BODY COMPOSITION AND POWER PERFORMANCE IMPROVED AFTER WEIGHT REDUCTION IN MALE ATHLETES WITHOUT HAMPERING HORMONAL BALANCE

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ABSTRACT

Huovinen, HT, Hulmi, JJ, Isolehto, J, Kyröläinen, H, Puurtinen, R, Karila, T, Mackala, K, and Mero, AA. Body composition and power performance improved after weight reduction in male athletes without hampering hormonal balance. J Strength Cond Res 29(1): 29–36, 2015—The aim of this study was to investigate the effects of a 4-week weight reduction period with high protein and reduced carbohydrate intake on body composition, explosive power, speed, serum hormones, and acid-base balance in male track and field jumpers and sprinters. Eight participants were assigned to a high weight reduction group (HWR; energy restriction 750 kcal·d−1) and 7 to a low weight reduction group (LWR; energy restriction 300 kcal·d−1). Energy and carbohydrate intake decreased significantly (p ≤ 0.05) only in HWR by 740 ± 330 kcal·d−1 and 130 ± 29 g·d−1, respectively. Furthermore, total body mass and fat mass decreased (p ≤ 0.05) only in HWR by 2.2 ± 1.0 kg and 1.7 ± 1.6 kg, respectively. Fat-free mass (FFM), serum testosterone, cortisol, and sex hormone–binding globulin did not change significantly. Ca2+ ion and pH decreased (p ≤ 0.05) only in HWR (3.1 ± 2.8% and 0.8 ± 0.8%, respectively), whereas HCO3− declined (p ≤ 0.05) in both groups by 19.3 ± 6.2% in HWR and by 13.1 ± 8.5% in LWR. The countermovement jump and 20-m sprint time improved consistently (p ≤ 0.05) only in HWR, by 2.6 ± 2.5 cm and 0.04 ± 0.04 seconds, respectively. Finally, athletes with a fat percentage of 10% or more at the baseline were able to preserve FFM. In conclusion, altered acid-base balance but improved weight-bearing power performance was observed without negative consequences on serum hormones and FFM after a 4-week weight reduction of 0.5 kg·wk−1 achieved by reduced carbohydrate but maintained high protein intake.

KEY WORDS explosive power, testosterone, protein

INTRODUCTION

Weight reduction is a common practice among weight category athletes (e.g., weightlifters, wrestlers, bodybuilders) ski jumpers, and some track and field athletes. Arguments for weight reduction in athletes include optimizing athletic performance, losing weight to compete in a certain weight category, and aesthetic reasons (7). Reduction of body weight, particularly fat, improves power-to-weight ratio and may be beneficial in weight-bearing efforts, such as jumping and running (for review see study by Fogelholm (7)).

In weight category sports, most of the athletes generally compete in a weight class about 10% below their off-season body mass (1,3). In many other sports, athletes reduce weight either before the competition season or before major competitions in the hope of improving performance (7). Although weight reduction is widely used by many athletes, it has been studied modestly in this population. The present study focuses on a gradual weight reduction (GWR) procedure, which lasts 7 days or longer (7).

Two of the most powerful variables that influence the outcomes of a GWR procedure seem to be the magnitude of energy deficit and protein intake (11). A weight reduction rate of 0.5 kg·wk−1, corresponding to an energy deficit of about 550 kcal·d−1, may provide better results than either a more modest or higher loss of body mass in terms of gains in explosive power performance (10), improving body composition (10,11), and minimizing hormonal alterations (21). In addition, high-protein diets (>2 g·kg−1·d−1) have been noted to preserve lean mass during weight reduction in resistance-trained individuals during a resistance training period (22). However, an adverse effect of high-protein diet
on acid-base balance has been proposed (6), but this has not been investigated during weight loss together with performance markers.

The purpose of this study was to investigate the effects of a high energy deficit diet (\(750 \text{ kcal} \cdot \text{d}^{-1}\)) and a moderate one (\(300 \text{ kcal} \cdot \text{d}^{-1}\)) in athletes just before their actual competitive season. Furthermore, the functionality of an optimal GWR diet with high protein and low carbohydrate (CHO) to optimize jumping and sprint running performance while maintaining fat-free mass (FFM), as well as hormonal parameters and acid-base balance, was examined.

**Methods**

**Experimental Approach to the Problem**

Study design is shown in Figure 1. The weight reduction period (WRP) occurred at the end of the training season just before the beginning of indoor competitions. One week before the beginning of the 4-week diet, the participants had a familiarization session with the exercises used in the physical tests (most athletes used them, however, also in their normal training) and received general instructions for the study. The participants were then instructed to record diet, body-weight, and training diaries for the next 4 days. The diet diaries were analyzed using the Micro Nutrica nutrient analysis software (version 3.11; Social Insurance Institution of Finland, Helsinki, Finland). Resting metabolic rate (RMR) was calculated as follows: 

\[
\text{RMR (kcal} \cdot \text{d}^{-1}) = -857 + 9.0 \text{ (weight in kg)} + 11.7 \text{ (height in cm)}
\]

This formula has been shown to give a standard error estimation of 91 kcal \(\cdot\) d\(^{-1}\) in male athletes (5). Energy expenditure through physical activity was estimated using the Internet application EnergyNet (University of Kuopio, Kuopio, Finland). The diet of each athlete during WRP was then evaluated and formulated according to the analysis of the diaries; the diet consisted of foods and drinks that the athlete was normally consuming. Energy restriction was achieved by decreasing CHO and fat intake while maintaining high protein (\(\geq 2 \text{ g} \cdot \text{kg}^{-1} \cdot \text{d}^{-1}\)) intake.

The participants recorded diet diaries for 2 days each week during the WRP. Using these diaries and morning body scale weight, researchers monitored the reduction in body weight and its progression as planned. Micronutrient supplements (vitamins and minerals) were allowed and the participants were instructed to use them during the study period. The use of creatine supplementation was not allowed, and no participants followed vegetarian/vegan or any other special diets. All participants were advised to keep their training program consistent during WRP, which was also controlled and monitored for volume and intensity each week by the researchers and the athletes' coaches.

**Subjects**

The present study was approved by the Ethics Committee of the University of Jyväskylä. The volunteers were 20- to 35-year-old national and international level Finnish track and field male athletes from jumping and short distance running events (e.g., 100–200 m). The participants had at least 5-year background in competitive

### Table 1. Nutritional intake before and during weight reduction period. *

<table>
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<th>LWR Before</th>
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<th>HWR Before</th>
<th>HWR During</th>
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<tr>
<td>EI (kcal·kg(^{-1})·d(^{-1}))</td>
<td>36.9 ± 8.0</td>
<td>32.8 ± 6.6</td>
<td>35.7 ± 5.6</td>
<td>27.1 ± 3.4††</td>
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<tr>
<td>Protein (g·kg(^{-1})·d(^{-1}))</td>
<td>2.1 ± 0.5</td>
<td>2.1 ± 0.5</td>
<td>2.1 ± 0.7</td>
<td>2.1 ± 0.3</td>
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<tr>
<td>Fat (g·kg(^{-1})·d(^{-1}))</td>
<td>1.3 ± 0.2</td>
<td>1.1 ± 0.3</td>
<td>0.9 ± 0.3†</td>
<td>0.7 ± 0.2†</td>
</tr>
<tr>
<td>CHO (g·kg(^{-1})·d(^{-1}))</td>
<td>4.2 ± 1.5</td>
<td>3.6 ± 0.9</td>
<td>4.6 ± 0.6</td>
<td>3.0 ± 0.3††</td>
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</table>

*LWR = low weight reduction; HWR = high weight reduction; EI = energy intake; CHO = carbohydrates.
†Significant difference vs. before, \(p < 0.01\).
††Significant difference vs. LWR, \(p < 0.05\).
athletics. The risks and benefits of participating in the study were explained to each participant and they signed a written informed consent before participating in the study. The athletes were randomly divided into 2 groups: high weight reduction (HWR; energy deficit $750 \text{ kcal d}^{-1}$; $n = 8$) and low weight reduction (LWR; energy deficit $300 \text{ kcal d}^{-1}$; $n = 7$).

**Procedures**

**Body Composition Measurements.** Body weight was determined in the familiarization session, before and after measurements, and in weekly control measurements with the same electric digital scale (Seca; Dayton Ltd, Espoo, Finland). Total body composition was determined before and after WRP using a dual-energy x-ray absorptiometry device (Lunar Prodigy Densitometer; GE Lunar Corporation, Madison, WI, USA). This method can differentiate total percentage fat, total body tissue mass, fat mass, lean mass, bone mineral density, bone mineral content, and total bone calcium with precision errors of 1.89, 0.63, 2.0, 1.11, 0.62, 1.10, and 1.09%, respectively (17).

**Blood Sampling and Biochemical Analysis.** Two blood samples were drawn from the antecubital vein in the morning at 8:00 of both measurement days after a 12-hour fast. The measurement days were separated by 4 weeks. Analysis of the blood sample included hemoglobin (Hb), hematocrit (HCT), serum total testosterone (T), sex hormone–binding globulin (SHBG), cortisol, pH, calcium ion in pH 7.4 ($\text{Ca}^{2+}$), and bicarbonate ($\text{HCO}_3^-$). The fasting samples were taken in the sitting position 2 times with 30-minute intervals. Serum samples were kept frozen at $-80^\circ \text{C}$ until analyzed. All results are presented as the mean value of the 2 samples.

For the determination of serum hormone concentrations, 5 ml of blood was taken into serum separator tubes and the concentrations were analyzed by an immunometric chemiluminescence method with Immulite 1000 (DPC, Los Angeles, CA, USA). The sensitivities of the assays were 0.5 nmol-L$^{-1}$ for serum testosterone, 0.2 nmol-L$^{-1}$ for SHBG, and 5.5 nmol-L$^{-1}$ for cortisol. Reliability (coefficient of variation, CV) for between-day measurements was 8.3% for testosterone, 5.0% for SHBG, and 6.1% for cortisol. Intra-assay CV was 5.7% for testosterone, 2.4% for SHBG, and 4.6% for cortisol. The serum hormones were analyzed from the before and after measurements all in one run.

pH, calcium ion ($\text{Ca}^{2+}$), and $\text{HCO}_3^-$ were analyzed with IL GEM Premier 3000 Blood Gas System (Instrumentation Laboratory, Lexington, MA, USA). The intra-assay CV was 0.1% for pH and 1.7% for calcium ion. $\text{HCO}_3^-$ was calculated by the Henderson-Hasselbalch equation based on pH and $\text{CO}_2$ values.

**Explosive Power and Speed Performance.** Jumping ability was measured by using a countermovement jump (CMJ) performed on a contact mat. The vertical rise of center of gravity was calculated from flight time (18). For the estimation of maximal running speed, running time with photocells was...
Weight Reduction in Male Power Athletes

Table 3. Hormone concentrations at rest before and after weight reduction period.*

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<tr>
<td></td>
<td>Before</td>
<td>After</td>
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<tr>
<td>S-Testo (nmol·L⁻¹)</td>
<td>21.9 ± 5.1</td>
<td>19.7 ± 4.5</td>
</tr>
<tr>
<td>S-Cor (nmol·L⁻¹)</td>
<td>462 ± 139</td>
<td>461 ± 103</td>
</tr>
<tr>
<td>Testo/Cor ratio</td>
<td>0.06 ± 0.03</td>
<td>0.04 ± 0.01</td>
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<tr>
<td>S-SHBG (nmol·L⁻¹)</td>
<td>39.9 ± 15.0</td>
<td>41.4 ± 14.4</td>
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*LWR = low weight reduction; HWR = high weight reduction; S-Testo = serum testosterone; S-Cor = serum cortisol; Testo/Cor = testosterone-to-cortisol ratio; S-SHBG = serum sex hormone–binding globulin.
†Significant difference vs. LWR, p ≤ 0.05.

Table 4. Acid-base balance variables, hemoglobin, and hematocrit at rest before and after weight reduction period.*

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<thead>
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<th>LWR</th>
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<tr>
<td></td>
<td>Before</td>
<td>After</td>
</tr>
<tr>
<td>Ca²⁺ (mmol·L⁻¹)</td>
<td>1.22 ± 0.04</td>
<td>1.19 ± 0.03</td>
</tr>
<tr>
<td>pH</td>
<td>7.34 ± 0.07</td>
<td>7.30 ± 0.04</td>
</tr>
<tr>
<td>HCO₃⁻ (mmol·L⁻¹)</td>
<td>31.2 ± 3.0</td>
<td>27.9 ± 2.2†</td>
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<tr>
<td>Hb (g·L⁻¹)</td>
<td>156 ± 8</td>
<td>156 ± 6</td>
</tr>
<tr>
<td>HCT</td>
<td>0.46 ± 0.02</td>
<td>0.45 ± 0.02</td>
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*LWR = low weight reduction; HWR = high weight reduction; Ca²⁺ = calcium ion in pH 7.4; HCO₃⁻ = bicarbonate ion; Hb = hemoglobin; HCT = hematocrit.
†Significant difference vs. before, p ≤ 0.05.
†Significant difference vs. before, p ≤ 0.01.

Table 5. Power performance results before and after weight reduction period.*

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<tr>
<td></td>
<td>Before</td>
<td>After</td>
</tr>
<tr>
<td>CMJ (cm)</td>
<td>53 ± 4</td>
<td>55 ± 5</td>
</tr>
<tr>
<td>20m (s)</td>
<td>2.13 ± 0.06</td>
<td>2.10 ± 0.08</td>
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</table>

*LWR = low weight reduction; HWR = high weight reduction; n = number of participants who were able to complete the test out of all the participants in the group; CMJ = countermovement jump; 20m = 20 m sprinting time.
†Significant difference vs. before, p ≤ 0.05.

Measured during a 20-m sprint test with a 20-m flying start (20m). Repetition recovery was 3–5 minutes between each of the 3 test trials and ≥5 minutes between different tests. The best result out of the 3 trials was recorded. Continuous verbal encouragement was given during all tests. Warm-up was an individual routine for each athlete and was the same for both tests. The correlation coefficient between 2 successive maximal CMJ trials has been shown to be 0.95 and CV ranging between 4 and 5% (29). Also, the 20-m running test is well reproducible in sprinters, as the correlation coefficient between 2 successive maximal sprints has been reported as 0.99 and CV 1.2% (16). These tests are routinely performed by the athletes throughout the year. Because of injuries in LWR group, 2 of the participants could not perform the 20m measurement but all 7 were able to do the CMJ without problems. Similarly, in HWR, 2 of the participants were not able to complete CMJ and 1 was not able to complete 20m. Therefore, the sample size (n) in CMJ is 6 in HWR, and in the 20m measurement, the sample sizes in LWR and HWR are 5 and 7, respectively.

Statistical Analyses
Analysis of variance (2 × 2 ANOVA), independent t-tests, Pearson’s correlation coefficients, and regression analysis were used for statistical analysis and p ≤ 0.05 was considered statistically significant. Fisher’s least significant difference test was used for post hoc analysis.

Results
Macronutrient Intake
Nutritional intake before and during WRP is presented in Table 1. Significant differences between groups in nutritional intake during WRP were observed in fat (p ≤ 0.05), total energy intake (p ≤ 0.05), and CHO (p ≤ 0.05), which were lower in HWR than in LWR without differences in protein intake (~2.1 g·kg⁻¹·d⁻¹ in each situation) as planned. A significant time effect for energy intake and CHO per body
mass (2 × 2 ANOVA) was observed (p ≤ 0.01), and although the total energy and CHO intake decreased in both groups during WRP, these changes were significant only in HWR (p ≤ 0.01).

Body Composition
There were no significant differences between the groups in body composition values before or after WRP (Table 2). Weight reduction period resulted in total body mass losses of 0.4 ± 1.2 kg in LWR (ns) and -2.2 ± 1.0 kg in HWR (p ≤ 0.01), respectively (Figure 2). Also, fat mass was significantly reduced only in HWR (p ≤ 0.05). Fat-free mass and bone mass (BM) remained statistically unaltered in both groups.

Hormone Concentrations
There were no differences between the groups in serum hormone concentrations before and after WRP (Table 3) except cortisol, which was greater (p ≤ 0.05) in HWR than in LWR before WRP. Hormone concentrations did not differ significantly after the 4-week WRP.

Acid-Base Balance
Blood acid-base balance variables are presented in Table 4 along with Hb and HCT. Plasma Ca²⁺ (in pH 7.4; p ≤ 0.05), pH (p ≤ 0.05), and HCO₃⁻ (p ≤ 0.01) decreased in HWR and HCO₃⁻ (P ≤ 0.05) also in LWR. There were no differences before or after measurements between LWR and HWR.

Explosive Power and Speed Performance
There were no differences in CMJ or sprinting time (20m) between the groups before or after WRP (Table 5). However, CMJ and sprinting time improved significantly after the WRP (p ≤ 0.05) only in HWR.

Relationships Between Measured Variables
The performance in CMJ correlated negatively (r = -0.765; p = 0.002; n = 13) with the fat percentage at baseline (Figure 3A). The HWR, the fat percentage at baseline correlated significantly with the change in FFM during WRP (r = 0.77; p ≤ 0.05) (Figure 3B). Furthermore, the decrease in pH correlated with the decrease in BM in HWR during WRP (r = 0.81; p ≤ 0.05) (Figure 3C).

Discussion
The purpose of this study was to investigate the effects of a 4-week WRP with high protein and reduced carbohydrate intake on body composition, explosive power, speed, serum hormones, and acid-base balance in male jumpers and sprinters. Weight reduction gradually by 2 kg in 4 weeks was accompanied by improved weight-bearing vertical jumping and sprinting performance, without severe negative consequences on serum anabolic and catabolic hormones and FFM. However, some signs of slightly hampered acid-base balance were observed. Furthermore, another aim of the study was to examine the relationship of initial body composition with the outcomes of the weight reduction. It was observed that athletes with fat percentage over 10% were more able to preserve FFM than more lean individuals. The present study used elite athletes in studies, which is very rare in research. One reason is that it is very difficult to get enough of them and adapt their training and nutrition to the study protocols. This was a challenge of the present study as well. However, the participants did a good job in complying with the study protocol.

In the present study, only athletes following HWR successfully and systematically reduced their energy intake, whereas the ones in LWR did not reach statistical significance. The mean daily energy restriction from baseline was 310 kcal in LWR, and 740 kcal in HWR, with subsequent
average weight loss rates of 0.1 and 0.55 kg·wk−1, respectively. Protein intake was high (~2 g·kg−1·d−1) in both groups before and during WRP. As planned, however, the percentage of total energy intake from protein increased and absolute carbohydrate intake decreased in HWR.

The 4-week diet decreased total body mass (2.2 ± 1.0 kg) and fat mass (1.7 kg ± 1.6 kg) in HWR. Only a slight and nonsignificant loss of FFM occurred in HWR (0.5 ± 1.2 kg). This is probably not because of dehydration, as indicated by unchanged Hb and HCT. However, the glycogen content of the body (with combined water) may have decreased because of energy restriction, therefore leading to FFM and total body mass loss (25). This could, at least partially, explain the loss of FFM in some of the participants in HWR. Forbes (9) stated that individuals with lower initial fat percentage would experience more lean mass loss during weight reduction than individuals with higher fat percentage, whereas Helms et al. (11) concluded that it might be unrealistic to expect a lack of FFM loss during weight reduction in lean populations. Interestingly, supporting these claims, the fat percentage at baseline in those who were in the HWR group, correlated significantly with the change in FFM during WRP (Figure 3B). From that figure it seems that individuals with fat percentages greater than 10% were less likely to lose FFM during GWR compared with leaner athletes. This is a slightly higher value than speculated earlier by Mäiestu et al. (20). Also the lower the fat percentage at baseline, the better was the vertical jumping ability. This suggests the particular importance of weight reduction for the athletes with higher fat mass to improve power-to-weight ratio for competition without the loss of muscle mass. And, however, individuals with low initial fat mass probably should be careful with dieting because it is a risk for losing more substantial amount of muscle mass.

From a practical perspective, Helms et al. (11) argued that the magnitude of caloric deficit is likely one of the most powerful variables that impact FFM loss. In the present study, that lasted only 4 weeks, neither low nor (moderately) high energy restriction seemed to decrease FFM in most of the subjects. Mettler et al. (22) showed that 2 weeks of weight reduction with substantial energy deficit of 1,500 kcal·d−1 (40% reduction in energy intake) did not result to lean mass loss in high protein group (i.e., protein intake ~2.3 g·kg−1·d−1) unlike in low protein group (i.e., ~1.0 g·kg−1·d−1) in previously resistance-trained men. Thus, relatively high protein intake such as in the present study (~2 g·kg−1·d−1 and >30E%) seems to spare FFM even when energy deficit is extensive, at least during short-term energy restriction, which is supported by several other studies (20,21,31), at least in the less lean athletes.

Higher concentrations of testosterone have been linked to body fat reduction and accumulation of lean tissue, as well as to bone status improvements (13). Substantial weight reduction (>1 kg·wk−1) has been reported to correlate strongly with a decrease in testosterone concentrations (15,21,26). Furthermore, Roemmich and Sinning (26) have shown that decreased testosterone is associated with reduced lean body mass. However, such connections between testosterone and body composition changes were not observed in the present study with body mass reductions of ~2 kg over 4 weeks.

The energy restriction in the present study (740 kcal·d−1 or ~24% total energy intake) seems not to have adversely affected serum testosterone, cortisol, and SHBG concentrations, whereas these effects have been observed with restriction exceeding 1,000 kcal·d−1 (15,21,22,24). However, it should be acknowledged that 6 of 8 subjects in the HWR group demonstrated slightly reduced testosterone and increased SHBG concentration during the WRP. Nevertheless, even moderate energy restriction (~500 kcal·d−1), when continued for months and combined with high energy expenditure (>4,000 kcal·d−1), can lead to a significant reductions in testosterone (20,27). Thus, the magnitude of energy restriction and duration of intervention seem to be very powerful “interactive” variables in determining the effects of a GWR procedure on hormonal environment.

The skeleton represents a large alkaline reservoir, which can be degraded by even mild forms of long-term metabolic acidosis (30). Signs of mild metabolic acidosis were observed in the present study. In HWR, Ca2+, pH, and HCO3− were significantly reduced, whereas BM tended to decrease slightly (40 g). We found low fasting blood pH values in the measurements after the intervention in both groups (mean 7.27 and 7.30) while normal values in adults vary between 7.35 and 7.45. Furthermore, a significant relationship was observed between the change in pH and the change in BM in HWR. This may verify the acidic and subsequent bone degrading effect of a high protein weight reduction diet suggested by Eisenstein et al. (6). It is worth mentioning that even with a slightly acidifying effect there is no evidence that a high protein diet alone would be detrimental for BM or strength (2,14). Furthermore, protein intake is beneficial to athletes engaging in resistance exercise (4,12,22). In addition, the possible harmful effects of a high protein diet on acidosis could be counterbalanced by consumption of alkaline-generating foods (23), such as fruits and vegetables, or supplements high in either potassium (28) or bicarbonate (19).

However, future studies need to assess whether consumption of alkaline foods in conjunction with a high protein diet could protect acid-base balance and bone status during energy restriction, for this was not examined in the present study.

Explosive power and sprint running performance improved in HWR group. Improvements in vertical jump height after weight reduction have also been noted in some previous studies (8,10,21,29). In the study by Garthe et al. (10), vertical jump was improved significantly by 7% in a group with an energy deficit of 470 kcal·d−1 for 8.5 weeks, whereas it was not changed in a group with an energy deficit of 850 kcal·d−1 for 5.3 weeks, although total weight
reduction was 4.2 kg in both groups. Similarly, Mettler et al. (22) observed no change in squat jump height when energy restriction was large (i.e., 40%) for 2 weeks. The improvement in running speed because of weight reduction in the present study has not been observed in previous studies. Therefore, this finding needs to be verified by further studies. Nevertheless, these findings suggest that extra body weight in the form of fat, even in already lean individuals, may interfere with running and jumping performance.

An observation worth discussing was a trend for greater improvement in explosive power, measured by vertical jump, in individuals who had initial fat percentage over 10%. The improvement ranged from 6 to 14% in subjects with body fat over 10%, whereas the improvement was ≤5% in the subjects that were leaner. Thus, it seems that less lean athletes (body fat over 10%) will experience more improvement in explosive power (and less lean mass loss as discussed above) than more lean athletes because of GWR procedure and, as mentioned earlier, also better preserve their FFM. This notion needs further studies with a bigger sample size than used in the present study to be confirmed.

**Practical Applications**

In conclusion, weight reduction of about 2 kg over 4 weeks achieved by reduced carbohydrate but high protein intake was accompanied by signs of altered acid-base balance but improved weight-bearing power performance without negative consequences on serum hormones and FFM. According to previous studies, when energy deficit increases beyond 500 kcal·d−1, the effects of weight reduction on FFM, explosive power performance, and hormonal parameters progressively gets worse. However, high protein intake (~2 g·kg−1·d−1) during weight reduction seems to protect FFM, especially when energy restriction is more than 500 kcal·d−1. Nevertheless, a protein-rich diet has the potential to at least transiently negatively influence the acid-base balance and bone status especially during weight reduction. Also, the literature and the present study show that the adverse effects of weight reduction on FFM, and thus probably on muscle size, may be more substantial if the initial fat percentage of the participant is low. Thus, very lean athletes (i.e., body fat <8–10%) should be discouraged from undergoing periods of energy restriction because health and muscle mass may be compromised and the performance benefits of weight reduction may not be noticeable as suggested also by the present study. Further studies need to investigate the individual effect of the magnitude and duration of energy restriction and the amount of protein in the diet with a larger sample size to clarify the causalities behind GWR outcomes in terms of body composition, hormones, performance and acid-base balance.

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**References**


