Estimation of Energy Expenditure of Nordic Walking: A Crossover Trial

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Abstract

Background: Nordic walking (NW) requires more energy compared with conventional walking (W). However, the metabolic equation for NW has not been reported. Therefore, this study aimed to characterize responses in oxygen uptake ($\dot{V}O_2$), minute ventilation ($\dot{V}E$), heart rate (HR), systolic blood pressure (SBP), and surface electromyography (sEMG) of the upper and lower limb muscles during NW and W and to develop a metabolic equation for energy expenditure (E) of NW.

Methods: Fifty healthy young men constituted our sample (aged 23.7 ± 3.0 years). Two randomly assigned walking tests (NW and W) on a treadmill at a predetermined stepwise incremental walking speed (3–5 km·h^{-1}) and grade (0%–7%). The $\dot{V}O_2$, $\dot{V}E$, HR, and SBP were measured. The sEMG signals of the three upper limb muscles and three lower limb muscles in their right body were recorded. Linear regression analysis was used to draw estimation of EE during W and NW.

Results: $\dot{V}O_2$ (+15.8%), $\dot{V}E$ (+17.0%), RR (+18.2%), HR (+8.4%), and SBP (+7.7%) were higher in NW than in W. NW resulted in increased muscle activity in all of the upper limb muscles (P<.05). In the lower limb, sEMG activities in two of the three lower limb muscles were increased in NW than in W only during level walking (P<.05). EE during W and NW was estimated as follows: E_W = 4.4 + 0.09 × speed + 1.20 × speed × grade; E_{NW} = 6.1 + 0.09 × speed + 1.19 × speed × grade.

Conclusion: NW showed higher work intensity than W, with an oxygen consumption difference of 1.7 mL·kg^{-1}·min^{-1}. The coefficients were not different between the two walking methods. NW involved more muscles of the upper body than W.

Background

Nordic walking (NW) refers to a particular type of walking with alternating movements of the arms and hands pushing off NW poles [1]. NW exerts beneficial effects on resting heart rate, blood pressure, exercise capacity, maximal oxygen consumption, and quality of life in patients with various diseases. Thus, it can be recommended to a wide range of people as primary and secondary preventions [2].

The use of poles actively engages the upper body to propel the person forward during walking, resulting in higher activation of the upper body musculature, and NW increases cardiovascular metabolism compared with conventional walking (W) at the same walking speed. When the differences in oxygen consumption between NW and W were reported as % difference, the degree of increased oxygen consumption, however, varies from 7–23% during flat walking [3–6].

NW walking showed higher oxygen consumption in contrast to W, regardless of the walking speed. From the results of previous studies analyzing the not-fast walking speed (3–5 km·h^{-1}), NW at 3.6 and 4.8 km·h^{-1} (Sugiyama et al. [14]), and 4 km·h^{-1} (Figard-Fabre et al. [7]; Pellegrini et al. [8]) showed higher oxygen consumption than W. At a walking speed faster than 5 km·h^{-1}, such as 5.6 and 5.9 km·h^{-1}

(Church et al. [4]), 5.4, 6.0, 6.6, and 7.2 $km \cdot h^{-1}$ (Sugiyama et al.[14]), and 6.5 and 7.6 $km \cdot h^{-1}$ (Schiffer et al.[6]), oxygen consumption was significantly higher in NW than in W.

Moreover, not proportional to the increase in energy expenditure during NW, the subjectively perceived exertion was not significantly increased [5, 7]. During uphill walking, NW also showed a greater amount of oxygen consumption than W; however, the extents of the increase in energy expenditure were reduced when walking uphill than flat walking [7, 8]. When incorporating NW in exercise training of patients, the intensity of exercise should be considered, and exact energy expenditure-estimation of NW would be required for both flat and uphill walking. Energy expenditure during exercise is estimated as the sum of the resting, horizontal, and vertical components. Regarding walking exercise, the metabolic calculation equation with walking speed ($m \cdot min^{-1}$) and fractional grade was proposed as E ($mL \cdot kg^{-1} \cdot min^{-1}$) = 3.5 + 0.1 × speed + 1.8 × speed × fractional grade [American College of Sports Medicine (ACSM) equation] [9].

NW requires more energy than W, but its metabolic equation has not been reported. The purpose of this study was to measure the metabolic, cardiovascular, and muscular responses during NW and W on a treadmill at an incremental speed and grade. We also aimed to derive a metabolic equation for NW's energy expenditure (E), which includes the horizontal and vertical elements (gait speed and slope, respectively).

Methods

Participants

The experimental group constituted 15 healthy men. Table 1 shows the means and standard deviations for age, weight, body mass index, waist circumference, umbilicus height, resting systolic and diastolic blood pressure (SBP and DBP, respectively), resting heart rate (HR), room temperature, and room humidity. All participants had no experience with NW before this study and were fully informed about the study's procedures and their participation's possible risks. All voluntarily participated in the study after they provided written consent. This study was approved by the Institutional Review Board. It was conducted together with a study that analyzed the accuracy of HR measurement using a wearable band during NW [10].

Table 1
Characteristics of participants (N = 15)

	Mean ± SD	(Min–Max)
Age (years)	23.7 ± 3.0	(19–30)
Height (cm)	174.6 ± 4.9	(167.2–182.6)
Weight (kg)	76.3 ± 13.9	(57–111.9)
Body mass index (kg/m^2)	25.0 ± 4.1	(18.9–34.5)
Waist circumference (cm)	86.9 ± 10.7	(72–104.5)
Umbilicus height (cm)	104.9 ± 3.6	(98–113)
Resting SBP (mmHg)	124.4 ± 10.6	(110–146)
Resting DBP (mmHg)	78.9 ± 7.0	(65–88)
Resting HR (beat/min)	83.2 ± 8.3	(73–99)
Room temperature (℃)	25.9 ± 1.6	(23.4–28.2)
Room humidity (%)	33.0 ± 11.2	(21–61)

SBP, systolic blood pressure; DBP, diastolic blood pressure; HR, heart rate

NW Technique

Participants visited the exercise testing laboratory on the day of the graded walking tests. They underwent a 1 h training for NW with a NW instructor of the Korean Nordic Walking Federation/Korean Walking Association (Y. Ha) before the walking test. The NW technique emerged from a training modality that is typical of cross-country skiing, requiringa specific technique: moving the extended arms similar to the range of movement of natural walking, maintaining the upper body upright, maintaining a backward pole position during the loading phase, using the poles actively and dynamically, and controlling the poles by hands gripping with grasp/release patterns [11]. Each participant's poles' lengths (Nordic Friend, Gabel, Italy) were set at the umbilicus' height. The weight of the walking pole was 196 g. All participants were familiarized with W and NW on a treadmill. They were asked to rest for at least 30 min before the start of the walking test (Fig. 1A).

Graded Walking Test Protocol

The graded walking test protocol on the treadmill constituted 20 min stages of rest, adaptation, walking, and recovery. The participants warmed up and familiarized for 2 min at 2 $km \cdot h^{-1}$, the same speed with the first walking test stage. Walking tests constituted seven stages with a 2 min duration for each stage: walking on a treadmill (STEX 8100TD; Taeha Mechatronics, Anyang-Si, Korea) at 3 $km \cdot h^{-1}$, 4 $km \cdot h^{-1}$, and 5 $km \cdot h^{-1}$ at 0% inclination and 1%, 3%, 5%, and 7% inclination at 5 $km \cdot h^{-1}$ (Fig. 1B).

The participants walked on the treadmill at a stepwise incremental speed and grade. Two walking conditions (NW and W) were used with a randomized sequence using a random number. The blood pressure cuff was worn on the left upper arm, and SBP/DBP were measured at the end of each stage. HR was assessed in 30-s intervals using 12-lead electrocardiography (Philips StressVue, Philips, the Netherlands), and the highest HR value was selected for each walking stage. Exertion was also rated at each walking stage; they were rated using the 6–20 point Borg rating of perceived exertion (RPE) scale. [12]

Ventilatory Gas Analysis

The volume of oxygen consumed per minute ($\dot{V}O_2$), volume of carbon dioxide per minute ($\dot{V}CO_2$), expired ventilation per minute ($\dot{V}E$), respiratory exchange ratio (RER), and respiratory rate (RR) were measured using a ventilatory gas analysis system (Ultima PFX®, MGC Diagnostics Corporation, St Paul, MN, USA). The measured values during the 2 min of each walking stage were averaged.

Surface Electromyography

The surface electromyographic signals of the mid deltoid (DEL, the midpoint between the acromion and the deltoid tubercle), the biceps brachii (BB, the thickest muscle belly of BB), the triceps brachii (TB, the midpoint between the acromion and the olecranon), the vastus lateralis (VL, five finger's breadth upward and lateral from the patella), the emedial gastrocnemius (GCM, the medial belly of the calf muscle), and the tibialis anterior (TA, four finger's breadth downward from the tibial tuberosity) in their right body were recorded using Model 586 Desktop DTS Receiver and Model 542 Desktop DTS EMG Sensor (Noraxon USA, Inc., Scottsdale, AZ).

Before applying the surface electrodes, the skin was cleaned with an alcohol swab to reduce impedance. A skilled physiotherapist attached all electrodes to the skin on the midpoint of the contracted muscle belly parallel to the muscle fibers with an adhesive tape. The sampling frequency was 1500 Hz. The data were filtered with a bandpass filter in the acquisition software. The root of the mean square value was acquired for each walking stage.

Statistical Analysis

The acquired data were analyzed using the SPSS ver. 23 (IBM, Armonk, NY). Hemodynamic responses, ventilatory gas analysis, and surface electromyographic results were compared between NW and W using the paired t-test. A P-value < 0.05 was considered significant. Simple and multiple linear regression analyses were conducted to estimate E for NW and W.

Results

Ventilatory Gas Analysis, HR, and Blood Pressure during Graded W and NW

Ventilatory gas analysis results showed increased metabolism and hemodynamic responses in NW than in W. The $\dot{V}O_2$ (+ 15.8%), $\dot{V}CO_2$ (+ 17.0%), $\dot{V}E$ (+ 17.0%), RR (+ 18.2%), SBP (+ 7.7%), DBP (+ 6.9%), and HR (+ 8.4%) were significantly higher in NW than in W (P-value < 0.05) (Table 2). $\dot{V}O_2$, $\dot{V}E$, HR, and SBP showed significant differences between W and NW in all walking stages (Fig. 2). Conversely, RPE was less in NW than in W (Table 2). Chest pain was absent in both W and NW. The degree of difficulty in breathing was very low, with no significant difference between W and NW.

Table 2
Ventilatory gas analysis and surface electromyographic results during walking (W) and Nordic walking (NW)

	W	**NW**	***P*-value**	**Δ(NW−W)**	**Δ(NW−W)/W (%)**
$\dot{V}O_2$ ($mL \cdot kg^{-1} \cdot min^{-1}$)	13.5 ± 3.7	15.5 ± 3.9	< .01	2.0 ± 1.6	15.8
$\dot{V}CO_2$ ($mL \cdot min^{-1}$)	840.3 ± 281.2	968.9 ± 300.0	< .01	128.6 ± 111.4	17.0
$\dot{V}E$ ($L \cdot min^{-1}$)	21.6 ± 6.1	25.0 ± 6.9	< .01	3.4 ± 3.3	17.0
RER	0.815 ± 0.069	0.823 ± 0.058	< .05	0.007 ± 0.035	1.1
RR ($beat \cdot min^{-1}$)	21.0 ± 3.1	24.6 ± 3.5	< .01	3.5 ± 3.8	18.2
SBP (mmHg)	134.5 ± 11.2	144.5 ± 11.5	< .01	10 ± 9.1	7.7
DBP (mmHg)	74.4 ± 5.1	79.2 ± 5.5	< .01	4.9 ± 5.9	6.9
HR ($beat \cdot min^{-1}$)	106.9 ± 13.2	115.8 ± 14.4	< .01	8.8 ± 5.6	8.4
RPE	9.0 ± 2.7	8.3 ± 2.6	< .01	-0.6 ± 1.4	-5.9
DEL (μV)	6.7 ± 3.7	12.0 ± 4.8	< .01	5.3 ± 3.1	94.9
BB (μV)	5.6 ± 4.5	18.9 ± 7.2	< .01	13.3 ± 8.8	381.4
TB (μV)	6.4 ± 3.2	21.8 ± 10.1	< .01	15.4 ± 9.2	308.6
VL (μV)	67.6 ± 57.9	65.4 ± 57.7	.60	-2.2 ± 39.1	34.7
TA (μV)	40.9 ± 11.3	45.7 ± 14.4	< .01	4.8 ± 9.8	13.3
GCM (μV)	36.5 ± 12.3	39.7 ± 11.8	< .01	3.3 ± 6.8	11.7

RER, respiratory exchange ratio; RR, respiratory rate; SBP, systolic blood pressure; DBD, diastolic blood pressure; HR, heart rate; RPE, rating of perceived exertion; DEL, deltoid; BB, biceps brachii; TB, triceps brachii; VL, vastus lateralis; TA, tibialis anterior; GCM, gastrocnemius; L3, L3 paraspinals

Activation of the Upper and Lower Limb Muscles during Graded W and NW

The differences in muscle activities between W and NW varied between the upper and lower extremities. The upper limb muscle activities (DEL, BB, and TB) were significantly higher in NW than in W (*P*-value < 0.05) (Table 2). These differences were significant in all walking stages (Fig. 3). No significant difference was found in the activity of VL between the two walking conditions (Table 2) in lower extremity muscles. TA and GCM activities were higher in NW (Table 3), but it showed a significant difference only in level walking (stages 1 and 2 for TA; stage 1 for GCM) (Fig. 3).

Table 3

Oxygen consumption ($\dot{V}O_2$, mL·kg^{-1}·min^{-1}) at each walking stage during walking (W) and Nordic walking (NW)

Walking stage	Treadmill speed (km·h^{-1})	Treadmill grade (%)	$\dot{V}O_2$ W	$\dot{V}O_2$ NW	$\Delta\dot{V}O_2$ (% $\dot{V}O_2$)	*P*-value
Stage 1	3	0	9.0 ± 1.5	10.9 ± 2.2	1.9 (20.9)	< .01
Stage 2	4	0	10.1 ± 1.5	12.1 ± 2.1	2.0 (19.3)	< .01
Stage 3	5	0	12.0 ± 1.5	14.0 ± 2.5	2.0 (16.2)	< .01
Stage 4	5	1	13.0 ± 1.6	15.3 ± 2.1	2.3 (17.4)	< .01
Stage 5	5	3	14.8 ± 1.8	16.5 ± 2.0	1.7 (11.6)	< .01
Stage 6	5	5	16.7 ± 1.5	18.6 ± 2.0	1.8 (10.9)	< .01
Stage 7	5	7	19.0 ± 1.4	21.2 ± 1.7	2.1 (11.3)	< .01

$\Delta\dot{V}O_2 = \dot{V}O_2NW - \dot{V}O_2W$

$\%\dot{V}O_2 = (\dot{V}O_2NW - \dot{V}O_2W) / \dot{V}O_2W \times 100$

Estimation of Oxygen Consumption of W and NW

Ventilatory gas analysis results during W and NW showed that the oxygen uptake was 9.0 ± 1.5 to 19.0 ± 1.4 mL·kg^{-1}·min^{-1} during W and 10.9 ± 2.2 to 21.2 ± 1.7 mL·kg^{-1}·min^{-1} during NW. The difference between NW and W regarding oxygen consumption from stage 1 to 7 ranged 1.7–2.3 mL·kg^{-1}·min^{-1} (Table 3).

The E or $\dot{V}O_2$ (mL·kg^{-1}·min^{-1}) during W and NW with different walking speed at flat walking (walking stage 1 to 3; grade = 0%; speed 3 to 5 km·h^{-1} or 50 to 83 m·min^{-1}) was analyzed using a simple linear regression analysis, and coefficients for walking speed were estimated (Table 4). Speed is expressed in m·min^{-1}, and fractional grade is grade percentage expressed in decimal formal (e.g., 10% = 0.10):

Table 4
Estimation of oxygen consumption during conventional walking (W) and Nordic walking (NW) using simple linear regression analysis

	Walking stage (treadmill grade = 0.00)			**Linear regression analysis**			
	Stage 1	Stage 2	Stage 3	Constant	Estimate	R	R^2
Treadmill speed	50.0 m·min^{-1} (3 km·h^{-1})	66.7 m·min^{-1} (4 km·h^{-1})	83.3 m·min^{-1} (5 km·h^{-1})				
$\dot{V}O_2$ W	9.0 ± 1.5	10.1 ± 1.5	12.0 ± 1.5	4.36	0.09	0.648	0.420
$\dot{V}O_2$ NW	10.9 ± 2.2	12.1 ± 2.1	14.0 ± 2.5	6.16	0.09	0.497	0.247

	Walking stage (treadmill speed = 83.3 m·min^{-1})					**Linear regression analysis**			
	Stage 3	Stage 4	Stage 5	Stage 6	Stage 7	Constant	Estimate	R	R^2
Treadmill grade	0.00	0.01	0.03	0.05	0.07				
$\dot{V}$O2 W	12.0 ± 1.5	13.0 ± 1.6	14.8 ± 1.8	16.7 ± 1.5	19.0 ± 1.4	11.9	100.1	0.821	0.675
$\dot{V}$O2 NW	14.0 ± 2.5	15.3 ± 2.1	16.5 ± 2.0	18.6 ± 2.0	21.2 ± 1.7	13.9	99.2	0.757	0.573

$E_W = 4.4 + 0.09 \times \text{speed}$

$E_{NW} = 6.3 + 0.09 \times \text{speed}$

Oxygen consumption during W and NW in different grades with constant speed (walking stage 3 to 7; speed = 5 km·h^{-1} or 83 m·min^{-1}) was estimated using a simple linear regression analysis, and coefficients for fractional grade were estimated (Table 4):

$E_W = 11.9 + 100.1 \times \text{fractional grade}$

$E_{NW} = 13.9 + 99.2 \times \text{fractional grade}$

Coefficient 0.09 for speed and speed value (83.3 m·min^{-1}) were integrated to the equation:

E_W = (11.9–7.5) + 7.5 + (100.1 / 83.3) × 83.3 × fractional grade

= 4.4 + 0.09 × 83.3 m·min^{-1} + 1.20 × 83.3 m·min^{-1} × fractional grade

E_{NW} = (13.9–7.5) + 7.5 + (99.2 / 83.3) × 83.3 × fractional grade

= 6.4 + 0.09 × 83.3 m·min^{-1} + 1.19 × 83.3 m·min^{-1} × fractional grade

From the estimation equations from the two-step simple linear regression analysis, the constant values were 4.4 for W and 6.4 for NW, and the difference was 2.0 mL·kg^{-1}·min^{-1}. Coefficients for speed were 0.09 in both W and NW. Coefficients for fractional grade were 1.20 for W and 1.19 for NW.

As a result of multiple linear regressions for speed and speed × fractional grade, the final formula is shown below (Table 5):

Table 5
Estimation of oxygen consumption during conventional walking (W) and Nordic walking (NW) using multiple linear regression analysis

		Model coefficients			Overall model fit			
		Estimate	**t**	**P-value**	**R**	**R^2**	**Adjusted R^2**	**P-value**
$\dot{V}O_2$ W	Constant	4.39	4.24	< 0.001	0.911	0.829	0.826	< 0.001
	Speed	0.09	6.26	< 0.001				
	Speed × grade	1.20	14.88	< 0.001				
$\dot{V}O_2$ NW	Constant	6.14	4.38	< 0.001	0.852	0.725	0.720	< 0.001
	Speed	0.09	4.78	< 0.001				
	Speed × grade	1.19	10.97	< 0.001				

E_W (mL·kg^{-1}·min^{-1}) = 4.4 + 0.09 × speed (m·min^{-1}) + 1.20 × speed × fractional grade

E_{NW} (mL·kg^{-1}·min^{-1}) = 6.1 + 0.09 × speed (m·min^{-1}) + 1.19 × speed × fractional grade

Both final formulae were statistically significant, explaining 82.6% of the relationship between $\dot{V}O_2$-W and speed, speed × fractional grade, and 72.0% of the relationship between $\dot{V}O_2$-NW and speed, speed × fractional grade. The constant value in the final equation for W was 4.4, and this is somewhat higher than the known resting oxygen consumption (3.5 mL·kg^{-1}·min^{-1}) [9]. The coefficient for speed was 0.09, which was similar to the known value of 0.1 [9]. However, the coefficient for grade × speed was 1.2, which was less than the known value of 1.8 [9]. In the above estimation, NW required more oxygen consumption than walking, and the difference of constants of the two formulae was 1.7 mL·kg^{-1}·min^{-1} in multiple linear regression analysis. The coefficients for speed and speed × fractional grade were not different between the two walking methods.

Discussion

When walking at the given speed and slope, NW had higher exercise intensity than W. The $\dot{V}O_2$ (+ 15.8%), $\dot{V}CO_2$ (+ 17.0%), $\dot{V}E$ (+ 17.0%), RR (+ 18.2%), SBP (+ 7.7%), DBP (+ 6.9%), and HR (+ 8.4%) were significantly higher in NW than in W in all walking stages. The activities of the upper limb muscles (DEL, BB, and TB) were significantly higher in NW than in W. No significant differences were found between the two walking conditions in the lower extremity muscles, except the TA and GCM muscles during slow level walking.

In this study, we derived new energy estimation equations of NW and W from the measured $\dot{V}O_2$ and walking speed and slope: E_W = 4.4 + 0.09 × speed (m·min^{-1}) + 1.20 × speed × fractional grade; E_{NW} = 6.1 + 0.09 × speed (m·min^{-1}) + 1.19 × speed × fractional grade. The constant value in the final equation for W was 4.4 mL·kg^{-1}·min^{-1}, which is somewhat higher than the ACSM equation's known resting oxygen consumption of 3.5 mL·kg^{-1}·min^{-1} [9]. The coefficient for speed was 0.09, which is similar to the known value of 0.1 [9].

In the previous studies, the energy consumption of NW was presented as a percent difference compared to the consumption of W. The result varied depending on the walking speed and the slope. In our results, NW consumed more oxygen than walking, and the difference of $\dot{V}O_2$ between NW and W was rather constant than proportional. The difference between constants of the two formulae for NW and W was 1.7 mL·kg^{-1}·min^{-1} in multiple linear regression analysis derived from speed and speed × grade.

The coefficient for walking speed × grade was 1.20 and smaller than ACSM's coefficient. The ACSM regression equations developed to estimate oxygen uptake have known limitations that lead to overestimation of energy expenditure, particularly at higher work rates [13]. Kokkinos et al. recently developed a new energy equation for walking from the Fitness Registry and the Importance of Exercise National Database [FRIEND] and suggested small cofficient value of 0.79 for walking speed × grade: E (mL·kg^{-1}·min^{-1}) = 3.5 + 0.17 × speed (m·min^{-1}) + 0.79 × speed × fractional grade [FRIEND equation] [13].

In our study, as the slope of the uphill increased (from 0–7%) at a constant speed (5 km·h^{-1}), the amount of oxygen consumption increased in both NW and W. However, the difference ($\Delta\dot{V}O_2$) between NW and W was constant (1.7 to 2.3 mL·kg^{-1}·min^{-1}); thus, %$\dot{V}$O2 decreased from the highest (17.4%) to the lowest (10.9%). Previous studies using a treadmill were reviewed to compare the uphill oxygen consumption patterns. Figard-Fabre et al. [7] measured oxygen consumption at 0% and 5% grade when walking at 4 km·h^{-1}. Oxygen consumption was higher at NW; the %$\dot{V}O_2$ was 16% at 0% grade and reduced to to 12% at 5% grade. This value is consistent with the value for our Eq. (4 km·h^{-1}, 0%: 10.4 mL·kg^{-1}·min^{-1} for W, 12.1 mL·kg^{-1}·min^{-1} for NW, 16% for %$\dot{V}O_2$; 4 km·h^{-1}, 5%: 14.4 mL·kg^{-1}·min^{-1} for W, 16.1 mL·kg^{-1}·min^{-1} for NW, 12% for %$\dot{V}O_2$). Pellegrini et al. [8] measured oxygen consumption at 15% grade when walking at 4 km·h^{-1}, and %$\dot{V}O_2$ was 6.9%. This value is consistent with the value for our Eq. (4 km·h^{-1}, 15%: 22.4 mL·kg^{-1}·min^{-1} for W, 24 mL·kg^{-1}·min^{-1} for NW, 7% for %$\dot{V}O_2$).

On the other hand, the oxygen consumption results of studies conducted in an environment other than the treadmill (outdoor field study) showed a difference from the predicted value of our formula [4, 6]. Church et al. [4] reported that the average amounts of oxygen consumption at average self-selected walking speeds of 5.6 km·h^{-1} (male participants) and 5.9 km·h^{-1} (female participants) were overall 13.9 mL·kg^{-1}·min^{-1} during W and 16.7 mL·kg^{-1}·min^{-1} during NW. The estimated $\dot{V}O_2$ values using our equation were 12.8 and 13.3 mL·kg^{-1}·min^{-1} for W and 14.5 and 15.0 mL·kg^{-1}·min^{-1} for NW. The oxygen consumption values measured in the field study [4] were greater than our predicted values, particularly the $\dot{V}O_2$ during NW was higher than the predicted value. Regarding the field test, terrain characteristics would differ from a treadmill, potentially causing a difference in poling force or muscle activity. The difference in walking terrain leads to a difference in oxygen consumption during NW [15]. According to a study by Schiffer et al. [15], the oxygen consumption during NW was significantly increased in a naturally grown soccer lawn than concrete.

The increase in exercise intensity and oxygen consumption by NW is due to the increased upper limb muscle activity. The upper extremity's increased activity was identified through the surface EMG signals. Walking with upper body exercise [16] or the use of hand weight [17] also increases the $\dot{V}O_2$. Oxygen consumption was significantly increased when walking with the weight in hand compared with walking at the same speed. When walking with 1.36 kg of weight held in each hand, it increased by about 3.5 mL O_2·kg^{-1}·min^{-1} compared with walking without weight, which was constant even at different walking speeds [17]. The degree of increase in oxygen consumption increases further as the weight of the weight increases,[17], however, it is difficult to say that lifting heavy weights reflects the increase in oxygen consumption. According to Owens et al. [18], a significant increase in oxygen consumption was not observed using a 2.27 kg weight at walking speed (4.8 and 6.4 km·h^{-1}), whereas a significant increase in oxygen consumption at running speed (8.0 and 9.6 km·h^{-1}) was observed. Both the movement of the arm used for walking and the weight are potentially related to the increase in the amount of oxygen consumed. Regarding walking while exercising the upper limbs, the amount of oxygen consumption significantly increased compared with normal walking [16]. The increase in oxygen consumption at NW seems to contribute to an increase in the activity of the upper limb muscles.

In our study, oxygen consumption increased significantly in NW compared with W, but the subjective difficulty, the RPE, did not show a significant difference between NW and W at level walking and rather lower RPE with NW during uphill walking. Previous studies showed higher RPE [3], lower RPE [5], or no difference [7] with pole walking compared with W. During uphill walking, decreased RPE with NW was reported in previous studies with pole walking [7, 19]. According to a study comparing the RPE of NW and

W on downhill, uphill, and level walking, the RPE in NW on uphill walking was significantly decreased compared with W [7].

The participants of our study were all beginners with no Nordic pole experience and all were young males. The proficiency of NW methods can affect gait technique; however, even after a 4-week NW training three times a week, the difference in oxygen consumption between NW and W did not significantly change before and after the training [7]. Moreover, the activation pattern of the surface electromyography of our results was similar to the NW-skilled participants'. In a result of surface electromyography analysis in participants who were experienced in NW, the activities of the BB, TB, and deltoid anterior in NW were significantly increased compared with those in W, which was significant in both level and uphill [8]. Furthermore, the activities of the lower extremity muscles, such as the TA, gastrocnemius lateralis, and VL did not show a significant difference in NW and W, which was the same in level and uphill [8]. These muscle activation patterns are similar to those found in our study. According to a previous study, the changes in the aspects of respiratory gas analysis did not differ by sex [3].

We proposed a prediction formula for oxygen consumption in NW; however, this is a formula derived only from a non-fast walking speed (3–5 $km \cdot h^{-1}$) and a slope within 7% and may differ from the predicted values in a faster or higher slope. NW energy consumption could also be influenced by several factors other than walking speed and slope grade. Energy consumption during NW is known to be affected by the ground's condition [15]. When a relatively short pole was used, energy consumption was increased in the uphill than in the case of a normal length pole [20]. By contrast, pole weight does not appear to have a significant effect on energy consumption [21]. As a result of comparing W and four different types of NW, muscle activity and metabolic response were different according to the type of NW, but all types of NW showed higher metabolic response and muscle activity than W [22].

Conclusions

We developed an equation to estimate oxygen consumption during NW, which was constantly consuming more oxygen by 1.7 $mL \cdot kg^{-1} \cdot min^{-1}$. Estimation of oxygen consumption during NW in faster speed is necessary for more precise exercise prescription. The difference in $\dot{V}O_2$ between NW and W was constant both in slow and fast walking speeds and both in level and uphill grades.

Abbreviations

(NW)
Nordic walking
(W)
conventional walking
($\dot{V}O_2$)
oxygen uptake
($\dot{V}E$)

minute ventilation
(RER)
respiratory exchange ratio
(RR)
respiratory rate
(DEL)
mid deltoid
(BB)
biceps brachii
(TB)
triceps brachii
(VL)
vastus lateralis
(GCM)
medial gastrocnemius
(TA)
tibialis anterior
(HR)
heart rate
(SBP)
systolic blood pressure
(DBP)
diastolic blood pressure
(sEMG)
surface electromyography
(*E*)
energy expenditure
(ACSM)
American College of Sports Medicine
(RPE)
rating of perceived exertion

Declarations

Ethics approval and consent to participate:

All research activities were reviewed and approved by Kangwon National University Hospital Institutional Review Board (approval number: KNUH-A-2017-11-005-003). Written informed consent was obtained from participants prior to study commencement.

Consent for publication:

Not applicable

Competing interests:

No conflict of interest to declare

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Authors' contributions:

SB and YH designed the research. SB and YH has performed different parts of the research, analyzed the data and drafted the paper. SB and YH contributed to the final analyses, further drafting and critical revision and editing, and final approval of the final version.

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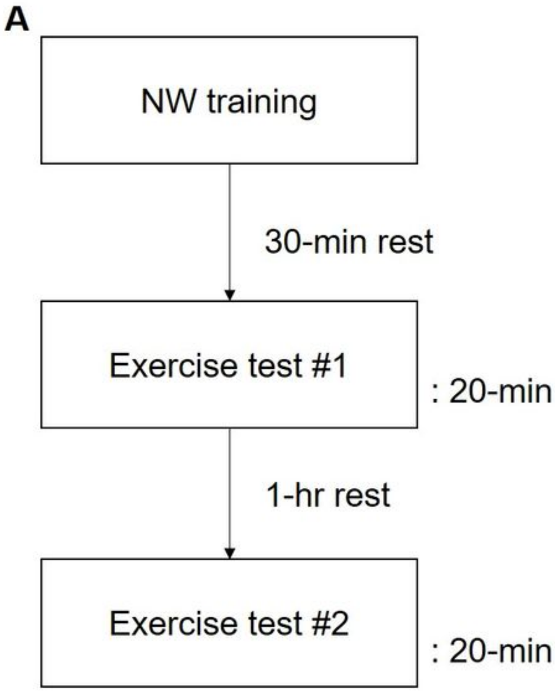
Figures



B

Stage		Duration (min)	Treadmill speed (km/h)	Treadmill grade (%)
Rest		2	0	0
Adaptation		2	2	0
Walking	Stage 1	2	3	0
	Stage 2	2	4	0
	Stage 3	2	5	0
	Stage 4	2	5	1
	Stage 5	2	5	3
	Stage 6	2	5	5
	Stage 7	2	5	7
Recovery		2	0	0
Total		20		

Figure 1

Study protocol. A. Study flow diagram. B. Walking test protocol.

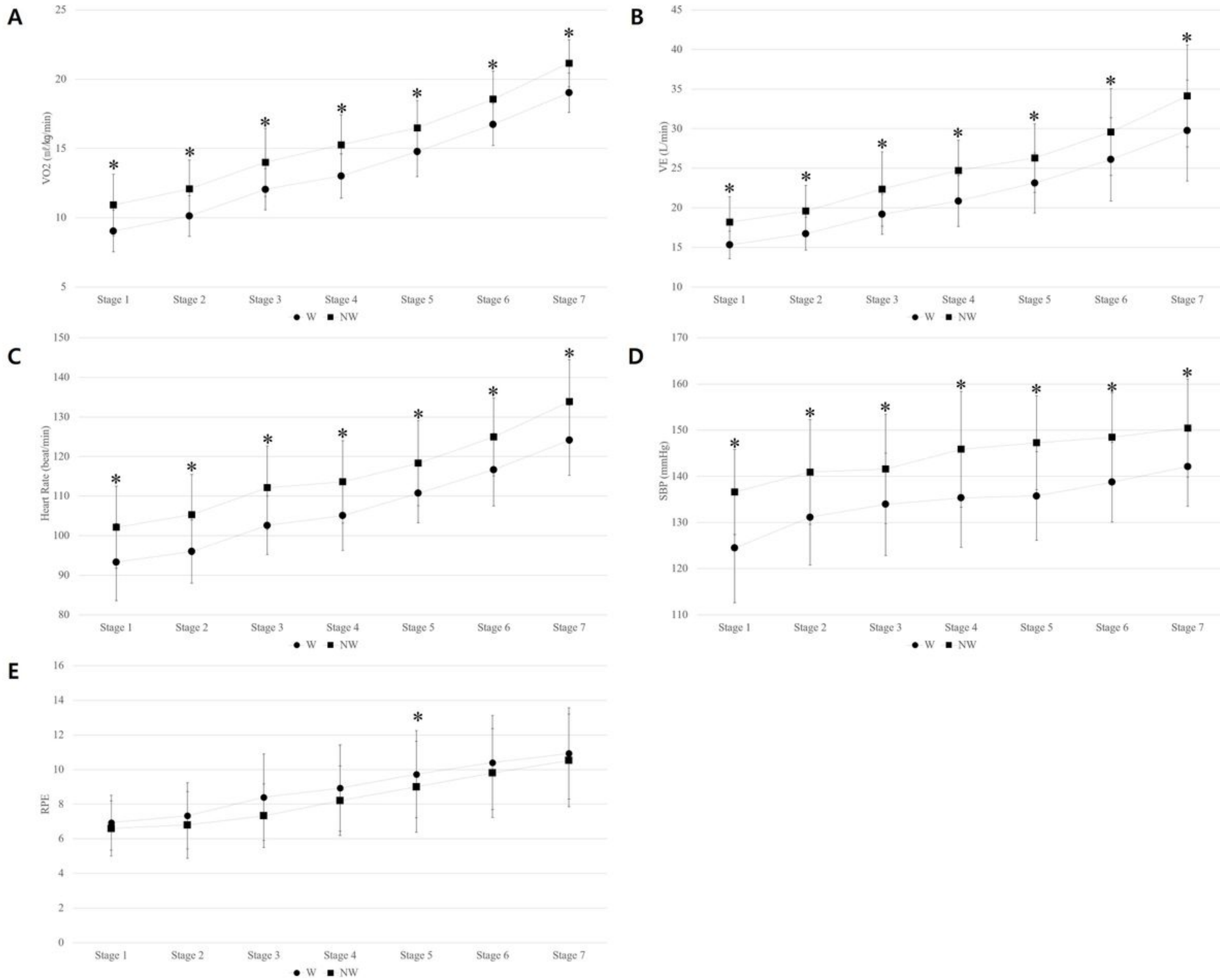


Figure 2

Ventilatory gas analysis results during walking (W) and Nordic walking (NW). A. Oxygen uptake (V̇O2). B. Ventilation (V̇E). C. Heart rate. D. Systolic blood pressure (SBP). E. Rate of perceived exertion (RPE). * P<.05

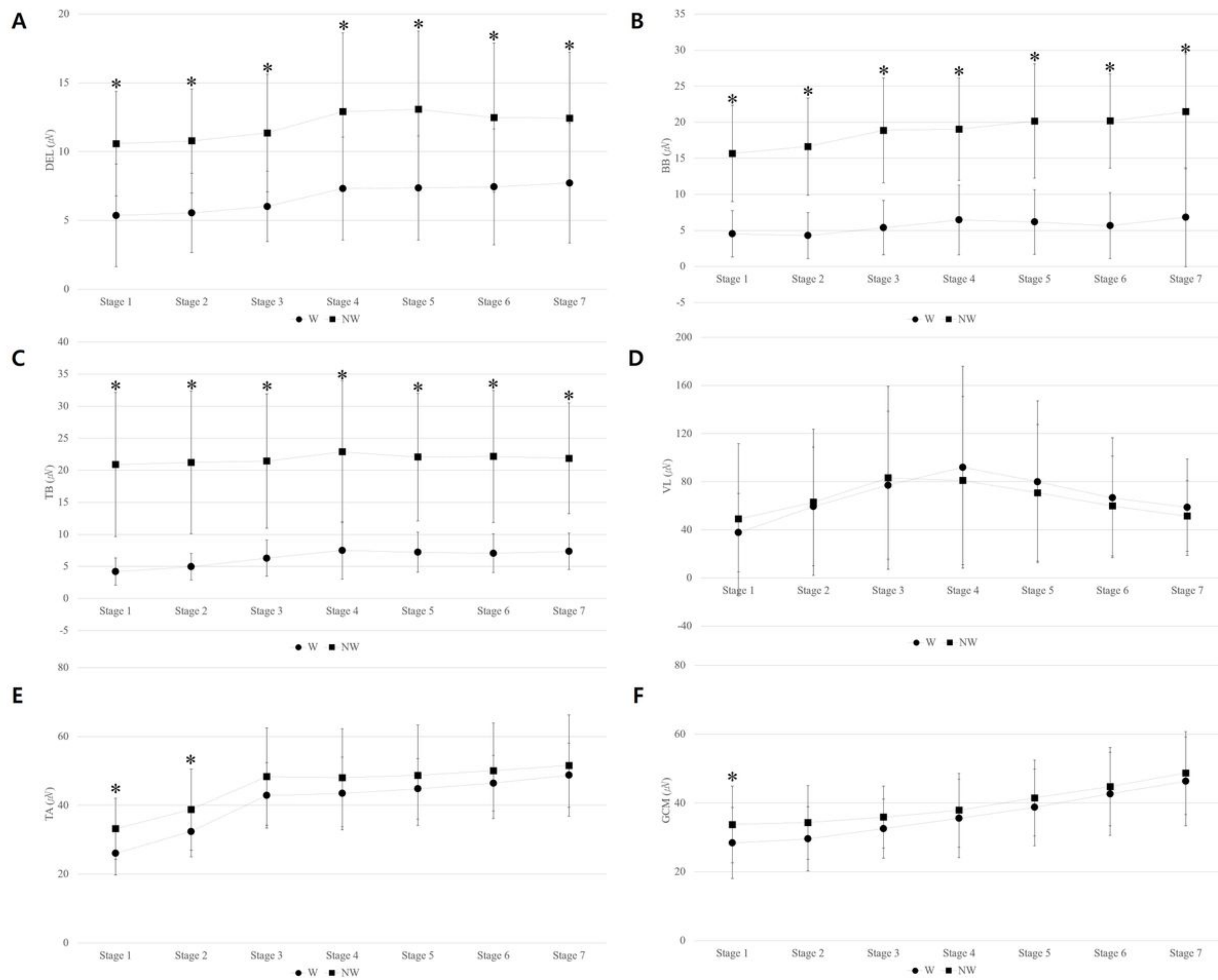


Figure 3

Surface electromyographic results of the upper and lower limb muscles during conventional walking (W) and Nordic walking (NW). A. Lateral deltoid (DEL). B. Biceps brachii (BB). C. Triceps brachii (TB). D. Vastus lateralis (VL). E. Tibialis anterior (TA). F. gastrocnemius (GCM). * P<.05