The Effects of Restricted Energy and Fluid Intake on Simulated Amateur Boxing Performance

Marcus Smith, Rosemary Dyson, Tudor Hale, Matthew Hamilton, John Kelly, and Peggy Wellington

This study examined the effects of serial reductions in energy and fluid intake on two simulated boxing performances separated by 2 days recovery. Eight amateur boxers (age: 23.6 ± 3.2 years; height 175 ± 5 cm; body mass [BM] 73.3 ± 8.3 kg [Mean ± SD]) performed two simulated boxing bouts (BB) under normal (N-trial) and restricted (R-trial) diets in a counterbalanced design over 5 days. The trials were separated by a 9-day period of normal dietary behavior (X-trial). BM was recorded on days 1, 3, and 5 of each trial. Simulated bouts of three, 3-min rounds with 1-min recovery were completed on days 3 (BB1) and 5 (BB2) of each 5-day trial. Punching force (N) was recorded from 8 sets of 7 punches by a purpose-built boxing ergometer. Heart rate (f_c) was monitored continuously (PE3000 Polar Sports Tester, Kempele, Finland), and blood lactate (BLa) and glucose (BG) were determined 4-min post-performance (2300 StaPlus, YSI, Ohio). Energy and fluid intakes were significantly lower in the R-trial (p < .05). Body mass was maintained during the N-trial but fell 3% (p < .05) during the R-trial. There were no significant differences in end-of-bout f_c or post-bout BG, but BLa was higher in the N- than the R-trial (p < .05). R-trial punching forces were 3.2% and 4.6% lower, respectively, compared to the corresponding N-trial bouts, but the differences did not reach statistical significance. These results suggest that energy and fluid restrictions in weight-governed sports do not always lead to a significant decrease in performance, but because of the small sample size and big variations in individual performances, these findings should be interpreted with care.

Key Words: amateur boxing, weight management, energy provision, punching force

Introduction

Amateur boxing is a repeated-effort, high intensity sport (27), and the evidence of high post-bout blood lactate concentrations of 9–18 mM (14, 27) indicate the critical nature of carbohydrate availability in punching performance. At major events such
as the Olympic Games amateur boxers invariably include energy and fluid restriction strategies immediately prior to the official weigh-in to ensure compliance with the rules, and to compete at a weight division below their natural body mass (3). If successful, they may be required to make this artificially low weight up to six times over a 14-day period. Maughan and Shirreffs (16) suggest that weight governed athletes who adopt such a weight cycling strategy may become glycogen depleted prior to competition resulting in decreases in aerobic (4) and anaerobic performance (15).

The effects of thermally-induced dehydration on a single simulated boxing performance have already been investigated (26), but the effects of serial energy and fluid restriction on repeated boxing performance have not. This study mimics part of a typical major championship framework to examine the effects of restricted energy and fluid intake on the simulated boxing performance of amateur boxers competing twice in 3 days.

Methods

Subjects

Eight male members of the University College Chichester’s Amateur Boxing Club (age: 23.6 ± 3.2 years; height: 175 ± 5 cm; body mass [BM] 73.3 ± 8.3 kg [Mean ± SD]), who were technically adept at boxing but naive in terms of energy and fluid restriction techniques, gave their informed consent to take part in the study. Approval for the project was given by the Ethics Committee of University College Chichester, and the subjects were made aware that they could withdraw at any time.

Boxing Ergometer

A sport specific ergometer was designed to assess boxing performance and provide ecological validity for the study. It consisted of an adjustable padded target area, in the shape of a head and upper half of a body, attached to a plate mounted onto a force plate (Kistler Instruments, Winterthur, Switzerland). The position of the target pad was aligned perpendicular to each subject’s leading shoulder. Each time a punch landed on the target, a three-dimensional force analysis of the punch was determined and passed to a 12-bit Amplicon (Brighton, England) analogue-to-digital converter. The digital information was processed, converted into newtons, and displayed using a modified Orthodata (Lüdenscheid, Germany) Provec 5.0 software package sampling at 500 Hz, developed specifically for this application. Data were stored on a hard disk (Viglen 486 PC) for subsequent analysis. The validity and reliability of this device was tested using high speed cinematography and a range of weights of known mass released from a known distance to compare calculated force with the actual output from the ergometer.

Experimental Design

Two boxing simulations were performed under normal energy and fluid (N-trial) and restricted energy and fluid intakes (R-trial) in a counterbalanced design. Each condition lasted 5 days. Energy and fluid intakes were recorded for all 5 days, and BM on days 1, 3, and 5. The boxing simulations occurred on days 3 (BB1) and 5
(BB2). Subject order was randomized, and subjects acted as their own controls. Each trial was followed by a 9-day recovery period (X-trial) when normal energy and fluid intakes were consumed. During the X-trial, energy and fluid intake was recorded on days 3 to 7. R-trial energy intake was restricted to 1,000 kcal per day. Fluid intake of either low calorie flavored water or plain water was restricted to 1,000 ml per day. A Compeat 4 nutrition package (Nutrition Systems, London, England) was used to determine the composition and total quantity of energy intake in each trial.

**Procedures**

On days 3 and 5, the subjects reported to the laboratory about an hour prior to the start of each trial to allow for appropriate preparation. They were weighed nude (Avery scales, Birmingham, England, calibrated ±50 g), then fitted with crepe hand bandages (2.5 m length, 5 cm width) underneath Top Ten competition gloves weighing 284 g and a heart rate monitor (PE 3000 Sports Tester, Polar Electro, Finland). Prior to the experimental boxing bout simulation, they undertook a 15-min self-selected warm-up comprised of jogging, stretching, and striking hand-held coaching pads, which elevated heart rate to 140–150 b·min⁻¹. Heart rates (fᵢ) were recorded continuously during the boxing simulations to provide a record of cardiac responses within and between trials. The individual heart rates at the end of the final round of each trial, based on 15-s recordings, were used to assess the maximum responses. A 50μL thumb-prick blood sample was drawn 4 min post simulation to determine blood lactate (BLa) and blood glucose (BG) (Yellow Springs Instruments 2300 Statplus Automated Analyser, Ohio).

**Performance Task**

The boxing simulation consisted of three, 3-min rounds, interspersed with 1-min seated recovery periods. Video analysis of bouts at the 1994 Commonwealth Games revealed an average of 112 punches a round, with approximately half being delivered in 5-s bursts of seven punches. A prescribed audio-cue sequence was constructed based on this evidence, and these 5-s bursts of activity were analyzed for performance assessment. The subjects were instructed to produce the maximum effort with every punch. Following each punch or combination of punches, the subjects were instructed to move away from the ergometer and simulate defensive trunk movements, similar to those observed in competition, and to move back into punching distance when the appropriate audio cue was provided. The subjects were habituated to the task prior to the experiment.

**Statistical Analysis**

Linear regression analysis was used to establish the validity and reliability of the boxing ergometer. BM, boxing performance, fᵢ, and end of bout BG and BLa were analyzed using 2-way ANOVAs with repeated measures to examine the main effects and interaction between either Condition and Time or Condition and Bout. One-way ANOVAs examined changes in energy, carbohydrate, protein, fat, and fluid intakes between trials. When a significant F ratio was found, Tukey's post-hoc
tests identified differences between means. Finally, Pearson product-moment correlations were used to examine the significance of the relationship between changes in BM and punching performance, and between punching performance and BLa. The level of significance was set at $p < .05$.

Results

Ergometer Output

The differences between the calculated and measured ergometer impact forces (N) (punch unit [PU]) are shown in Table 1. Within the common working punch impact range (i.e., above approximately 500 N), the percentage error between the calculated and measured impact force was < 3%, and the coefficients of variation in ergometer output lay between 0.36–1.07%. Linear regression analysis of the straight punch calibration data showed a positive relationship between mass and force ($R^2 = 0.9994$, $p = .001$).

Table 1  Comparison of Calculated Impact Forces on the Boxing Manikin of Simulated Straight Lead Hand Punches With Recorded Ergometer Forces (Mean ± SD)

<table>
<thead>
<tr>
<th>Mass (kg)</th>
<th>Acceleration (m · s⁻²)</th>
<th>Calculated force (N)</th>
<th>Ergometer (PU)</th>
<th>Difference</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.4</td>
<td>80.4 ± 2.5</td>
<td>434.1 ± 13.5</td>
<td>324.2 ± 2.1</td>
<td>109.9</td>
<td>25.3</td>
</tr>
<tr>
<td>9.8</td>
<td>53.2 ± 1.1</td>
<td>521.4 ± 11.6</td>
<td>512.8 ± 3.4</td>
<td>8.6</td>
<td>1.7</td>
</tr>
<tr>
<td>25.4</td>
<td>42.5 ± 1.1</td>
<td>1,079.1 ± 29.8</td>
<td>1,052.4 ± 5.5</td>
<td>26.7</td>
<td>2.5</td>
</tr>
<tr>
<td>50.4</td>
<td>37.3 ± 0.6</td>
<td>1,882.3 ± 30.4</td>
<td>1,856.9 ± 6.0</td>
<td>25.4</td>
<td>1.4</td>
</tr>
<tr>
<td>65.4</td>
<td>36.1 ± 2.0</td>
<td>2,360.1 ± 132</td>
<td>2,359.8 ± 5.0</td>
<td>0.3</td>
<td>0</td>
</tr>
</tbody>
</table>

Note. Regression equation is $y = 33.518x + 170.49$.

Table 2  Changes in N-Trial and R-Trial Body Mass Recorded on Days 1, 3, and 5

<table>
<thead>
<tr>
<th>Condition</th>
<th>Day 1 (kg)</th>
<th>Day 3 (kg)</th>
<th>Day 5 (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>N-trial</td>
<td>73.29 ± 8.31</td>
<td>73.09 ± 8.35*</td>
<td>73.08 ± 7.91*</td>
</tr>
<tr>
<td>R-trial</td>
<td>73.50 ± 8.21</td>
<td>71.91 ± 8.01b</td>
<td>71.32 ± 7.85c</td>
</tr>
</tbody>
</table>

* $p < .05$ between conditions; ^$p < .05$ between days 1 and 3; ^$p < .05$ between days 1 and 5.
Table 3  Total Energy and Fluid Intakes, and Dietary Sub-Components for Each Trial

<table>
<thead>
<tr>
<th>Variable</th>
<th>N-trial</th>
<th>X-trial</th>
<th>R-trial</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy intake (kcal · day⁻¹)</td>
<td>2294 ± 759</td>
<td>2241 ± 361</td>
<td>936 ± 61</td>
</tr>
<tr>
<td>Carbohydrate (g · day⁻¹)</td>
<td>307 ± 103</td>
<td>294 ± 51</td>
<td>135 ± 11</td>
</tr>
<tr>
<td>(g · kg⁻¹BM)</td>
<td>4.18 ± 1.41</td>
<td>4.1 ± 0.7</td>
<td>1.84 ± 0.15</td>
</tr>
<tr>
<td>Protein (g · day⁻¹)</td>
<td>91 ± 28</td>
<td>88 ± 16</td>
<td>41 ± 5</td>
</tr>
<tr>
<td>(g · kg⁻¹BM)</td>
<td>1.24 ± 0.38</td>
<td>1.2 ± 0.21</td>
<td>0.56 ± 0.07</td>
</tr>
<tr>
<td>Fat (g · day⁻¹)</td>
<td>78 ± 29</td>
<td>79 ± 15</td>
<td>25 ± 5</td>
</tr>
<tr>
<td>(g · kg⁻¹BM)</td>
<td>1.06 ± 0.39</td>
<td>1.07 ± 0.2</td>
<td>0.34 ± 0.07</td>
</tr>
<tr>
<td>Fluid (L · day⁻¹)</td>
<td>2.4 ± 0.6</td>
<td>2.6 ± 2.7</td>
<td>0.9 ± 0.03</td>
</tr>
</tbody>
</table>

*Note.* R-trial significantly different (p < .05) from N- and X-trials for all variables.

**Body Mass**

Over the 5 days, R-trial BM fell 2.95 ± 1.08%, with 2.15 ± 1.01% of this loss occurring in the first 3 days. There were significant main effects for Condition (p = .006) and Time (p = .001), and an interaction between the two (p = .001) was identified (Table 2). Post hoc Tukey analysis revealed significant differences between R-trial days 1 and 3, and between R-trial days 3 and 5, compared to N-trial days 3 and 5.

**Dietary Manipulation**

Total energy and fluid intakes, and the sub-components of the different diets (total and expressed in relation to BM), are shown in Table 3. R-trials values were significantly lower (p < .001) than both N- and X-trials in all components. There were no differences between any N- and X-trial intakes.

**Heart Rate**

End of bout heart rates were lower in BB1 (N-trial, 183 ± 7.7; R-trial, 183 ± 9.3 b · min⁻¹) than in BB2 (N-trial, 186 ± 7.1; R-trial, 186 ± 7.3 b · min⁻¹), but there was no main effect for Condition (p = .59) or interaction between Condition by Time (p = .10).

**Blood Glucose**

There was no main effect for Condition (p = .38), Bout (p = .99), or interaction between Condition by Bout (p = .94) (Table 4).
Figure 1 — Difference in N-trial and R-trial heart rate response during the two boxing performances (Mean ± SE, n = 8).

<table>
<thead>
<tr>
<th>Condition</th>
<th>Bout 1</th>
<th>Bout 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>N-trial</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Blood glucose (mM)</td>
<td>6.3 ± 1.4</td>
<td>6.3 ± 1.1</td>
</tr>
<tr>
<td>Blood lactate (mM)</td>
<td>5.6 ± 2.9</td>
<td>5.8 ± 1.8</td>
</tr>
<tr>
<td>R-trial</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Blood glucose (mM)</td>
<td>6.5 ± 1.7</td>
<td>6.5 ± 1.3</td>
</tr>
<tr>
<td>Blood lactate (mM)</td>
<td>4.5 ± 1.7</td>
<td>4.7 ± 1.3</td>
</tr>
</tbody>
</table>

Table 5 Total Punching Forces Measured in Newtons (N) Exerted for Each Condition in the Two Bouts

<table>
<thead>
<tr>
<th>Trial</th>
<th>Bout 1</th>
<th>Bout 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>N-trial (N)</td>
<td>6,428 ± 852</td>
<td>6,780 ± 814</td>
</tr>
<tr>
<td>R-trial (N)</td>
<td>6,225 ± 749</td>
<td>6,472 ± 667</td>
</tr>
</tbody>
</table>
Blood Lactate

A main effect for Condition ($p = .03$) indicated that R-trial BLa values were significantly lower compared to the N-trial. While R-trial BLa were generally lower in both bouts, no significant main effect for Bout ($p = .54$) or the Condition by Bout interaction was seen.

Boxing Performance

The N-trial boxing performances were consistently higher than that of the R-trial, and BB2 performances were higher than BB1 under both conditions. However, there was no main effect for Condition ($p = .21$) or interaction between Condition by Bout ($p = .65$). The total punching forces for each bout under the two conditions are shown in Table 5.

There were no significant relationships ($p > .05$) between the percentage falls in BM and boxing performance (BB1 $r = 0.17$; BB2 $r = 0.45$), nor between boxing performance and BLa (N1 $r = 0.31$; R1 $r = 0.34$; N2 $r = 0.26$; R2 $r = 0.46$).

Discussion

The weight management strategies of athletes preparing for competition in weight-governed sports like boxing have been a matter of concern for some time (1, 2). However, research findings into the effects of fluid and energy restriction are equivocal, and there have been no studies examining the outcomes of such restrictions on serial boxing performance conducted under ecologically valid conditions. In this investigation, we found that in spite of a fall of 3% in BM between trials, average reductions of 59% in total energy and fluid intakes, and a 56% fall in carbohydrate intake, the 3% (BB1) and 4% (BB2) reductions in mean R-trial boxing performances compared to the equivalent N-trials did not reach statistical significance. The reductions in R-trial boxing performance were reflected in lower R-trial BLa values, but not in peak R-trial heart rates, which were similar for both conditions. Furthermore, in spite of the significant reduction in total energy and carbohydrate intake during the R-trial compared to the N-trial, there were no significant differences in post bout blood glucose values between trials.

The main finding is supported by two earlier studies. Houston et al. (12) found no significant difference in $V_{O_{2(max)}}$ anaerobic capacity or isokinetic leg strength at 180° and 300° s$^{-1}$ following a significant reduction in muscle glycogen content through dietary manipulation. Symons and Jacobs (28) also reported no significant difference in repeated maximal isokinetic, single maximal isometric, or externally evoked muscle force following glycogen depleting exercise. However, it is difficult to make direct comparisons because no precise information was provided on the carbohydrate intake during the energy-restricted diet of either of these studies.

The main result does conflict with three relatively recent studies that have considered relationships between diet and repeated effort activities. Horswill et al. (11) found a significant reduction in repeated arm crank performance of eight 15-s sprints separated by 30 s recovery following a 96-hour diet during which carbohydrate intake fell from 3.59 g · CHO · kg$^{-1}$BM · day$^{-1}$ on day 1 to 1.93 g · CHO · kg$^{-1}$BM · day$^{-1}$ on day 4. McMurray et al. (18) examined the effect of a 7-day restricted energy intake of 2.47 g · CHO · kg$^{-1}$BM · day$^{-1}$ on a 30-s Wingate test and found 6%
and 7% reductions in total and mean power output, respectively. Rankin et al. (23) reported a significant reduction in repeated arm crank performance of eight 15-s sprints separated by 20 s recovery following a 72-hour diet containing 2.47 g · CHO · kg⁻¹BM · day⁻¹.

There are two major differences between these three studies and ours. The first is that the reported reductions in performance occurred following daily carbohydrate intakes that were all higher than the 1.84 ± 0.15 g · CHO · kg⁻¹BM · day⁻¹ consumed over the 5 days of our study. The second is that the three performance tasks described in these studies were 2 min or less in duration and thus essentially anaerobic in nature, whereas our task had both aerobic and anaerobic components as indicated by the sustained high heart rates and the raised blood lactate levels.

Our investigation raises two main issues, namely the critical nature of carbohydrate availability during intense exercise, and the physiological mechanisms that typically attenuate the deleterious effects of fluid restriction. Bergstrom and Hultman (4) and Bergstrom et al. (5) found that muscle glycogen content was decreased after a 3-day low carbohydrate diet, and although no direct measures of muscle glycogen were taken in the present investigation, it is likely that glycogen depletion had taken place. Hultman and Nilsson (13) and Maughan and Williams (17) have also reported significantly reduced liver glycogen concentration after an overnight fast or following the consumption of a low carbohydrate diet over several days.

On the other hand, Houston et al. (12) have argued that muscular concentrations of creatine phosphate and ATP are not significantly altered following a 5-day low carbohydrate diet. Furthermore, Bogdanis et al. (6), Boobis et al. (7), Hermansen and Medbo (10), and Saltin and Karlsson (24) have provided evidence of the important roles played by the aerobic and anaerobic glycolytic pathways in ATP resynthesis, and Houston et al. (12) and Neville et al. (19) have reported energy derived through muscle glycogenolysis during repeated bouts of high intensity exercise.

If after the 5-day low carbohydrate diet, muscle and liver glycogen had been reduced, a lower post-bout blood glucose concentration may have been expected in the R-trials. In fact, post-bout R-trial values were slightly higher than N-trial values, but no significant differences in post-bout blood glucose concentrations were recorded either within or between N- and R-trials. This suggests that carbohydrate, from whatever source, was available in the restricted condition. Pascoe et al. (21) have suggested that where exercise is separated by a recovery period of several days, a carbohydrate intake of 4–5 g · kg⁻¹BM · day⁻¹ is sufficient to maintain muscle glycogen stores. It is not clear whether a protocol of 48 hours recovery with an average intake of 1.84 ± 0.1 g · CHO · kg⁻¹BM · day⁻¹ would have been sufficient to maintain adequate carbohydrate stores sufficient to sustain boxing performances over the relatively short time span of amateur boxing bouts. However, the maintenance of boxing performance on such a low carbohydrate intake raises questions about the rationale behind the AIBA Medical Commission’s (3) recommendation that amateur boxers’ total daily energy consumption should reach 70 kcal · kg⁻¹BM, and include a carbohydrate intake of 8.75 g · kg⁻¹BM · day⁻¹.

The second potential performance inhibitor, namely the restriction of fluid intake and the consequent dehydration, did not affect boxing performance and confirmed findings from an earlier study (26), which showed that boxing performances in euhydrated and dehydrated states were not significantly different. This can be explained in two ways. First, Houston et al. (12) found that the concentrations
of ATP and PCr in skeletal muscle were not reduced following dehydration. Second, several studies have estimated that the utilization of 1 g of muscle glycogen is associated with the release of -2.5-4.0 g of water (8, 9, 20, 25). Pivarnick et al. (22) suggested that muscle glycogen is used to maintain power output; the subsequent metabolic production of water is redistributed from intracellular to extracellular compartments to defend plasma volume and cardiovascular function.

The results show that there were no significant differences in body mass; total energy consumption; proportions of carbohydrate, protein, and fat intakes; or fluid ingestion between N- and X-trials, indicating adequate dietary control had been achieved. Thus the evidence leads to the conclusion that even with low carbohydrate consumption, there is sufficient energy from other sources to maintain multiple bursts of relatively short-term, high intensity activity, interspersed with recovery periods, for two bouts of 9-min duration within a 48-hour period. It is conceivable that the liver’s ability to take up gluconeogenic precursors, such as BLa, via the Cori cycle, glycerol, and amino acids, may help to maintain hepatic glucose release (13) and may have provided sufficient blood glucose to maintain punching performance very close to its normal baseline. However, the relatively low post-bout BLa indicates that either an active Cori cycle was at work, as mentioned earlier, or that whilst ecological validity may have been enhanced in our study by the use of sport-specific ergometry and a performance task based on analysis of competitive bouts, it is still difficult to replicate precise competitive conditions in the laboratory. Punching performance is only part of the total requirements of amateur boxing at the highest level. An obvious caveat is that inter-subject variability and a small sample size may have been factors that mitigated against the demonstration of statistically significant differences in punching performance. Thus it is important that these findings are viewed with caution and further studies are undertaken.

References


