Increased Caloric Intake Soon After Exercise in Cold Water

Lesley J. White, Rudolph H. Dressendorfer, Eric Holland, Sean C. McCoy, and Michael A. Ferguson

We examined the acute effect of cold-water temperature on post-exercise energy intake (EI) for 1 h. In a randomized, crossover design, 11 men (25.6 ± 5 y) exercised for 45 min on a submersed cycle ergometer at 60 ± 2% VO_{max} in 33°C (neutral) and 20°C (cold) water temperatures, and also rested for 45 min (control). Energy expenditure (EE) was determined using indirect calorimetry before, during, and after each condition. Following exercise or rest, subjects had free access to a standard assortment of food items of known caloric value. EE was similar for the cold and neutral water conditions, averaging 505 ± 22 (± standard deviation) and 517 ± 42 kcal, respectively (P = NS). EI after the cold condition averaged 877 ± 457 kcal, 44% and 41% higher (P < 0.05) than for the neutral and resting conditions, respectively. Cold-water temperature thus stimulated post-exercise EI. Water temperature warrants consideration in aquatic programs designed for weight loss.

Key Words: appetite, aquatic exercise, energy expenditure, weight loss

The prevalence of adult obesity is increasing among both affluent and developing nations while the percentage of overweight children and adolescents has rapidly increased for several decades (7). Increased consumption of low-nutrient, high caloric density (“junk”) foods and insufficient physical activity clearly contributes to this unfavorable trend (10). Body fat accumulates when total daily energy intake (EI) persistently exceeds energy expenditure (EE) over the long term. Regular exercise augments EE and promotes a more favorable balance between total daily EI and EE (2). Accordingly, walking is a commonly recommended activity for overweight persons to increase EE.

Aquatic programs for weight loss provide a popular alternative to walking and other forms of activity on land because the buoyancy of water reduces weight-bearing stress on muscles and joints. Some studies suggest, however, that aquatic exercise might influence energy balance and weight loss differently than exercise on land (8, 19, 21). Gwinup (8) found swimming to be less effective for weight reduction than walking or cycling. Following 6 months of daily exercise, study participants who walked lost 10% of their initial body weight and cyclists lost 12% while the swimmers did not lose weight. Exercising in water possibly increased the swimmers’ EI, preventing significant weight loss.

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Dressendorfer (4) reported that EI immediately following exercise in cold water was increased as compared to the same exercise on land or in warm water, despite similar exercise EE between conditions. Our preliminary study (4) lacked a resting condition, however, and did not account for excess post-exercise oxygen consumption (EPOC). Continuing this line of research, the present investigation determined EPOC and EI immediately after moderate exercise in cold (20 °C) and neutral (33 °C) water. Cycling exercise was used to control the mode, intensity, and duration of exercise and thus to explore the independent effect of water temperature. It was hypothesized that EPOC and EI would be higher in the cold-water trial.

**Methods**

**Subjects**

Eleven college men (25.6 ± 5 y) were randomly selected from volunteers who received study orientation and met initial screening criteria. Study volunteers were not eligible if they reported a chronic health problem, engaged in regular training for fitness or sport, consumed a special diet, or were attempting to lose weight. Subjects accustomed to aquatic exercise were excluded. In addition, subjects were not habituated to the water exercise before data collection. Other exclusionary criteria included the use of tobacco products or other agents thought to influence appetite and metabolism. Informed consent was obtained in accordance with the guidelines of the university human subjects committee.

Body weight and height were measured with a Stadiometer (Vogel & Halke GmbH & Co., Hamburg, Germany) and standard balance scale. Mean skinfold thickness and relative body fat were determined using the method of Jackson and Pollock (11). Respiratory gas-exchange measurements were obtained with a calibrated TrueMax 2400 metabolic cart (Parvomedics, Salt Lake City, UT) every minute. Maximal oxygen consumption (VO\(_{2\text{max}}\)) was assessed using an incremental bicycle ergometer protocol, starting at 50 W and increasing by 25 W every 2 min to exhaustion (1). Test termination included a plateau in oxygen uptake (VO\(_{2}\)) or a respiratory-exchange ratio (RER) greater than 1.10 with increasing work (23). Characteristics of subjects are shown in Table 1.

**Table 1 Descriptive Characteristics of Subjects**

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean ± standard deviation</th>
<th>Range</th>
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<tbody>
<tr>
<td>Age (y)</td>
<td>25.6 ± 5.0</td>
<td>21–31</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>84.5 ± 9.7</td>
<td>68–92</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>180.1 ± 5.2</td>
<td>171–186</td>
</tr>
<tr>
<td>VO(_{2\text{max}}) (mL · kg(^{-1}) · min(^{-1}))</td>
<td>46.8 ± 10.3</td>
<td>35–63</td>
</tr>
<tr>
<td>Body fat (%)</td>
<td>13.1 ± 6.3</td>
<td>5–20</td>
</tr>
</tbody>
</table>
**Experimental Conditions**

Subjects served as their own controls in a randomized crossover study design and were tested separately. They reported to the laboratory rested, hydrated, and 12 h postprandial. Subjects wore only swim shorts during the two exercise conditions and shorts and a cotton T-shirt during the resting control trial. Trials on a given subject were conducted at the same time of day and at least 4 d apart. Each exercise condition consisted of a 30-min rest period, 45 min of exercise while immersed to the mid sternum in water, 20 min of recovery, and 1 h of monitored food consumption.

Baseline VO\(_2\) and RER were measured at the end of the 30-min rest period as subjects sat quietly in an air-conditioned room (25 °C) before each experimental condition. During the resting trial, subjects continued to sit for an additional 45 min. In the two exercise trials, subjects were immersed to the mid sternum and cycled for 45 min on a Monark (Monark Exercise AB, Varberg, Sweden) ergometer modified for underwater use (18). Water temperature was maintained via externally mounted controls within ± 0.5 °C of intended temperature during the cold and neutral trials. Work rates were prescribed according to the Morlock and Dressendorfer equation (18) to produce a steady state at 60% of VO\(_{2\text{max}}\). Dressendorfer et al. (5) found that VO\(_{2\text{max}}\) on the modified ergometer was not significantly different during head-out immersion in cold and warm water compared with cycling on land.

In each condition, VO\(_2\) and RER monitoring continued without interruption after exercise for the determination of EPOC while subjects sat quietly on dry land for 20 min. The net calories expended in EPOC were calculated as the difference between the caloric equivalent of total recovery VO\(_2\) and total resting VO\(_2\).

After the EPOC period, subjects dressed in comfortable clothes and remained in the laboratory. They were then allowed free access for 60 min to a standard buffet assortment of food items that consisted of energy bars, raisins, donuts, a variety of chips, crackers, cookies, pastries, high- and low-fat muffins, fruit juice, cola, and water. These foods were chosen to represent commonly consumed snack foods identified from dietary-intake records acquired in the preliminary screening of subjects. Blood pressure was obtained at 15-min intervals to covertly monitor food intake. After study completion, all subjects reported being unaware that their EI had been monitored.

Energy expenditure during the resting control and two exercise trials was computed using the caloric equivalent of VO\(_2\) for the observed nonprotein RER. EI was determined from the caloric value and nutrient composition of food items actually consumed, as obtained from the package label or assessed with a nutritional analysis program (Food Processor II, ESHA Research, Salem, OR).

Tympanic temperature was taken at 10 min intervals during exercise with an infrared probe (Thermoscan, Braun Kronbergt, Germany). This probe has been found to be reliable for monitoring tympanic temperature during exercise (20). In addition, tympanic temperature with this probe was shown to accurately reflect pulmonary artery and rectal temperatures (17). Heart rates were obtained at 5-min intervals during exercise via telemetry (Polar Electro, Woodbury, NY).

**Statistical Analysis**

Data were analyzed with SAS System for Windows®, version 8.01 software (SAS Institute, Cary, NC) using a two-way ANOVA repeated measures design and the
PROC MIXED function. The least-squares mean $t$-test was used to locate pairwise significant differences. The interaction term for temperature, heart rate, and RER was not significant and thus, the interaction term was excluded from the final model. The main effects were analyzed to identify differences between the trials. Caloric intake was evaluated using a one-way ANOVA. $P$ values < 0.05 were considered significant in all analyses.

Results

Resting energy expenditure prior to exercise was not significantly different across the 3 conditions (Table 2). Caloric expenditure during exercise was also similar between the cold and neutral conditions. Total gross EE was not significantly different between exercise conditions, averaging 505 ± 22 kcal in neutral water and 517 ± 42 kcal in cold water (Table 2). Net EE during EPOC was higher after the neutral water trial, averaging 39 ± 10 kcal, compared with 19 ± 6 kcal for the cold-water trial ($P < 0.05$). Oxygen consumption was significantly lower ($P < 0.05$) immediately after exercise at 60 min in the cold water than in the neutral water (Figure 1). During the final 15 min of the EPOC period, oxygen consumption for both exercise trials was similar to values obtained at rest.

The mean respiratory exchange ratio (RER) was greater ($P < 0.05$) during the cold (0.89) and neutral (0.87) water compared to the resting control (0.81). RER in the cold water was higher ($P = 0.05$) than during the neutral water at most time points except at 40 min ($P = 0.08$; Figure 2). RER returned to pre-exercise values after 10 min of EPOC.

Mean exercise heart rate was lower ($P < 0.05$) during and after the cold water (107 beats/min [bpm]) compared to the neutral water (117 bpm; Figure 3). Heart rate after exercise in the cold-water trial was similar to rest following 10 min of EPOC, whereas heart rate after the neutral water remained significantly elevated ($P < 0.05$) for 15 min of EPOC.

Mean tympanic temperature was higher ($P < 0.05$) during exercise in the neutral water (36.7 °C) compared to the cold water (36.4 °C; Figure 4). Tympanic temperature remained significantly elevated (0.6 °C) above rest during the final 15 min of exercise in the neutral water ($P < 0.05$). Tympanic temperature decreased ($P < 0.05$) during EPOC in both trials but remained elevated above baseline values.

Table 2  Gross Caloric Expenditure (kcal) during the Resting Control and Two Exercise Trials

<table>
<thead>
<tr>
<th></th>
<th>Pre-exercise (15 min)</th>
<th>Exercise (45 min)</th>
<th>Recovery (20 min)</th>
<th>Total kcal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resting control</td>
<td>23 ± 8</td>
<td>71 ± 24</td>
<td>29 ± 11</td>
<td>123 ± 14</td>
</tr>
<tr>
<td>Neutral water</td>
<td>25 ± 8</td>
<td>408 ± 30*</td>
<td>72 ± 13*</td>
<td>505 ± 22*</td>
</tr>
<tr>
<td>Cold water</td>
<td>21 ± 4</td>
<td>439 ± 76*</td>
<td>47 ± 9*</td>
<td>517 ± 42*</td>
</tr>
</tbody>
</table>

Note. Values are mean ± standard deviation. *$P < 0.05$ between the resting control and exercise trials.
Figure 1 — Oxygen consumption during the neutral- and cold-water exercise trials. Significant main effect of time and trial (resting control vs. exercise) $P \leq 0.001$. Significant interaction term $P \leq 0.001$. * = warm (neutral) vs. cold trial $P \leq 0.05$.

Figure 2 — Respiratory-exchange ratio during the neutral- and cold-water exercise trials. Significant main effect of time and trial $P \leq 0.001$. *=warm (neutral) vs. cold trial $P \leq 0.05$. 
Figure 3 — Heart rate during the neutral- and cold-water exercise trials. Significant main effect of trial and time $P \leq 0.001$. * = warm (neutral) vs. cold trial $P \leq 0.05$.

Figure 4 — Tympanic temperature during the neutral- and cold-water exercise trials. Significant main effect of trial and time $P \leq 0.05$. * = warm (neutral) vs. cold trial $P \leq 0.05$. 
(P > 0.05) throughout the recovery period. Weight loss was greater in the neutral water (P < 0.05, 0.8 ± 0.15 kg) compared to the cold water (0.4 ± 0.05 kg).

Mean EI was 873 ± 457 kcal in the cold water, 608 ± 203 kcal in the neutral trial and 618 ± 277 kcal in the resting control (Table 3). Caloric intake after exercise in cold water was thus 269 kcal (44%) higher compared to the neutral water (P < 0.005) and 259 kcal (41%) higher compared to the resting control. Total fat and percentage of fat calories consumed after the cold trial were higher (P < 0.05) than either the resting control or neutral trial. EI after exercise in the neutral water and for the resting control were not significantly different, however.

**Discussion**

The purpose of this study was to determine whether exercise in cold water influences appetite and caloric intake soon after exercise, as compared to rest, or the same exercise in a neutral water temperature. Energy expenditure during 45 min of aquatic exercise was not different between the cold and neutral water trials. Excess post-exercise oxygen consumption was slightly higher after the neutral water, contrary to our hypothesis. Subjects consumed 269 kcal (44%) more calories, however, during the hour following exercise in cold water than in the neutral trial. Furthermore, caloric intake after the cold-water trial was twofold greater than exercise energy expenditure.

The results confirm our previous report that exercising in cold water can increase post-exercise caloric intake compared to the same mode, intensity, and duration of exercise in neutral water temperature or on land (4). The current data also indicate that the observed greater caloric intake of 269 kcal after exercise in cold water was not associated with higher EPOC. Further research is needed to determine whether this positive post-exercise energy balance persists beyond the short term. Augmented energy intake for 1 h clearly would not disturb daily energy balance if later compensated by reduced intake. If uncompensated, however, appetite stimulation after exercise in cold water might explain why swimming was found less effective for weight reduction than walking or cycling (8).

<table>
<thead>
<tr>
<th></th>
<th>Resting control</th>
<th>Neutral trial</th>
<th>Cold trial</th>
</tr>
</thead>
<tbody>
<tr>
<td>Caloric intake (kcal)</td>
<td>618 ± 277</td>
<td>608 ± 203</td>
<td>877 ± 457\textsuperscript{a}</td>
</tr>
<tr>
<td>liquid</td>
<td>115 ± 86</td>
<td>180 ± 106</td>
<td>155 ± 114</td>
</tr>
<tr>
<td>solid</td>
<td>503 ± 193</td>
<td>428 ± 162</td>
<td>732 ± 425\textsuperscript{a}</td>
</tr>
<tr>
<td>Fat (%)</td>
<td>27 ± 21</td>
<td>28 ± 14</td>
<td>35 ± 20\textsuperscript{ab}</td>
</tr>
<tr>
<td>Carbohydrate (%)</td>
<td>71 ± 26</td>
<td>71 ± 25</td>
<td>62 ± 30</td>
</tr>
<tr>
<td>Protein (%)</td>
<td>2.5 ± 0.5</td>
<td>1.3 ± 0.3</td>
<td>4.0 ± 0.5</td>
</tr>
</tbody>
</table>

*Note.* Values are mean ± standard deviation. \textsuperscript{a}P < 0.05 between the neutral- and cold-water exercise trials. \textsuperscript{b}P < 0.05 between resting control and cold-water exercise trials.
Several studies have investigated caloric intake and food selection after acute and chronic exercise on land (2, 3, 8-10, 12-16, 25-28). Some investigators found no association between energy expenditure and post-exercise energy intake (3, 8, 12), whereas others concluded that caloric intake depended on the type or intensity of exercise (10, 14, 15). For example, Imbeault et al. (10) found that treadmill exercise favored negative energy balance after exercise. Similarly, Klausen et al. (14) compared low- and high-intensity treadmill running at 30% and 60% of VO$_{2\text{max}}$ on nutrient intake for 24 h after exercise. Subjects in the high-intensity running group consumed more fat calories, but total caloric intake was similar between groups. Thompson et al. (25) reported that compared with exercise at 35% of VO$_{2\text{max}}$, higher intensity cycle exercise at 68% of VO$_{2\text{max}}$ suppressed caloric intake during a test meal provided 1 h after the exercise. During consumption of the test meal, however, liquid-source kilocalories and carbohydrate intake were higher after the intense exercise session (25).

King et al. (12) found ratings of hunger were suppressed in fasted male subjects after cycle-ergometer exercise at 70% of VO$_{2\text{max}}$ compared with low-intensity exercise at 30% of VO$_{2\text{max}}$ and control conditions. In another study, King et al. (13) found that appetite was suppressed and food consumption was delayed after subjects were provided a free-selection test meal after a 50-min bout of treadmill running at 70% of maximal heart rate. Importantly, the bout of treadmill exercise had no significant influence on subsequent energy intake within 24 or 48 h after exercise.

Sheldahl et al. (21) found that an 8-wk program of cycling 5 times per week in cold water (17 to 22 °C) at 30% to 40% VO$_{2\text{max}}$ for 90 min did not produce significant weight loss in obese women. In addition, self-reported food intake also did not change significantly in these women despite the increased energy expenditure. The authors recommended further research because individuals attempting to lose weight might prefer aquatic exercise for injury prevention or to avoid the heat stress associated with land exercise (21).

Several physiological and behavioral factors such as resting metabolic rate, body composition, transition to a new steady state, and exercise efficiency might influence caloric intake and food choices, making it difficult to unravel the independent effect of exercise on appetite (2). We tested subjects in a fasted state to reflect the early morning exercise habits observed in many college-age students. Exercise in the fasted state has not been shown to alter energy intake or energy expenditure but might influence food selection as subjects consume lower percentages of carbohydrate-containing foods under fasting conditions than under nonfasting conditions (24). The foods provided in this study were representative of subject preferences, as indicated on food logs collected at study entry.

While the present study did not explore hormonal factors that might regulate appetite after exercise, the mechanism appears linked to body temperature. Heat loss in water is three to four times greater than at a similar air temperature and depends in large part on the skin-to-water temperature difference (22). Although tympanic temperature was significantly lower in the cold trial than in the neutral trial, the actual difference of 0.3 °C was unlikely the physiological trigger for the observed higher caloric intake. Immersion in water below neutral mean skin temperature (∼ 33 °C) promotes “cutaneous vasoconstriction,” narrowing of the skin-to-water temperature difference and high tissue insulation (6, 19). Reheating of skin
temperature after immersion in cold water might involve the release of hormonal factors that stimulate appetite.

In summary, caloric intake was significantly higher for 1 h following exercise in cold water compared to the same exercise in a neutral water temperature. Furthermore, more fat calories were consumed after exercise in cold water. This finding should be considered when choosing water temperature in aquatic exercise programs that target weight loss. Further studies are needed to elucidate the mechanism and the duration of increased appetite after exercise in cold water.

Acknowledgments

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References


