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Original Article

Cardiorespiratory endurance evaluation using heart rate analysis during ski simulator exercise and the Harvard step test in elementary school students

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Abstract. [Purpose] Efficient management using exercise programs with various benefits should be provided by educational institutions for children in their growth phase. We analyzed the heart rates of children during ski simulator exercise and the Harvard step test to evaluate the cardiopulmonary endurance by calculating their post-exercise recovery rate. [Subjects and Methods] The subjects (n = 77) were categorized into a normal weight and an overweight/obesity group by body mass index. They performed each exercise for 3 minutes. The cardiorespiratory endurance was calculated using the Physical Efficiency Index formula. [Results] The ski simulator and Harvard step test showed that there was a significant difference in the heart rates of the 2 body mass index-based groups at each minute. The normal weight and the ski-simulator group had higher Physical Efficiency Index levels. [Conclusion] This study showed that a simulator exercise can produce a cumulative load even when performed at low intensity, and can be effectively utilized as exercise equipment since it resulted in higher Physical Efficiency Index levels than the Harvard step test. If schools can increase sport durability by stimulating students' interests, the ski simulator exercise can be used in programs designed to improve and strengthen students' physical fitness.
Key words: Cardiorespiratory endurance, Ski simulator, Harvard step test

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INTRODUCTION

The human body develops rapidly during childhood and adolescence. During this period, physical fitness directly affects one's health state and becomes the basis of healthy adulthood[1)]. Therefore, suitable physical activity in children and adolescents contributes to the development of their physique, strength, and balance. Many developed countries have national projects designed to encourage students to enhance their physical fitness, e.g., FITNESSGRAM in the United States, Trimming 130 in Germany, ParticipACTION in Canada, EUROFIT in Europe. Health-related physical fitness measures were first developed in 2009 in Korea to evaluate students' physical strengths (cardiorespiratory endurance, muscular strength, muscular endurance, flexibility, and body fat). The Physical Activity Promotion System (PAPS) is used for continuous management of the degrees of improvement in physical fitness and activities among elementary, middle, and high school students through systematic evaluation of their physical fitness as well as the recommendation of desirable physical activities to the students via their parents and teachers. A cardiorespiratory endurance test includes stepping, running, and walking, and its evaluation results are classified into five grades using the heart rate to evaluate heart function[2)]. The current study focuses only on the measured physical fitness levels and lacks follow-up management. Efficient management by exercise programs that provide

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various benefits should be offered to elementary school children. In the recent years, studies have been conducted on exercise machines, such as the simulator, that are used to enhance the muscle strength and cardiorespiratory endurance, improve flexibility, and reduce body fat[3, 4]. These exercises improve the balance and effectively reduce sports-related injuries[5]. The ski simulator exercises in particular are designed to mimic snow surface repulsion; hence, they have the advantage of providing resistance. Such resistance exercises enhance the muscle mass and stimulate muscle strengthening, thus efficiently aligning the body parts and maintaining good posture. They also improve one's ability to perform various exercises requiring muscle strength, endurance, and energy; thus, they can positively influence basic health functions such as metabolism and cardiovascular functioning[6, 7]. In a study on the effects of simulator-based exercises on injury prevention, Lee et al.[8] reported that training with a ski simulator contributes to increased range of motion and improved hamstring strength, which help to prevent sports-related injuries. However most previous studies analyzed the skier's posture[9, 10], and some differences were noted between individuals depending on the exercise intensity and the simulator type. Due to continuous demand for research in this area, in this study, the heart rate was measured and analyzed after a ski simulator exercise and the Harvard step test. These exercises have various effects that can be used to evaluate the cardiopulmonary endurance by calculating the post-exercise recovery rate. The body mass index (BMI) analysis can provide useful information. Because simulator exercises improve the muscle strength and endurance, this study aimed to assess the exercise performance capacity improvements of elementary school students.

SUBJECTS AND METHODS

Participants included 77 elementary school students (normal weight, 40 students; overweight and obesity, 37, based on the Asia Oceania Association for the Study of Obesity standards) with no previous or current foot injury. This study was approved by the ethics committee of the institutional review board of Pukyong National University. The cohort size was calculated using the G*power 3.1 version program by Faul et al[11]. The specifications of the sample calculated by this analysis was 70 participants with a 0.05 significance level, 0.95 power, and 0.8 effect size being the largest size; therefore, this cohort (77 participants) satisfied the required sample size criteria (Table 1). This study was conducted after obtaining written informed consent of the participants and their parents and teachers. The study was conducted at the S Elementary School in B City. The ski simulators (Pro ski simulator; Slovenia) were fixed onto a flat surface consisting of a platform on wheels that moved left and right on two bowed parallel metal rails. Rubber belts fastened the platform to the rails and ensured that it regained its resting position in the middle of the apparatus. The ski simulator's band elasticity had a rotation radius of 1–6 levels; larger the rotation radius, weaker was the band elasticity. This study conducted the experiment with two elasticity strength levels. To ensure accuracy, sufficient time was given to each subject for practice, and then the actual skiing was performed for 3 minutes. Each subject held a strap in each hand to maintain balance, and a low intensity ski simulator setting was used for the study. Each participant performed the Harvard step movements for 3 minutes and then rested in a chair for 3 minutes. The height of the step box for Harvard step test was 20.3 cm, and the steps were performed at a rate of 24 steps per minute. To ensure postural accuracy, each subject was given sufficient time to practice. A heart rate monitor and a stopwatch were used in this study, and cardiorespiratory endurance was calculated by the Physical Efficiency Index (PEI) formula described below.

$$PEI = D/(2 \times P) \times 100$$

D: Duration of the exercise (s)

P: First phase (60–90 s) + Second phase (120–150 s) + Third phase (180–210 s) Heart rates

Using these methods, the heart rate in each phase as well as the differences in the 2 groups and the 2 exercises were computed through analysis of the biomechanical factors. Each subject rested for 10 minutes between the conditions, which were performed in a random order to avoid compromising the results. The data were statistically processed using the Statistical Package for the Social Sciences, version 23.0. The independent t-test and paired t-test were used to examine the differences, which were considered statistically significant at p values <0.05.

Table 1. Participants characteristics

	Normal (40)	Over weight/Obesity (37)
Height (cm)	149.2±8.1	151.9±7.2
Weight (kg)	45.1±6.4	55.8±6.3
BMI (kg/m^2)	20.2±1.6	24.1±1.0

Normal group (18.5 ≤ BMI < 23.0 kg/m^2), Overweight, Obesity (BMI ≥ 23.0 kg/m^2) − AOASO (Asia Oceania Association for the Study of Obesity)'s standards

RESULTS

Using the aforementioned methods, the movement-dependent cardiorespiratory endurance factors of heart rate and PEI were calculated. There was a significant difference among the BMI based groups at 2 and 3 minutes when participants were exercising and at 6 minutes when they had cooled down. Furthermore, the normal weight group had higher PEI levels (Table 2). The t-test results regarding the participants' heart rate before and after the exercises showed that the average heart rate of the normal weight group was higher during step-boxing; however, the overall PEI was higher during skiing. The obesity group revealed significant differences in the initial stages of the exercise, and the overall PEI of the obese group was higher during skiing.

DISCUSSION

The American College of Sports Medicine has underscored the importance of physical strength with regard to health over physical strength in terms of motor skills based on the fact that a decline in the capacities of body composition, cardiorespiratory endurance, muscular strength, and muscular endurance and flexibility significantly increases the probability of lifestyle

Table 2. Heart rate and Physical Efficiency Index (PEI)

Ski simulator	Normal	Overweight/Obesity
1 minute	84.3±21.4	81.8±13.7
2 minute	122.1±10.1	139.6±12.7***
3 minute	130.1±7.4	150.0±10.5***
4 minute	84.7±11.7	87.4±11.5
5 minute	81.1±11.1	84.4±11.1
6 minute	80.6±11.8	87.5±13.0*
PEI	61.4±5.6	56.3±3.5***
Harvard step	Normal	Overweight/Obesity
1 minute	92.8±19.7	93.6±15.5
2 minute	129.6±12.6	140.4±14.8**
3 minute	137.8±9.3	147.9±14.9**
4 minute	87.1±16.6	85.8±18.6
5 minute	83.8±19.0	83.5±17.4
6 minute	85.1±12.4	86.5±14.2
PEI	57.5±5.5	55.2±4.2*
Normal	Ski simulator	Harvard step
1 minute	84.3±21.4	92.8±19.7*
2 minute	122.1±10.1	129.6±12.6**
3 minute	130.1±7.4	137.8±9.3***
4 minute	84.7±11.7	87.1±16.6
5 minute	81.1±11.1	83.8±19.0
6 minute	80.6±12.4	85.1±12.4
PEI	61.4±5.6	57.5±5.5**
Overweight/Obesity	Ski simulator	Harvard step
1 minute	81.8±13.7	93.6±15.5**
2 minute	139.6±12.7	140.4±14.8
3 minute	150.0±10.5	147.9±14.9
4 minute	87.4±11.5	85.8±18.6
5 minute	84.4±11.1	83.5±17.4
6 minute	87.5±13.0	86.5±14.2
PEI	56.3±3.5	55.2±4.2

*<0.05, **<0.01, ***<0.001
PEI = D/(2 × P) × 100; D: Duration of the exercise (s);
P: First phase (60–90 s) + Second phase (120–150 s) + Third phase (180–210 s) Heart rates

diseases and health impairments. One of the most critical elements of physical fitness is cardiorespiratory endurance. Relying on the kinetic functions of the heart and lungs, cardiorespiratory endurance refers to the body's ability to continue supplying energy to the human circulatory system and muscles over extended periods. There have been positive reports[12–14] about how advanced cardiorespiratory endurance not only enables one to engage in aerobic exercises, such as walking and jogging for a longer time, but also enhances one's academic accomplishments by improving concentration levels. There are many methods to evaluate cardiorespiratory endurance considering various aspects such as assessment purpose, targets, and social influences. A certain method may or may not be superior to another; however, the PAPS evaluation method is currently considered an optimal standard method. Continued research[15] showed that a solution is required to reduce the gaps among the different methods evaluating cardiorespiratory endurance. In this regard, skiing has developed as a popular health-improving sport that can facilitate students' physical fitness development and provide great exercising benefits. The ski simulator exercise is a training machine that uses a band to simulate an environment of reduced resistance force between the snow surface and ski plates. Due to these mechanical features, the ski simulator exercise is considered to have an effect similar to that of the elastic resistance exercises. Anderson et al.[16] reported that elastic resistance exercises are more effective for training small muscle groups, such as the muscles of the neck, shoulders, and arms, as compared to the strength training exercises using free weights. Elastic bands undergo a linear increase in tension from the beginning of the contraction to the full range of motion[17]. The tension generated may make it difficult to maintain a balanced posture, thus facilitating the transition to the next movement with a different heart rate as evident from the PEI data difference between two groups and exercises. O'Loughlin et al.[18] emphasized on the absolute lack of physical activities due to increased time spent on video games and computers. On the other hand, Kim et al.[19] claimed that the interest in sports can promote the development of physical fitness by increasing the level of participation in exercises. The importance of adequate exercising applies to both obese and normal weight children; therefore, as mentioned in this study, skiing as an ideal sport can be practically utilized in real-life settings. Taking BMI, physical fitness level, and sport durability into consideration, this study showed that the ski simulator exercise could produce a cumulative load even when performed at low intensity. Furthermore, the ski simulator exercise can be effectively utilized as exercise equipment since it resulted in higher PEI levels than the Harvard step test. If the schools can increase sport durability by stimulating students' interests, the ski simulator exercise can be practically used in programs designed to improve and strengthen students' physical fitness.

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