Exercise responses to running and in-line skating at self-selected paces

EDWARD L. MELANSON, PATTY S. FREEDSON, RUSS WEBB,
STEPHEN JUNGBLUTH, and NATALIE KOZLOWSKI

Department of Exercise Science,
University of Massachusetts,
Amherst, MA 01003

ABSTRACT

MELANSON, E. L., P. S. FREEDSON, R. WEBB, S. JUNGBLUTH, and N. KOZLOWSKI. Exercise responses to running and in-line skating at self-selected paces. *Med. Sci. Sports Exerc.*, Vol. 28, No. 2, pp. 247–250, 1996. The purpose of this investigation was to compare physiological responses to in-line skating and running at preferred levels of exertion. Ten males and ten females performed 15 min of in-line skating or running on two separate days. Subjects were instructed to exercise at an intensity that represented an effective cardiovascular workout. Heart rate (HR) and oxygen consumption ($\dot{V}O_2$) were monitored continuously using a portable, telemetric, open-circuit spirometry system. Subjects maintained steady rate $\dot{V}O_2$ over minutes 11–15 of in-line skating and running at speeds ($\bar{X} \pm SD$) of 21.7 ± 2.4 and 12.2 ± 2.3 $km\cdot h^{-1}$, respectively. A significantly higher ($P = 0.03$) $\dot{V}O_2$ ($\bar{X} \pm SEM$, 44.0 ± 1.7 $ml\cdot kg^{-1}\cdot min^{-1}$) was observed during running compared with in-line skating (42.0 ± 2.0 $ml\cdot kg^{-1}\cdot min^{-1}$), but there were no differences in ventilation, HR, or rating of perceived exertion. Consistent with the results of previous investigations, we conclude that in-line skating is an appropriate form of exercise for improving cardiorespiratory fitness. Future studies should compare the cardiovascular training effects of in-line skating and running in individuals of varying levels of fitness and skating ability.

ENERGY EXPENDITURE, PREFERRED EXERTION,
PERCEIVED EXERTION

Despite its popularity as a form of exercise, no field study has been undertaken which directly compares the physiological demands of in-line skating with running. However, several investigations have used laboratory measures to compare in-line skating with other forms of exercise. Snyder et al. (14) reported that in-line skating elicited higher heart rate responses in nine trained subjects than treadmill running or stationary cycling at the same level of $\dot{V}O_2$. Although it was concluded that in-line skating is an effective mode of aerobic exercise, a leftward shift was observed in the HR/$\dot{V}O_2$ curve for in-line skating compared with other forms of exercise. These results suggested that training adaptations for in-line skating may be less than running at a given heart rate (HR). In contrast, Wallick et al. (15) found no difference between the HR/$\dot{V}O_2$ curves of 16 "active males" during in-line skating and treadmill running.

The hypothesis that training adaptations resulting from in-line skating may be less than running is supported by Hoffman et al. (7). Based on extrapolation of $\dot{V}O_2$ measured in 10 competitive male cross-country skiers during in-line skating at speeds between 14.6 and 18 $km\cdot h^{-1}$, it was suggested that highly fit individuals may need to travel at unsafe and technically difficult speeds to achieve appropriate training benefits from in-line skating. However, Fedel et al. (5) reported that 12 male competitive in-line skaters were capable of safely skating at speeds sufficient enough to elicit an adequate cardiovascular training stimulus. At speeds of 22.5 and 27.4 $km\cdot h^{-1}$, HR was 74% and 85% of peak, and $\dot{V}O_2$ was 51% and 72% of peak. Similar results were reported by Wallick et al. (15) in 16 "active males." They showed that between 17.7 and 20.9 $km\cdot h^{-1}$, $\dot{V}O_2$ and HR were 60–75% and 75–90% of peak, respectively.

Although the HR/$\dot{V}O_2$ relationship between running and in-line skating may be different (7,14), the interpretation that in-line skating does not provide the same aerobic training benefit as running may be premature. Doing so ignores the possibility that participants may naturally self-select intensities that would provide similar cardiovascular overloads independent of exercise mode. Selection of exercise intensity is probably dependent upon a multitude of metabolic responses (e.g., HR, blood lactate, ventilation, respiratory rate). As recreational exercisers would find it impractical to measure these variables, and given the surge in popularity of in-line skating as a form of exercise, data are needed that directly compare the demands of running and in-line skating at preferred exercise intensities. Therefore, the purpose of this study was to compare the physiological demands of in-line skating and running at self-selected exercise intensity levels.

0195-9131/96/2802-0247$3.00/0
MEDICINE AND SCIENCE IN SPORTS AND EXERCISE®

Submitted for publication January 1995.
Accepted for publication June 1995.

METHODS

Subjects

Ten males (24.7 ± 4.5 yr, 72.5 ± 5.6 kg, 179.2 ± 6.0 cm) and 10 females (25.7 ± 4.6 yr, 60.7 ± 8.2 kg, 167.8 ± 6.9 cm) provided informed written consent in accordance with the university Human Subjects Review Committee Guidelines. Subjects were required to demonstrate proficient in-line skating technique and reported previous experiences with in-line skates ranging from a few times (3 or 4) up to several years of experience. None of the subjects were considered novice in-line skaters. Several subjects reported in-line skating as a regular form of exercise during summer months, but none of the subjects were training as competitive in-line skaters. Although maximal aerobic capacity was not determined, subjects reported various forms and levels of regular physical activity.

Experimental Design

Testing was conducted on two separate days during the months of July and August. On each day, subjects performed either 15 min of in-line skating or running. Tests were separated by at least 1 but no more than 7 d. The order of running and in-line skating trials was balanced across subjects. Testing was conducted outdoors over a rectangular course that measured 0.48 km (0.3 miles) on a smooth and level asphalt parking lot. Subjects were instructed to select an exercise intensity that would represent a cardiovascular or aerobic workout (an intensity high enough so that they would get a good workout), and to maintain a steady pace throughout the 15 min of exercise. Average speed over each 15-min trial was monitored by a cyclocomputer-equipped bicycle ridden approximately 3–5 m behind the subject. Subjects wore their own running shoes during the running trials, but the same model of in-line skates (Rollerblade® Macroblade Equipe™, Rollerblade, Inc., Minnetonka, MN) was used during skating trials. On at least one occasion before testing, subjects practiced skating while wearing the Macroblades. During in-line skating trials, subjects were provided a pair of knee, wrist, and elbow guards but were not given any instructions regarding skating technique.

Metabolic Measurements

During each trial, heart rate and $\dot{V}O_2$ were monitored continuously via telemetry using a portable open-circuit spirometry system (Cosmed K2, Vacumetrics, Inc., Ventura, CA). The specifications and validity of the Cosmed K2 have been previously reported (8,9,11). The K2 was turned on at least 60 min before intended use and was calibrated prior to each trial. The K2 is not equipped with a carbon dioxide analyzer; therefore, an estimate of caloric expenditure was obtained by multiplying $\dot{V}O_2$ ($l \cdot min^{-1}$) by 5.05, which represents the caloric equivalent of a respiratory exchange ratio of 1.0 (10).

Before each trial standardized instructions for rating of perceived exertion (RPE) were read to each subject. After each trial, subjects were again read the instructions, and were asked to provide an overall rating of perceived effort during the exercise trial. The Borg 6–20 RPE scale was used to estimate perception of effort, with perceptual scale anchors established as previously reported (2).

Data Analysis

One-factor analysis of variance (ANOVA) with repeated measures was used to detect differences in $\dot{V}O_2$ over minutes 11–15. Paired *t*-tests were performed on selected dependent measures to determine differences between running and in-line skating. Pearson product-moment correlation coefficients were used to compare running and in-line skating responses. All comparisons were considered significant at $P < 0.05$.

RESULTS

There were no differences in $\dot{V}O_2$ over minutes 11–15 during either in-line skating ($P = 0.41$) or running ($P = 0.71$). Therefore, HR, $\dot{V}O_2$, and energy expenditure for each subject were calculated as the mean values observed over the last 5 min of each trial.

Average speeds observed during the in-line skating and running trials are presented in Table 1, and mean values for dependent measures are presented in Table 2. No significant differences in $\dot{V}e$ ($P = 0.72$), HR ($P = 0.69$), or RPE ($P = 0.91$) were observed between in-line skating and running. However, $\dot{V}O_2$ and energy expenditure were significantly higher during running ($P = 0.03$).

DISCUSSION

Consistent with previous investigations (5,7,14,15), we conclude that in-line skating is an appropriate mode of exercise for improving cardiovascular fitness. Preferred level of exertion corresponded to an intensity that was 73–98% of age-predicted maximal heart rate (HR_{max}) during in-line skating, and 66–97% HR_{max} during running (Fig. 1). These levels are considered sufficient to promote a cardiovascular training effect (1). The short duration of the trials (15 min) probably contributed to selection of an intensity higher than would be chosen for a longer (30–60 min) exercise bout. However, inspection of Figure 1 suggests that subjects could reduce intensity and still be within the suggested range for improving cardiovascular fitness (1). Although pace was not controlled, maintenance of steady rate $\dot{V}O_2$ suggests that subjects were in a physiological steady state during the last 5 min of both running and in-line skating.

TABLE 1. Running and in-line skating speeds ($km \cdot h^{-1}$) at preferred intensities of exertion (mean ± SD).

	All Subjects	Males	Females
Running	12.2 ± 2.3	13.8 ± 1.9	10.8 ± 1.7
In-line skating	21.7 ± 2.4	22.9 ± 1.8	19.5 ± 1.8

In the present study, subjects perceived no differences in exercise intensity during self-selected speed running and skating although steady rate $\dot{V}O_2$ and energy expenditure were significantly lower during in-line skating (Table 2). However, because the magnitude of these differences in steady rate responses was small (0.2 $l \cdot min^{-1}$ (2.0 $ml \cdot kg^{-1} \cdot min^{-1}$), 0.7 kcal·min) we conclude that the intensity of exercise was equivalent during running and in-line skating.

The conclusion that intensity of exercise was equivalent during the in-line skating and running bouts assumes that RPE is a valid marker of relative exercise intensity independent of variations in ambient conditions, mode of exercise, or fitness level. Results from several published studies support this assumption. Potteiger and Weber (12) investigated the influence of temperature on HR and RPE and found no significant differences in HR or RPE during constant load cycle ergometry work performed at 14°, 22°, and 33°C. In the present study, there were also no differences in RPE and HR, and ambient temperature during testing varied within a narrow range (21–32°C). Dishman et al. (4) compared responses to preferred intensities of exertion by high-active and low-active men during 20 min of cycle ergometry. There were no differences in exercise intensity (%$\dot{V}O_{2peak}$) between groups during the last 10 min, and RPE was identical between groups for the entire 20 min. These results suggest that RPE is a valid indicator of exercise intensity independent of fitness levels. Finally, Robertson et al. (13) reported no differences in RPE during several modes of exercise (treadmill running, cycle ergometry, and bench stepping with hand weights) performed at 70% of the exercise-specific relative $\dot{V}O_{2peak}$. Thus, it appears that RPE can be used to equate exercise intensity during various modes of exercise.

There have been conflicting results regarding the effectiveness of in-line skating as a form of aerobic exercise when compared with other exercises. Leftward shifts in the HR/$\dot{V}O_2$ curves have been reported when in-line skating was compared with treadmill running (14) and skate skiing (7). However, these results may have been affected by the environments in which testing was performed (5). In previous studies, in-line skating was performed on an indoor, 200-m Tartan track (14) or an outdoor, 432-m rubberized track (7). These relatively short courses resulted in more frequent turning and may have affected the achievement of a steady-state response (5), particularly in recreational or inexperienced skaters.

TABLE 2. Comparison of steady state values for running and in-line skating at preferred intensities of exertion (mean ± SE).

	Running	In-line Skating	% Diff	r
$\dot{V}e$ ($l \cdot min^{-1}$)	88.9 ± 3.8	90.2 ± 5.3	+1.5	0.76
HR ($beats \cdot min^{-1}$)	176.1 ± 2.7	176.7 ± 2.7	+0.3	0.60
$\dot{V}O_2$ ($l \cdot min^{-1}$)	3.0 ± 0.1	2.8 ± 0.2*	−7.1	0.92
$\dot{V}O_2$ ($ml \cdot kg^{-1} \cdot min^{-1}$)	44.0 ± 1.7	42.0 ± 2.0*	−4.8	0.89
$kcal \cdot min^{-1}$	14.9 ± 0.7	14.1 ± 0.8*	−5.7	0.92
RPE	14.3 ± 0.5	14.2 ± 0.5	−0.7	0.80

* Significant difference between running and in-line skating values ($P < 0.05$). % Diff = percentage difference between in-line skating and running responses.

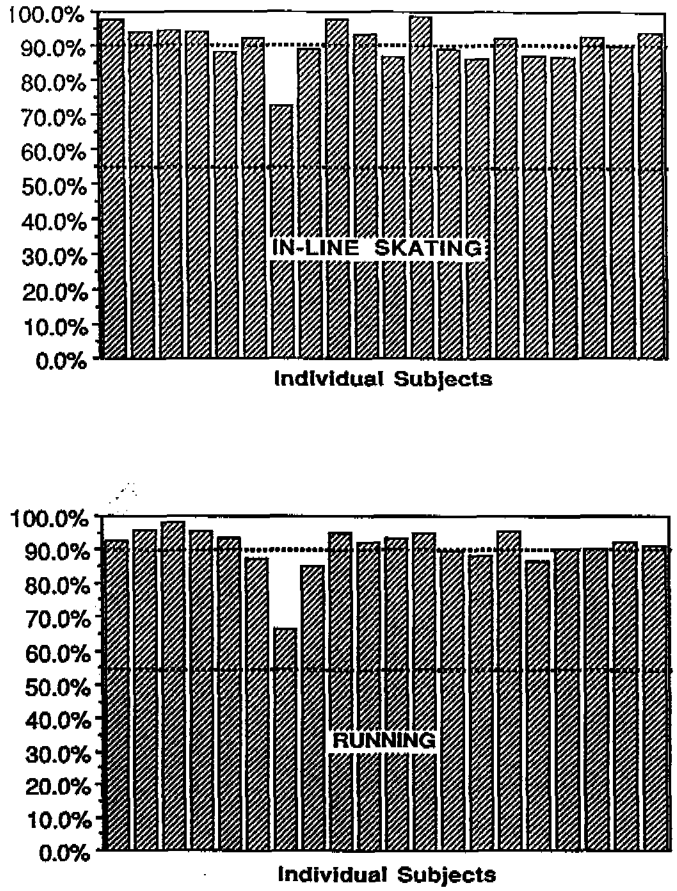

Figure 1—Preferred exercise intensity classified as a percentage of age-predicted maximal heart rate. Dashed lines correspond to recommended limits for improving cardiovascular fitness.

In addition, in-line skating on these surfaces may have produced a higher coefficient of rolling resistance (5). In contrast to Snyder et al. (14) and Hoffman et al. (7), Wallick et al. (15) reported no difference in the HR/$\dot{V}O_2$ curves of treadmill running and in-line skating when in-line skating was performed over a straight, level, asphalt surface.

The present study was unique in that it compared the physiological responses to running and in-line skating in the environment in which they are normally performed, e.g., outdoors on an asphalt surface at preferred levels of exertion. Snyder et al. (14) reported that at 30 $ml \cdot kg^{-1} \cdot min^{-1}$ HR elicited by in-line skating was 14 $beats \cdot min^{-1}$ higher than running, and it appeared that this difference increased as $\dot{V}O_2$ increased. In contrast, our results suggest that at a $\dot{V}O_2$ of 42–44 ml·kg^{-1}·min^{-1}, in-line skating and running elicit similar HR responses (approximately 176 beats·min^{-1}). The difference in experimental design between studies makes direct comparisons difficult. For example, Snyder et al. (14) compared responses over a broad range of exercise intensity (30–90%$\dot{V}O_{2max}$), whereas the present study compared responses only at a preferred level of exertion, and % $\dot{V}O_{2max}$ was not known. Furthermore, track conditions and lengths may have influenced the relationship between HR and $\dot{V}O_2$. Differences in the HR/$\dot{V}O_2$ relationships between running and in-line skating should be determined by comparing these exercises across a range of exercise intensities in a controlled, laboratory setting. Actual differences in cardiovascular adaptations cannot be determined until a controlled, systematic training study is completed.

It may be hypothesized that the weight of the protective gear and in-line skates may have significantly increased the energy cost and $\dot{V}O_2$ of in-line skating as compared with running. Frederick et al. (6) reported that as little as 15 g added to each foot had significant effects on aerobic demands of running at certain speeds. The combined weight of the wrist, knee, and elbow guards is approximately 0.7 kg, but since they are not worn on the feet, this probably had negligible effects on $\dot{V}O_2$. Although the weight of each in-line skate is approximately 1.8 kg, Carroll et al. (3) suggest that "the mechanical differences between running and skating, particularly in the recovery phase of the strides, suggest that skate weight would have less affect on the aerobic demand for the skater than would shoe weight for the runner, since in skating the foot stays closer to the ground."

Wallick et al. (15) reported that in active males, in-line skating at speeds of 14.5, 17.7, 20.9, and 24.1 km·h^{-1}, $\dot{V}O_2$ was 26.7, 34.5, 43.4, and 51.4 ml·kg^{-1}·min^{-1}, which corresponded to an intensity of 60–75% of $\dot{V}O_{2peak}$. In collegiate hockey players, Carroll et al. (3) reported that at in-line skating speeds of 12.5, 16.5, and 20.5 km·h^{-1}, $\dot{V}O_2$ was approximately 19, 34, and 42 ml·kg^{-1}·min^{-1}, though no peak or maximal data were presented. In competitive in-line skaters, Fedel et al. (5) reported that at 27.4 km·h^{-1}, $\dot{V}O_2$ was 40.8 ml·kg^{-1}·min^{-1} (72% of $\dot{V}O_{2peak}$). In our heterogeneous sample, in-line skating at a mean speed of 21.7 km·h^{-1} elicited a $\dot{V}O_2$ of 42.0 ml·kg^{-1}·min^{-1}, which corresponded to 73–98% HR$_{max}$. These results suggest that an appropriate cardiovascular training effect may be achieved with in-line skating in individuals of varying levels of fitness and skating ability.

This project was funded by Rollerblade, Inc., Minnetonka, MN

Address for correspondence: Edward L. Melanson Jr., Department of Exercise Science, Room 212 Boyden Building, University of Massachusetts, Amherst, MA 01003.

REFERENCES

1. American College of Sports Medicine. *Guideline for Exercise Testing and Prescription*, 4th Ed. Philadelphia: Lea and Febiger, 1991, pp. 95–100.
2. Borg, G. A. V. Psychophysical bases of perceived exertion. *Med. Sci. Sports Exerc.* 14:377–381, 1982.
3. Carroll, T. R., D. Bacharach, J. Kelly, E. Rudrud, and P. Karns. Metabolic cost of ice and in-line skating in division I collegiate hockey players. *Can. J. Appl. Physiol.* 18:255–262, 1993.
4. Dishman, R. K., R. P. Farquhar, and K. J. Cureton. Responses to preferred intensities of exertion in men differing in activity levels. *Med. Sci. Sports Exerc.* 26:783–790, 1994.
5. Fedel, F. J., S. J. Keteyian, C. A. Brawner, C. R. C. Marks, M. J. Hakim, and T. Kataoka. Cardiorespiratory responses during exercise in competitive in-line skaters. *Med. Sci. Sports Exerc.* 27:682–687, 1995.
6. Frederick, E. C., J. R. Daniels, and J. W. Hayes. The effect of shoe weight on the aerobic demands of running. In: *Proceedings of the World Congress on Sports Medicine.* Vienna: World Congress on Sports Medicine, 1984, pp. 616–625.
7. Hoffman, M. D., G. M. Jones, B. Bota, M. Mandli, and P. S. Clifford. In-line skating: physiological responses and comparisons with roller skiing. *Int. J. Sports Med.* 13:137–144, 1992.
8. Kawakami, Y. D., D. Nozaki, A. Matsuo, and T. Fukunaga. Reliability of measurement of oxygen uptake by a portable telemetric system. *Eur. J. Appl. Physiol.* 65:409–414, 1992.
9. Lucia, A., S. J. Fleck, R. W. Gotshall, and J. T. Kearney. Validity and reliability of the Cosmed K2 instrument. *Int. J. Sports Med.* 14:380–386, 1992.
10. McArdle, W. D., F. I. Katch, and V. L. Katch. *Exercise Physiology: Energy, Nutrition, and Human Performance*, 3rd Ed. Philadelphia: Lea and Febiger, 1991, p. 153.
11. Peel, C. and C. Utsey. Oxygen consumption using the K2 telemetry system and metabolic cart. *Med. Sci. Sports Exerc.* 25:396–400, 1993.
12. Potteiger, J. A. and S. F. Weber. Rating of perceived exertion and heart rate as indicators of exercise intensity in different environmental temperatures. *Med. Sci. Sports Exerc.* 26:791–796, 1994.
13. Robertson, R. J., F. L. Goss, T. E. Auble, et al. Cross-modal exercise prescription at absolute and relative oxygen uptake using perceived exertion. *Med. Sci. Sports Exerc.* 22:653–659, 1990.
14. Snyder, A. C., K. P. O'Hagan, P. S. Clifford, M. D. Hoffman, and C. Foster. Exercise responses to in-line skating: comparisons to running and cycling. *Int. J. Sports Med.* 14:38–42, 1993.
15. Wallick, M. E., J. P. Porcari, S. B. Wallick, K. M. Berg, G. A. Brice, and G. R. Arimond. Physiological responses to in-line roller skating compared to treadmill running. *Med. Sci. Sports Exerc.* 27:242–248, 1995.

Changes in $\dot{V}O_{2max}$ and maximal treadmill time after 9 wk of running or in-line skate training

EDWARD L. MELANSON, PATTY S. FREEDSON, and STEPHEN JUNGBLUTH

Department of Exercise Science, University of Massachusetts, Amherst, MA 01003

ABSTRACT

MELANSON, E. L., P. S. FREEDSON, and S. JUNGBLUTH. Changes in $\dot{V}O_{2max}$ and maximal treadmill time after 9 wk of running or in-line skating. *Med. Sci. Sports Exerc.*, Vol. 28, No. 11, pp. 1422–1426, 1996. This study tested the hypothesis that running and in-line skating training elicit similar improvements in cardiorespiratory fitness. Changes in maximal oxygen consumption ($\dot{V}O_{2max}$) and maximal treadmill endurance time were compared in runners ($N = 16$), in-line skaters ($N = 19$), and controls who did no systematic training ($N = 7$). Training volumes were similar for runners and skaters (3 $d \cdot wk^{-1}$, 20–40 min/session, 80–90% of exercise specific maximal heart rate) and included both continuous and interval workouts. Pre- and post-training $\dot{V}O_{2max}$ and maximal treadmill time were measured in all subjects using a running protocol and in skaters using an in-line skating protocol. The groups did not differ in pre-training running $\dot{V}O_{2max}$ or maximal treadmill time. After 9 wk, significant increases in running $\dot{V}O_{2max}$ and maximal treadmill time were observed in runners (mean ± SE, 9.3 ± 1.3%, 14.9 ± 2.5%) and skaters (6.6 ± 1.0%, 9.1 ± 3.4%), but not controls. Skaters also significantly increased their skating $\dot{V}O_{2max}$ and maximal treadmill time (8.6 ± 1.8%, 7.9 ± 2.9%). The magnitude of these increases was not different between the two training groups. In conclusion, in moderately active college-aged students, similar improvements in $\dot{V}O_{2max}$ are achieved with running and in-line skating programs that are equivalent in training volume and intensity.

AEROBIC ENDURANCE TRAINING, MAXIMAL OXYGEN UPTAKE

Conflicting reports have been presented regarding the potential cardiorespiratory benefits attainable from in-line skating as compared with more traditional forms of aerobic exercise. The heart rate (HR) responses to in-line skating have been reported to be higher than treadmill running (8) and skate-skiing (5) at the same level of oxygen consumption ($\dot{V}O_2$). These results suggest that a higher steady rate HR is required during in-line skating to achieve cardiorespiratory benefits similar to other forms of aerobic exercise, particularly in highly fit individuals (5). However, several investigators have concluded that an appropriate training stimulus is achievable with in-line skating independent of fitness level or skating ability (2,4,7,10). In a study from our laboratory (7), the metabolic responses during running and in-line skating were compared at self-selected exercise intensities. Although running elicited a significantly higher steady rate $\dot{V}O_2$ (44.0 ± 1.7 vs 42.0 ± 0.2 $ml \cdot kg^{-1} \cdot min^{-1}$), the small difference between exercise modes suggests that running and in-line skating at self-selected speeds may offer a similar training stimulus.

No definitive statements regarding the cardiorespiratory benefits of in-line skating can be proposed until the adaptations to an in-line skate training program are examined. Furthermore, as in-line skating is generally considered an alternative exercise training modality to running, data that quantify and compare adaptations to these two modes of exercise are needed. This study was designed to test the hypotheses that: 1) in-line skate training at intensities recommended by the ACSM will increase maximal aerobic capacity ($\dot{V}O_{2max}$); and 2) increases in $\dot{V}O_{2max}$ will be equivalent to those elicited by a running program similar in training volume and intensity.

METHODS

Subjects. Participants were recruited from undergraduate exercise science classes and were enrolled in a special section of a physical education course. Potential subjects were carefully screened regarding their physical activity levels to obtain a sample that was neither highly fit nor sedentary. Volunteers who reported any form of systematic aerobic training over the previous 6 months were excluded. Systematic aerobic training was defined as participation in any dynamic activity involving the lower extremity (e.g., cycling, running), performed two or more times per week for 6 wk or longer with the specific goal of improving fitness. Based on questionnaire responses, the subjects were classified as moderately physically active.

Thirty-eight subjects were selected from the initial screening and assigned to one of the training groups. To eliminate a learning effect, the in-line skate training group consisted only of individuals who demonstrated the ability to safely skate, turn, and brake ($N = 21$).

0195-9131/96/2811-1422$3.00/0
MEDICINE AND SCIENCE IN SPORTS AND EXERCISE®

Submitted for publication May 1995.
Accepted for publication January 1996.

TABLE 1. Subject descriptive characteristics (mean ± SD).

	Skaters		Runners		Controls	
	Males	Females	Males	Females	Males	Females
N	8	11	6	10	3	4
Age	21.5 (3.2)	20.4 (1.1)	21.6 (2.5)	21.0 (1.1)*	20.7 (1.8)	18.5 (1.3)
Ht (cm)	172.1 (8.9)	162.5 (8.0)	174.5 (6.6)	164.3 (8.3)	175.1 (6.1)	161.6 (5.4)
Wt (kg)	75.8 (9.7)	58.6 (7.0)	72.8 (5.5)	59.1 (7.9)	67.5 (8.5)	56.4 (3.9)

* Significantly different from control subjects ($P < 0.05$).

Remaining subjects ($N = 17$) were assigned to the running group. A third group ($N = 7$) served as controls who were asked not to alter their exercise patterns over the course of the study. The same physical activity screening procedures were used for the controls. All subjects provided informed written consent in accordance with the university Human Subjects Review Committee Guidelines.

Subject descriptive characteristics are presented in Table 1. Two skaters and one runner did not satisfy requirements of the training program. Therefore, the final sample consisted of 19 skaters, 16 runners, and 7 controls. Although female runners were significantly older than female controls, the groups were homogeneous with respect to all other physical characteristics. No significant changes in body mass were observed over the course of the study in any of the three groups.

Training protocol. Training sessions were conducted three times each week for 9 wk. All sessions were supervised, and subjects were asked not to alter their regular activity patterns outside of training. To be included in the final analysis, subjects were required to attend a minimum of 90% of the training sessions (24 of a possible 27 sessions). Running sessions during the first week were conducted indoors on a 160-m rubberized surface track. After the first week runners were given the option of training outdoors but were provided with prescribed courses to ensure that all training was conducted on level terrain. In-line skating sessions were conducted at an indoor skating facility (115-m oval) with a hardwood polished surface.

Exercise intensity was based on a percentage of the exercise-specific maximal heart rates (HR_{max}) observed during $\dot{V}O_{2max}$ testing. The training program was designed to satisfy the ACSM guidelines for improving cardiorespiratory fitness (1) and was divided in two stages. The first stage (weeks 1–4) imposed a gradual increase in exercise duration and intensity and consisted of continuous exercise. Duration and intensity were gradually increased from 20 min per session at 80% HR_{max} during the first week, to 40 min at 90% HR_{max} by the end of the fourth week. In the second stage (weeks 5–9), training days alternated between long, high intensity bouts (40 min at 85% HR_{max}), and interval workouts. A sample interval workout is presented in Table 2.

TABLE 2. Sample interval workout with prescribed target heart rate zones (Subject 12; training session 18 (34 min); HR_{max} = 193 beats·min^{-1}).

Description of Workout	Target HR Zone
10 min warm-up @ 80% HR_{max}	(HR = 150–60 beats·min^{-1})
24 min 6 sets of:	
3 min @ > 90% HR_{max}	(HR > 175 beats·min^{-1})
1 min easy	(HR < 175 beats·min^{-1})

During all training sessions, subjects wore a heart rate telemetry system (AMF Quantum XL HeartWatch, Polar Electro, Inc., Kempele, Finland). The duration and desired HR zone for each subject's workout was pre-programmed into memory. If HR was not maintained within ±5 beats·min^{-1} of the desired intensity, an alarm sounded signaling the subject to either increase or decrease speed to restore HR to the target zone. All training heart rate data were downloaded to a personal computer and reviewed after each training session to ensure that subjects were adhering to the training program.

Maximal oxygen consumption. Pre- and post-training, runners and controls performed an incremental running test to volitional exhaustion, and skaters performed both a running and skating test (separated by at least one but not more than 7 d). All $\dot{V}O_{2max}$ tests were performed on a customized motor driven treadmill (2.4 m long × 1.8 m wide) designed to accommodate in-line skating (Trackmaster, JAS Fitness Systems, Pensacola, FL). Subjects were required to practice running on the treadmill prior to the pre-training test. Skaters also practiced skating on the treadmill. To ensure safety during skating trials, subjects wore a nonrestrictive harness suspended from the ceiling. Subjects ran or skated at several different grades to become familiarized with the testing protocol. At the end of the practice session, subjects selected a comfortable speed for use during pre- and post-training testing. Treadmill speed was verified using a high precision digital tachometer (Biddle, Inc., Plymouth Meeting, PA).

A constant speed, incremental grade protocol was used with 2-min stages. Running tests began at 0% grade with increments of 2.5%, and in-line skating tests began at a 2% grade with increments of 2%. The skating protocol was modified because pilot testing indicated that skating on a level grade was technically difficult due to lack of resistance against the moving belt and that increments of 2.5% caused most subjects to terminate the test prior to attaining criteria acceptable for $\dot{V}O_{2max}$. Each $\dot{V}O_{2max}$ test was preceded by a 5-min warm-up at the speed and grade used during the initial stage. To be considered $\dot{V}O_{2max}$, two of the following criteria had to be satisfied:

1) a respiratory exchange ratio (RER) ≥1.0; 2) HR within 15 beats·min^{-1} of age predicted maximal heart rate; 3) a leveling off in $\dot{V}O_2$ despite an increase in workload (6).

$\dot{V}O_{2max}$ was determined using indirect calorimetry. Subjects breathed through a Hans Rudolph high velocity two-way non-rebreathing valve (model 2700, dead space 95 ml, Kansas City, MO). Inspired volume of air was measured with a calibrated dry gas meter (Rayfield Equipment, Waitsfield, VT). Expired gases were dried and analyzed using Ametek (Pittsburgh, PA) O_2 (Model S-3A1) and CO_2 (Model CD-3A) analyzers. The analyzers were calibrated before each test using verified gases of known concentration. Analog data from the analyzers and dry gas meter were converted to digital signals and transmitted to a personal computer. An on-line program ($\dot{V}O_2$PLUS, Exeter Research, Exeter, NH) sampled data every 30 s and automatically calculated ventilation ($\dot{V}_E$), oxygen consumption, carbon dioxide production, and the respiratory exchange ratio (RER). Heart rate was monitored using a heart-rate telemetry system and was sampled every 30 s.

Data Analysis. A two-factor (group × time) repeated measures ANOVA was used to determine differences in running $\dot{V}O_{2max}$ and maximal treadmill time. To determine differences in training-specific adaptations, the magnitude of changes in running data from the runners and controls were compared to skating data from the skaters using a two-factor repeated measures ANOVA. *Post-hoc* comparisons for all ANOVAs were performed using the Scheffe test. Running and skating $\dot{V}O_{2max}$ data from the skaters only were compared using paired *t*-tests. Correlations were calculated using the Pearson product-moment formula. An alpha level of 0.05 was required for statistical significance.

RESULTS

The groups did not differ in pre-training running $\dot{V}O_{2max}$ (absolute or relative) or maximal treadmill time (see Figs. 1–3). After 9 wk of training, significant increases in running absolute $\dot{V}O_{2max}$ (Fig. 1) were observed in runners (3.0 ± 0.2 to 3.3 ± 0.2 l·min^{-1}) and skaters (3.1 ± 0.2 to 3.3 ± 0.2 l·min^{-1}), but not in controls (2.9 ± 0.3 to 3.0 ± 0.3 l·min^{-1}). Likewise, significant increases in running relative $\dot{V}O_{2max}$ (Fig. 2) were observed in runners (46.3 ± 1.8 to 50.8 ± 1.9 ml·kg^{-1}·min^{-1}) and skaters (46.1 ± 1.7 to 48.9 ± 1.7 ml·kg^{-1}·min^{-1}), but not in controls (46.7 ± 2.7 to 47.7 ± 2.8 ml·kg^{-1}·min^{-1}). Post-training running $\dot{V}O_{2max}$ (absolute and relative) of the skaters and runners were significantly higher than that of the controls ($P < 0.001$), but not different between the two training groups. Significant increases were also observed in running maximal treadmill time (Fig. 3) in runners (625.9 ± 35.4 to 716.6 ± 33.7 s) and skaters (621.6 ± 32.4 to 665.9 ± 30.9 s), but not in controls (639.0 ± 35.4 to 648.6 ± 50.9 s). Skaters also significantly increased their skating $\dot{V}O_{2max}$ (2.8 ± 0.2 to 3.1 ± 0.2 l·min^{-1}) and maximal treadmill time (549.5 ± 22.0 to 592.1 ± 24.3 s).

Evaluation of the individual responses revealed that all but one of the runners improved running $\dot{V}O_{2max}$ (mean ± SE = 9.3 ± 1.3%). The one subject who did not improve remained at pre-training level. Similarly, all but one of the skaters increased running $\dot{V}O_{2max}$ (6.2 ± 0.8%). The one subject who did not improve had a small decrease in running $\dot{V}O_{2max}$ (−0.8%). The magnitude of increase in running $\dot{V}O_{2max}$ was not different between the

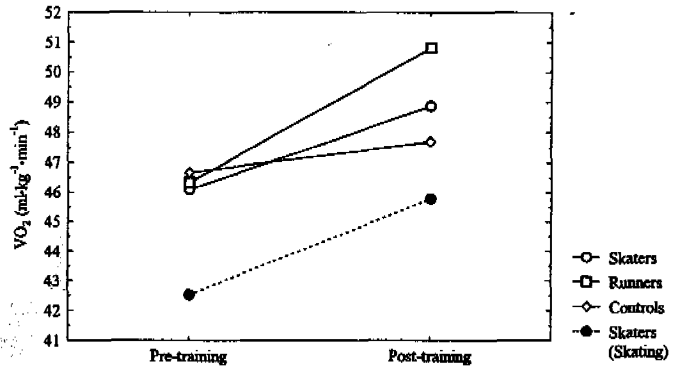

Figure 1—Changes in absolute $\dot{V}O_{2max}$ (l·min^{-1}) in the training and control groups. Dashed lines indicate results from the skating $\dot{V}O_{2max}$ test.

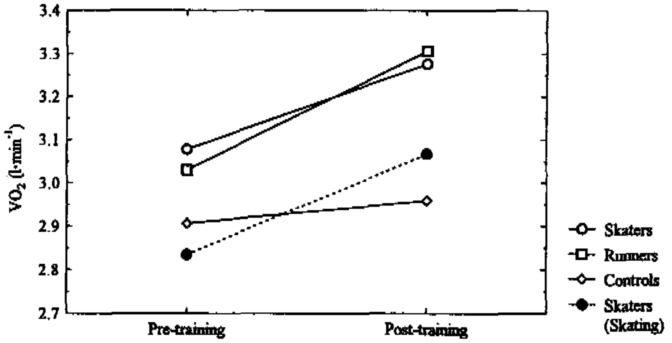

Figure 2—Changes in relative $\dot{V}O_{2max}$ (ml·kg^{-1}·min^{-1}) in the training and control groups. Dashed lines indicate results from the skating $\dot{V}O_{2max}$ test.

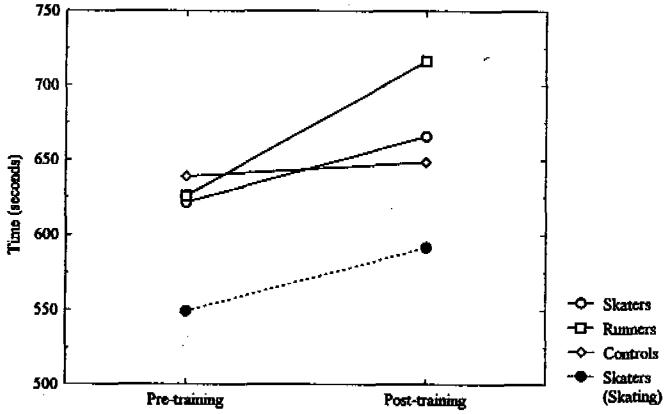

Figure 3—Changes in maximal treadmill endurance time in the training and control groups. Dashed line indicates results from the skating $\dot{V}O_{2max}$ test.

two groups. Two skaters had decreases in skating $\dot{V}O_{2max}$ (−5.1% and −2.9%) despite having small increases in running $\dot{V}O_{2max}$ (+3.6% and +0.9%). All other skaters had an increase in skating $\dot{V}O_{2max}$. The magnitude of increase in skating $\dot{V}O_{2max}$ (8.6 ± 1.8%) in the skating group was not different from the increase in running $\dot{V}O_{2max}$ of the runners (9.3 ± 1.3%).

Interestingly, a comparison of the running and skating $\dot{V}O_{2max}$ data for the skaters before and after training showed that the running protocol elicited greater absolute and relative $\dot{V}O_{2max}$ values ($P < 0.001$) but no differences in HR_{max} or $\dot{V}_{Emax}$. Using pooled data from pre- and post-training, the correlation ($r = 0.98$) between running and skating $\dot{V}O_{2max}$ was strong.

DISCUSSION

The magnitude of increases in $\dot{V}O_{2max}$ observed in this study are consistent with previous running studies that used previously untrained subjects and programs of similar frequency, duration, and intensity (3,11). Our results support the hypothesis that a cardiorespiratory training effect is achievable with an in-line skating exercise program (2,4,7,10). Our second hypothesis was that increases in $\dot{V}O_{2max}$ resulting from running and skating programs similar in training volume and intensity would be equivalent. There was no difference in post-training running $\dot{V}O_{2max}$ between the two training groups. Furthermore, the magnitude of increases in running $\dot{V}O_{2max}$ of the runners and skating $\dot{V}O_{2max}$ of the skaters were not different. In conclusion, in moderately active college-aged students, similar improvements in $\dot{V}O_{2max}$ may be achieved with running and in-line skating exercise programs.

To our knowledge, this is the first investigation that has measured $\dot{V}O_{2max}$ using an incremental graded protocol while in-line skating on a motorized treadmill. Paired *t*-tests indicated no differences in $\dot{V}_{Emax}$ or HR_{max} between running and skating $\dot{V}O_{2max}$ at pre- and post-training. Moreover, there was a high correlation between running and skating $\dot{V}O_{2max}$. However, the skating protocol produced lower $\dot{V}O_{2max}$ values than running both before (2.8 ± 0.2 vs 3.1 ± 0.2 $l \cdot min^{-1}$) and after (3.1 ± 0.2 vs 3.3 ± 0.2 $l \cdot min^{-1}$) training. The reason for this difference is not readily apparent but is consistent with the findings of Wallick et al. (10) who reported lower $\dot{V}O_{2peak}$ values during in-line skating over level terrain as opposed to treadmill running. They suggested that the lower values during in-line skating may have been a result of the inability of their subjects to skate fast enough at 0% grade to maximally challenge the cardiovascular system. However, in this study, the running and skating protocols elicited similar maximal values for heart rate and ventilation. Our data suggest that differences in $\dot{V}O_{2max}$ may be due to the oxygen demands of the active musculature. The exact cause of this difference remains to be elucidated.

We are unable to explain why two skaters had lower skating $\dot{V}O_{2max}$ after training despite having small increases in running $\dot{V}O_{2max}$. However, several subjects suggested that the in-line skating test was more difficult than the running test due to the novelty of skating on a treadmill at an elevated grade.

True differences in the $HR/\dot{V}O_2$ relationship of running and in-line skating remain equivocal at this time. Several investigators have reported a disproportionate increase in HR relative to $\dot{V}O_2$ during in-line skating (4,5,8). Snyder et al. (8) reported that compared with treadmill running at a given HR, in-line skating elicited a lower $\dot{V}O_2$. However, in-line skating was performed over a 200-m Tartan-surfaced track, which may have increased the rolling resistance (and thus the metabolic responses) above that which would be encountered while skating over other surfaces, particularly concrete and asphalt. In addition, skating on an oval track increases the frequency of turning, which may effect the achievement of a steady state response (4). Fedel et al. (4) also reported a higher HR response relative to $\dot{V}O_2$ during in-line skating at 60 and 80% of $\dot{V}O_{2peak}$ compared to the ACSM guidelines (1). However, their study used competitive in-line skaters who may assume a more horizontal thigh position during the glide phase than recreational or untrained skaters. This position produces a static contraction of the thigh muscles that may produce a pressor response and elevate heart rate (9). Recreational skaters assume a less horizontal position and probably for a shorter duration of each stride; thus, they may be less likely to experience a disproportionate increase in HR during in-line skating.

In contrast, Wallick et al. (10) reported no difference in the $HR/\dot{V}O_2$ curves of treadmill running and in-line skating using subjects not previously trained as in-line skaters. In the present study, most training was performed in the 80–90% HR_{max} range, which resulted in similar increases in $\dot{V}O_{2max}$ for both groups. Therefore, we believe there is sufficient evidence to support prescribing in-line skating exercise intensity as a percentage of HR_{max} in inactive and moderately active individuals. However, a higher exercise HR may be required in trained or competitive in-line skaters to elicit cardiovascular benefits similar to running.

We conclude that in-line skating provides an adequate stimulus for improving cardiorespiratory fitness in moderately active individuals. To achieve cardiovascular training effects similar to those in running, in-line skate training programs should be similar in frequency, duration, and intensity. As there were no differences in HR_{max} for running and in-line skating, it appears that in-line skating exercise intensity can be prescribed for moderately active individuals using the traditional percentage of age predicted maximal heart rate.

We would like to extend our gratitude to Greg Kline for his assistance with the data analysis. We also would like to acknowledge the enthusiasm and dedication of the subjects in the training groups.

This project was funded by Rollerblade, Inc., Minnetonka, MN.

Address for correspondence: Patty S. Freedson, Department of Exercise Science, Room 212 Boyden Building, University of Massachusetts, Amherst, MA 01003.

REFERENCES

1. American College of Sports Medicine. Position stand on the recommended quantity and quality of exercise for developing and maintaining cardiorespiratory and muscular fitness in healthy adults. *Med. Sci. Sports Exerc.* 22:265–274, 1990.
2. Carroll, T. R., D. Bacharach, J. Kelly, E. Rudrud, and P. Karns. Metabolic cost of ice and in-line skating in division I collegiate hockey players. *Can. J. Appl. Physiol.* 18:255–262, 1993.
3. Daniels, J. T., R. C. Yarbrough, and C. Foster. Changes in $\dot{V}O_2$ max and running performance with training. *Eur. J. Appl. Physiol.* 29:249–254, 1978.
4. Fedel, F. J., S. J. Keteyian, C. A. Brawner, C. R. C. Marks, M. J. Hakim, and T. Kataoka. Cardiorespiratory responses during exercise in competitive in-line skaters. *Med. Sci. Sports Exerc.* 27:682–687, 1995.
5. Hoffman, M. D., G. M. Jones, B. Bota, M. Mandli, and P. S. Clifford. In-line skating: physiological responses and comparisons with roller skiing. *Int. J. Sports Med.* 13:137–144, 1992.
6. McArdle, W. D., F. I. Katch, and V. L. Katch. Measurement of maximal aerobic power. In: *Exercise Physiology: Energy, Nutrition, and Human Performance,* 3rd Ed. Philadelphia: Lea & Febiger, 1991, pp. 211–213.
7. Melanson, E. L., P. S. Freedson, R. Webb, S. Jungbluth, and N. Kozlowski. Exercise responses to running and in-line skating at self-selected paces. *Med. Sci. Sports Exerc.*, 28:247–250, 1996.
8. Snyder, A. C., K. P. O'Hagan, P. S. Clifford, M. D. Hoffman, and C. Foster. Exercise responses to in-line skating: comparisons to running and cycling. *Int. J. Sports Med.*, 14:38–42, 1993.
9. Van Ingen Schenau, G. J., G. de Groot, and A. P. Hollander. Some technical, physiological, and anthropometrical aspects of speed skating. *Eur. J. Appl. Physiol.* 50:343–354, 1983.
10. Wallick, M. E., J. P. Porcari, S. B. Wallick, K. M. Berg, G. A. Brice, and G. R. Arimond. Physiological responses to in-line roller skating compared to treadmill running. *Med. Sci. Sports Exerc.* 27:242–248, 1995.
11. Wilmore, J. H., J. Royce, R. N. Girandola, F. I. Katch, and V. L. Katch. Physiological alterations resulting from a 10-week program of jogging. *Med. Sci. Sports Exerc.* 2:7–14, 1970.

physical fitness and performance

Physiological responses to in-line skating compared to treadmill running

MARK E. WALLICK, JOHN P. PORCARI, SHARI B. WALLICK,
KEITH M. BERG, GLENN A. BRICE, and GEORGE R. ARIMOND

La Crosse Exercise and Health Program and the Human
Performance Laboratory,
University of Wisconsin,
La Crosse, La Crosse, WI 54601

ABSTRACT

WALLICK, M. E., J. P. PORCARI, S. B. WALLICK, K. M. BERG, G. A. BRICE, and G. R. ARIMOND. Physiological responses to in-line skating compared to treadmill running. *Med. Sci. Sports Exerc.*, Vol. 27, No. 2, pp. 242–248, 1995. The physiologic responses to in-line skating were compared to those during treadmill running in 16 active males (18–37 yr). Each subject performed a $\dot{V}O_{2max}$ test during in-line skating and treadmill running using speed-incremented, discontinuous protocols. Protocols were designed so that each subject completed 4–6 stages. Stages were 3 min in duration and separated by a 5-min rest period. It was found that absolute $\dot{V}O_{2max}$ (4.19 vs 4.44 $l\cdot min^{-1}$, $P = 0.045$), relative $\dot{V}O_{2max}$ (56.8 vs 59.9 $ml\cdot kg^{-1}\cdot min^{-1}$, $P = 0.054$), and HR_{max} (189 vs 194 $b\cdot min^{-1}$, $P < 0.05$) were lower for in-line skating compared to treadmill running. Regression analyses were used to determine the submaximal relationship between modalities. There were no significant ($P > 0.05$) differences in the slope and y-intercept of the $HR/\dot{V}O_2$ relationship, indicating a similar metabolic load at a given heart rate for both modes of exercise. Skating between 17.7–20.9 $km\cdot h^{-1}$ corresponded to 60–75% of $\dot{V}O_{2max}$ or 75–90% of HR_{max}, which are common training intensities and within the guidelines recommended by the ACSM. Across the speeds investigated, caloric expenditure was 9.5–19.0 $kcal\cdot min^{-1}$. These results indicate that in-line skating elicits physiological responses comparable to treadmill running and thus would be another exercise alternative for improving aerobic capacity or maintaining body weight.

ENERGY COST, FITNESS, BODY COMPOSITION

In the past several years, a mode of exercise that is commonly referred to as "roller-blading" has become increasingly popular. Rollerblade^R skates (in-line roller skates) have three to five wheels on each skate, with the wheels set in line with each other. The configuration of in-line skates gives them the appearance of ice skates that have been modified to use wheels.

Before 1980, in-line skating was used primarily as a dry land training technique by hockey players, speed skaters, and alpine and nordic skiers. However, with the advent of faster polyurethane wheels and sturdier, more supportive boots, the popularity of in-line skating has risen dramatically. Information from American Sports Data (2) lists in-line skating as the fastest growing sport in the United States for the past 3 yr and estimates that in 1994 over 15 million people will own in-line skates.

Although the popularity of in-line skating is growing, research supporting this exercise modality is limited. There is only one study that has compared the physiologic responses elicited during in-line skating to other exercise modalities (15). Therefore, this study sought to examine and document the physiologic responses to in-line skating compared to treadmill running and to investigate the validity of using in-line skating as an exercise mode to positively effect aerobic capacity and body composition.

METHODS AND PROCEDURES

Subject Selection

Eighteen males volunteered for participation in the study. All subjects completed a written informed consent form before undergoing any testing procedures. Sixteen of the subjects successfully completed the testing; one subject failed to complete the in-line skating test because of scheduling conflicts, and the other subject withdrew from testing because of a pre-existing injury that limited his ability to run on the treadmill. All subjects actively participated in recreational aerobic activities, including in-line roller skating. Descriptive data for the subjects are presented in Table 1.

Experimental Protocol

The subjects were scheduled for a maximal treadmill test and a maximal in-line skating test on two different days. The tests were separated by at least 2 d but not more than 14 d. All subjects were given a detailed description of the testing procedures. All subjects completed a medical history questionnaire and signed an informed consent document before testing. The order of testing was randomly assigned by a coin toss for each subject. Ten

0195-9131/95/2702-0242$3.00/0
MEDICINE AND SCIENCE IN SPORTS AND EXERCISE®

Submitted for publication July 6, 1993.
Accepted for publication April 19, 1994.

TABLE 1. Descriptive characteristics of the subjects ($N = 16$).

	Mean	SD	Range
Age (yr)	24.8	5.7	18–37
Height (cm)	175.9	6.9	164.5–188.0
Weight (kg)	74.8	10.3	57.3–95.2

subjects performed the treadmill test first, and six subjects performed the skating test first.

Testing Procedures

Before each test, height (cm) and weight (kg) were recorded with the subject barefoot and wearing exercise clothing. Maximal exercise testing was performed using discontinuous, non-graded, incremental protocols (speed protocols) for both in-line skating and treadmill running. Test endpoints were volitional exhaustion or an inability to keep up with the pace of the treadmill or the pace car.

In-line Skating Protocol

All subjects were supplied with safety equipment during testing, including wrist guards, elbow pads, and knee pads. Protective helmets could not be worn because of the headgear worn for gas collection. Rollerblade^{R} Lightning^{TM} skates were worn for all trials. Wind velocity was determined by a hand-held anemometer immediately before and periodically during the testing procedures. Testing was rescheduled if wind velocity exceeded 12.9 km·h^{-1}.

The in-line skating test was held on a 1.6-km long roadway that was newly paved (within 1 yr) and that varied in grade by no more than 0.6% (as verified by the City Engineers Office). Subjects were given a 5-min, self-paced, skating warm-up before testing began. The test began at either 14.4 or 17.7 km·h^{-1} and increased 3.2 km·h^{-1} each stage. The subjects were paced by a car equipped with a calibrated digital speedometer. Each stage was 3 min in duration and was separated by a 5-min rest period during which time the subject was driven back to the starting point. Skating velocity was verified at each stage by dropping bean bags on the roadway at the beginning and end of each stage. In between stages, the distance traveled during the stage was measured with a measuring wheel and divided by the stage length (3 min) to determine actual speed. All recorded speeds were within ±0.75 km·h^{-1} of speedometer values. The subjects were verbally encouraged to give a maximal effort, and the test was terminated when they could no longer keep up with the pace car.

Heart rates (HR) were determined every 30 s using a CIC (Model 8699) heart rate watch. Ratings of perceived exertion (RPE) were determined immediately after each stage using the 15-point Borg scale (5).

Treadmill Running Protocol

All treadmill testing was conducted on a Quinton (Model 24–72) motor driven treadmill. Treadmill speed and grade were calibrated before the beginning of the study.

The protocol for the treadmill test was also an incremented speed protocol, with the grade remaining constant at 0%. Subjects were given a 5-min warm-up at a self-selected speed and 0% grade. The test began at 9.6, 11.2, or 12.8 km·h^{-1} and was increased 1.6 km·h^{-1} every stage until the subject reached volitional exhaustion. Each stage was 3 min in length and was separated by a 5-min rest period. The subjects were given verbal encouragement to give a maximal effort. Heart rates were recorded every 30 sec using a telemetry-based HR watch (CIC, model 8699), and ratings of perceived exertion (RPE) were recorded during the last 60 s of each stage.

Gas Collection

For all testing, expired gases were collected into 200 liter (l) meteorologic balloons using a Hans Rudolph non-rebreathing valve connected to a Collins 3-way valve. Gases were collected during the last 30 sec of each stage. During the in-line skating test, the subjects wore the gas collection apparatus on a shoulder harness, with the meteorologic balloon attached to a frame on the back, and the Collins 3-way valve strapped across the front of the chest with elastic bandage (Fig. 1). The gas collection was initiated and terminated by the skater on the verbal command of a researcher who was riding in the pace car. The valve was easy to turn in either direction and offered no interference with the subject's skating technique. The subjects were given an instruction period to learn how to operate the valve properly and a practice skating period with the collection device in place to become accustomed to using the valve during skating. The weight of the backpack and gas collection apparatus was 1.1 kg.

During the treadmill running test the gas collection device was located off of the treadmill, and a researcher initiated and terminated gas collection.

Gas Analysis

Expired volumes were determined by pumping the air contained in the meteorologic balloons through a standard dry gas meter using a 7-l calibration syringe. The dry gas meter had been previously calibrated with analysis of various known volumes in meteorologic balloons and with a 120-l Tissot tank. The gas meter was found to be within ±0.5 l for volumes up to 200 l. For the in-line skating tests, volume determination was performed in the field, whereas for the treadmill testing measurements were made in the laboratory.

For the determination of expired gas fractions a sample of gas was transferred from the meteorologic balloons

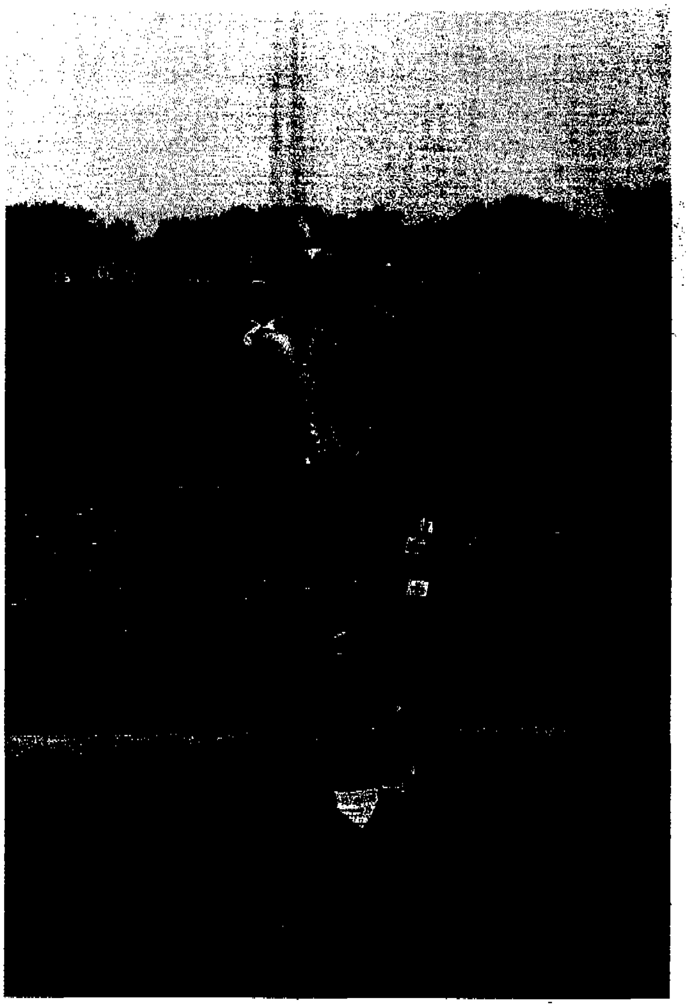

Figure 1—Picture of a subject wearing the gas collection apparatus while in-line skating.

into 1.5-l mylar balloons (commercially available from Anagram International Inc., Minneapolis, MN), using the 3-way valve and calibration syringe set-up. The mylar balloons had previously been tested for O_2 and CO_2 diffusion over a 5-h period. The balloons did not show any change in gas fractions when stored for up to 5 h. The 1.5 l of air that was removed for determination of gas fractions was accounted for by adding it to the measured expired volume. Gas samples from the in-line skating test were collected in the field and transported back to the laboratory for analysis.

The expired gases contained in the mylar balloons were analyzed for oxygen and carbon dioxide fractions using Beckman OM-11 and Beckman LB-2 analyzers. The analyzers were calibrated against known gas concentrations (determined by the micro-Scholander technique) immediately before and after analyzing each gas sample. All gas samples were analyzed for percentage of O_2 and CO_2 within 2 h of gas collection.

Statistical Analysis

Standard descriptive statistics were used to define the subject population. Paired *t*-tests and Pearson product moment-correlations were performed on maximal values to determine whether there were significant differences between in-line skating and treadmill running. Individual linear regressions were calculated for each subject to describe the relationship between HR/$\dot{V}O_2$, $\dot{V}_E$/$\dot{V}O_2$, RER/$\dot{V}O_2$, and RPE/$\dot{V}O_2$ for each modality.

TABLE 2. Comparison of maximal values for in-line skating versus treadmill running.

	In-line skating $\bar{X}$ ± SD	**Treadmill Running** $\bar{X}$ ± SD	r	**Difference (%)**
VO_2 (L · min^{-1}	4.19 ± 0.682	4.44 ± 0.686	0.77	−0.25 (5.6)*
VO_2 (ml · kg^{-1} · min^{-1})	56.8 ± 9.69	59.9 ± 8.53	0.79	−3.1 (52.)
V_E (L · min^{-1})	138.3 ± 20.88	144.1 ± 27.93	0.66	−5.8 (4.0)
RER	0.97 ± 0.07	1.00 ± 0.04	0.63	−0.03 (3.0)
HR (bpm)	189 ± 10.1	194 ± 9.0	0.89	−5 (2.6)*
RPE	18.4 ± 1.15	19.1 ± 0.05	0.78	−0.7 (3.8)

*Significant difference between modalities ($P<0.05$).

RESULTS

Maximal speeds (mean ± SD) attained during in-line skating and treadmill running were 25.8 ± 1.84 km·h^{-1} and 17.6 ± 1.85 km·h^{-1}, respectively. Wind velocity during the in-line skating tests averaged 6.1 ± 2.79 km·h$^{-1\cdot}$ Ambient temperature averaged 22.6 ± 1.35 degrees C for the treadmill tests and 27.2 ± 1.96°C for the in-line skating rests, respectively. A comparison of the maximal values measured during in-line skating and treadmill running are presented in Table 2.

Absolute $\dot{V}O_{2max}$ (l·min^{-1}) and relative $\dot{V}O_{2max}$ (ml·kg^{-1}·min^{-1}) were both approximately 5% lower for in-line skating compared to treadmill running, with the significance values being $P = 0.045$ and $P = 0.055$, respectively. Maximal heart rate was 5 b·min^{-1} lower ($P < 0.05$) for in-line skating versus treadmill running. There were no significant differences in maximal $\dot{V}_E$ (l·min^{-1}), RPE or RER between modalities. Correlations between maximal treadmill and in-line skating values ranged from 0.66 to 0.89.

Results of the regression analysis are presented in Figures 2–5. There were no significant ($P > 0.05$) differences in the slope and y-intercept of the HR/$\dot{V}O_2$ line between modalities (Fig. 2). This indicates that at a given exercise HR, there was a similar metabolic load during both in-line skating and treadmill running. Similarly, there was no significant ($P > 0.05$) difference in the RPE/$\dot{V}O_2$ relationship between modes (Fig. 3). At any given level of $\dot{V}O_2$, subjects perceived the effort to be almost identical for the two exercise conditions.

There was no significant ($P > 0.05$) difference in the RER/$\dot{V}O_2$ relationship (Fig. 4); however, there was a difference ($P < 0.05$) in the slope and y-intercept of $\dot{V}_E$/$\dot{V}O_2$ lines between modes (Fig. 5). At lower levels of $\dot{V}O_2$, $\dot{V}_E$ is slightly higher for in-line skating. At similar levels of $\dot{V}O_2$, $\dot{V}_E$ was higher for in-line skating. It should be noted, however, that even though there was a signif-

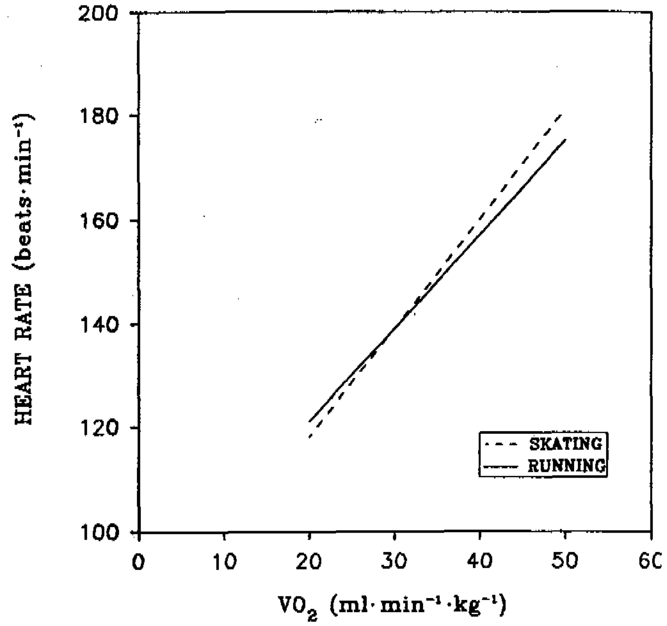

Figure 2—Relationship between heart rate (HR, beats·min^{-1}) and oxygen uptake ($\dot{V}O_{2max}$, ml·min^{-1}·kg^{-1}) for in-line skating and running. Regression equations—in-line skating: HR = 2.12 ($\dot{V}O_2$) + 75.3; running: HR = 1.81 ($\dot{V}O_2$) + 84.3.

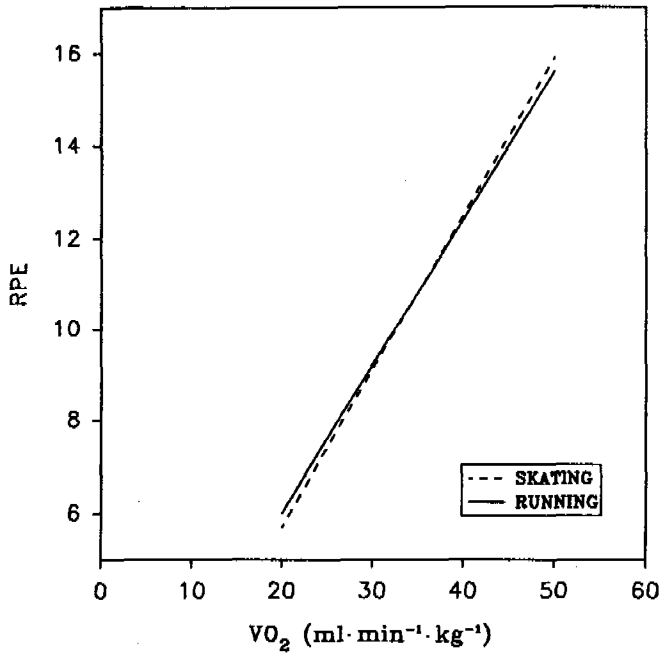

Figure 3—Relationship between rating of perceived exertion (RPE) and oxygen uptake ($\dot{V}O_{2max}$, ml·min^{-1}·kg^{-1}) for in-line skating and running. Regression equations—in-line skating: RPE = 0.340 ($\dot{V}O_2$) − 1.14; running: RPE = 0.321 ($\dot{V}O_2$) − 0.486.

icant difference between in-line skating and running, the greatest difference at any workload was approximately 5 l·min^{-1}.

DISCUSSION

The $\dot{V}O_{2max}$ values measured during treadmill running (59.9 ml·kg^{-1}·min^{-1}) in the present study are similar to values reported in the literature for similarly aged subjects (3,12,17). There is limited information in the literature regarding the maximal responses to in-line skating. In the present study, in-line skating elicited $\dot{V}O_{2max}$ values of 4.19 l·min^{-1} and 56.8 ml·kg^{-1}·min^{-1}. These values are slightly higher than the results of de Boer et al. (6) who reported $\dot{V}O_{2max}$ values of 3.93 l·min^{-1} and 53.3 ml·kg^{-1}·min^{-1} on speed skaters skating at 25.9 km·h^{-1} using in-line skates. Results similar to those in the present study were reported by Ferguson et al. (7) on hockey players skating on ice. They reported $\dot{V}O_{2max}$ values of 4.06 l·min^{-1} and 55.1 ml·kg^{-1}·min^{-1}, respectively, skating at speeds of 26.5 km·h^{-1}.

We found slightly higher maximal values for $\dot{V}O_{2max}$ and maximal HR treadmill running compared to in-line skating. The question arises as to whether these are real differences or are related to some other factor. Hoffman (8) suggests that because of technological advances in wheel design and materials, in-line skates may not provide enough rolling resistance or drag to the skater, thus reducing the physiologic demand at any given speed. This could be compensated for by simply increasing velocity to attain a higher $\dot{V}O_2$. However, at maximal levels of exertion it may become biomechanically or technically difficult to skate fast enough at 0% grade to maximally challenge the cardiovascular system.

The maximal RER values measured during this study were 1.00 and 0.97 for treadmill running and in-line roller skating, respectively. These values are below those considered to represent a maximal effort during $\dot{V}O_{2max}$ testing (13,14). The subjects in this study were highly motivated during all testing procedures, and it was felt that the subjects performed to the best of their ability. At the maximal workloads most subjects were unable to finish the stage because of exhaustion or inability to keep up with the speed of the treadmill or pace car. Also, RPE values exceeded 18 on all tests.

A possible explanation for the lower RER values in the present study could relate to the type of protocol used, because differences in maximal RER values have been reported between both continuous and discontinuous protocols and graded versus speed protocols. This study used discontinuous, level (speed) protocols for both the in-line skating and treadmill tests. McArdle et al. (12) found significant differences between RER values measured during continuous and discontinuous treadmill running protocols. They found a maximal RER value of 1.16 during continuous treadmill testing versus 1.07 during discontinuous testing. Weltman et al. (17) found a maximal RER of 0.97 using a continuous, level treadmill protocol compared to 1.11 measured during a continuous, graded protocol. Thus, the lower maximal RER values in the present study are probably more a function of the type of protocol used as opposed to a lack of effort on the part of the subjects.

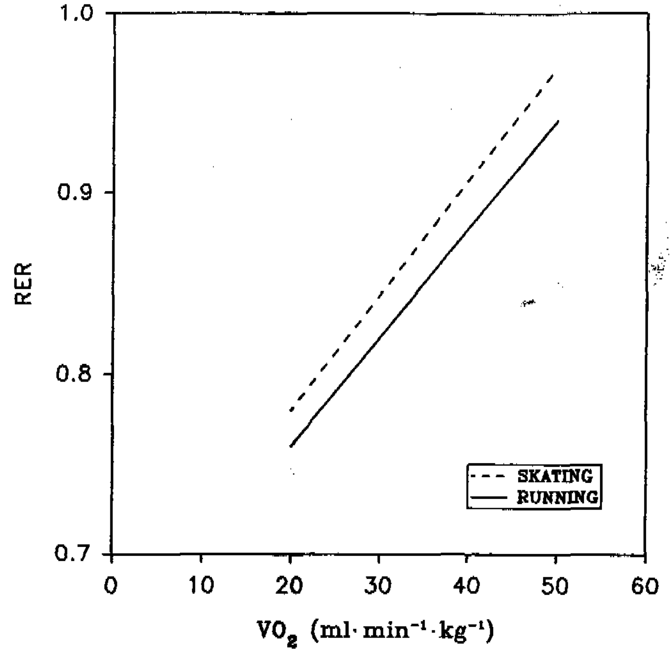

Figure 4—Relationship between respiratory exchange ratio (RER) and oxygen uptake ($\dot{V}O_{2max}$, ml·min^{-1}·kg^{-1}) for in-line skating and running. Regression equations—in-line skating: R = 0.0063 ($\dot{V}O_2$) + 0.656; running: R = 0.0061 ($\dot{V}O_2$) + 0.633.

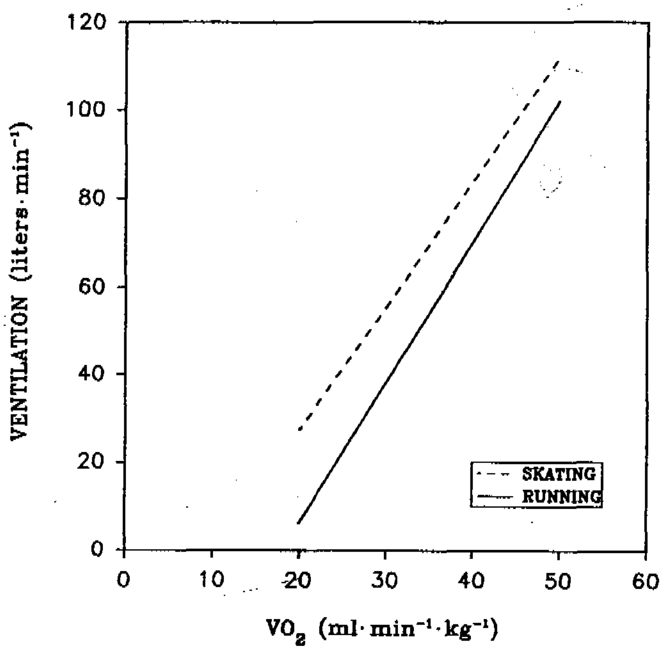

Figure 5—Relationship between ventilation (V_E, l·min^{-1}) and oxygen uptake ($\dot{V}O_{2max}$, ml·min^{-1}·kg^{-1}) for in-line skating and running. Regression equations—in-line skating: V_E = 2.82 ($\dot{V}O_2$) − 29.1; running: V_E = 3.19 ($\dot{V}O_2$) − 57.5.

In the present study, submaximal oxygen consumption and HR values for in-line skating were almost identical to those reported by Hoffman et al. (9) at similar velocities. At 14.6 km·h^{-1}, they reported HR and $\dot{V}O_2$ values of 133 bpm and 26.9 ml·kg^{-1}·min^{-1} (compared to 133 bpm and 26.7 ml·kg^{-1}·min^{-1} in the present study) and at 18.0 km·h^{-1} found values of 153 bpm and 35.7 ml·kg^{-1}·min^{-1} (vs 149 bpm and 34.5 ml·kg^{-1}·min^{-1} in the present study).

A linear relationship between HR and $\dot{V}O_2$ was observed for both in-line skating and treadmill running. A similar relationship has been reported for a variety of exercise modalities (4,7,10,15,16). However, Snyder et al. (15) found that HR during in-line roller skating was 10–15 bpm higher than during running or cycling at the same VO_2. Those findings were not supported by this study, as demonstrated by the similar slopes and y-intercepts of the HR/$\dot{V}O_2$ regression lines developed for in-line skating and treadmill running. A possible explanation could be the dissimilarities in methodology between the two studies. Snyder et al. used a graded treadmill protocol for the treadmill tests and a speed protocol for skating. Another possible factor could relate to the gas collection apparatus used and to the method for measuring V_E. The present study used meteorological balloons to collect expired gases for both the skating and treadmill tests. Gas volumes were then measured manually with a dry gas meter of known accuracy. In the study by Snyder et al., meteorological balloons were used for gas collection and manual analysis during the skating tests, but a Quinton Q-plex metabolic cart was used for gas analysis and volume measurements during the treadmill tests. Direct comparisons between methods in our laboratory have found that the Q-plex produces erroneously high $\dot{V}_E$ measurements relative to manual determinations of ventilatory volumes using a dry gas meter. Thus, the $\dot{V}O_2$ values obtained from the Q-plex will be overestimated. This might explain the apparent discrepancy between the two studies.

Another possible explanation could relate to differences between subjects used for the two studies. The present study used 16 males with an average age of 24.8 years. Snyder et al. used nine subjects (two males and seven females) with an average age of 30.6 years. It is possible that age and gender could have played a role in the different physiological results obtained by the two studies.

Regardless of the reason for the discrepancy between the results of Snyder et al. (15) and this study, the present findings indicate that data from treadmill exercise tests can be used to generate exercise prescriptions for in-line skating. The relationship between training heart rates and ratings of perceived exertion at any given level of $\dot{V}O_2$ were virtually identical for skating and running. This also implies that individuals would attain similar training benefits from training with each mode of exercise.

The physiologic responses during in-line skating at specific submaximal speeds are presented in Table 3. One question to be answered was whether or not in-line skating could provide a training stimulus sufficient to increase cardiorespiratory endurance. The ACSM (1) recommends exercising at 40–85% of $\dot{V}O_{2max}$ or HR re-

TABLE 3. Physiologic responses during in-line skating at submaximal speeds.

Variable	14.4 km · h^{-1} $\bar{X}$ ± SD	17.7 km · h^{-1} $\bar{X}$ ± SD	20.9 km · h^{-1} $\bar{X}$ ± SD	24.2 km · h^{-1} $\bar{X}$ ± SD
Sample size	n = 14	n = 16	n = 16	N = 15
VO_2 (L · min^{-1}	1.97 ± 0.411	2.55 ± 0.503	3.21 ± 0.510	3.83 ± 0.631
VO_2 (ml · kg^{-1} · min^{-1})	26.7 ± 4.93	34.5 ± 6.84	43.4 ± 6.41	51.4 ± 8.22
METS	7.6 ± 1.4	9.8 ± 1.9	12.4 ± 1.8	14.7 ± 2.3
V_E (L · min^{-1}	49.0 ± 11.77	65.4 ± 16.04	89.1 ± 21.06	119.1 ± 26.95
RER	0.82 ± 0.05	0.87 ± 0.06	0.93 ± 0.06	0.97 ± 0.04
HR (bpm	131 ± 19.0	149 ± 18.1	168 ± 17.5	184 ± 16.4
RPE	8 ± 1.5	11 ± 2.0	13 ± 2.0	17 ± 2.0
kcal · min^{-1}	9.5 ± 1.89	12.4 ± 2.50	15.8 ± 2.57	19.0 ± 3.21

serve, or 55–90% of maximal HR, to improve aerobic capacity.

As indicated in Table 3, the skating speeds of 14.4–24.2 km·h^{-1} resulted in $\dot{V}O_2$ values of 26.7 to 51.4 ml·kg^{-1}·min^{-1}, which should be sufficient to attain a training threshold in most subjects. In our subjects, skating between 17.7–20.9 km·h^{-1} corresponded to approximately 60–75% of $\dot{V}O_{2max}$ or 75–90% of HRmax, which are common training intensities and within the guidelines recommended by ACSM (1). Accordingly, these speeds corresponded to values of 11–13 on the Borg RPE scale. ACSM recommends that intensities in this range be used to maximize cardiorespiratory training.

Even though the attained $\dot{V}O_2$ values in the present study were fairly high, they may not represent adequate training intensities for highly trained individuals. Another factor to consider is that achieving and maintaining the speeds necessary to achieve these levels of exertion is difficult and may be inherently dangerous. Therefore, very fit individuals may need to skate on a grade to adequately challenge themselves (9).

Another major goal of most exercise programs is to lose body weight. Across the speeds studied in the current investigation, subjects expended 9.5 to 19.0 kcal·min^{-1}. These values are within the range of most exercise modalities currently used (e.g., walking, running, and cycling) for exercise training. For example, a 70 kg male walking 7.3 km·h^{-1} at 5% and 10% grade would expend 9.24 and 13.1 kcal·min^{-1}, respectively. Running at 9.7, 12.9, and 16.1 km·h^{-1} at 0% grade would expend 12.5, 16.2, and 20 kcal·min^{-1}, respectively for the same individual. Cycling at the rates of 8.9 and 15.1 km·h^{-1} would expend 4.7 and 7.4 kcal·min^{-1} (1,11). Thus in-line skating would appear to be another exercise alternative for people trying to control body weight.

SUMMARY

The physiologic and perceptual responses to submaximal and maximal in-line skating were found to be similar to those attained during treadmill running. Any differences in maximal values probably relate to biomechanical limitations associated with attainable skating speed when skating on level terrain. The data also show that in-line skating at various speeds provides a wide ranged of exercise intensities and should provide an adequate stimulus to improve aerobic capacity and promote weight control in most individuals.

The authors would like to thank the following people: Dr. Patty Freedson from the University of Massachusetts-Amherst for her editorial comments regarding the manuscript; Dr. Bruce Erdmann of Gundersen Clinic, La Crosse, Wisconsin for helping with the design of the study; and Virginia Fisher for typing of the manuscript.

This study was partially supported by Rollerblade, Inc., which supplied Lightning™ brand skates for the study.

Address for correspondence: John P. Porcari, Ph.D., La Crosse Exercise and Health Program, Room 221, Mitchell Hall, University of Wisconsin-La Crosse, La Crosse, WI 54601.

REFERENCES

1. American College of Sports Medicine. *Guidelines for Exercise Testing and Prescription*, 4th Ed. Philadelphia, Lea & Febiger, 1991, p. 96.
2. American Sports Data, Inc. Hartsdale, New York. *Phys. Sports Med.* 19(6):49, 1991.
3. Astrand, P. O. and K. Rodahl. *Textbook of Work Physiology*, 3rd ed. New York, McGraw Hill, 1986, pp. 330–341.
4. Astrand, P. O. and B. Saltin. Maximal oxygen uptake and heart rate in various types of muscular activity. *J. Appl. Physiol.* 16: 977–981, 1961.
5. Borg, G. Perceived exertion as an indicator of somatic stress. *Scand. J. Rehabil. Med.* 2:92–98, 1970.
6. De Boer, R. W., E. Vos, W. Hutter, G. De Groot, and G. J. Van Ingen S. Physiological and biomechanical comparison of roller skating and speed skating on ice. *Eur. J. Appl. Physiol.* 56:562–569, 1987.
7. Ferguson, R. J., G. G. Marcotte, and R. R. Montpetit. A maximaloxygen uptake test during ice skating. *Med. Sci. Sports* 1:207–211, 1969.
8. Hoffman, M. D. Physiological comparisons of cross-country skiing techniques. *Med. Sci. Sports Exerc.* 24(9):1023–1032, 1992.
9. Hoffman, M. D., G. M. Jones, B. Bota, M. Mandli, and P. S. Clifford. In-line skating: Physiological responses and comparison with roller skiing. *Int. J. Sports Med.* 13(2):137–144, 1992.
10. Margaria, R., P. Cerretelli, P. Aghemo and G. Sassi. Energy cost of running. *J. Appl. Physiol.* 18:367–370, 1963.
11. McArdle, W. D., F. I. Katch, and V. L. Katch. *Exercise Phys-*

iology: Energy, Nutrition, and Human Performance, 3rd ed. Philadelphia: Lea & Febiger, 1991, pp. 804–811.

12. McArdle, W. D., F. I. Katch and G. S. Pechar. Comparison of continuous and discontinuous treadmill and bicycle tests for max VO_2. *Med. Sci. Sports* 5:156–160, 1973.
13. McConnell, T. R. Practical considerations in the testing of VO_2max in runners. *Sports Med.* 5:57–68, 1988.
14. Shepard, R. J. Tests of maximum oxygen intake—a critical review. *Sports Med.* 1:99–124, 1984.
15. Snyder, A. C., K. P. O'Hagen, P. S. Clifford, M. D. Hoffman, and C. Foster. Exercise responses to in-line skating: Comparisons to running and cycling. *Int. J. Sports Med.* 14(1):38–42, 1993.
16. Taylor, H. L., E. Buskirk, and A. Henschel. Maximal oxygen intake as an objective measure of cardio-respiratory performance. *J. Appl. Physiol.* 8:73–80, 1955.
17. Weltman, A., D. Snead, P. Stein, R. Seip, R. Schurrer, R. Rutt and J. Weltman. Reliability and validity of a continuous incremental treadmill protocol for the determination of lactate threshold, fixed blood lactate concentrations, and VO_2max. *Int. J. Sports Med.* 22:26–32, 1990.