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Research Article

Foot Landing Pressure Measurement to Prevent Injuries in Middle-Aged and Elderly Trekkers

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ABSTRACT

Purpose: Preventing knee and foot joint problems in elderlies may decrease alpine emergencies. The aim of this study was to construct a device for measuring foot landing impact when descending steps and to evaluate the effectiveness of an educational program that used the device to lessen landing impact in older trekkers.

Methods: Care taken in landing was evaluated by a device, which measured peak foot-landing pressure. The value during descending was divided by comparable value during ascending (step down/step up ratio). The ratio was evaluated among 30 young volunteers, and 81 middle-aged and elderly trekkers who were participants of a trekking education program.

Results: In young volunteers, the step down/step up ratio (%) was 149 ± 29 prior to instruction explaining how to achieve a soft landing, and decreased to 121 ± 21 after the instruction ($P<0.05$). In the middle-aged and elderly trekkers, the ratio was 157 ± 74 before instruction of soft landing, and decreased to 135 ± 41 after instruction ($P<0.05$). Comparison of ratios measured between before and after an 8-month education program revealed that there was no further reduction in the ratio after the first soft landing instruction. No participant reported exacerbation of pre-existed knee pain, and no new musculoskeletal injuries were reported during the program.

Conclusion: Problems in joints of the lower extremities in senior trekkers can cause accidents in the mountain environment. Foot landing pressure measurement and its educational use might be an effective means of preventing joint injury and decreasing emergency rescue calls.

Keywords: Joint pain; Mountain accident; Senior trekker; Foot landing pressure

INTRODUCTION

Due to the improvements in public health and easy access to medical services, life expectancy has increased in many industrialized countries [1], and the elderly population continues to increase annually. Japan is the most aged society in the world, with more than 27% of the population being older than 65 years [2]. As many middle-aged and elderly people enjoy moderate outdoor exercise, non-challenging middle-altitude trekking is gaining popularity in Japan [3]. In addition, "green exercise", defined as physical activity in an outdoor environment (such as forest or low-altitude mountains), is widely recommended for senior citizens to maintain their physical performance and prevent lifestyle-related diseases [4-8].

The increasing popularity of green exercise in mountains that are easily accessible from suburban areas has led to a significant increase in the number of accidents. Data published by the Japanese National Police Agency show that the number of outdoor accidents has increased markedly over the past 20 years (Figure 1) [9].

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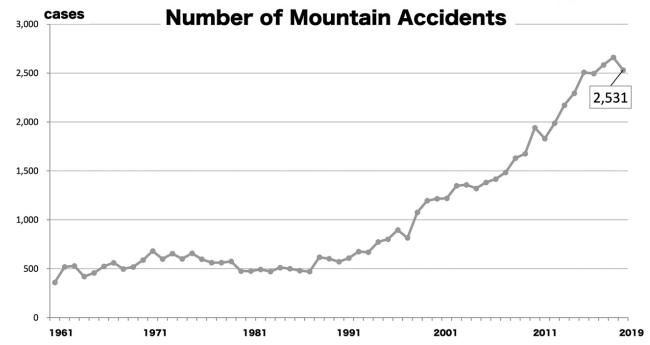

Figure 1: Number of outdoor accidents in Japan published by the Japanese National Police Agency.

Almost 80% of the trekkers involved in accidents were aged>40 years, and more than half were aged>60 years (Table 1).

Table 1: Mountain accidents and emergency calls reported to the Japanese national police agency.

	Year			
	2016	2017	2018	2019
Number of accidents	2929	3111	3129	2937
Number of deaths	319	354	342	299
Age of victims	Younger than 40	40-60 y	Older than 60	
% in 2019	20.5	28.9	50.6	
Cause of accidents	Falling down	Slipping	Falling off	Diseases and fatigue
% in 2019	16.8	16.5	3.0	14.5

More than a third of these accidents occurred due to slipping or falling. Such events often result from weakness of muscles involved in posture control and weakness of lower extremity muscles, especially those around the knee and foot joints [10]. Most alpine accidents that involve older trekkers occur in the afternoon because prolonged climbing predisposes to muscle weakness and joint problems [11]. In addition, joint pain is common while descending, especially in the knee and foot joints, which prevents smooth movements of the legs and interferes with balance on unstable mountain routes [12]. These effects are seen more commonly in aged or novice trekkers than young or experienced trekkers [10]. We have previously proposed that educating the trekkers on using a soft-landing stepping technique while descending on a slope may prevent knee and foot joint problems as well as decrease the frequency of orthopedic emergencies [13,14].

The aims of this study were to construct a device that measures foot landing impact while descending on steps and to evaluate the effectiveness of a program that teaches the use of this device for reducing the landing impact on the joints of inexperienced older trekkers.

METHODOLOGY

This study was prospective study approved by the human ethics committee of the institute, and the study protocol was registered in UMIN Clinical Trials Registry (#000020659). We acquired the written consent from subjects beforehand.

Foot landing pressure measurement

Foot landing (plantar) pressure was measured using a pressure gauge (Fuso-8230 digital manometer; Fuso, Tokyo, Japan) connected to a square-shaped balloon, placed beneath a cover board (30 × 40 cm, 10-mm thick) that was set 42 cm above a flat concrete floor (Figure 2a). The study participants placed their dominant foot on the cover board when stepping up or down (Figure 2b). The pressure on the balloon was measured continuously, and peak pressures during stepping up and down were recorded.

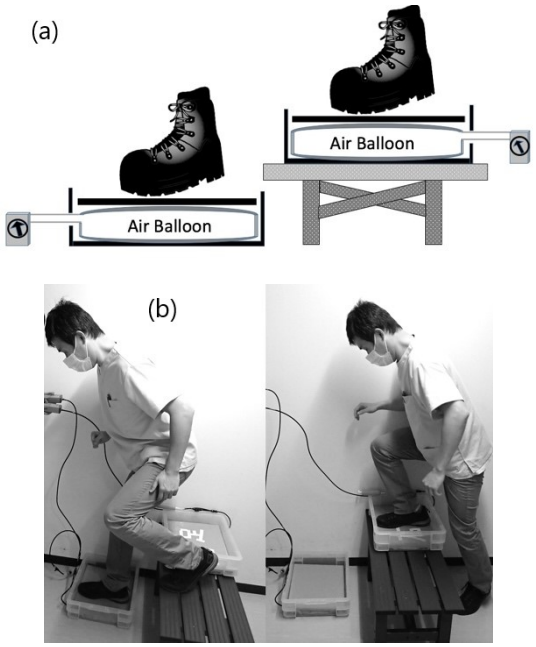

Figure 2: A conventional device to measure the foot landing pressure. (a) Cross-sectional view of the device. (b) A participant placed their dominant foot on the covering board when stepping up or down. The pressure transmitted to the balloon was measured continuously, and the maximal pressures were recorded.

To cancel the effects of body weight on the measurements, care taken while descending was calculated as peak balloon pressure when descending divided by peak pressure when ascending (step down/step up ratio). This ratio was used to evaluate the difference in pressures before and after physical activity. In addition to being convenient, the use of this ratio eliminated the effects of changes in the total weight of participants after exercise (due to increased weight of clothes and shoes from sweating or soil and foreign bodies attached to clothing; physiological weight alteration provoked by insensible and sensible water losses during respiration and excretion; and food

or water intake during activity). In addition, calculation of the step down/step up ratio eliminated the need to measure body weight, which is disliked by women.

Foot landing in young volunteers

We conducted preliminary measurements in 30 volunteers aged<40 years to evaluate the efficacy of this device. The volunteers were office workers who did not exercise regularly in the mountains. Two trials were performed. In the first trial, each participant was instructed to ascend and descend the step with the foot placed as usual. In the second trial, they were instructed to ascend with the foot placed as usual but descend with the foot placed carefully, with the least landing pressure possible. They were informed that the peak landing pressure could be most effectively reduced by bending the knees to bend the trunk lower prior to landing, thereby slowing their body movement and landing with the sole flat (10, 13).

Foot landing during an educational program for senior trekkers

An 8-month program was organized by the Gunma Division of the Japan Alpine Club (Maebashi, Japan) that promoted green exercise and included monthly educational lectures and short treks. Following completion of the program, all data were sent to Gunma University for analysis and evaluation.

The program, called 'Educational Program for Healthy Trekkers,' was conducted in a Japanese prefecture with 2 million people. The program was advertised for one month using leaflets and social media, and 317 people applied to the program. Free software was used to generate random numbers to select 90 participants aged>40 years without any co-existing diseases (except controlled hypertension or diabetes). All participants were interviewed to evaluate their health problems, including joint pains in legs, at the first and last meetings of the program.

Following a brief lecture regarding the physiological effects of trekking and healthcare in daily life, the participants were asked to walk for at least 30 min every two days and participate in five short treks that were held at 1-month intervals during the 8-month study period. The treks were at an altitude of 800-1827 m above sea level, with a net altitude gain of approximately 300-500 m.

Before and after each trek, the participants were given brief instructions regarding healthcare during exercise. During the first and last treks, foot landing pressures were measured prior to and immediately after completing the trek.

Statistical analysis

The sample size for foot landing pressure measurements was determined by setting the expected Standard Deviation (SD) as 10%-20% of the mean value, estimated error as 10%, and confidence coefficient as 95%, as described in our previous study [15] and used for preliminary measurements in the volunteers. All data are expressed as means ± SDs. Prior to analysis, the data were checked for normal distribution. Paired t-test and Wilcoxon's signed rank test were used to compare the variables before and after the instruction. Mann-Whitney U test and t-test were used to compare the differences between the sexes. Friedman rank sum test was used to compare the variables measured before and after the first trek and compare the variables measured during the first and last treks. R statistical software (R 2.6-2 modified as EZR-ver.1.41; The R Foundation, Vienna, Austria; and Numbers; Apple Inc., Cupertino, CA, USA) [16] was used for all analyses. P-values<0.05 were considered statistically significant.

RESULTS

Foot landing in young volunteers

Table 2 lists the demographics of the 30 young volunteers (15 men and 15 women; age=34 ± 9 years).

Table 2: Demographics of young volunteers and effect of instruction for soft landing.

Gender	Age	Height (cm)	Weight (kg)	Landing pressure ratio %	
				before instruction	after instruction
Male (n=15)	34 ± 9	171 ± 6	67 ± 11	155 ± 26	119 ± 22*
Female (n=15)	33 ± 8	158 ± 4	52 ± 9	143 ± 32	123 ± 20
All (n=30)	34 ± 9	164 ± 8	60 ± 13	149 ± 29	121 ± 21*

Values are mean ± SD. *P<0.05 (paired t-test). Landing pressure ratio (%) was calculated by diving maximum pressure produced during downward foot landing on 40 cm high step with the value during upward landing, and by multiplying 100.

Standard body size in Japan (30-39 years): Male: 171 ± 6 cm, 71 ± 13 kg, Female: 159 ± 6 cm, 54 ± 10 kg.

The heights and weights of volunteers were similar to those of the Japanese population, as reported by the Japanese government [17]. The step down/step up ratios of the volunteers was 149 ± 29 and 121 ± 21 before and after instructions to achieve a soft landing, respectively (p<0.05). The ratios were 155 ± 26 and 143 ± 32 for men and women before the instructions, respectively. The ratio for men decreased to 119 ± 22 after the instructions (p<0.05).

Foot landing during an educational program for senior trekkers

Following the promotion of the program, 317 people applied to join the program (125 men and 192 women; age=61 ± 8 (range 28-82) years; hypertension: 16%; diabetes: 3.4%). Of the 90 randomly selected applicants, 9 did not join the program due to personal reasons. Table 3 lists the demographics of the 81 study

participants. Mean age of the participants was 60 ± 9 (42-77 years), and was lower for women compared to men. Body weight was lower for women compared to men, consistent with the weight for the general Japanese population [17]. Among the final participants, 14% had hypertension and 2.5% had diabetes, which were adequately controlled with medicines. In addition, all participants had been recommended by their primary physician to exercise regularly.

In the meeting prior to the first outdoor trek, the step down/step up ratios were 157 ± 74 (147 ± 55 for men and 166 ± 87 for women) and 135 ± 41 before and after instructions on achieving a soft landing, respectively ($p<0.05$) (Table 3).

Table 3: Demographics of program participants and effect of instruction for soft landing.

Gender	Age	Height (cm)	Weight (kg)	Landing pressure ratio %	
				before instruction	after instruction
Male (n=37)	63 ± 7	168 ± 5	67 ± 9	147 ± 55	141 ± 54
Female (n=44)	57 ± 9	158 ± 4	52 ± 6	166 ± 87	129 ± 21*
All (n=81)	60 ± 9	163 ± 6	59 ± 11	157 ± 74	135 ± 41*

Values are mean ± SD. * $P<0.05$ (paired t-test). Landing pressure ratio (%) was calculated by diving maximum pressure produced during downward foot landing on 40 cm high step with the value during upward landing, and by multiplying 100.

Standard body size in Japan (60-64 years): Male: 168 ± 6 cm, 69 ± 10 kg, Female: 155 ± 5 cm, 55 ± 9 kg.

The ratio decreased to 129 ± 21 for women after the instructions ($p<0.05$). A comparison of ratios measured before and after the first trek and those measured at the first and last treks revealed that there was no further reduction in the ratios after the first soft landing instructions (Table 4).

Table 4: Foot landing pressures in the first and last sessions of the program.

Gender	Landing pressure ratio %			
	In the first session of program		In the last session of program	
	before trek	after trek	before trek	after trek
Male (n=37)	141 ± 54	127 ± 28	120 ± 25	129 ± 35
Female (n=44)	129 ± 21	130 ± 29	134 ± 52	133 ± 37
All (n=81)	135 ± 41	128 ± 28	128 ± 43	131 ± 36

Values are means ± standard deviations. Landing pressure ratio (%) was calculated by dividing the maximum pressure produced during downward foot landing (from a height of 40 cm) by the value during upward landing, and multiplying it by 100. The values were obtained in the first and last sessions of the program, almost 6 months apart, before and after a short trek, respectively. The values before the trek in the first session of the program were identical to the values shown in "Table 2" as "after instruction."

During interviews conducted at the first meeting, 17% of participants stated that they had experienced temporary knee pain during long descents while trekking; however, no participant reported exacerbation of knee pain during the present program. No accidents occurred and no new musculoskeletal injuries were reported during the program. When asked at the end of the program whether the program was satisfactory, all participants expressed their satisfaction and willingness to participate again in the future.

DISCUSSION

Numerous recent studies have identified the benefits of green exercise [4-8]. In our previous study, we demonstrated the preference of middle-aged and elderly Japanese trekkers to undertake solo day-trips to nearby mid-altitude mountains. Conversely, young trekkers favored distant but famous mountains [3,10]. As a result of these social trends, 317 middle-aged and elderly individuals applied for the participation in the present program with 90 available slots. There were more female than male applicants. This trend was also seen in our previous study of blood pressure and heart rate [18].

According to the Japanese Ministry of Health and Social Welfare, the incidences of diabetes and hypertension demonstrate an annual increase in people aged>30 years. In those aged>60 years, approximately 20% have diabetes and > 50% have hypertension [19]. Of the 317 applicants for this program, 3.4% had diabetes and 16% had hypertension, which indicates that the applicants were relatively healthy and perhaps wished to enhance their physical condition. Therefore, these applicants may be more conscious about their health than the general population. Because hypertension and diabetes are common and exercise is recommended for all stable patients, we did not exclude applicants with hypertension or diabetes, as long as their condition had remained stable for>1 year and they had been recommended to exercise by their primary physician.

According to a Japanese governmental survey, 40% of people in Japan aged>50 years had knee joint problems [20]. A similar proportion was reported from the USA, where nearly 50% of those aged>65 years had knee joint arthritis [21]. Individuals with joint problems must remain cautious while walking to prevent orthopedic dysfunction and trauma. Outdoor exercise, particularly trekking in the mountains, is physically demanding for the elderly population [22]. Knee pain was reported among 75% of British mountain guides and was the most commonly reported occupational health problem [23]. Mountain trails are

usually uneven and sometimes unstable, which may lead to accidents such as falling down, slipping, falling off [12].

It is expensive to develop a device that measures the two-dimensional foot landing pressure for sports shoes, and data from such devices are difficult to analyze. Accordingly, we designed a simple and inexpensive device that would be suitable for use by a local trekking club. We tested the reliability of our device by measuring the step down/step up ratios in young volunteers. Instructions on achieving a soft landing were effective in reducing the ratios, which led to a reduced impact on the leg joints. Although there was more variability in the landing pressure ratios of the study participants compared to the younger volunteers, the effects of the instructions were also seen in the older participants. The step down/step up ratio reduced after the first instruction and remained low until the final measurement, indicating that the participants had mastered careful landing while descending.

However, we did not achieve any further reduction in the landing pressure ratio during the remainder of the 8-month program. Previously described techniques for reducing the landing pressures and ameliorating the impact on the leg joints include lowering the trunk by bending the knees prior to landing, slowing the body movements, and landing with the sole flat on the ground [10,13]. However, these postures and movements require considerable muscle strength in the lower extremities [10]. Although theoretical knowledge and caution are important to prevent orthopedic accidents, attention should also be paid to protect the joints by increasing muscle strength. The program in this study did not include comprehensive measures to further reduce the landing pressures during the 8-month period. Additional measures aimed at increasing the muscle strength may increase the strength of middle-aged and elderly trekkers.

The present study did not evaluate the long-term effects of educating middle-aged and elderly trekkers regarding reducing the landing impact while trekking. Further studies that include similar educational programs and longer follow-ups are required to evaluate the effects of such an educational program on reducing mountain accidents and on the wellbeing of trekkers. Notably, all participants stated that this program had been effective for establishing their habits of regular exercise and that they were willing to continue to exercise to enhance their longevity. Future studies should include longer program duration and follow up.

It is possible that increasing the duration of green exercise and decreasing the landing impact during descent can prevent mountain accidents in older trekkers. Several other studies have demonstrated that falls in the elderly are prevented with daily exercise programs that are designed to prevent immobility and frailty in aged citizens [24-26]. We hope that the results of the present study will contribute to decreasing the risk of mountain accidents caused by orthopedic problems and promoting life-long wellness in individuals at risk of knee and foot joint problems.

CONCLUSION

Many elderly people in Japan enjoy non-challenging middle-altitude trekking. A significant proportion of these senior trekkers have problems in the joints of the lower extremities, which predispose to accidents in the mountains. Instructions on reducing the foot landing pressure may prevent joint injury and reduce emergency rescue calls.

AUTHORS CONTRIBUTIONS STATEMENT

Yusuke Matsui: practical investigation

Rie Mieda: research design and data analysis

Masaru Tobe: practical investigation

Yuki Arai: practical investigation

Jo Ohta: practical investigation

Takashi Suto: research design and practical investigation

Masafumi Kanamoto: research design and practical investigation

Chizu Aso: research design and practical investigation

Tomonori Takazawa: research design and manuscript preparation

Shigeru Saito: research design, practical investigation, and manuscript preparation

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DECLARATION OF COMPETING INTEREST

The authors have no conflict of interest, either commercial or professional.

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