., 2014), making it a useful aerobic exercise for maintaining and improving physical fitness (Church et al., 2002). Walking with a walking pole disperses the impact of landing, which reduces floor reaction force and load on the lower extremities compared to normal walking (Willson et al., 2001). Additionally, it has been shown that walking training using a walking pole dramatically increased the walking distance for a patient with peripheral vascular disease who had difficulty walking (Schiffer et al., 2006). The benefits mentioned above of NW have been reported to be effective against various diseases (Tschentscher et al., 2013).

The effects of NW on healthy participants include improving balance ability and gait speed (Kocur et al., 2015; Takeshima et al., 2013), decreasing vertical floor reaction force, and increasing cadence and stride length (Park et al., 2015). In terms of muscle activity, comparisons between NW and normal walking have yielded varying results, including a significant increase in muscle activity in upper limb muscles (Shim et al., 2013), no significant difference in both upper and lower extremity muscle strength (Kukkonen-Harjula et al., 2007), and a decrease in muscle activity in the lower extremity (Sugiyama et al., 2013). While one study found that NW is an effective method of physical activity and has the potential to be used in physical rehabilitation and daily living (Roy et al., 2020), another report showed no clear results on the effects of NW interventions on pain, muscle strength, flexibility, fatigue, or gait parameters (Fritschi et al., 2012). Therefore, the effects of NW on physical function, particularly muscle activity and gait parameters, remain controversial.

Thus, while many studies have reported on the positive effects of NW on the physiological responses and the biomechanical aspects of NW, there have been few studies on how NW actually changes the normal gait, and almost no studies have examined it from a biomechanical perspective. Even if NW improves the range of motion and muscle strength, it would be meaningful to explore its effect on normal walking since people do not use Nordic walking poles for all activities in their daily lives. The purpose of this study was to compare and examine gait parameters, hip joint angle, and lower extremity muscle activity during normal walking before and after NW intervention.

MATERIALS AND METHODS

Participants

Nineteen healthy male participants (age 26.3 ± 2.4 years, height 171.8 ± 3.2 cm) were included in the study. The exclusion criteria were acute illness and difficulty walking, but none of the participants met these criteria.

Measurements Methods

Walking Task

The walking path was 16 m long and comprised a 6.8 m acceleration path, a 2.4 m measurement path, and a 6.8 m deceleration path. An 80 cm × 240 cm sheet-type foot pressure contact footprint measuring device (Anima Corporation, WalkWayMW-1000: WalkWay) was installed on the measurement path (Figure 1). This device consists of an 8-sheet footprint measuring device and a computer for analysis. When a person walks on the connected measurement sheets, the ground position coordinates of the footprint are displayed on the analysis computer. When the data are saved, the gait parameters in terms of time and distance factors are automatically calculated based on the landing position of one foot relative to the other. The sensor resolution is 10 mm × 10 mm, and 14,000 pressure sensors were used for the measurement. The participants walked barefoot and were instructed to "walk as usual," their comfortable walking speed was measured.

Protocol

During walking, we measured gait parameters using the WalkWay gait analysis system, and angular changes of the hip joint were measured with an IMU-type portable three-dimensional motion analyzer (MyoMotion: Sakai Medical Co. Ultium EMG) was used to measure the EMG activity of each muscle. During the task, the time axis of each measurement item was matched by sending a synchronization signal to MyoMotion and a high-speed camera (Noraxon High-Speed Camera, EM-V 125N, Sakai Medical Co.), which used a synchronization system (MyoSynchro, EM-MR262, Sakai Medical Co.).

The order of the measurements was as follows: after the walking measurements were performed, a one-hour NW training course was conducted, and then the walking measurements were undertaken again.

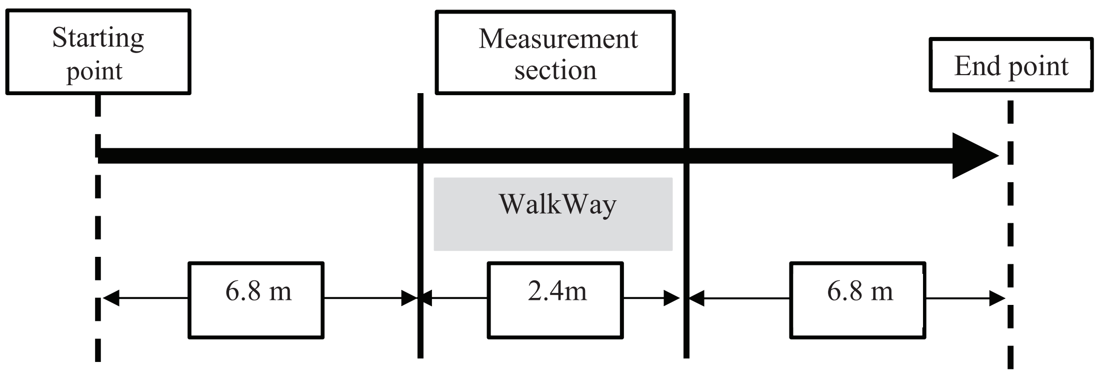


Figure 1. *Measurement environment*

Measurements Items

Perry's definition of the gait cycle described in the Rancho Los Amigos Hospital method was used for phase separation during one gait cycle (Perry, 2010). The phases were classified into the Initial Contact (IC), Loading Response (LR), Mid-stance (MSt), Terminal Stance (TSt), and Pre-Swing (PSw) phases based on the acceleration of the inertial sensor at the foot: The X-axis sensor was used to capture and identify the anteroposterior impact acceleration at the time of IC, and the foot release was identified by capturing the vertical acceleration using the Z-axis sensor. The gait cycle was divided into the following three phases: (1) IC–LR phase (stance side IC–swing side foot release), (2) MSt–Tst phase (swing side foot release–swing side IC), and (3) PSw phase (swing side IC–swing side foot release). The gait parameters of four strides were analyzed, and the average of all data was used as the measured value.

The gait parameters measured with the WalkWay system were as follows: (1) stride (cm), (2) stride/height (%), (3) step length (cm), (4) gait speed (cm/sec), (5) cadence (steps/min), (6) one cycle time (sec), (7) single standing time (sec), (8) double standing time (sec), and (9) swing time (sec).

The maximum hip flexion/extension angles during walking were calculated with MyoMotion in this study. Comparing the hip, knee, and ankle joint angles during walking on a treadmill between an inertial measurement device and a motion capture system similar to MyoMotion revealed no difference (Park et al., 2021). Hence, it was also considered a good measurement for this study. The sampling frequency was 100 Hz.

The muscle activity during walking was measured in the lumbar erector spinae, rectus abdominis, gluteus maximus, rectus femoris, biceps femoris, tibialis anterior, and medial head of the gastrocnemius. The muscle activity on the stance leg side was calculated for each gait cycle. The measured data for each muscle were normalized to 100% of the voluntary muscle contraction (MVC) and calculated as a percentage of MVC. The sampling frequency during the measurement was 2,000 Hz.

Contents of NW Training

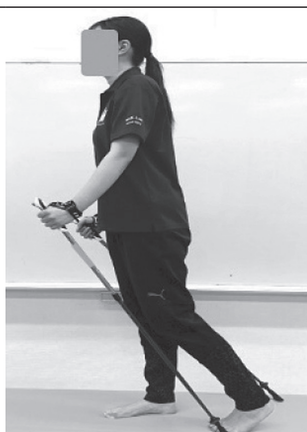
The NW training course was conducted by a certified activity leader of the Japan Nordic Walking Association (JNWA) for about 1 h. The content of the instruction was based on the lectures presented during the Activity Leader Training Course. It included the following three points (Figure 2): (1) place the pole on the ground with the opposite hand of the foot that stepped out, keeping the elbow joint at an extended angle; (2) push the body forward with the pole, being careful not to put too much pressure on the shoulders; and (3) when the body starts pushing off the ground, release the hand from the grip of the pole. All participants were given basic and individual instructions. The length of the poles was determined by multiplying the JNWA's standard height (cm) by 0.68.

The intervention protocol was as follows: (1) a 10-minute lecture on pole use, (2) a 20-minute lecture on walking, (3) a 5-minute break, (4) 2 sets of 10-minute walking practice at comfortable walking speed (5-minute interval break).

1.

The pole is stuck diagonally in the middle of the open leg, and the arm is swung at the center of the shoulder without bending and extending the elbow.

2.



Push the strap with the palm of your hand while walking forward. Gradually open your hands and release them from the grip.

3.		Swing the arm back around the shoulder without bending or extending the elbow. As the arm moves backward, release the hand slightly, and at the rear, release the hand from the grip. Hold the grip as the arm comes from back to front.

Figure 2. *Three guidance points*

Analysis Methods

The hip joint angle, muscle activity, and gait parameters were compared before and after the intervention in the same participants. The Shapiro-Wilk test was used to confirm the normality of all items; those determined to be normal were compared using the corresponding t-test, while those not normal were compared using the Wilcoxon signed-rank test. Statistical software (IBM, SPSS statistics version 25) was used for the statistical analysis, and the statistical significance level was set at 5%.

Ethical Consideration

This study was conducted in compliance with the Declaration of Helsinki and the "Ethical Guidelines for Medical Research Involving Human Participants". Informed consent was obtained from cooperating participants after explaining (1) the purpose, methods, and content of the research; (2) protection of privacy; (3) benefits and disadvantages associated with participation in the research; (4) withdrawal of consent; (5) cost-sharing; (6) publication of research results; (7) how to destroy materials and data after the research; and (8) infection control. This research was initiated after receiving approval for an ethical review by the Ethics Committee of Takasaki University of Health and Welfare (Takasaki University of Health and Welfare Ethics No. 2055).

RESULTS

In gait parameters, the stride length (63.4 ± 5.58 cm → 64.5 ± 6.04 cm, effect size (ES) = 0.15) and walking speed (105 ± 15.5 cm/sec → 109 ± 16.1 cm/sec, ES = 0.46) were significantly greater after the intervention, while the cadence (107 (99.9–110) steps/min → 105 (99.1–111) steps/min, ES = 0.32) decreased significantly. Both hip flexion and extension angles were significantly greater after intervention than before (hip flexion: 25.1 ± 4.92° → 26.2 ± 5.49°, ES = 0.19; hip extension: 18.6° (17.1°–22.7°) → 21.8 (19.2–25.7), ES = 0.66). In terms of muscle activity, the IC–LR phase of the rectus abdominis (3.76 ± 2.67%MVC → 4.52 ± 2.86%MVC, ES = 0.54), the MSt–Tst phase of the tibialis anterior (8.52 ± 4.98%MVC → 9.44 ± 4.12%MVC, ES = 0.40), and the MSt–Tst phase of the gastrocnemius (18.2 (12.2–33.6) %MVC → 24.6 (17.2–32.2) %MVC, ES = 0.50) were significantly higher after the intervention. The PSw phase of the anterior tibialis muscle was significantly lower after the intervention (5.56 (3.50–9.05) %MVC → 4.58 (2.27–5.59) %MVC, ES = 0.47).

Table 1. *Measurement results*

			Before intervention	After intervention	*p*-value	ES (d)
Gait parameter	Stride (cm)		115 ± 11.2	116 ± 11.6	.074	0.13
	Stride/height (%)		66.9 ± 6.4	67.8 ± 6.5	.075	0.13
	Step length (cm)		63.4 ± 5.58	64.5 ± 6.04	.006*	0.15
	Gait speed (cm/sec)		105 ± 15.5	109 ± 16.1	.0002*	0.46
	Cadence (steps/min)		107 (99.9, 110)	105 (99.1, 111)	.006*	0.32
	One cycle time (sec)		1.04 ± 0.06	1.04 ± 0.06	.77	0.04
	Single standing time (sec)		0.63 (0.62, 0.65)	0.63 (0.62, 0.65)	.47	0.07
	Double standing time (sec)		0.118 ± 0.012	0.116 ± 0.010	.26	0.14
	Swing time (sec)		0.40 (0.38, 0.41)	0.39 (0.37, 0.42)	.14	0.20
Joint angle	Hip flexion (deg)		25.1 ± 4.92	26.2 ± 5.49	.020*	0.19
	Hip Extension (deg)		18.6 (17.1, 22.7)	21.8 (19.2, 25.7)	.022*	0.66
	Erector spinae	IC ~ LR	6.36 ± 5.27	7.13 ± 4.92	.10	0.30
		MSt ~ TSt	7.61 (5.18, 8.93)	8.21(5.06, 9.25)	.15	0.20
		PSw	6.49 ± 4.20	7.04 ± 3.93	.08	0.14
	Rectus abdominis	IC ~ LR	3.76 ± 2.67	4.52 ± 2.86	.023*	0.54
		MSt ~ TSt	3.13 (2.39, 3.53)	3.51 (2.95, 4.45)	.15	0.16
		PSw	4.00 ± 2.46	4.18 ± 2.60	.54	0.08
	Gluteus maximus	IC ~ LR	4.66 (3.50, 7.10)	6.61 (4.51, 8.19)	.20	0.34
		MSt ~ TSt	2.25 (1.64, 3.89)	2.21 (1.50, 3.55)	.86	0.01
		PSw	1.21 (0.99, 3.07)	1.59 (1.07, 2.56)	.32	0.11
Muscle activity (%MVC)	Rectus femoris	IC ~ LR	5.63 ± 3.36	5.34 ± 2.83	.43	0.10
		MSt ~ TSt	4.83 (1.98, 7.20)	4.45 (2.33, 8.24)	.36	0.12
		PSw	2.65 (1.00, 4.52)	3.21 (1.89, 5.54)	.30	0.26
	Biceps femoris	IC ~ LR	5.54 (2.74, 8.53)	4.49 (3.31, 9.36)	.81	0.04
		MSt ~ TSt	3.98 (1.34, 6.30)	3.31 (1.90, 6.61)	.88	0.12
		PSw	2.24 (1.18, 3.52)	3.32 (2.25, 5.55)	.38	0.14
	Tibialis anterior	IC ~ LR	14.9 (7.66, 17.2)	17.9 (13.6, 20.6)	.27	0.38
		MSt ~ TSt	8.52 ± 4.98	9.44 ± 4.12	.047*	0.40
		PSw	5.56 (3.50, 9.05)	4.58 (2.27, 5.59)	.043*	0. 47
	Gastrocnemius	IC ~ LR	5.41 (2.23, 8.01)	4.58 (2.55, 6.62)	.72	0.06
		MSt ~ TSt	18.2 (12.2, 33.6)	24.6 (17.2, 32.2)	.047*	0.50
		PSw	9.94 (3.88, 14.1)	12.2 (7.22, 15.5)	.50	0.16

Note: Mean ± standard deviation, Central value (first quartile, fourth quartile)
**: significantly different (p < .05)*

DISCUSSION

As for changes in gait parameters, walking speed increased, and cadence decreased after the intervention. A systematic review of NW reported an increase in walking distance, walking speed, and stride length, as well as a decrease in cadence (Roy et al., 2020), which is corroborated by the results of this study. There were also changes in gait with NW training, including a longer stride length, a faster gait, and increased power production at the hip joint (Dalton et al., 2016). Similar to these previous reports, we anticipated that employing a large stride length during NW would affect the normal gait after the training. The participants' walking speed in this study was slower than that of healthy Japanese adults in their 20s, the stride length was shorter, and the number of steps per minute was lower than that of normal Japanese adults (Sekiya et al., 1998). This may be because the participants underwent the measurements in an unfamiliar environment. However, since we compared and examined the measurement results of the same participants under the same settings, it was unlikely to have affected the results of the analysis.

The increase mentioned above in stride length may be partly due to an improvement in the hip range of motion during walking. The relationship between walking speed and lower extremity joint range of motion has been reported (James et al., 1989 and Peyré-Tartaruga et al., 2022), and the possibility that an increase in hip flexion angle may have had an effect in this study was also greatly considered. The use of the Nordic pole may have stimulated a substantial forward movement in the lower extremities using the large range of motion of the hip joints. Step length and walking speed are important aspects of changes in physical function in the elderly. Although this was an immediate effect, the increase in the range of motion of the hip joint, especially the hip extension angle, is an auspicious aspect of future exercise intervention effects.

NW usually increases upper extremity muscle activity compared to walking. Therefore, the load on the upper limb muscles due to the use of poles for one hour is also considered, but this is a benefit of the training effect of NW, and no past reports of an increased risk of pain were found. The effect of the use of poles on cadence was not considered to be significant. Although it is unclear whether the observed decrease in cadence was due to the decline in walking speed or increased stride length, the generalization to arm swinging movements in normal walking due to upper limb muscle activation was considered more influential.

Regarding muscle activity, abdominal muscle activity increased from the IC to the MSt, while foot muscle activity increased directly from the MSt to the PSw. This is a good result considering that the trunk muscle activity increased during the shock-absorbing phase after foot contact, and the lower extremity movements were triggered in a stabilized state. The relationship between walking speed and ankle plantar flexion muscle strength has also been reported (Vandervoort et al., 1986), suggesting that increased foot activity may have also caused an increase in walking speed. It has also been reported that NW enhances trunk stability compared to walking (Peyré-Tartaruga et al., 2022 and Zoffoli et al., 2017), suggesting the possibility that assisted trunk extension may lead to activation of the trunk muscles, especially the abdominal muscles. In addition to increasing lower extremity mobility, NW has been reported to be effective in reducing back pain (Prost et al., 2021), and there are high expectations for preventing back pain associated with walking. The decrease in the anterior tibialis activity during the PSw phase following the intervention may be due to the beneficial effect of the mechanical dorsiflexion of the ankle joint that accompanies the hip extension. However, since walking is now accomplished without the use of foot dorsiflexors, it may potentially decrease toe clearance during walking, indicating the need for fall prevention care.

The functions of the plantar flexor muscles during the stance phase include the generation of forward propulsion and postural retention (Winter, 1983; Meinders et al., 1998; Perry, 1974). It has been reported that the energy generated by the plantar flexor muscles during the push-off phase has minimal direct effect on the body's forward motion (Meinders et al., 1998). Furthermore, it has been shown that the plantar flexor muscles in the push-off phase are primarily responsible for postural retention and play a limited role in forward propulsion (Perry, 1974). Although using poles during NW may have increased forward propulsion and posture retention, it was unclear if an increased activation of the gastrocnemius muscle following intervention also contributed to the increased walking speed observed in this study. On the other hand, it was reported that NW was safe, causing minimal trauma or impairment and that muscle injuries were encountered only in the gastrocnemius muscle (Knobloch et al., 2006). Whether or not increased gastrocnemius muscle activity is deemed beneficial is a subject for future study.

The benefits of NW include enhanced forward propulsion during gait and additional stability during the stance phase due to the greater support surface provided by the poles. We believe that the NW intervention in this study, which was performed only for about 1 h, increased muscle activity and joint angles to the point that normal walking could not have been achieved and that the effects may have been generalized during subsequent normal walking. This study suggests that the simple act of holding two poles while walking may have beneficial effects on muscle activity and joint angle during normal walking. The long-term effects of NW intervention should be examined in the future.

The limitations of the study include the fact that it was a novice intervention and that a control group was not prepared. Nevertheless, the study was meaningful in that it allowed us to examine the effects of NW on gait parameters, joint angles, and muscle activity, and subsequently on normal gait, which has not been clarified. It was reported that novice Nordic walkers require an initial 8-week training period to perfect their technique and restore a more natural and normal gait pattern after training (Dalton et al., 2016). To make this study even more useful, we would like to examine the effects of a longer intervention period and a rearrangement of the study's design. In addition, unfortunately, no measurements were taken in this study to standardize and confirm the loading amount, such as heart rate before and after exercise. This is an issue for future research.

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