Maximal Fat Oxidation During Running: A Reliability and Thermo-Metabolism Pilot Study

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Abstract

Introduction: We investigated the reliability of a novel Fatmax protocol on a treadmill, and if exercising at Fatmax in the cold would increase fat oxidation and energy expenditure.

Methods: On separate days, five participants performed two identical Fatmax tests. They then exercised at Fatmax in cold (~0°C) and thermoneutral (~22°C) environments for 30 min.

Results: Excellent reliability (ICC >.9) was found for the Fatmax protocol, and a non-significant increase in fat utilization was observed during cold exercise at Fatmax.

Conclusions: Our novel Fatmax protocol on a treadmill is reliable and its impact on fat utilization in the cold should be further studied.

Key Words: Substrates Oxidation, Running, Temperature

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Introduction

As rates of obesity and metabolic disorders continue to rise across the globe, understanding mechanisms governing lipid turnover is foundational in developing effective exercise interventions. Measures of fat oxidation (FO), such as maximal fat oxidation (MFO) and the intensity eliciting MFO, Fatmax are considered metabolic health markers1 and have been associated with insulin sensitivity2 as well as physical performance3,4. Both MFO and Fatmax have very high levels of inter-individual variability with coefficients of variations >20% observed5. One study previously examined Fatmax reliability during a running protocol6, despite its known higher MFO and Fatmax compared to cycling7. In this study, most participants (11/16) achieved Fatmax during the warm-up stage, set at 70% of lactate threshold (≈40-50% VO2max for their participants), with the first stage set at 100% lactate threshold (>60% VO2max for their participants). Fatmax generally occurs within 23%-88% VO2max, while lactate threshold rarely occurs below 50% VO2max8. Investigating individual responses of Fatmax with sufficient stages both above and below lactate threshold is necessary to evaluate the reliability of running protocols.

Moreover, MFO and Fatmax were recently found to be greater in the cold (4.6°C) compared to warm (34.1°C) environments during graded treadmill running9,10. Whether greater FO rates in the cold are maintained or increased during prolonged exercise at Fatmax, potentially further promoting metabolic health, have yet to be explored. Altogether, the purpose of this pilot study was to i) test a novel Fatmax protocol for reliability on a treadmill ergometer and ii) examine substrate oxidation rates during prolonged exercise at an individual’s Fatmax intensity in both cold and thermoneutral ambient temperatures.

Methods

Participants
Five young recreationally active (exercising 3-5 times a week) and in excellent health (VO$_{2\text{max}}$ 51.5 ± 1.93 ml·kg$^{-1}$·min$^{-1}$) male subjects took part in the study (Table 1) approved by the Laurentian University Research Ethics Board (LUREB) and in accordance with the Declaration of Helsinki. Participants provided written informed consent, were screened with a Get Active Questionnaire (GAQ), a health screening form, and recorded and repeated their diet 24hrs before each exercise session.

**Protocol**

An incremental maximal oxygen consumption (VO$_{2\text{max}}$) test was performed on a treadmill, starting at 6km/h 0% incline and increasing 2 km·h$^{-1}$ every 3 min until volitional exhaustion. For the second and third session (Fat$_{\text{max}}$ reliability sessions), participants performed identical Fat$_{\text{max}}$ tests, in a 22°C lab, consisting of 3-min stages starting at 2.2 mph at a 1% incline. Speed was then increased to 2.7 mph, 3.4 mph, 4.0 mph, and finally 4.7 mph every three minutes, from which point the gradient was increased by 2% at each subsequent stage until an RER of 1.0 was reached. The Fat$_{\text{max}}$ test was terminated once participants reached an RER of 1.0. The final two experimental sessions consisted of prolonged running at Fat$_{\text{max}}$ intensities completed in either a thermoneutral (~22°C) or cold environment (~0°C), following a balanced design. Skin (iButtonLink Technology) and core temperature (Physitemp) were measured during both experimental trials. Cardiopulmonary variables (Ultima CPX, MGC Diagnostics) were continuously assessed during all trials. All sessions were separated by at least seven days and were performed at the same time of day.

**Fat$_{\text{max}}$ data**

Data from the last minute of each Fat$_{\text{max}}$ trial stage was averaged and graphed using a 2nd order polynomial curve. Absolute values of MFO and Fat$_{\text{max}}$ were determined as the values corresponding to the peak of the curve. Fat$_{\text{max}}$ stages were then determined as the stage closest to the peak of the curve. Oxidation rates of CHO and fat were calculated as previously described.

**Statistical Analysis**

One participant exhibited a carbohydrate dominant curve in his first trial, followed by a fat dominant curve in the second (Randell 2013). Although the participant reported similar dietary intake, sleep pattern, and lifestyle, this shift in substrate dominance was likely caused by external variables and their data was thereby removed from the analyses. Data is presented as means ± standard error (SE). Reliability of Fat$_{\text{max}}$ and MFO were assessed via two-way mixed effects, absolute agreement, single measurement intraclass correlations (2,1) (ICCs). Reliability assessment between MFO at Fatmax and FO rates at the third min of experimental sessions was also conducted. Two-way RM ANOVA (factors: temperature [cold: CO; thermoneutral: TN] and time) was used to assess differences for rates of substrate oxidation, %VO$_{2\text{max}}$, skin temperature and core temperature. All statistics were conducted using SPSS version 26.

**Results**

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean (SE)</th>
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</thead>
<tbody>
<tr>
<td>Age (yrs)</td>
<td>21.5 ± 0.65</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>185.5 ± 2.48</td>
</tr>
<tr>
<td>Body Mass (kg)</td>
<td>87.7 ± 8.65</td>
</tr>
<tr>
<td>Body Mass Index (kg·m$^{-2}$)</td>
<td>25.3 ± 1.73</td>
</tr>
<tr>
<td>Body Fat (%)</td>
<td>17.4 ± 2.59</td>
</tr>
<tr>
<td>Fat Mass (kg)</td>
<td>15.7 ± 3.84</td>
</tr>
<tr>
<td>VO$_{2\text{max}}$ (ml·kg$^{-1}$·min$^{-1}$)</td>
<td>51.5 ± 1.93</td>
</tr>
</tbody>
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**Temperature**

Skin temperature ($T_a$) during the CO condition was significantly lower than TN (P=.011), and decreased significantly over trial duration (P=<.001). No differences were found in $T_i$ between TN and CO trials.
Reliability
Reliability assessment was found to be excellent for Fat max with an ICC of 0.928 (95% CI [.454, .995]) and good for MFO with an ICC of 0.882 (95% CI [.237, .992]) (Fig. 1). Reliability of MFO compared to FO rates in the third minute of experimental trials was found to be good for TN with an ICC of .771 (95% CI [-.061, .983]) but only moderate for CO with an ICC of .597 (95% CI [-.153, .963]).

Figure 1: Scatter plot of Fat Oxidation vs %VO₂max for two identical Fat max protocol trials on a treadmill.

Energy Metabolism
Fat oxidation rates significantly increased over time (P<.001). Neither fat nor CHO oxidation rates were different between conditions (Fat: CO=0.699 ± 0.02 g·min⁻¹, TN=0.612 ± 0.04 g·min⁻¹; P=.251; CHO: CO=1.32 ± 0.137 g·min⁻¹, TN=1.49 ± 0.133 g·min⁻¹; P=.071) (Fig. 2). Total energy expenditure from fat and CHO was not different between conditions (Fat: CO 201.8 ± 14.5 kcal, TN 180.4 ± 29.1 kcal; P=.536; CO 166.8 ± 47.91 kcal; P=.754; TN 189.47 ± 49.5 kcal) (Fig. 2). Total energy expenditure between the two trials was also not different (TN: 369.8 ± 62.3 kcal, CO: 368.6 ± 55.8 kcal; P=.909) (Fig. 2).
Figure 2. A) Substrate oxidation (g·min⁻¹) over time, B) energy expenditure (kcal) from Fat, CHO and Total, and C) relative energy expenditure (%) coming from Fat or CHO, for both TN and CO conditions.

Discussion
This study was preliminary and cautious interpretation of the results is warranted. Our novel treadmill Fat_max protocol demonstrated acceptable reliability (ICC >.9)¹³ and good reliability of MFO (ICC > .8)¹³, which has not been previously reported⁶,¹²,¹⁴. While the present pilot study was not designed to examine different methodologies to measure, assess, or calculate Fat_max, our preliminary findings seem to indicate that graphical depiction and subsequent identification of the peak of the curve, without mathematical modelling and alteration, is a reliable method. Our study is also the first to examine changes of FO rates at Fat_max over prolonged exercise in both CO and TN conditions. When comparing MFO to FO rate of the third minute of prolonged exercise bouts (following an identical build up to our Fat_max trial), good reliability was observed for TN (ICC>.75) but only moderate for CO (ICC = .597). No significant differences were found between MFO and FO rates in the third minute of CO (p=.262), however FO rates did trend towards higher values in the third minute of CO compared to MFO (0.595 vs. 0.466 g·min⁻¹), likely explaining the lower ICC. From this, it would seem that exercising at Fat_max is a reliable method.
for maximizing the utilization of fat in a thermoneutral environment and should be further studied to see if it further amplifies fat reliance in the cold, as previously observed. In conclusion, the treadmill Fatmax protocol utilized in this study demonstrated high intra-individual reliability (ICC > 0.9) which could be beneficial for metabolic investigations and training designs for maximizing fat utilization. Exercising at Fatmax in the cold could further improve oxidation of fat compared to a thermoneutral environment.

Media-Friendly Summary
Humans have been shown to utilize two main forms of fuel to power exercise: carbohydrates and fats. Over the years, an individualized exercise intensity has been theorized to promote the maximal utilization of fat possible for the individual during exercise termed Fatmax. This marker has been associated with numerous health markers including insulin sensitivity and fitness. Our pilot study has possibly found the first reliable and valid protocol to determine Fatmax during running. We have also found that running at ones individual Fatmax intensity in the cold may promote even greater fat utilization when compared to a neutral environment.

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References


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