Journal of Sports Science 5 (2017) 256-264
doi: 10.17265/2332-7839/2017.05.004

Effects of Trekking Pole Use on Metabolic Cost in Novice Hikers on Steep Terrains

Yong Bin Han[1], Ik Jin Kwon[1], Dae Taek Lee[2], Eun Jin Hwang[3], Jong Kwang Kim[3] and Eun Hyung Cho[4]

1. Graduate Program of Sports Engineering Convergence, Kookmin University, Seoul 02707, Korea

2. Department of Sports Health and Rehabilitation, Kookmin University, Seoul 02707, Korea

3. Graduate School of Sports Natural Science, Kookmin University, Seoul 02707, Korea

4. College of Sport Science, Sung Kyun Kwan University, Gyeonggi-do 16419, Korea

Abstract: PURPOSE: This study examined whether the use of trekking poles alters metabolic cost in steep hiking by novice hikers and whether the response would be dependent on the grade of the terrain. METHODS: Twelve participants completed two trekking trials (with poles [WP] and without trekking poles [NP]) with round trips comprising three grades: 7.0 ± 0.7°, 12.9 ± 0.7°, and 18.8 ± 1.3°) over a steep mountain at self-paced speeds. During the trials, time spent for trekking (TT), oxygen consumption (VO_2), heart rate (HR), ratings of perceived exertion (RPE), and step frequency (Sf) were measured, and step efficiency (Se) and oxygen pulse (OP) were calculated. RESULTS: TT tended to be longer in the WP than NP for both terrains ($P < 0.05$). HR, VO_2, and RPE were the same for the WP and NP. Sf was lower in WP going uphill ($P < 0.05$) but was unchanged going downhill. Se in the WP was higher than in the NP for both terrains ($P < 0.01$). When analyzed by slope, VO_2 during uphill at 18.8° was lower in WP (37.2 ± 6.3) than in NP (38.6 ± 7.1 $ml \cdot kg^{-1} \cdot min^{-1}$, $P < 0.05$), but no difference in VO_2 was found between WP and NP at the 12.9° and 7.0°. TT during uphill was slower in WP than NP at 12.9° (7.9 ± 1.1 vs. 7.4 ± 1.0) and 18.8° (5.3 ± 1.3 vs. 4.9 ± 1.0 min, respectively, $P < 0.05$). No differences were noticed in HR and OP during uphill at every grade. CONCLUSIONS: Pole use decreased metabolic cost in the novice hikers only in the highest grade but not in the other two lower grades.

Key words: Oxygen uptake, heart rate, uphill, downhill.

1. Introduction

The southern part of the Korean peninsula contains about 65% (63, 984/100, 306 km^2) mountainous areas [1, 2]. The average altitude above sea level is roughly 411 m (< 299 m, 45%; 300-499 m, 25%; 500-999 m, 25%; > 1000 m, 6%) with relatively lowland mountains [3]. The number of mountain hikers in Korea has consistently increased and reached over 4.6 million in 2014 [4]. Currently, hiking has become a popular form of exercise. In European countries, Nordic walking has increased in popularity [5].

As the prevalence of hiking with trekking poles has increased, various studies have been conducted to verify the effects of poles, primarily on both the motor mechanics and metabolic responses. The use of trekking poles enhances safety on uneven terrains, alleviates stress on the spine and lower extremities caused by load distribution, and enhances body balance [6, 7]. The use of trekking poles also reduces the movement of the lower body during downhill walking [8, 9], whereas others reported no reduction of knee joint compressive loads on leveled terrain [10, 11]. Pole use contributes to balancing the upper body while carrying a load and increases body stability, reducing the probability of falling [12].

Increases in metabolic responses with pole use have been reported while walking on both leveled treadmills [13-15] and field tracks [16]. During uphill treadmill walking, increases in metabolic responses [7, 17] have been reported. In contrast, other studies reported no changes in metabolic responses related to trekking pole use [6, 18, 19]. In three slopes of treadmill walking

Corresponding author: Dae Taek Lee, Ph.D., professor, research fields: exercise physiology, environmental physiology.

(downhill, level, and uphill), pole use increased metabolic responses only during the downhill walking [20]. A field experiment with five grades (two downhill, level, two uphill) reported an increase in metabolic responses in all grades [21]. Collectively, most previous studies showed an increase in metabolic response with pole use on all terrains, whereas others showed no differences. No studies have reported any decrement in metabolic cost from pole use on any terrain.

Variations in metabolic cost from pole use may be caused by factors such as walking speed, pole use frequency, backpack load, surface condition, and/or grade. From those factors, one that can be compared directly from study data is surface grade. A review of 11 peer-reviewed studies [6, 7, 13-21] that reported walking grade found that metabolic cost increased with pole use at grades below 5.5% (12 out of 13 experimental conditions, at 5%, 0%, -5%, -10%, -15%, -25% of grade, 2.9°, 0°, -2.9°, -5.7°, -8.6°, -14.5° in the same unit). On the contrary, metabolic cost increased with pole use at grades above 5.5% (5.7%, 10%, 15%, 20%, 25% of grade, 3.3°, 5.7°, 8.6°, 11.5°, 14.5° in the same unit) in only one out of eight experimental conditions. In addition, energy cost increased during three of three experimental conditions in down slopes and nine of twelve at 0-10% up slopes, whereas no differences were found in uphill grades above 15%. These observations suggest that the increment of metabolic cost of pole use may decrease or even reverse as uphill grades become steeper. We can also assume that the direction of energy cost variation by pole use may depend on the degree of grade.

At this point, no study has examined the influence of the degree of grade on metabolic cost during walking pole use. Thus, we conducted a field experiment designed to determine whether the use of trekking poles alters metabolic cost during steep trail hiking in novice hikers and whether these responses varied with the grade of the terrain.

2. Materials and Methods

2.1 Participants

Twelve physically active volunteers participated in this study (Table 1). Only novice mountain hikers, who have not used trekking poles more than five times and hiked regularly, were selected as participants. Once their eligibility was confirmed, the purpose and experimental procedures of this study were explained and they signed a written informed consent form. This study was approved by the Institutional Review Board.

A total of 18 individuals were recruited as participants in this research; 14 participants completed all procedures of the experiment and four dropped out during the experiment for physical, mechanical, or personal reasons. Two participants were excluded from data analysis because they had recorded outlier tracking times. Therefore, data for a total of 12 participants were calculated and analyzed for the study.

Table 1 Characteristics of the participants.

		Age (year)	Height (m)	Weight (kg)	BMI (kg/m^2)	%Fat (%)
Men (*n* = 10)	M	25.2	1.745	74.1	24.2	17.6
	SD	3.3	0.077	9.5	1.6	4.3
	m-M	22.0-32.0	1.620-1.870	63.6-90.2	22.2-27.8	10.3-24.4
	CV	0.13	0.04	0.13	0.06	0.24
Women (*n* = 2)	M	26.0	1.59	55.8	22.1	30.7
	SD	4.2	0.042	0.6	1.0	1.8
	m-M	23.0-29.0	1.560-1.620	55.4-56.2	21.4-22.8	29.4-32.0
	CV	0.16	0.03	0.01	0.04	0.06

M: mean; SD: standard deviation; m-M: minimum-maximum; CV: coefficient of variation; BMI: body mass index; %Fat: body fat content.

2.2 Study Design

The experiments were conducted at the Bukhan Mountain trail. Participants engaged in two different trekking trials on two different days separated by at least five days. On the first day, they hiked either with trekking poles (WP) or without poles (NP). On the second day, they tried the other condition. The trial order was randomly assigned and balanced. In each trial, participants walked at self-paced speeds. The trail round-trip time was around 80 min, including a fixed 10-min resting period at the turning point of the course. No treatment (e.g. beverages and icing muscles) was provided to the participants during the rest period. The experimenter followed the participants approximately 5 m behind. The participants were asked to walk at their preferred speed and could walk with the posture and number of poles of their choice. Two trials were conducted in the same time block to ensure similar conditions.

2.3 Procedure

Before the first trial, participants were instructed on the usage of trekking poles (Al Carbon, Bigten, Korea), for 30 min. At each trial, they were equipped with an electronic wireless heart rate (HR) monitor (RS800CX, Polar, Finland), a mobile respiratory gas analyzer (Oxycon Mobile, Jarger, Germany), and a global positioning system (GPS; Garmin Foretrx 401, GARMIN, USA). The total weight of equipment worn was 1.82 kg and consisted of a gas analyzer (0.80 kg), vest (0.36 kg), mask (0.14 kg), poles (0.44 kg), and HR monitor (0.06 kg). At the starting point, the participants rested until their resting HR was achieved. The experimenter set and calibrated the gas analyzer, GPS, stopwatch, pole length, and manual pedometer. The length of the poles on level ground was adjusted with reference to the elbow's transverse line. The elbow was at 90° while the pole was held in a vertical position to the ground. The trekking trail was mainly uphill with some leveled terrain. To ensure a suitable pole length, the experimenter decreased the length of the trekking poles 0.10-0.15 m for uphill treks before hiking and extended them 0.10-0.15 m for downhill treks prior to descending the mountain. The grip method for the trekking poles involved the participants inserting a hand through the band of the handle segment from the bottom to the top and then gripping the handle by pressing down on the band with their thenar and hypothenar eminence. At the end of the uphill (at the turning point) and the downhill (returning to the starting point) segments, they were asked for their ratings of perceived exertion (RPE) on the 6-20 graded scale proposed by Borg [22].

2.4 Measures

Participants' metabolic response was measured from the HR (in beat$\cdot$min^{-1}) monitor and the gas analyzer. HR and oxygen consumption (VO_2 in ml$\cdot$kg$^{-1}\cdot$min^{-1}) were monitored continuously and recorded every 20 seconds. A GPS unit was positioned on the posterior shoulder, and the data were used to verify altitude, walking speed, horizontal distance traveled, and the grade of terrain. The step frequency (Sf, in frequency) and time spent for trekking (TT, in min or second) were recorded manually with a pedometer (Hand Tally Counter, Dolphin, India) and stopwatch (HS-70W, Casio, Japan), respectively, temperature and relative humidity were measured by wet and dry bulb thermometers prior to each experiment.

2.5 Data Reductions

The slope of the hiking trail was categorized into three grades; low, middle and high of 7.0 ± 0.7°, 12.9 ± 0.7°, and 18.8 ± 1.3°, respectively. The metabolic response parameters were averaged during uphill and downhill trekking by each of the three grades. Features of Bukhan Mountain's hiking trail were averaged by pole usage conditions by the GPS data of altitude, walking speed, horizontal distance traveled, and the grade of terrain (Fig. 1). Irregular terrains were excluded from the analysis. From the measured variables,

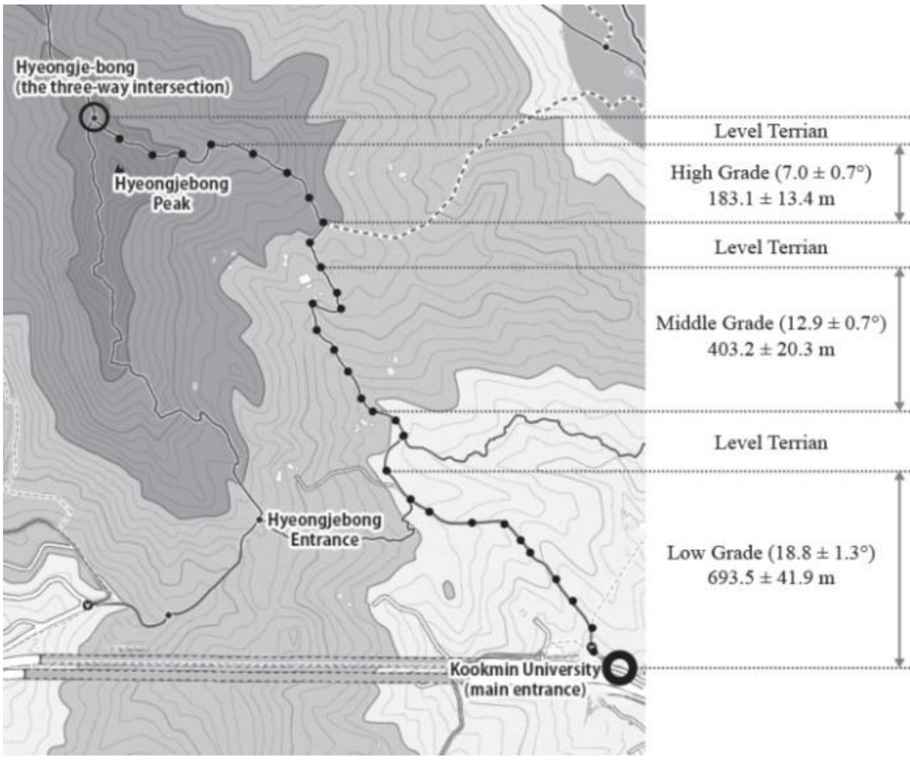

Fig. 1 Bukhan-mountain's trekking trail and contour line (by 10 meter). The bold circle at bottom right corner is the starting point. Circle at upper left corner is the turning point. Black dots are the trekking route. Text at right hand shows a mean grade level and a horizontal distance.

steps per unit time (St) was calculated by dividing Sf by TT. Step efficiency (Se) was calculated by VO_2 divided by Sf. Oxygen pulse (OP) was calculated by VO_2 divided by HR.

2.6 Statistical Analysis

All data are presented as means and standard deviations. Statistical differences for trekking pole use and terrain were analyzed by paired *t*-tests. We compared the following dependent variables: HR, VO_2, Sf, TT, RPE, Se, St, and OP. The significance level was set at $\alpha = 0.05$. Correlation analysis was used for verification of the relation between the measured variables. All data were calculated using the SPSS statistical software ver. 21.0 (SPSS Inc., Chicago, IL).

3. Results

Average temperature and humidity were 27.9℃ ± 2.5℃ and 67.0% ± 7.5%, respectively, in the 24 (12 participants × 2 trials) experiment days and were recorded at 28.2℃ ± 2.2℃ and 67.6% ± 7.9% on the WP days and 27.6℃ ± 2.9℃ and 66.4% ± 7.5% on the NP days. A *t*-test of paired data found no significant differences in either temperature or humidity overall ($P > 0.05$). The elevation of the starting point was 125.5 ± 22.5 m, and the highest elevation reached was 431.2 ± 10.3 m. The one-way horizontal and total distance of the trail was 1,929.2 ± 63.4 m, and each sectioned horizontal distance of low, middle, and high grades was 693.5 ± 41.9, 403.2 ± 20.3, and 183.1 ± 13.4 m, respectively.

Table 2 shows the results of a paired *t*-test comparing selected variables analyzed by terrain grade and pole use. HR, VO_2, and RPE were only significantly influenced by terrain grade. HR and VO_2 were significantly higher in the uphill than downhill grades but did not differ by pole use. Total round-trip time excluding the resting period was 73.1 min in WP and 68.7 min in NP. TT was significantly longer in WP than NP on both uphill ($P = 0.002$) and downhill

Table 2 Results of metabolic responses (HR, VO_2, Se), TT, Sf and St depending on terrain.

	T	P	M ± SD	*P*
HR (beat·min^{-1})	UT	WP	148.6 ± 13.7	0.729
		NP	147.4 ± 9.7	
	DT	WP	121.0 ±12.3	0.645
		NP	119.8 ± 8.5	
VO_2 (ml·kg^{-1}·min^{-1})	UT	WP	31.0 ± 4.3	0.486
		NP	31.5 ± 4.6	
	DT	WP	17.1 ± 3.2	0.405
		NP	16.9 ± 3.0	
Sf (steps)	UT	WP	3186 ± 272	0.004**
		NP	3307 ± 242	
	DT	WP	3719 ± 459	0.953
		NP	3716 ± 405	
TT (min)	UT	WP	37.2 ± 4.7	0.002**
		NP	35.0 ± 4.2	
	DT	WP	35.9 ± 4.5	0.001***
		NP	33.7 ± 5.2	
Se (EC·Sf^{-1})	UT	WP	0.359 ± 0.038	0.001***
		NP	0.330 ± 0.034	
	DT	WP	0.166 ± 0.033	0.008**
		NP	0.152 ± 0.024	
St (Sf·TT^{-1})	UT	WP	86.0 ± 4.7	0.001***
		NP	95.1 ± 5.9	
	DT	WP	103.7 ± 6.0	0.004**
		NP	111.0 ± 7.6	
RPE	UT	WP	15.6 ± 1.6	0.477
		NP	15.1 ± 1.7	
	DT	WP	11.5 ± 2.0	0.358
		NP	11.1 ± 1.4	

Paired *t*-test on both [Terrain (T) and Pole (P)] factors; M: mean; SD: standard deviation; UT: uphill terrain; DT: downhill terrain; WP: with trekking poles; NP: without trekking poles; HR: heart rate; EC: energy cost; Sf: step frequency; TT: time spent for trekking; Se: step efficiency; St: steps per time; RPE: ratings of perceived exertion; *$P < 0.05$, **$P < 0.01$, ***$P < 0.001$.

terrains ($P = 0.001$). St was significantly lower in WP than NP on both uphill ($P = 0.001$) and downhill terrains ($P = 0.004$). Sf was significantly lower in WP than NP ($P = 0.004$). There were no significant differences between WP and NP during downhill treks. Se was significantly higher in WP than NP for both uphill ($P = 0.001$) and downhill terrains ($P = 0.008$). RPE was higher for uphill than downhill terrains. During uphill treks, five participants scored higher RPE but three scored lower in WP than NP. During downhill treks, four scored higher and three lower in WP than NP. Marginal individual differences were noticed.

Table 3 shows the results of a paired *t*-test comparing selected variables analyzed by terrain grade and pole use. TT was longer in WP than NP in both the middle ($P = 0.010$) and high ($P = 0.019$) grades. However, there was no significant difference for the low grade.

VO_2 was significantly lower in WP than NP for the high grade ($P = 0.044$), whereas the opposite trend held for the low grade. No significant differences were found between the WP and NP trials during the low and middle grades. VO_2 showed opposing values between the low and high grades. No differences in VO_2 were observed for the middle grade. Thus, the trend of HR,

Table 3 Results of metabolic responses (HR, VO_2, OP) and TT depending on grade.

	G	P	M ± SD	*P*
HR (beat·min^{-1})	LG	WP	132.8 ± 15.2	0.194
		NP	127.8 ± 12.0	
	MG	WP	154.7 ± 15.6	0.788
		NP	153.6 ± 11.5	
	HG	WP	166.8 ± 12.8	0.575
		NP	168.7 ± 8.7	
VO_2 (ml·kg^{-1}·min^{-1})	LG	WP	27.6 ± 3.9	0.275
		NP	26.4 ± 3.1	
	MG	WP	34.1 ± 5.1	0.946
		NP	34.1 ± 4.9	
	HG	WP	37.2 ± 6.3	0.044*
		NP	38.6 ± 7.1	
OP (ml·beat^{-1}·min^{-1})	LG	WP	0.290 ± 0.033	0.943
		NP	0.210 ± 0.038	
	MG	WP	0.222 ± 0.040	0.775
		NP	0.224 ± 0.041	
	HG	WP	0.224 ± 0.043	0.227
		NP	0.230 ± 0.048	
TT (min)	LG	WP	10.5 ± 1.5	0.620
		NP	10.3 ± 1.0	
	MG	WP	7.9 ± 1.1	0.010*
		NP	7.4 ± 1.0	
	HG	WP	5.3 ± 1.3	0.019*
		NP	4.9 ± 1.0	

Paired *t*-test on both [Grade (G) and Pole (P)] factors; M: mean; SD: standard deviation; LG: low grade; MG: middle grade; HG: high grade; WP: with trekking poles; NP: without trekking poles; HR: heart rate; EC: energy cost; OP: oxygen pulse; TT: time spent for trekking; *$P < 0.05$, **$P < 0.01$, ***$P < 0.001$.

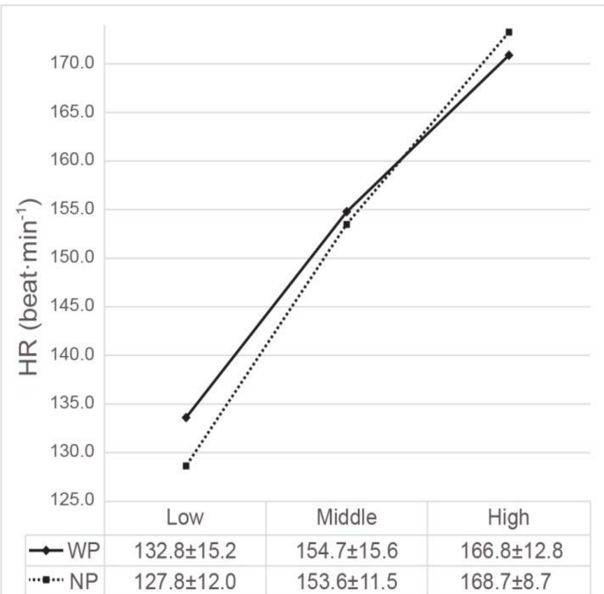

Fig. 2 Heart rate (HR) progression during different uphill grade conditions with and without trekking poles.

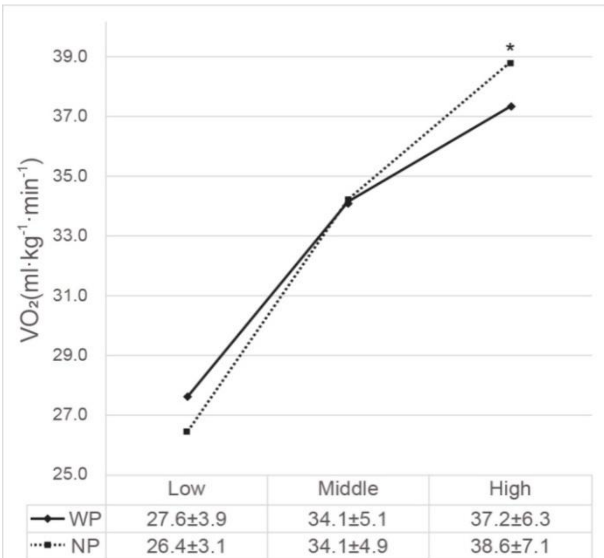

Fig. 3 Oxygen consumption (VO_2) progression during different uphill grade conditions with and without trekking poles.

OP, and VO_2 responses to grades shows the metabolic requirement reversed for the middle grade (Figs. 2 and 3).

4. Discussion

This study was designed to verify whether trekking pole use affects novice hikers' metabolic responses during steep terrain hiking. We measured and compared metabolic variables (i.e., HR, VO_2, OP, Se), Sf, St, TT, and RPE during steep mountain round-trip trekking. The results we observed are more or less in agreement with many points made by previous studies. But the major differences between this and previous studies are the experimental conditions. Most previous studies were conducted in laboratory settings where walking speed, time, and/or slopes were controlled, but we provided more self-dependent experimental conditions in a natural environment. Therefore, the results of this study can be of practical value and may not be directly comparable with those of previous studies related to energy expenditure and metabolic responses. To ensure participants' comfort and to replicate the conditions of actual hiking, our design did not control for speed, time, Sf, or number of poles used. In our design, all participants were novice hikers; hence, they did not take advantage of adaptation to poles and trails.

In this study, participants freely chose their walking speed which was close to their natural trekking. While a previous study has kept a preferred walking speed on a treadmill [20], it is difficult to maintain a constant walking speed in a natural trekking environment as in this study. In addition, it was considered that self-selected walking speed was more appropriate for each participant at a natural environment since their physical condition was not identical. Considering that trekking poles affect walking speed [7, 9, 20], the control of speed could interfere the aim of this study. During a usual locomotion, human reduces and optimizes energy cost by continuous adjustments of the walking speed, stride length, and stride frequency [23-26]. And at a preferred walking speed, there were no age and sex differences of metabolic responses [27].

To analyze walking patterns during hiking, stride frequency, length, and rate are the commonly selected variables and are assumed to be interrelated. Our study noticed differences among the conditions, and our findings were consistent with those of previous studies [7, 20]. During uphill treks, walking poles reduced Sf and increased TT, which indicated lengthy stride and slow walking speed. However, no difference was noticed in Sf, whereas TT was increased during downhill treks with pole use. This indicated that pole use influenced walking speed but not stride length in downhill treks. In addition, St, which was derived by Sf and TT, decreased with pole use in both uphill and downhill treks. For the influence of trail steepness, TT was unchanged with pole use at 7.0° uphill but increased at both 12.9° and 18.8° uphill grades. These results indicated that the walking speed slowed with pole use as the uphill grade increased. Collectively, pole use increased stride length and decreased stride rate in uphill treks [7] and decreased stride rate as the grade increased [20].

Perception of the walking intensity did not differ with pole use in this study. Previous studies also reported no changes in RPE while using poles during hiking [6, 14, 16, 17, 20, 21]. However, other studies reported a reduction [19] or an increment [13] of RPE with hiking pole use. We could not provide obvious interpretations of this pattern in this study, but the duration of hiking or fatigue level may be possible causes.

Responses were equivocal for metabolic rate. In uphill treks, some studies observed no changes [6, 18-20] but others reported an increase in metabolic response [7, 17, 21] with pole use. In downhill treks, WP increased metabolic responses more than NP [20, 21]. In our study, Se showed a higher value for WP than NP conditions in both uphill and downhill treks. We considered this parameter objective since we did not intervene in the participants' speed or bodily movement during hiking. This finding indicated an increase in metabolic cost with pole use on both terrains. Since the majority of previous studies were conducted in laboratory settings and/or with controlled time or speed, no direct comparisons of metabolic responses can be made with the present study.

VO_2 was not affected by pole use on a less-steep terrain. At the 18.8° grade, however, VO_2 was lower with pole use. These results suggest that a linear slope of metabolic rate change along with the grade of terrain may depend on pole use. In addition, the slope of metabolic rate change is smaller in the NP condition. For example, at low grades, VO_2 is higher with poles, but at high grades, it is lower. In other words, trekking pole use affects metabolic efficiency only at higher grades during uphill trekking. The results obtained confirm the hypothesis that metabolic cost with pole use may vary by the grade of terrain. Previous studies also suggested the possibility of a reduction in metabolic cost with increased grades and a possible threshold of grade from which metabolic cost is reversed [6, 7, 13-21]. One notable aspect of this study is that we examined a grade of 18.8°, which has not been previously done.

This study has some limitations. Outdoor environments including temperature, humidity, and weather conditions may be involved in participants' conditions. The self-determined and administered bodily movements during hiking may have influenced the outcomes. In addition, the participants were only novice hikers. Sequential increase of the trekking slope and/or training effects at each slope may be the additional confounding factors of this experiment. For these reasons, additional studies are needed considering the trekking time, fatigue level, step frequency, fitness level of participants at each slope.

In conclusion, our results show that metabolic responses during steep terrain round-trip hiking were affected by pole use. Pole use decreases metabolic cost only at the steepest grade but not in the two lower grades. This study suggests that trekking pole use may be recommended only for terrains with the steepest terrains, the only context in which novice hikers took advantage of metabolic cost during uphill walking.

Acknowledgments

This research was a part of the master's research project of Han YB, who was a recipient of the Graduate Associateship of the Graduate Program of Sports Engineering Convergence of Kookmin University. This research was supported by the Graduate School Operation Program of Korea Sports Promotion Foundation (Grant number: SISU01052015). This project was also partially supported by the Sports Promotion Fund of Seoul Olympic Sports Promotion Foundation from Ministry of Culture, Sports and Tourism (Grant number: s072016122016).

References

[1] Korea Forest Service. 2015. "Statistics of Preservation Area." Accessed June 1, 2016. http://www.forest.go.kr/newkfsweb/html/HtmlPage.do?pg=/fli/UI_KFS_7004_020000.htmlandorgId=fliandmn=KFS_02_05_04_02.

[2] Ministry of Land, Infrastructure, and Transport. 2014. "National Spatial Information Statistics." Accessed June 1, 2016. http://stat.molit.go.kr/portal/stat/yearReport.do

[3] National Geographic Information Institute. 2014. "National Mountain Altitude." Accessed June 1, 2016. http://www.ngii.go.kr/kor/board/view.do?rbsIdx=31andpage=1andidx=632

[4] Korea National Park Service. 2015. "Korea National Park Service General Statistics–Annual Visitors." Accessed June 1, 2016. http://knps.or.kr/front/portal/stats/statsDtl.do?menuNo=7070020andrefId=REFM000114andpage=1andsearchAllValue=

[5] Tschentscher, M., Niederseer, D., and Niebauer, J. 2013. "Health Benefits of Nordic Walking: A Systematic Review." *American Journal of Preventive Medicine* 44 (1): 76-84.

[6] Duckham, R. L., Bassett, D. R., Fitzhugh, E., Swibas, T., and McMahan, A. 2009. "The Effects of Hiking Poles on Performance and Physiological Variables during Mountain Climbing." *Journal of Exercise Physiology* 12 (3): e34-41.

[7] Knight, C. A., and Caldwell, G. E. 2000. "Muscular and Metabolic Costs of Uphill Backpacking: Are Hiking Poles Beneficial?" *Medicine and Science in Sports and Exercise*

32 (12): 2093-101.
[8] Schwameder, H., Roithner, R., Müller, E., Niessen, W., and Raschner, C. 1999. "Knee Joint Forces during Downhill Walking with Hiking Poles." *Journal of Sports Sciences* 17 (12): 969-78.
[9] Willson, J., Torry, M. R., Decker, M. J., Kernozek, T., and Steadman, J. R. 2001. "Effects of Walking Poles on Lower Extremity Gait Mechanics." *Medicine and Science in Sports and Exercise* 33 (1): 142-7.
[10] Hansen, L., Henriksen, M., Larsen, P., and Alkjaer, T. 2008. "Nordic Walking Does Not Reduce the Loading of the Knee Joint." *Scandinavian Journal of Medicine and Science in Sports* 18 (4): 436-41.
[11] Jensen, S. B., Henriksen, M., Aaboe, J., Hansen, L., Simonsen, E. B., and Alkjaer, T. 2011. "Is It Possible to Reduce the Knee Joint Compression Force during Level Walking with Hiking Poles?" *Scandinavian Journal of Medicine and Science in Sports* 21 (6): e195-200.
[12] Jacobson, B. H., Caldwell, B., and Kulling, F. A. 1997. "Comparison of Hiking Sticks Use on Lateral Stability while Balancing with and without Load." *Perceptual and Motor Skills* 85: 347-50.
[13] Porcari, J. P., Hendrickson, T. L., Walter, P. R., Terry, L., and Walsko, G. 1997. "The Physiological Responses to Walking with and without Power Poles on Treadmill Exercise." *Research Quarterly for Exercise and Sport* 68 (2): 161-6.
[14] Rodgers, C. D., VanHeest, J. L., and Schachter, C. L. 1995. "Energy Expenditure during Submaximal Walking with Exerstriders." *Medicine and Science in Sports and Exercise* 27 (4): 607-11.
[15] Sugiyama, K., Kawamura, M., Tomita, H., and Katamoto, S. 2013. "Oxygen Uptake, Heart Rate, Perceived Exertion, and Integrated Electromyogram of the Lower and Upper Extremities during Level and Nordic Walking on a Treadmill." *Journal of Physiological Anthropology* 32 (1): 2.
[16] Church, T. S., Earnest, C. P., and Morss, G. M. 2002. "Field Testing of Physiological Responses Associated with Nordic Walking." *Research Quarterly for Exercise and Sport* 73 (3): 296-300.
[17] Duncan, M. J., and Lyons, M. 2008. "The Effect of Hiking Poles on Oxygen Uptake, Perceived Exertion and Mood State during a One Hour Uphill Walk." *Journal of Exercise Physiology* 11 (3): e20-5.
[18] Foissac, M. J., Berthollet, R., Seux, J., Belli, A., and Millet, G. Y. 2008. "Effects of Hiking Poles Inertia on Energy and Muscular Costs during Uphill Walking." *Medicine and Sciencein Sports and Exercise* 40 (6): 1117-25.
[19] Jacobson, B. H., Wright, T., and Dugan, B. 2000. "Load Carriage Energy Expenditure with and without Hiking Poles during Inclined Walking." *International Journal of Sports Medicine* 21 (5): 356-9.
[20] Perrey, S., and Fabre, N. 2008. "Exertion during Uphill, Level and Downhill Walking with and without Hiking Poles." *Journal of Sports Science and Medicine* 7: 32-8.
[21] Saunders, M. J., Hipp, G. R., Wenos, D. L., and Deaton, M. L. 2008. "Trekking Poles Increase Physiological Responses to Hiking without Increased Perceived Exertion." *The Journal of Strength and Conditioning Research* 22 (5): 1468-74.
[22] Borg, G. 1982. "Psychological Bases of Perceived Exertion." *Medicine and Sciencein Sports and Exercise* 14: 377-87.
[23] Alexander, R. 2002. "Energetics and Optimization of Human Walking and Running: The 2000 Raymond Pearl Memorial Lecture." *American Journal of Human Biology* 14 (5): 641-8.
[24] Baker, C. S., and Cinelli, M. E. 2014. "Visuomotor Deficits during Locomotion in Previously Concussed Athletes 30 or More Days Following Return to Play." *Physiological Reports* 2 (12): e12252.
[25] Cavanagh, P. R., and Kram, R. 1985. "Mechanical and Muscular Factors Affecting the Efficiency of Human Movement." *Medicine and Science in Sports and Exercise* 17 (3): 326-31.
[26] Dickinson, M. H., Farley, C. T., Full, R. J., Koehl, M. A., Kram, R., and Lehman, S. 2000. "How Animals Move: An Integrative View." *Science* 288 (5463): 100-6.
[27] Blessey, R. L., Hislop, H. J., Waters, R. L., and Antonelli, D. 1976. "Metabolic Energy Cost of Unrestrained Walking." *Physical Therapy* 56 (9): 1019-24.