Physiological Demands of Off-Road Vehicle Riding

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ABSTRACT

BURR, J. F., V. K. JAMNIK, J. A. SHAW, and N. GLEDHILL. Physiological Demands of Off-Road Vehicle Riding. *Med. Sci. Sports Exerc.*, Vol. 42, No. 7, pp. 1345–1354, 2010. **Introduction**: The purpose of this study was to characterize the physiological demands of recreational off-road vehicle riding under typical riding conditions using habitual recreational off-road vehicle riders (*n* = 128). **Methods**: Comparisons of the physical demands of off-road vehicle riding were made between vehicle types (all-terrain vehicle (ATV) and off-road motorcycle (ORM)) to the demands of common recreational activities. Habitual riders (ATV = 56, ORM = 72) performed strength assessments before and after a representative trail ride (48 ± 24.2 min), and ambulatory oxygen consumption was measured during one lap (24.2 ± 11.8 min) of the ride. **Results**: The mean $\dot{V}O_2$ requirement (mL·kg^{-1}·min^{-1}) while riding an off-road vehicle was 12.1 ± 4.9 for ATV and 21.3 ± 7.1 for ORM (P = 0.002), which is comparable to the $\dot{V}O_2$ required of many common recreational activities. Temporal analysis of activity intensity revealed approximately 14% of an ATV ride and 38% of an ORM ride are within the intensity range (>40% $\dot{V}O_2$ reserve) required to achieve changes in aerobic fitness. Riding on a representative course also led to muscular fatigue, particularly in the upper body. **Conclusions**: On the basis of the measured metabolic demands, evidence of muscular strength requirements, and the associated caloric expenditures with off-road vehicle riding, this alternative form of activity conforms to the recommended physical activity guidelines and can be effective for achieving beneficial changes in health and fitness. **Key Words:** MOTORCYCLE, ATV, HEALTH-RELATED FITNESS, ALTERNATIVE PHYSICAL ACTIVITY, METABOLIC, AEROBIC

Examination of the physiological and psychological characteristics of recreational off-road vehicle riders has demonstrated that persons who are habitual off-road riders have some health, fitness, and quality-of-life advantages over the normative population (Burr et al., unpublished observations). Many of these changes, which are vehicle-type–dependent (all-terrain vehicle (ATV) vs off-road motorcycle (ORM)), manifest in riders with increasing age and result from years of involvement (Burr et al., unpublished observations). It is unclear, however, if the observed attributes of Canadians who habitually ride recreational off-road vehicles are different from the normative Canadian profile as a result of participation in the off-road riding itself, or if some underlying selection factor is responsible for the group differences. To understand more fully the health-related fitness consequences of participation in recreational off-road vehicle riding, an evaluation of the immediate physical demands of riding is required.

The majority of scientific literature pertaining to the physical demands of off-road vehicle riding is specific to "motocross" racing, which is a competitive form of ORM riding in which riders navigate a manmade track consisting of obstacles and jumps. The HR response (≥90% HR_{max}) and oxygen consumption (70%–95% $\dot{V}O_{2max}$) associated with motocross racing indicate that this sport is of extremely vigorous intensity and is associated with a considerable metabolic demand and physiological stress (3,19,20). However, the physical demands noted in competitive sprint-based motocross, which typically lasts <30 min, likely do not reflect the demands of the average recreational trail ride, which is of considerably longer duration. It is also unlikely that the average Canadian recreational off-road vehicle rider chooses to cover riding terrain of the same difficulty or at the same speed as competitive motocross racers do. To date, recreational ORM and ATV riding have not been examined.

The purpose of this study was to characterize the physiological demands of recreational off-road vehicle riding under typical riding conditions using habitual recreational off-road vehicle riders. A secondary purpose was to make comparisons of the physical demands of off-road vehicle riding between vehicle types to common recreational activities. We hypothesized that the physical demands of riding an off-road vehicle would be comparable to other, more

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commonly accepted, recreational activities and that the physical demands of riding an ORM would be greater than those involved in riding an ATV. We further hypothesized that the demands of riding an off-road vehicle would be of sufficient intensity to be associated with health-related fitness adaptations.

MATERIALS AND METHODS

Assessments

Composition of a typical ride. A nationwide survey was distributed to off-road vehicle riders (N = 303; ATV = 141, ORM = 162), soliciting information regarding frequency and duration of occurrence of terrain features normally encountered on a ride. This informed the composition of a representative riding trail to be used during the assessment of physical demands. To clarify survey results and ensure accuracy when designing a representative trail riding course, focus groups were held (ATV = 17, ORM = 20) to elaborate on survey responses, aid with interpretations, and clarify questions of the research team. Before measuring the physical demands of riding, the lead researcher visited each selected site and, with the guidance of an expert familiar with the local trails, developed a representative off-road trail circuit conforming to the information gained from the nationwide survey. Each course was scaled such that one lap contained all terrain types of a typical ride and took an average rider approximately 20 min to complete. A ride length of 20 min was selected because it allowed sufficient time for data collection without causing undue discomfort to the participants who were required to wear the measurement apparatus throughout the test. Testing took place in a variety of summer weather conditions, with the majority of days clear and sunny with a mean temperature of 28°C (range = 16°C–34°C).

Physical demands analysis. ***Participants.*** Habitual recreational off-road vehicle riders (n = 128) older than 16 yr, of both genders and both vehicle types (ATV: males = 43, females = 13; ORM: males 57, females = 15), were recruited from local off-road riding clubs. Male participants were 44 ± 12.9 yr, 179.1 ± 6.5 cm, and 91.7 ± 20.8 kg, and female participants were 38 ± 12.1 yr, 165.9 ± 7.4 cm, and 72.2 ± 18.0 kg. Mean participant age was 41 ± 12.5 yr, with representation from all age groups 16–29 yr (18.8%), 30–49 yr (49.2%), and 50+ yr (32%). This study was approved by the university's human research ethics review board, and in accord with research ethics guidelines; written informed consent was provided by all participants, with those younger than 18 yr also providing parental consent after verbal explanation of procedures.

At the onset, riders were led through the trail for accommodation and safety. All riders used their own off-road riding gear and vehicle to avoid the necessity for habituation to new equipment. Before data collection, which is detailed below, participants rode laps of the course for varying amounts of time (range from 0 to 140 min, mean = 48 ± 24.2 min) at a typical riding pace. This pretesting ride volume was divided into quartiles of time (<30 min, 30–59 min, 60–89 min, and ≥90 min) and used to determine whether the demands of riding changed as the duration of a ride increased. Speed and distance were collected using portable GPS technology (T6; Suunto Oy, Vantaa, Finland). To determine the total time spent sitting and standing while riding, a subset of participants (n = 40) were monitored using a specifically designed pressure-sensitive seat switch with an automatic timing device to record the total time the rider's buttocks were not in contact with the seat. Standing time was subtracted from total ride time to calculate the sitting time.

Aerobic involvement. The acute cardiorespiratory demand of off-road riding was assessed using ambulatory oxygen consumption (COSMED Fitmate, Rome, Italy) and HR monitoring. After the pretesting ride of varying lengths, riders were monitored for one complete lap of the course. The analyzer, which has been shown to be valid and reliable for use with adults (24), was worn by participants in a backpack, with the sampling lines running from the top of the bag, over the rider's shoulder, and to the mouthpiece, which passed through the front of a specially modified helmet (Fig. 1). The mouthpiece, which contained both

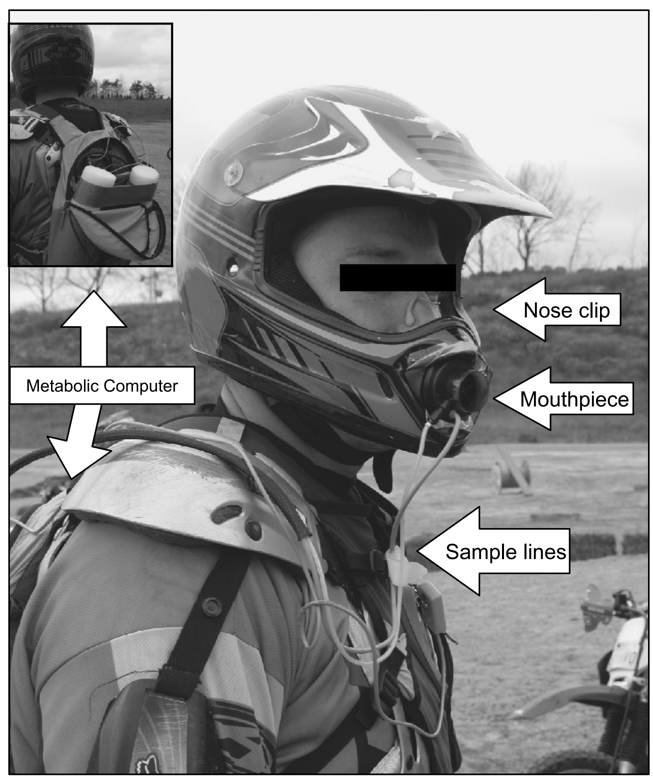

FIGURE 1—Ambulatory oxygen consumption measurement while riding an off-road vehicle. The rider's nose is plugged and all expired air is expelled through the mouthpiece which contains a volume meter and expired air sample line held in place by the modified chin guard of the helmet. *Inset top left:* Reverse angle view of the metabolic computer (with protective padding) in the backpack as worn by riders.

the open end of the expired air sample line and a flow meter, was secured in place by the chin guard of the helmet, and enough length was provided in the sampling lines that the rider's movement was unrestricted. HR was recorded using a chest strap that transmitted information to a wristwatch where it was stored. A sampling frequency of 5 s was used, on the basis of pilot study experience, to avoid data loss due to sampling noise. Data were uploaded to a computer using Suunto Training Manager Software (Suunto Oy) and were visually inspected for noise outliers. After the graphical confirmation of steady-state exercise, points that fell more than 2 SD and did not represent a systematic divergence from the mean were considered outliers and were removed.

The majority of riders (n = 90) also participated in a laboratory exercise test with analysis of expired gas using open-circuit spirometry (S-3A/II oxygen, CD-3A carbon dioxide; AEI Technologies, Pittsburgh, PA) to determine $\dot{V}O_2$ and HR relationship during a progressively ramped treadmill test to $\dot{V}O_{2max}$ using 2-min stages. Participants began walking (1.6 m·s^{-1}, 0% elevation), progressed to a slow jog (2.2 m·s^{-1}, 0% elevation), and then ramped with 0.45 m·s^{-1} increases until the individual's maximal safe running speed was reached, followed by 2% incremental increases in elevation. If subjects were unable to jog/run, the speed was adjusted to accommodate the fastest pace they could maintain, and the incline was increased incrementally as above. The test was terminated when $\dot{V}O_2$ did not increase at least 150 mL·min^{-1} with an increase in workload, when HR did not increase with increases in exercise intensity, or when the participant reached volitional fatigue and had an RPE greater than 17 on the Borg 6–20 scale (14). This allowed for comparison of the metabolic demand recorded while riding to the laboratory HR–$\dot{V}O_2$ relationship throughout submaximal to maximal workloads (Fig. 2). For analysis, the aerobic component of riding was described as both the mean %VO_{2max} and the cumulative percentage of time spent above each intensity: 40%, 50%, 60%, 70%, 80%, and 90% of $\dot{V}O_2$ reserve ($\dot{V}O_2R$). To determine whether the HR response while riding was artificially elevated above the metabolic demand of the activity, we created a linear regression of HR and $\dot{V}O_2$ for each rider to compare the riding HR with the laboratory exercise test HR, matched for oxygen consumption (Fig. 2B). The difference between riding HR and exercise test HR was examined to determine whether any group was artificially inflated.

Anaerobic involvement. A lactate sample was obtained via a finger prick blood sample from each rider at the completion of the representative course. A stopwatch was started immediately upon riding cessation, and a blood sample was obtained 1 min after riding, which allowed removal of riding gloves and preparation of the hand. A 1-min rest period protocol was used on the basis of the work of Heck et al. (13) and under the assumption that lactate would have equilibrated throughout the systemic circulation during the prolonged steady-state ride. To maintain consistency, a 1-min postexercise blood lactate sampling period was also used after the laboratory maximal treadmill test for comparison with riding values.

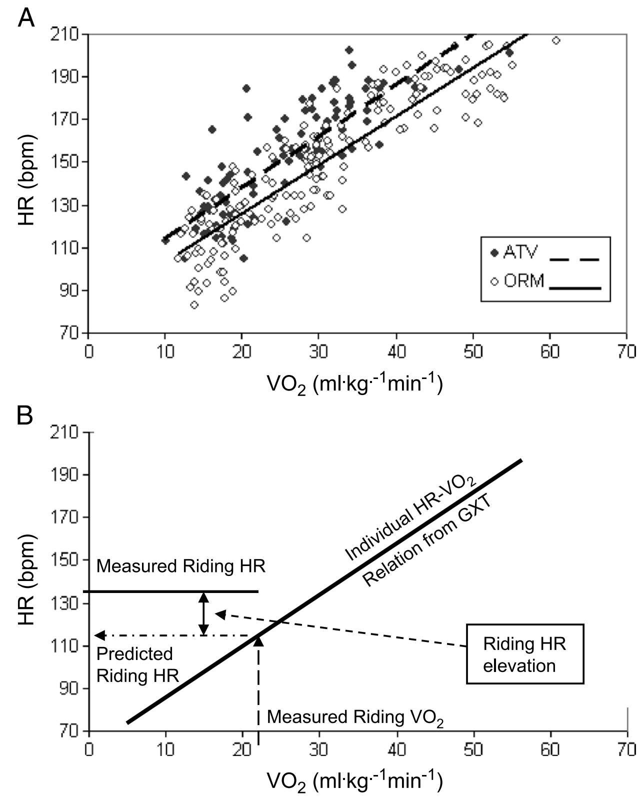

FIGURE 2—*A*, Group HR–$\dot{V}O_2$ relationship of ORM and ATV riders during a treadmill graded exercise test. Each participant is represented at walking pace (1.6 m·s^{-1}, 0% grade), jogging (2.2 m·s^{-1}, 0%), and $\dot{V}O_{2max}$. *B*, Example of the determination of an individual rider's heart rate elevation above the linear regression of HR–$\dot{V}O_2$ determined during the laboratory treadmill test.

Perceived exertion. Riders reported their RPE using the Borg 6–20 scale (6) considering the ride as a whole (RPE_{avg}) and also during the part of the ride that they considered to be the most physically demanding (RPE_{max}).

Muscular strength and power involvement. Muscular strength was assessed both before and after riding to determine whether off-road vehicle riding is associated with quantifiable strength decrements. The assumption of this testing was that if riding is a fatiguing physical activity (PA), decreases in maximal strength would be observed after a typical ride. Handgrip strength was measured using a dynamometer (Smedley Hand Dynamometer; Stoelting Co, Wood Dale, IL) adjusted to the second knuckle, and three trials were allowed per hand, alternating hands each trial with the maximum grip strength recorded. Upper body push and pull strengths were assessed using a specifically designed isometric spring-resisted device, which allowed for quantification of both push and pull strengths at a standardized elbow joint angle of 110°. Three trials were allowed, alternating push and pull with the highest value recorded.

Leg power was quantified using a four-jump repeated-jumping protocol on a digital timing mat (Just Jump; Probotics, Huntsville, AL), which has been shown to be a valid method for assessing jump height (22). Subjects were instructed to jump four times as high and as quickly as possible without pausing between jumps while keeping their hands on their hips to control for arm swing (7). This protocol allowed for the quantification of 1) average jump height; 2) time on the ground between jumps (ground time); and 3) power factor, which is the air time divided by the ground time. For analysis, postriding strength measures were subtracted from preriding measures and were expressed as a fatigue score. Using these fatigue measures, *z*-scores were calculated for each individual measure. For a greater power to detect fatigue, right and left handgrip, and push and pull strength z-scores were summed to create a composite upper body fatigue score, called the upper body fatigue index.

Statistical Analyses

Aerobic exercise intensities, riding characteristics (speed, standing time), lactate measures, deviation in riding HR from the exercise test HR–$\dot{V}O_2$ regression, and muscular fatigue scores were compared across vehicle type, gender, and age (16–29, 30–59, and >50 yr) using a 2 × 2 × 3 factorial ANOVA with *post hoc* Bonferroni comparisons. An *a priori* power calculation, using $\dot{V}O_2$ as the prime variable of interest, revealed the necessity of individual subgroup (vehicle type × gender) participation of $n \geq 13$ to achieve ≥80% power to detect group differences of 5 $mL{\cdot}kg^{-1}{\cdot}min^{-1}$. Strength measures were examined using Wilks λ repeated-measures ANOVA to determine whether strength differed before and after riding. We examined the association between total riding time including ride time before data collection and RPE using Pearson correlation to determine whether riders reported a higher RPE as a result of accumulated fatigue. Pearson correlation was further used to examine the association between RPE and end-ride lactate as well as standing time versus work of riding and average speed. All analyses were performed using SPSS software (version 16.0; SPSS, Inc., Chicago, IL). Significance for all tests was set *a priori* at $P \leq 0.05$. Results are reported as mean ± SD.

RESULTS

Composition of a Typical Ride

The components of a typical off-road trail ride by vehicle type are presented in Figure 3. Differences were reported regarding the estimated trail width selected by ATV versus ORM riders because the larger four-wheeled ATV do not fit on the narrow "single-track" trails often traveled by ORM. Riders reported a perceived importance of standing while negotiating rough and/or difficult terrain and a belief that the use of this technique would greatly affect the demand of riding. The duration of an off-road trail ride varied between vehicle types, with ORM riders reporting a typical duration of 60–120 min and ATV riders reporting 120–180 min.

Physical Demands Analysis

General riding. On average, riders required 24.2 ± 11.8 min to complete the 9.4 ± 4.0-km ride, with no difference between ATV and ORM. Riding speed (mean 25.0 ± 8.6 $km{\cdot}h^{-1}$) differed among age groups, with those in the 16- to 29-yr age group riding significantly faster (≈10 $km{\cdot}h^{-1}$) than both the 30- to 49- and >50-yr groups (P = 0.003). No relationship existed between years of riding experience and riding speed. There were no differences in riding speed between vehicle types or genders. The percentage of time spent standing on a typical ride is greater in ORM riders (62.0% ± 28.3%) than that in ATV (23.1% ± 27.1%) riders (P = 0.003), but no differences existed among

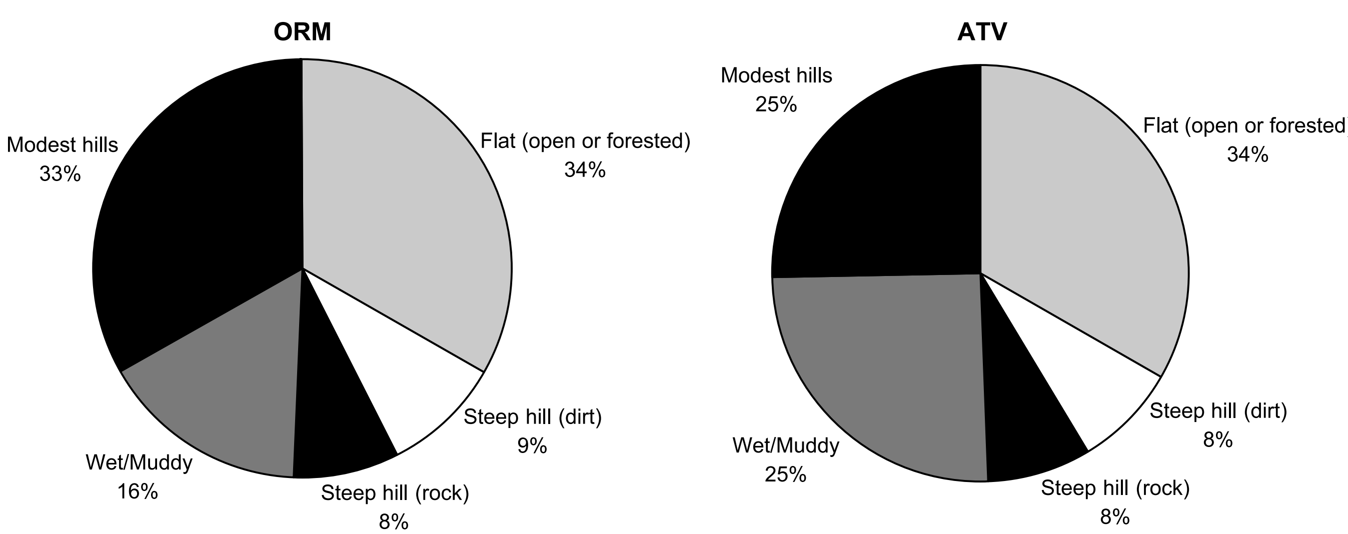

FIGURE 3—Percentage of a typical off-road ride spent navigating specific terrain features divided by vehicle type.

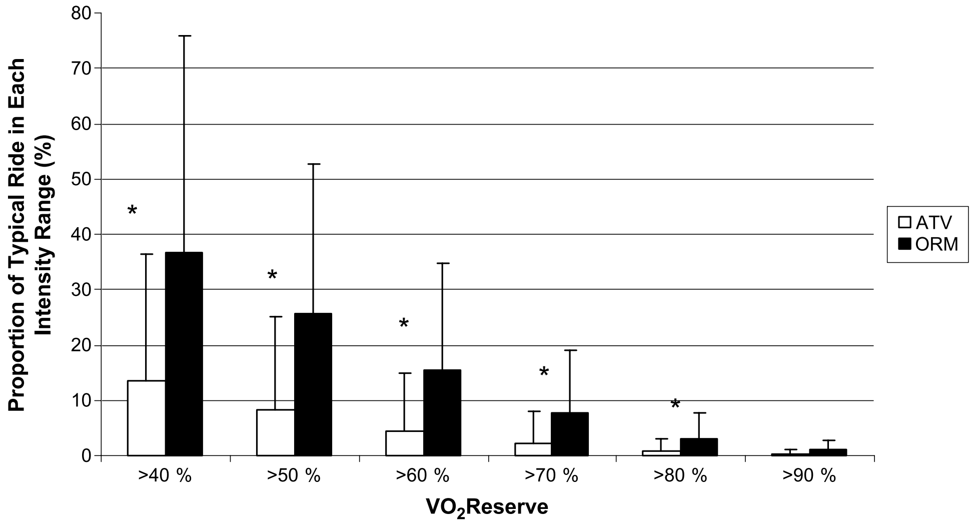

FIGURE 4—The cumulative proportion of a recreational trail ride in each exercise intensity range (%$\dot{V}O_2R$) and by vehicle type. *Significantly different proportion of ride spent at a given intensity between ATV and ORM, $P < 0.05$.

age groups or between genders. No relationship existed between time standing and riding speed or metabolic demand ($\dot{V}O_2$).

Aerobic involvement. The mean $\dot{V}O_2$ requirement while riding an off-road vehicle was significantly different between vehicle types, with a mean requirement ($mL{\cdot}kg^{-1}{\cdot}min^{-1}$) of 12.1 ± 4.9 for ATV and 21.3 ± 7.1 for ORM ($P = 0.002$). The absolute cost ($L{\cdot}min^{-1}$) of riding an ORM (1.6 ± 0.7) was higher than that required to ride an ATV (1.0 ± 0.7, $P = 0.006$). There were differences in $\dot{V}O_2$ while riding between men and women (1.5 ± 0.7 and 0.9 ± 0.5 $L{\cdot}min^{-1}$, respectively, $P = 0.001$), but no difference existed among age groups. The %$\dot{V}O_{2max}$ while riding was higher in ORM than in ATV (51.3% ± 15.3% vs 39.3% ± 19.9%, $P = 0.004$), with male riders of both vehicle types typically working at a higher %$\dot{V}O_{2max}$ than females (49.9% ± 16.9% vs 39.3% ± 18.8%, $P = 0.016$). ORM riders had a higher HR while riding compared with ATV riders (141.3 ± 22.9 vs 123.1 ± 19.4 bpm, respectively, $P = 0.003$), and there was a difference between age groups, with the youngest riders exhibiting higher HR than the oldest riders (≈9 bpm, $P < 0.05$). No association existed between the metabolic demand of riding and years of riding experience. There was also no evidence that the demands of riding change as the ride increases in duration because there was no association between $\dot{V}O_2$ and pretest ride volume.

Riding an ATV was approximately 4.6 $mL{\cdot}kg^{-1}{\cdot}min^{-1}$ easier than walking with no incline at 1.6 $m{\cdot}s^{-1}$ for ATV riders ($P < 0.001$). The same comparison between ORM participants revealed the work of riding an ORM to be harder than walking but 4.5 $mL{\cdot}kg^{-1}{\cdot}min^{-1}$ less than jogging at 2.2 $m{\cdot}s^{-1}$ with no incline ($P < 0.001$). Using linear regression, the difference between individual mean riding HR and the HR at the equivalent $\dot{V}O_2$ during the treadmill test (Fig. 2) revealed an HR elevation in both ATV (8.6 ± 20.7 bpm) and ORM (14.4 ± 20.0) in response to the riding, with no differences in the elevation by age, gender, or between vehicle types.

The metabolic demand of riding, expressed as the cumulative proportion of time spent above a given %$\dot{V}O_2R$, is presented in Figure 4. On the basis of the typical ride length ranges of 60–120 min for ORM and 120–180 min for ATV, cumulative time per riding session above each 10% increment in %$\dot{V}O_2R$ is presented in Table 1.

Anaerobic involvement. Mean postriding blood lactate was 3.4 ± 2.2 $mmol{\cdot}L^{-1}$ with no difference between vehicle types or age groups. Men (4.2 ± 2.9 $mmol{\cdot}L^{-1}$) had a significantly higher postriding lactate value than women (2.7 ± 1.8 $mmol{\cdot}L^{-1}$, $P = 0.012$). Compared with postexercise test levels, male and female ATV riders were, respectively, working at 35% (3.8/11.7 $mmol{\cdot}L^{-1}$) and 26% (2.4/9.3 $mmol{\cdot}L^{-1}$) and ORM riders were working at 39% (4.4/12.8 $mmol{\cdot}L^{-1}$) and 36% (2.9/10.9 $mmol{\cdot}L^{-1}$) of peak lactate levels while riding.

Perceived exertion. Within vehicle types, all riders rated their perceived exertion similarly with no divergence in RPE_{avg} or RPE_{max} among age groups or between genders. Considering their ride as a whole, ORM riders reported a higher RPE_{avg} (ORM = 13.5 ± 2.0 vs ATV = 11.8 ± 2.7, $P = 0.007$) and RPE_{max} (ORM = 15.5 ± 2.2 vs ATV = 13.6 ± 2.9, $P = 0.002$) than did ATV riders. RPE_{avg}

TABLE 1. Cumulative time (min) spent in each exercise intensity range (%$\dot{V}O_2R$) above the threshold required for changes in fitness (40% $\dot{V}O_2R$) during a typical 60- to 120-min ORM or 120- to 180-min ATV ride.

	Cumulative Time (min per Ride)	
Intensity (%$\dot{V}O_2R$)	ATV	ORM
>40	16.2–29.2	22.1–26.5
>50	9.8–17.7	15.4–18.5
>60	5.4–9.7	9.3–11.2
>70	2.6–4.8	4.7–5.6
>80	1.0–1.7	1.9–2.2
>90	0.4–0.6	0.7–0.8

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was similar to their RPE while jogging at 2.2 m·s^{-1} during the graded exercise test. Pretesting ride time, by quartile, showed no effect on either RPE_{avg} or RPE_{max}. There was no correlation between riding lactate and RPE_{avg} or RPE_{max}.

Muscular strength and power involvement. ORM riders showed a decrease in both left (0.7 ± 5.2 kg) and right (1.8 ± 6.6 kg) grip strength, and ATV riders showed an increase in left (1.7 ± 5.6 kg) and right (1.8 ± 6.5 kg) strength ($P < 0.05$) as a result of riding. Changes in handgrip strength in both ORM and ATV did not differ between the left and right hands, and right or left hand dominance did not relate to the increase or decrease in scores. Further, there was no influence of gender or age. Push and pull strengths decreased by 1.5 ± 13.3 and 3.4 ± 11.6 kg, respectively, in ATV riders and by 4.2 ± 17.3 and 2.6 ± 9.4 kg in ORM riders ($P < 0.05$), but these did not differ by age, gender, or vehicle type. There was a significant difference in the upper body fatigue index score between ORM and ATV because ORM fatigued to a greater extent as a result of riding ($P = 0.028$), but no differences among age categories or between sexes existed. There was no fatiguing effect of off-road riding in either jump height or power factor. However, an interaction occurred for ground time between age and sex ($P = 0.037$), such that riding caused the oldest female riders to increase ground time to a greater extent than the two younger female age groups. No such effect occurred in males.

DISCUSSION

This is the first study to conduct a detailed physiological examination of recreational off-road vehicle riding and to consider the potential health and fitness effects that participation in this activity may have on Canadians. In general, off-road riding was found to impose a true physiological demand that would be expected to have beneficial effects on health and fitness according to current PA recommendations (12,26). These objectively measured demands of off-road vehicle riding can be used to refine previously estimated levels of this type of alternative PA in future studies and in the commonly referenced compendium of PA (1).

Physical Demands Analysis

Aerobic involvement. ATV and ORM riding elevate oxygen consumption by approximately 3.5 and 6 times resting (METs), respectively. According to current American College of Sports Medicine (ACSM) guidelines (12), these MET levels are considered moderate intensity, with ATV and ORM being at the lower and upper ends of the moderate-intensity spectrum, respectively. Given the variability in the rides, some individual ATV rides would be classified as a light-intensity activity (<3 METs), and some ORM rides would be classified as vigorous-intensity activity (>6 METs) (1,12). Despite possessing a higher $\dot{V}O_{2max}$ than ATV riders (43.3 ± 8.3 vs 33.5 ± 7.1 mL·kg^{-1}·min^{-1}), ORM riders still work at a higher $\%\dot{V}O_{2max}$ while riding. Using HR alone, the demands of riding belong to the category of "hard" exercise (15), but this value is likely inflated because of riding-related psychoemotional responses (20). There was a disproportionate increase in HR compared with $\dot{V}O_2$ while riding both an ORM (14 bpm) and an ATV (9 bpm). This increase in HR was also likely influenced by repeated isometric contractions of the forearms, which have been suggested to increase HR during activities such as rock climbing (33) and motocross riding (19,20). Although exercising blood pressure was not monitored in the current study, based on both the aerobic and resistance exercise related demands of riding and the established relationship with blood pressure response (1a,21a,22a), it seems likely that systolic blood pressure would increase while riding. Combined with the effect of an inflation in HR over the objectively measured metabolic demands, it is possible that the rate pressure product increases dramatically in riders. This has potential to present a problem to those with occult heart disease (27a), and is an area for future research. ORM riders stand for a much larger portion of a typical ride compared with ATV riders. It is commonly believed by riders that standing allows them to travel over rough ground more quickly and easily. However, this was not confirmed in the current study because we found no relationship between standing time and speed or $\dot{V}O_2$.

Comparison of $\dot{V}O_2$ while riding an ATV with submaximal treadmill $\dot{V}O_2$ values revealed the aerobic work of riding an ATV to be less taxing than walking at 1.6 m·s^{-1}. Because the habitual ATV riders in the current study were not avid exercisers, reached $\dot{V}O_{2max}$ at relatively low treadmill workloads, and had perceptibly inefficient gaits, it is likely that the work of walking was exaggerated. This highlights the potential importance of alternative PA such as off-road riding to promote PA in a group who might otherwise forgo exercise altogether. ORM riders had moderately high aerobic fitness but were also inefficient at translating the work of running into high speeds on the treadmill when compared with true runners. Thus, the finding that riding an ORM was more taxing than walking and less than a slow jog gives a reasonable reference for this particular group. However, comparison between the physical demands of off-road riding and those of other common sports is also informative.

Table 2 reveals the aerobic demands of off-road riding to be in a similar $\dot{V}O_2$ range (12–23 mL·kg^{-1}·min^{-1}) as other common self-paced individual activities (i.e., golf (9), rock climbing (27,33), alpine skiing (28,29), and active video gaming (32)), whereas intermittent sprint-based team sports (hockey (4,30), soccer (10), water polo (11), and basketball (23)) and predominantly aerobic endurance sports (cycling (17) and Nordic ski racing (21,37)) tend to have a higher aerobic demand. Although the acute aerobic demand and temporally standardized caloric expenditure of an off-road

TABLE 2. The metabolic demand of common physical activities for comparison with off-road riding.

	Sport	Level of Play	Participants (*n*, Age, and Gender)	Mean Relative $\dot{V}O_2$ (mL·kg^{-1}·min^{-1}) (Absolute $\dot{V}O_2$ L·min^{-1})	MET	Percentage of $\dot{V}O_{2max}$	Percentage of HR_{max}	Lactate (mmol·L^{-1})	RPE	Net Energy Expenditure (kcal)
Recreational	Off-road riding	Recreational (current study)	*n* = 128, 43 ± 13 yr, male and female	12.1 ATV, 21.3 ORM (1–1.6)	3.5–6	42.5 ATV, 51.3 ORM	69 ATV, 78 ORM	3.5 ATV, 4.1 ORM	11.8 ATV, 13.5 ORM	218–436 (1 h)
	Golf	Recreational, pulling cart[a]	*n* = 20, 64 ± 7.7 yr, male	14.7[b] (1.2)	4.2	46	—	—	—	458 (9 holes)
	Alpine skiing	Recreational, ski instructor guided[c,d]	*n* = 9, 62.6 ± 5.1 yr, 1 female, 8 males/*n* = 10, 22.7 ± 4 yr, female	13.6–18.6 (1–1.4)	4–6	30–60[e]	48–94	0.7–6.0	6–17	216–320 (1 h)
	Active video games	Leisure time, dance video game[f]	*n* = 19, 21.8 ± 3.5 yr, male	13.1–25.2 (1.1–2)	4–7	23–50	48–80	—	11–14	210–516 (1 h)
	Racquetball	Recreational[g]	*n* = 14, 23.1 ± 2.8 yr, 3 females, 11 males	27.3 (2.2)	8	—	79[h]	—	12.9	551 (1 h)
	Rock climbing	Noncompetitive (outdoor)[i]	*n* = 8 43 ± 8 yr, male/*n* = 5, 31 ± 8 yr, female	27.5–28.3 (1.6–2.0)	8	70–72	84–93	1.6–3.3	—	400–503 (1 h)
		Elite climbers (indoor)[j]	*n* = 6 males, 3 females, 18.2 ± 5.6 yr	20.1–22.7 (1.3–1.4)	6–7	44–50	67–75	—	—	310–372 (1 h)
	Ice hockey	Recreational[k,l]	*n* = 19, 42.7 ± 6.9 yr, male/junior and men	32–35 (2.4–2.8)	10	—	50–85	—	—	675–713 (1 h)
Competitive	Motocross	Elite and nonelite competitive[m,n]	*n* = 7 elite, 23 ± 4 yr, *n* = 5 recreational, 28 ± 4 yr, male/*n* = 9, 21 ± 4 yr, male	34–42 (2.6–3.2)	10–12	69–94	96–98	4–6	—	624–657 (1 h)
	Mountain biking	Elite-level course, competitive, and elite riders[o]	*n* = 5, 21 ± 4 yr, male	63 (4)	18	84	90	30% above 4 mmol·L^{-1}	—	1105 (1 h)
	Nordic skiing	National level[p,q]	*n* = 10, 17.9 ± 1 yr, male/*n* = 5 18 ± 1 yr, female	53–55 (3.8–4)	15–16	72	93	5.9–10.5	—	840–1008 (1 h)
	Water polo	Competitive, nonelite (5-min quarters)[r]	*n* = 8, 25 ± 5.7 yr, male	40–50 (3–4.3)	11–14	75–94	85–99	3.8–3.9[s]	—	485–617 (20 min)
	Tennis	Elite[t,u]	*n* = 20, 26 ± 3.7 yr, male	27.3–29.1 (2–2.2)	7.8–8.3	51	60–78	2.1	—	510–634 (1 h)
	Basketball	Competitive collegiate level (NCAA)[v]	*n* = 6, 21 ± 1.0 yr, male/*n* = 6, 20 ± 1.3 yr, female	33.4–36.9 (2.2–3.4)	9.5–10.5	64.7–66.7	88–89	3.2–4.2	13–14	379–582 (40 min)
	Soccer	Amateur competitive[w]	*n* = 7, 25.3 ± 1.2 yr, male	34–48 (2.5–3.5)	10–14	70–94	82–97	1.9–13.4	2.3–9.1	657–949 (1 h)

Absolute $\dot{V}O_2$ values calculated using activity representative participant weight (kg) from published literature.
[a] Dobrosielski et al. (9).
[b] Calculated from MET, healthy adult only. Energy expenditure (kcal) estimated using MET (minus resting) multiplied by body weight and duration.
[c] Scheiber et al. (28).
[d] Seifert et al. (29).
[e] Karlsson et al. (18).
[f] Sell et al. (32).
[g] Berg et al. (5).
[h] Calculated using estimated HR_{max} (220 − age).
[i] Rodio et al. (27).
[j] Sheel et al. (33).
[k] Atwal et al. (4).
[l] Seliger et al. (30).
[m] Konttinen et al. (19).
[n] Konttinen et al. (20).
[o] Impellizzeri et al. (17).
[p] Larsson and Henriksson-Larsen (21).
[q] Welde et al. (37).
[r] Goodwin and Cumming (11).
[s] Platanou and Geladas (25).
[t] Seliger et al. (31).
[u] Smekal et al. (34).
[v] Narazaki et al. (23).
[w] Esposito et al. (10).

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vehicle ride are lower that those in sports such as competitive mountain biking, the likelihood of PA adherence and duration are important considerations. If the caloric expenditure of a 60-min cross-country mountain bike ride (1105 kcal at an elite race pace) is compared with a typical-duration (ORM = 120 min and ATV = 180 min) off-road vehicle ride (ATV = 654 kcal and ORM = 872 kcal), the caloric discrepancy in Table 2 greatly decreases.

If performed on at least 5 d of the week for a duration of ≥30 min, off-road riding would fit the ACSM's updated PA recommendations as an acceptable form of PA to stimulate changes in health-related fitness and health; however, the typical pattern of long-duration and infrequent bouts reported by habitual riders may be less effective considering the ACSM's statement that aerobic endurance training <2 $d \cdot wk^{-1}$, at <40%–50% of $\dot{V}O_2R$ generally does not provide sufficient stimulus for maintaining fitness in healthy adults (2). Furthermore, given that only 14% of an ATV ride and 38% of an ORM ride are within the intensity range required to stimulate changes in aerobic fitness (Fig. 4), exercise training time, as opposed to simple ride duration, must be considered in PA guideline adherence. In a ride lasting from 120 to 180 min, an ATV rider only spends 16–30 min above the level required to stimulate changes in aerobic fitness. Similarly, ORM riders are above this level for 22–27 min during a 60- to 120-min ride. Nevertheless, given the guideline of approximately 450–750 $MET \cdot min \cdot wk^{-1}$ of combined moderate- and vigorous-intensity PA, habitual riders are accumulating between 420 $MET \cdot min \cdot wk^{-1}$ (3.5 METs × 120 min, ATV) and 720 $MET \cdot min \cdot wk^{-1}$ (6 METs × 120 min, ORM), which approximates this recommended value. It has yet to be determined if infrequent longer bouts of PA, summing to the same absolute weekly energy expenditure, lead to the same health benefits as shorter-duration, frequent exercise. This particular dose–response issue examining the effects of long-duration low-frequency exercise on health-related fitness outcomes is an area for future research.

Anaerobic involvement and perceived exertion. Lactate levels measured at the end of exercise confirmed that off-road vehicle riding is primarily aerobic exercise (13). We did not have the capacity to measure lactate levels throughout the duration of a ride. However, assuming that the values observed after ride were representative of mean riding levels, off-road riding is at an intensity just below the level of uncompensated blood lactate accumulation (4 $mmol \cdot L^{-1}$). On the basis of participants' common reference to "arm pump," or a rigid contracture of the forearm musculature, which occurs from squeezing the handlebars while riding, we speculate that riders purposely adjust riding speed to maintain their exercise intensity below a level that could impair their ability to safely operate the vehicle due to the arm muscle pain associated with lactate accumulation. Blood lactate accumulation after the graded exercise test was considerably higher than levels recorded while riding, supporting our postulation that riders adjust-down the riding workload to avoid acidosis despite a physiological ability to function at higher anaerobic workloads and blood lactate levels.

Perceived exertion is closely, but not perfectly, related to HR response because it is influenced by many physiological processes and it has input signals from the peripheral muscles and joints, the cardiovascular and respiratory systems, and the central nervous system (6). When allowed to self-select a training intensity, both fit and unfit individuals choose an intensity of approximately 60% of $\dot{V}O_{2max}$, or 11–14 RPE (8), and self-adjust their overall power output accordingly to maintain this level. In this study, both ORM and ATV riders selected exercise intensities within this RPE range, with ORM riders choosing a slightly higher RPE_{avg} and RPE_{max} corresponding to the greater aerobic work they were accomplishing. While jogging on the treadmill within this 11–14 RPE range, both ATV and ORM participants in our study were working at approximately 60%–65% $\dot{V}O_{2max}$ as expected; however, while riding at the same RPE, participants were only working at between 43% and 51% $\dot{V}O_{2max}$.

Off-road vehicle riders perform considerable physical work using their arms and upper body while riding, evident in the observed fatigue in this study and as documented using EMG monitoring in an examination of motocross riding (20). Because upper body work involves relatively small muscle groups compared with locomotive work using the legs (i.e., running or cycling), $\dot{V}O_2$ is lower, and these smaller muscle groups of the upper extremities are pushed toward anaerobic energy pathways. Repeated isometric contractions are also likely to occlude blood flow thus restricting oxidative pathways further. Although the lactic acid production of these smaller muscles does not greatly elevate systemic blood lactate levels, riders likely perceive the local acid buildup as a high level of exertion thus explaining the elevated RPE scores.

Muscular strength and power involvement. Off-road vehicle riding caused fatigue, indicating a strength involvement to off-road vehicle riding, which corroborates evidence of high EMG muscle activation in motocross riders (20). Unexpectedly, we observed an increase in ATV grip strength from before to after the ride, potentially explainable as a stimulatory effect of riding. Elite motocross riders have been shown to have elevated urinary catecholamine levels (adrenaline, noradrenalin, dopamine) after a simulated race (20), and there is evidence that forearm strength can be augmented as a result of sympathetic nervous stimulation caused by an unexpected loud noise (16). Although it is unlikely that the moderate-intensity off-road riding caused a stimulatory effect itself, it is possible that this effect was driven by the thrill of riding and/or the fear of a fall. This makes the observed decrease in ORM grip strength a stronger evidence of fatigue because the effect of riding was powerful enough to overcome this excitatory effect in these riders. Considering previous research comparing the grip strength of habitual recreational off-road

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riders to the normative Canadian population (Burr et al., unpublished observations) in which there was no improvement in strength (except in older riders), it seems that off-road riding affects muscular endurance more so than strength.

Increases in musculoskeletal fitness are beneficial in attenuating weight gain, preventing obesity, and improving insulin sensitivity as well as a host of other risk factors for disease (35,36). Upper body push and pull strengths showed a clear fatiguing effect of riding in both vehicle types, signifying an upper body strength requirement to off-road riding, which could lead to beneficial training increases in musculoskeletal fitness. An effect of lower body fatigue was observed only in the "ground time" of older female participants, suggesting that lower body musculature may be important in off-road riding in older females, but this effect was not seen in younger female riders or in males who may have been more habituated to the activity. EMG measures of motocross riders have shown that the lower body musculature is highly activated during motocross riding. However, similar to handgrip, a fatiguing effect in leg extension was evident only in the less experienced, and less habituated, motocross riders (20). Further examination of both the upper and the lower body musculoskeletal demands of riding using quantifiable strength outcomes is required.

In conclusion, off-road vehicle riding is a recreational activity associated with moderate-intensity cardiovascular demand and fatigue-inducing muscular strength challenges, particularly for upper body musculature. The metabolic demand of off-road riding is at an intensity level associated with health and fitness benefits in accord with the guidelines of both Health Canada and the ACSM. Potential effects on health and fitness may be augmented by the beneficial effect of increased caloric expenditure. In general, off-road vehicle riding is similar in aerobic demand to many other recreational, self-paced, sporting activities such as golf, rock climbing, and alpine skiing. This examination of off-road vehicle riding is valuable for understanding the physical demands of this alternative mode of recreational PA in the context of potential health-related fitness outcomes.

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