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Original Research

Energy Expenditure and Muscular Recruitment Patterns of Riding a Novel Electrically Powered Skateboard

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ABSTRACT

International Journal of Exercise Science 13(4): 1783-1793, 2020. Analysis of metabolic gas exchange and muscular output measures have enabled researchers to index activity intensity and energy expenditure for a myriad of exercises. However, there is no current research that investigates the physiological demands of riding electrically powered skateboards. The aim of this study was to measure the energetic cost and muscular trends of riding a novel electrically powered skateboard engineered to emulate snowboarding on dry-land. While riding the skateboard, eight participants (aged 21-37 years, 1 female) donned a portable breath-by-breath gas analyzer to measure energy expenditure (*mean* = 12.5, *SD* = 2 kcal/min), maximum heart rate (*mean* = 158, *SD* = 27 bpm), and metabolic equivalent (*mean* = 10.5, *SD* = 2 kcal/kg/h). By comparison, snowboarding has a metabolic equivalent (MET) of 8.0. Per the *Compendium of Physical Activities* guidelines, the predicted MET values for riding an electrically powered skateboard qualifies as vigorous-intensity activity. Four participants additionally wore a surface EMG embedded garment to record the percentage of maximum voluntary contraction (%MVC) of lower limb muscle groups. The inner quadriceps had the most pronounced mean peak muscle activation of 145%MVC during frontside and 164%MVC during frontside turns. EMG recordings showed 11.7%MVC higher utilization during backside turns compared to frontside turns while riding the electrically powered skateboard, which is similar to trends observed in alpine snowboarders. Therefore, electrically powered skateboards may be a promising technology for snowboarders and non-snowboarders alike to burn calories and increase physical activity year-round.

KEY WORDS: Exercise, indirect calorimetry, metabolic, electromyography, snowboard

INTRODUCTION

Methods of active transportation, such as bicycling and skateboarding, require human effort and exertion and therefore are commonly used as instruments of exercise. A recent study found that electrically assisted bike users had similar, if not greater, physical activity gains compared to their traditional cyclist counterparts, possibly secondary to increased frequency and duration of use (2). As of 2020, less than 20% of adolescents adequately perform aerobic activity and less than 20% of adults adequately perform both aerobic and muscle building activities, as outlined by the Physical Activity Guidelines for Americans (PAG) (4). Physical activity has been shown to be essential for chronic disease prevention, personal wellness, and mental health (16). A recent study investigating the effects of regular Leisure-Time Physical Activity (LTPA) on all-cause mortality among more than 300,000 participants found that those who engaged in the highest amount of LTPA at least 2-8 hours per week in adulthood had a 34% to 42% lower risk of mortality than inactive individuals (12). Furthermore, those who increased their LTPA in later stages of life had mortality risks as low as those who had maintained similar levels of LTPA throughout their life (12). Therefore, characterizing novel forms of effective exercise, such as riding an electrically powered skateboards, may contribute to greater awareness and participation in LTPA.

One commercially available electrically powered skateboard (Summerboard®; New Leif Tech, Stanton, CA, USA.) is a 6-wheeled street board designed to reproduce the riding mechanics of a snowboard on dryland while controlled with a handheld wireless remote (Figure 1). It contains four traditional street board wheels and two omnidirectional centerwheels that enable 360-degree rotation while maintaining a constant velocity – an essential snowboarding characteristic which was previously unavailable to street boards. Preliminary snowboarding data suggests board control, maneuvering, and balance require a sustained muscular activation and energetic demand. Specifically, the performance of frontside (shifting weight anteriorly) and backside (shifting weight posteriorly) turns has been shown to activate the muscles of the lower limbs (18). Although the board was engineered to emulate snowboarding, it is currently marketed as a recreational, electrically powered mode of transportation, similar to the common electric skateboard (13).

In a prospective, exploratory study of eight physically active subjects, we investigated the energy expenditure (EE) and lower limb muscle activation patterns associated with riding the Summerboard. Considering the novelty of this electronically powered skateboard, our aim was to validate its ability to mimic the physiological and mechanistic demands of snowboarding. We hypothesize that use of the Summerboard will not only encourage a comparable degree of metabolic demand and EE, but also induce similar muscular recruitment patterns relative to that of traditional snowboarding.

METHODS

Participants

Eight amateur alpine snowboarders (aged 21-37 years, 1 female) were recruited by word-of-mouth, direct email solicitation and social media (e.g., Facebook and Twitter) at the University of California, Los Angeles (UCLA). Due to the fact that there are no studies regarding this novel riding device, this investigation was treated as an exploratory study and the sample size was not formally determined. Informed consent was obtained after discussing the study procedures in detail, including voluntary participation and the right to withdraw at any point in the study.

For safety, during testing participants were required to wear pre-fitted helmets, elbow pads, knee pads, and wrist plates. The inclusion criteria included (*i*) a reported activity level of 3-5 days of exercise per week, and (*ii*) the ability to operate the electrically powered skateboard safely (validated by initial training). Exclusion criteria were (*i*) the presence of musculoskeletal, cardiovascular, pulmonary, metabolic, or other disorders that would preclude high-intensity exercise training and (*ii*) a lack of snowboarding experience. The study was conducted according to the Declaration of Helsinki and was approved by the university Institutional Review Board.

Protocol

Testing and Training: This was a prospective, exploratory study using apparently healthy, aerobically trained individuals in the Los Angeles community. The study utilized a portable gas analyzer, heart rate (HR) monitor, and surface EMG garments to track performance measures in individuals during sustained periods of riding an electrically powered skateboard. Participants underwent (*i*) training on the operation and performance of riding the electrically powered skateboard during an initial visit, followed by (*ii*) a 5-hour period of cumulative free-living training (as determined by each participant) and, finally, (*iii*) performance assessments of selected cardio-respiratory and muscular activity metrics. Individual data were collected during a 10-minute period of riding in a predetermined closed area which were used to identify lower limb muscle activation trends, caloric expenditure, and cardiopulmonary trends. We used these data to determine the relative exercise intensity and muscular activity required while riding the electrically powered skateboard. This research was carried out fully in accordance to the ethical standards of the International Journal of Exercise Science (8).

Instructional 'Free-Living' Training: The initial instructions for the electrically powered skateboard (electric-motor system and riding technique) were given to participants during a single visit prior to performance testing. Participants were taught all safety components and operational procedures described by experts within the UCLA Exercise Physiology Research Laboratory, followed by an hour-long session of active instruction while riding the board. Afterwards, participants agreed to a month-long period of free-living training in which they would not deviate from their regular physical activity and diet. Participants watched instructional videos provided by the device manufacturer followed by guided practice on turning and sliding mechanics. Initial active instruction and testing occurred at a local parking structure with predetermined criteria (at least 100m x 100m of open, flat space, no pedestrian or car traffic, smooth pavement surface spanning the entire area, and an open view for researchers to supervise testing).

Performance Assessment Calibration: Prior to individual assessment, four out of eight participants underwent calibration measurements using a surface electromyogram (EMG) system (Athos®, Redwood City, CA, USA). EMG garments were only available in one size, which accommodated 4 out of the 8 subjects. Individual users were asked to perform maximal voluntary contractions of their inner quadriceps and outer quadriceps (IQ and OQ), hamstrings (HS), and glutes (GlM). As these baseline measurements are taken when individuals are standing straight, it should be noted that individuals' power of muscle contraction regularly exceeded their baseline measure. It should also be noted that the Athos app interface does not specifically define the individual muscles are being measured; rather, it records muscle activity within the given regions. Therefore, we were unable to distinguish the individual lower limb muscles that were recruited and instead used the surface EMG-provided groups (IQ, OQ, HS, GlM). Following a portable metabolic analysis system (PNOĒ®, Palo Alto, CA, USA) calibration against ambient air conditions, the proper mask size was determined for each participant and instruction on test procedures was given.

Post-Calibration Performance Assessment: Prior to the testing phase, the "exercise" period was initialized on the metabolic analysis system mobile application to collect resting conditions, accompanied by the initialization of the surface EMG mobile application recording. The breath-by-breath gas analyzer was attached by a shoulder harness and carried on the participants' backs throughout the 10-minute measurement. Before beginning the assessment, the electrically powered skateboard device was switched to the beginner mode, in which the speed and acceleration capabilities of the board are moderated. Under this setting, riders were instructed to fully engage the accelerator on the handheld remote in order to maintain a constant speed throughout the assessment. Furthermore, this allowed for each participant to ride at the same speed with respect to each other. During this period, participants were prompted to ride in a figure-8 pattern along the length of the predetermined riding area in order to ensure that both frontside and backside turns would be performed with equal frequency in each lap. During the straightaway segments of the course, participants performed carving maneuvers—shifting from frontside to backside while maintaining a forward trajectory—that require postural and balance control. Continuous gas-exchange measurements were recorded by the metabolic analysis system. Mean values were obtained from recorded metrics for evaluation of estimated cardiopulmonary expenditure requirements. Percentage of lower-limb maximum voluntary muscle contraction (%MVC) was continuously recorded by the surface EMGs and uploaded to the paired mobile application. Peak %MVC per individual run was extracted for evaluation of muscular activity requirements.

Statistical Analysis

Energy Expenditure: EE was assessed using a validated portable indirect calorimeter (14). This lightweight (~800 g) open-circuit, portable indirect calorimeter measures breath-by-breath ventilation and concentration of expired oxygen and carbon dioxide. The gas analyzers were calibrated prior to each assessment per manufacture instructions. The participant wore a standard facemask and head support (Hans Rudolph Inc., Shawnee, KS, USA) and breathed through a microelectromechanical hot film anemometer flow sensor (for ventilation measures) that directed expired air to the gas analyzer for measures of oxygen consumption and carbon dioxide production. To allow time for participants to acclimate to the facemask and to determine if the indirect calorimeter was functioning properly, EE was measured for ~5 minutes prior to data collection. This data was not included in the analysis. Participants wore the indirect calorimeter for the duration of the riding session; however, data from the warm-up and cooldown segments were not included in the analysis. Data were transmitted via telemetry and stored in the manufacturer's cloud-based computing platform for further analysis. The average EE was calculated from measured oxygen consumption and carbon dioxide production using the abbreviated Weir equation ($EE = (3.9 \times [VO_2] + 1.1 \times [VCO_2]) \times 1.44$). Calorimeter data were reduced to 15 second segments, and average values were calculated over steady-state regions towards the end of the measurement in order to estimate average performance values. Measurements were then averaged between all recorded trials and reported as mean values. MET levels were calculated using standard values for resting EE (3.5 mL/kg/min). In order to compare this activity to similar exercises, calculated MET values were compared with those of alpine sports (i.e., snowboarding and skiing) and aerobic exercise (i.e., running and jump roping).

Heart Rate: HR was assessed by a mobile, wrist-worn HR monitor (RS400; Polar Electro Inc., Kempele, Finland). HR during the high-intensity functional training session was recorded in 15-second segments and simultaneously time-aligned with the portable indirect calorimeter.

Lower Limb Muscle Output: Peak power outputs of selected lower limb muscles during each run were measured by the validated surface EMG garments (6) and automatically uploaded to the paired mobile application on an iPhone 7® (Apple, Cupertino, CA, USA). Muscle output of the left and right lower limb muscles (IQ, OQ, HS, and GIM) were reported as the peak %MVC relative to maximal contraction performed during calibration. Average %MVC across all trials were then calculated for each represented muscle group, and then analyzed to identify patterns in muscle activation and overall muscular output.

RESULTS

Ergometry: Cardiopulmonary measurements were successfully recorded over steady-state in all trials (Table 1). Figure 1 depicts representative cardiopulmonary data collected from indirect calorimetry over the course of one trial. Gas exchange measures and HR were reported as the maximum level reached, while EE was reported as the mean across the steady-state portion of trials. The mean EE was found to be 12.5±2 kcal/min, mean total EE was 127±25 kcal, and mean MET value was 10.5±2 kcal/kg/h.

Muscle Activation: Lower limb muscular activity was measured in four out of eight trials. It is characterized by the peak %MVC measured over the entire test run relative to maximum voluntary contraction recorded per individual during calibration. Table 2 displays mean %MVC of the following muscle groups: Inner Quadricep (IQ), Outer Quadricep (OQ), Hamstring (HS), and Gluteus Maximus (GlM). The muscles are further divided by left (L) and right (R) limbs. Substantial mean peak activation was observed in both divisions of IQs, as mean %MVCs of 145±93 and 164±102 greater than that observed in frontside OQs, with a mean of 79±56. Across all represented lower limb muscle groups, the lowest measured mean %MVC was 43±22, corresponding to the
backside GlM.

Table 1. Calculated ergometry metrics for participants.

Participant	Wt. (kg)	Ht. (cm)	Age (years)	Mean EE (kcal/mi)	Total EE (kcal)	Max HR (bpm)	MET (kcal/kg/h)	% HR Max (HR/220-Age)
1	65	173	21	9.00	90.0	185	8.31	93
2	64	172	22	13.0	130.	174	12.2	88
3	84	180	22	9.20	92.0	94	6.57	48
4	81	185	37	12.3	123	160	9.11	87
5	76	182	26	12.7	133	164	10.5	85
6	74	178	23	14.8	147	162	11.9	82
7	70	173	21	15.4	154	161	13.2	81
8	72	176	24	13.9	149	164	12.4	84
Mean	73.3	177	24.5	12.5	127	158	10.5	80.9
SD	±7	±5	±5	±2	±25	±27	±2	±14

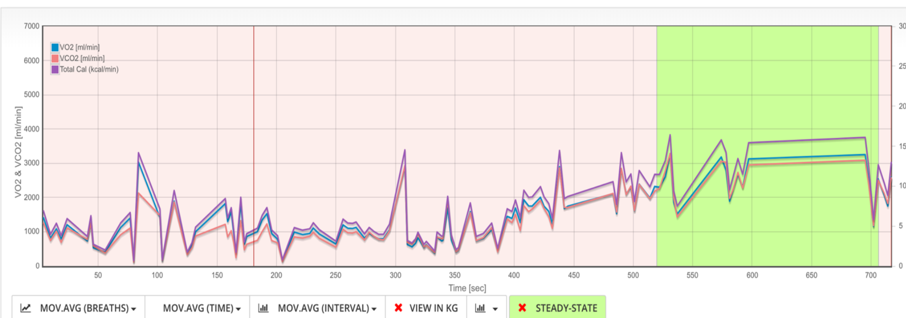

Figure 1. (Left) Representative data captured from the PNOĒ Device. VO_2 (ml/min), VCO_2 (ml/min), and Total Calories (kcal/min) are plotted for the duration of a 700 second run on the electically powered skateboard. The steady-state period is highlighted in green. (Right) Photo of Summerboard®; New Leif Tech, Stanton, CA, USA taken with permission from company website.

Table 2. Mean peak lower limb muscle activation (%MVC) with respect to stance.

	% Maximum Voluntary Contraction							
Muscle Group	IQ		OQ		HS		GlM	
Stance	F	B	F	B	F	B	F	B
Mean	145	164	79	87	52	51	49	43
SD	±93	±102	±56	±50	±18	±19	±26	±22

Indicated muscle groups: inner quadricep = IQ; outer quadricep= OQ; hamstring = HS; gluteus maximus= GlM. Stance: Frontside = F; Backside = B

DISCUSSION

To our knowledge, this study is the first to investigate and measure steady-state EE and peak muscle activation while riding a novel electrically powered skateboard. When comparing our MET value (10.5±2) to activities listed in the *Compendium of Physical Activities* (Table 3), it was found that riding the electrically powered skateboard classified as a vigorously intense form of activity (MET > 6) (1). This derived MET value implies that on average, our participants utilized over 10 times the amount of oxygen compared to their resting oxygen consumption (5, 7).

Moreover, our data suggest the METs required to ride the Summerboard exceed those of traditional skateboarding (MET = 6.0), snowboarding (MET = 8.0), and many steady-state aerobic training exercises including jump roping (MET = 10.0). Based on this data, riding the Summerboard for 30 minutes three times per week would satisfy the 75-150 minutes of vigorous exercise recommendations from the *Physical Activity Guidelines for Americans* (11). Furthermore, this data shows that riding an electrically powered skateboard may have similar, or potentially greater, metabolic requirements in comparison to common forms of aerobic training, in spite of the fact that the device is electrically powered. However, it is possible that the metabolic requirement associated with riding the Summerboard may be curtailed by higher level riding experience. Although larger cohort studies should be performed, our exploratory results suggest that Summerboard riding could supply users with a vigorous form of physical activity.

Table 3. MET values of the electrically powered skateboard compared to common activities.

	MET
Light Intensity Activities	<3
Sleeping	0.9
Sitting	1.0
Walking, 1.7 mph, level ground, strolling, very slow	2.3
Walking, 2.5 mph	2.9
Moderate Intensity Activities	3 to 6
Bicycling, Stationary, 50 watts, very light effort	3.0
Calisthenics, general, light- moderate effort	3.5
Walking, 3.4 mph	3.6
Bicycling, <10 mph, leisure, to work or for pleasure	4.0
Alpine snowboarding/skiing, downhill, light effort, active time only*	4.3
Alpine snowboarding/skiing, downhill, moderate effort, general, active time only*	5.3
Bicycling, Stationary, 100 watts, moderate effort	5.5
Skateboarding	6.0
Vigorous Intensity Activities	>6
Jogging, General	7.9
Calisthenics (e.g. pushups, sit-ups, pullups, jumping jacks), heavy, vigorous effort	8.0
Running/ jogging, in place	8.0
Alpine snowboarding/skiing, downhill, vigorous effort, general, active time only*	8.0
Cross-country skiing, moderate speed (5-7mph), moderate effort	9.0
Electrically Powered Skateboarding	*10.5*
Jump roping	10

Derived electrically powered skateboarding MET value is bolded and italicized. All other MET values were obtained from the Compendium of Physical Activity (1).

This electrically powered skateboard is aimed to emulate the riding mechanics of alpine snowboarding (13), in which the load on the leg muscles is primarily associated with the accelerative force the snowboarder exerts when turning (17). Despite the perceived similarities between riding a Summerboard and a traditional skateboard, the two activities are purportedly unique in their metabolic and muscle activation profiles. This can be explained by the fact that skateboarding requires individuals to push with one leg for propulsion, while propulsion is electrically powered in Summerboard riding. Therefore, previous research on the muscular requirements of skateboarding was not used to inform this study.

As the muscular output while snowboarding is posited to be most significant for turns (17), we hypothesized that riding a Summerboard would have similar muscular activation trends and metabolic requirements to alpine snowboarding. We collected surface EMG data in four of our participants to measure these trends and compare them to those seen in snowboarders. Surface EMG recordings conducted on alpine snowboarders showed that the average %MVC of select quadriceps muscles (i.e., rectus femoris and vastus lateralis) were greater during backside turns (18). Our study similarly showed elevated %MVC in both OQ and IQ during backside turns, suggesting that riding an electrically powered skateboard and snowboarding share similar lower body muscular recruitment. Previous thigh surface EMG recordings of 12 alpine snowboarders also indicated posterior leg muscles exert 9.9% more MVC than anterior leg muscles (18). It was found that Summerboard riders also exerted 11.7% MVC more on backside turns compared to frontside turns, further indicating similar patterns of leg muscle contribution between the two activities.

It must also be noted that in two out of four subjects, specific %MVC measured exceeds 100% — this is because all measurements recorded during trials are reported relative to subjects' initial MVC measurement during calibration of the Athos EMG garment. Therefore, mean %MVC exceeding 100 (as in mean muscle activation of inner quad regions) indicates that subjects recruited greater muscular activation in this region while actively riding during trials compared to their baseline activation during calibration. Furthermore, this method is also responsible for the large SD in %MVC data collected.

Additional EMG data in snowboarders found that %MVC of GIM in snowboarders to be 21.4±13.9 for frontside turns and 14.9±5.8 for backside turns (3). Our EMG data shows GIM %MVC of 49.3±26 for frontside turns and 43.0±22 for backside turns. The most striking difference seen is that electrically powered skateboard riders' mean %MVC was 43.4% higher for frontside turns and a 34.6% higher for backside turns. This higher %MVC could be a contributing factor in the higher caloric expenditure and MET values obtained for Summerboard riding, compared to snowboarding.

Differences between the board-surface interface may also contribute to a higher MET value for electrically powered skateboard riding compared to snowboarding (the former being a wheel-pavement interface and the latter a board-snow interface). Skiing mechanics theory attributes a lift effect to skiing and snowboarding which contributes to a lower frictional coefficient in the board-snow interface (19,20). The absence of this lift effect in pavement gives it a subsequently higher friction coefficient, and therefore more user generated force is required to turn the board to overcome the wheel-pavement friction. Future studies should explore the impact that different surfaces play on the user generated force required to operate the electrically powered skateboard. Furthermore, the average % HR_{max} of 80.9% falls into the category of high intensity exercise (60-84%) as described by the Physical Activity Guidelines for Americans (10,15). This is part may also rationalize the high metabolic cost and MET value associated with riding the Summerboard.

As previously mentioned, is it possible that more experienced snowboard athletes and or Summerboard riders may have already adapted to similar movements thus requiring less EE and muscular activation while riding. Similarly, less experienced riders may have less developed stabilizer muscles and, as a result, they must recruit more musculature in order to maneuver. Subject #3, for example, was the most experienced rider in our cohort with twelve years of self-reported snowboarding experience. Comparatively, all other subjects had one to four years of experience. This difference in level of experience can explain the measured lower max HR and MET value of subject #3 compared to the others (Table 1). This can be attributed to adaptation to the similar movements and training of the specific stabilizer muscles needed to perform the activity, leading to lower exertion and energetic requirements. It is important to note that even though subject #3 had a lower MET value at 6.57 compared to the mean of 10.5, it is still classified as vigorous intensity exercise. While the degree of specific influences on performance measures among the general population is unknown, this cohort demonstrated substantial metabolic and muscular activity while riding the electrically powered skateboard across a broad range of riding experience.

Future studies should include larger cohorts and look at the EE of riding the electrically powered skateboard in a straight path, mimicking a more common form of recreational riding. In this study, steady-state riding captured within the 10-minute measurement was used in order to represent average values for EE and thus, the aerobic cost of longer riding periods may be important for further characterizing this exercise. Furthermore, studies should investigate the EE associated with riding a traditional electrically powered skateboard.

The results of this study suggest that aerobically trained individuals riding this electrically powered skateboard with specified carving maneuvers may achieve levels of vigorous exercise demanding high EE. The metabolic equivalent value from riding this device is comparative to other aerobic exercises. Given that leisure physical activity improves fitness and aids in the prevention of cardiovascular disease (9), additional characterization of novel technology, such as the Summerboard, can promote public awareness and community health. As exercise seems to be increasingly engineered out of society, it is important to note that physical activity and electric modes of transportation are not mutually exclusive. The electrically powered skateboard in this study exemplifies how exercise can be integrated with technology and tailored to fit unique interests.

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