Ina Garthe

Acute and long-term weight loss and weight gain in elite athletes;

influences on body composition and performance

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"I remember feeling like I had just won a victory by making weight for a match, and then realised I still had to wrestle."

Bob Lefavi (former National, US, and North American wrestling champion)

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I started out as an athlete, wanting to lose weight to reach the weight class of -52 kg for the European Championships and still be able to perform at my best. Professional guidance was lacking, and the advice from coaches and co-athletes was certainly not helpful for me. My usual loss of 3 kg prior to competitions was "a piece of cake" – or should I say a piece of hard bread and egg white – but suddenly having about 6 kg to lose within a limited period made me think seriously about physiology and nutrition. My curiosity started my journey to the Norwegian School of Sports Sciences in 1996 and the final stage of the journey was to be enrolled in the PhD programme in August 2005. This journey has been one of the most noteworthy journeys I have made in my lifetime. To write a PhD dissertation is more than time and dedication, more than research, more than education and more than writing, joy and frustration. I have been so privileged to really get to know some wonderful people, athletes, coaches, colleagues, "big bosses" and sponsors who actually care. I have also confirmed what I always suspected; that I have definitely found the right husband for life. During this journey, I received the best gift you can get, the twins, Leah and Trym; and let me tell you: that puts PhD work into perspective, right there! I also lost one of my best colleagues and friends, Pella, in a bicycle accident right after our data collection in May 2009. This made it hard sometimes to even look at the data during the writing process, although it has always been easier to smile when thinking of Pella. He contributed great ideas, practical implications, humour and laughter in an otherwise busy schedule. Therefore I would like to dedicate the articles to Pella.

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Ina Garthe

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LIST OF PAPERS

This thesis is based on the following original research papers, which are referred to in the text by their Roman numerals:

I. Garthe I, Raastad T, Refsnes PE, Koivisto A, Sundgot-Borgen J. Effect of two different weight-loss rates on body composition and strength and power related performance in elite athletes. International Journal of Sports Nutrition and Exercise Metabolism. 2011, April:97-104.

II. Garthe I, Raastad T, Sundgot-Borgen J. Long-term effect of weight loss on body composition and performance in elite athletes. In press in International Journal of Sports Nutrition and Exercise Metabolism.

III. Garthe I, Raastad T, Refsnes P, Sundgot-Borgen J. Effect of nutritional intervention on body composition and performance in elite athletes. Submitted to European Journal of Sport Science (resubmitted with minor changes).

IV. Garthe I, Raastad T, Sundgot-Borgen J. Long-term effect of nutritional counseling during weight gain in elite athletes. In press in Applied Physiology, Nutrition and Metabolism.

ABBREVIATIONS

The following abbreviations in alphabetical order are used in this thesis.

ACSM	American College of Sports Medicine
ALG	Ad libitum group
AMA	American Medical Association
AMPK	AMP-activated protein kinase
AN	Anorexia nervosa
BIA	Bioelectric impedance analysis
BM	Body mass
BMD	Bone mineral density
BMR	Basal metabolic rate
BN	Bulimia nervosa
BW	Body weight
CMJ	Counter movement jump
DE	Disordered eating
DEXA	Dual energy x-ray absorptiometry
DLW	Doubly labelled water
DSM-IV	Diagnostic and Statistical Manual 4th edition
ED	Eating disorder
EDI	Eating Disorder Inventory
EDNOS	Eating Disorder Not Otherwise Specified
FFM	Fat-free mass
FM	Fat mass
FR group	Fast reduction rate group (1.4% weekly body weight loss)
IOC	International Olympic Committee
LBM	Lean body mass
mTOR	Mammalian target of rapamycin
NCG	Nutrition counselling group
RDA	Recommended daily allowance
RDI	Recommended daily intake
RM	Repetition maximum
RMR	Resting metabolic rate
SR group	Slow reduction rate group (0.7% weekly body weight loss)

SUMMARY

Many athletes attempt to change their weight in order to enhance their competitive performance level. Weight loss is generally motivated by a desire to optimise performance by improving power to weight ratio, making weight in order to compete in a certain weight category, or due to aesthetic reasons in sports that emphasise leanness. Weight gain is generally motivated by a desire to optimise performance by increasing muscle mass and thereby improving strength and power. Due to the negative effects of rapid weight loss and longer periods of restricted energy intake, existing literature recommends a gradual weight loss through moderate energy restriction and promotes a weekly weight loss of 0.5-1 kg. The same theoretical recommendation exists for weight gain; a moderate energy surplus for a gradual weight gain corresponding to a weekly weight gain of 0.5-1 kg. However, although recommended, the effect of such a weekly weight loss or gain on body composition and performance in elite athletes has not been examined. Further, the long-term effect on body composition and performance of such interventions is yet to be investigated.

Therefore, we first designed a study to compare the result of a weekly body mass (BM) loss of 0.7% (slow reduction rate (SR)) vs. 1.4 % (fast reduction rate (FR)) on changes in body composition and performance. Weekly reductions in body mass of 0.7% and 1.4% correspond to weekly reductions of 0.5 and 1 kg respectively, in a 70 kg athlete. Secondly, we designed a study to examine whether a controlled positive energy balance (~2090 KJ/~500 kcal) through nutritional counselling (NCG) could give a greater increase in lean body mass (LBM) and performance than *ad libitum* (ALG) intake during a strength training period. Finally, we looked at the long-term effect of both the weight loss and weight gain interventions.

Interestingly, with the strength training included in the weight loss study, most athletes managed to increase LBM during the weight loss intervention. Total LBM increased significantly more in SR than in FR, accompanied by improved performance in counter movement jump (CMJ) and all strength tests (1 repetition maximum tests (1RM)). There was no significant increase in LBM or improvements in performance except in 1RM squat in FR. Athletes in the FR intervention maintained body composition to a greater extent than SR athletes the first 6 months after the weight loss period, but athletes in the slow intervention tended to maintain 1RM performance to a greater extent than athletes

in the fast intervention. However, the distribution of athletes from a variety of sports probably had the greatest influence on these differences between groups. There was no significant difference between the slow and the fast intervention groups 12 months after the weight loss period, suggesting that several factors other than weight loss rate contribute to maintenance of body composition and performance after weight loss. Consequently, long-term follow-up after intervention seems to be an important factor for an elite athlete in order to maintain changes over time. One of the main challenges related to maintaining weight and body composition is a busy schedule with training, competitions, travelling and periods of injuries, studies and/or work.

Despite a weight loss of ~5% of BM, it is possible to increase LBM and performance during a gradual weight loss in normal-weight athletes. The magnitude of weekly weight loss seems to be one of the factors influencing loss of fat mass versus LBM and performance. However, there were no significant differences between groups 12 months after intervention, suggesting that weight loss rate is not the most important factor for maintenance of body composition and performance after weight loss intervention. Hence, strength training and nutritional follow-up are probably more important factors.

During the strength training period for the weight gain group, athletes who received nutritional counselling were more successful in reaching their weight gain goal than athletes who had an *ad libitum* energy intake. The NCG had significantly higher gains in LBM in legs than ALG, but there were no significant differences between groups in total LBM and strength- and power-related performance. Furthermore, there was a larger increase in fat mass in NCG (14.7±3.7%) than in ALG (2.5±2.6%). Interestingly, the NCG had significantly higher gains in BM and LBM 12 months after intervention. Thus, athletes who received nutritional counselling during a weight gain period were more successful in reaching their weight goal and maintaining the positive changes in BM and LBM than athletes who had an *ad libitum* energy intake during the intervention period.

In terms of reaching their weight gain goals, the athletes in NCG were significantly more successful than the ALG. Due to a long history of heavy strength training, the athletes had limited possibilities to increase LBM and strength-related performance. For the overall body composition goal, the excess energy intake in a weight gain protocol should be considered carefully because greater rates of gain are likely to include increments in body fat storage in trained athletes. Although BW and LBM increased in both groups during intervention, only NCG managed to maintain and even increase BM and LBM further after the intervention period. Hence, strength training combined with nutritional guidance seems to be preferable in order to obtain a long-term effect of weight gain and changes in body composition in elite athletes.

Introduction

For most athletes, body mass (BM) is relatively stable because energy intake is regulated in parallel with energy expenditure. However, many athletes attempt to change their weight in order to enhance their competitive performance level. Especially, athletes in sports emphasizing low weight and leanness are optimising performance by improving the power to weight ratio, making weight in order to compete in a certain weight category or for aesthetic reasons. Examples of such athletes are those representing aesthetic sports (e.g., gymnastics, diving, ice skating, dancing) endurance sports (e.g., long and middle distance running, cycling), weight class sports (e.g., boxing, kick boxing, taekwondo, wrestling, judo) (Table 1) and finally sports such as ski jumping, high jump and long jump, where the body mass is accelerated in the horizontal or vertical direction.

A high percentage of athletes use inappropriate weight loss methods such as dehydration, fasting, vomiting and laxatives in order to lose weight fast (Steen & Brownell 1990; Fogelholm 1994; Oppliger et al. 2003; Sundgot-Borgen & Torstveit 2004; Slater et al. 2005 a; Artioli et al. 2010 a) and it has been reported that weight class athletes lose between 2-13% of BM, whereas athletes in general usually lose 3-6% during the season (Steen & Brownell 1990; Oppliger et al. 2003; Alderman et al. 2004; Slater at al. 2005 a; Artioli et al. 2010 a). Athletes in the lighter weight categories seem to practice more extreme weight loss behaviour than athletes competing in the middle or heavy weight categories (Oppliger et al. 2003). It has also been reported that athletes start losing weight to make a weight category as early as at age 9-14 years (Steen & Brownell 1990; Alderman et al. 2004; Artioli et al. 2010 a).

Interestingly, it seems to be an association between the age at which athletes start losing weight and more extreme weight management behaviour (Kiningham & Gorenflo 2001; Artioli et al. 2010 a). Weight class athletes believe that weight loss is a necessary part of the sport, and few question the weight loss methods used (Marquart & Sobal 1994; Hall & Lane 2001). They often compete in a weight class below their natural body weight and therefore start dieting due to their experience of the specific body weight/composition demands in their sport. Further, in some sports the weight class system and/or the weight categories together with the weigh-in timing and procedure during competitive events may allow and encourage athletes to use extreme weight loss methods. This includes some weight classes which are separated by many kilograms, a long period from weigh-in to the start of competition (enabling reduction of larger amounts of weight) and only one weigh-in during tournaments (Table 1).

Also, in sports where low weight and leanness are considered important, the percentage of athletes who have one or more of the female athlete triad conditions (low energy availability, menstrual dysfunction and/or low bone mineral density (BMD)[1]) is high (Fogelholm 1994; Torstveit & Sundgot-Borgen 2005 a; Nattiv et al. 2007). Athletes competing in aesthetic sports experience a greater pressure to reduce weight than athletes competing in sports in which leanness and/or a specific weight is considered less important for performance (Byrne et al 2002). In addition to the socio-cultural demands on males and females to achieve and maintain an ideal body shape, elite athletes are also under pressure to improve performance and conform to the requirements of their sport. They are also evaluated by coaches and officials such as judges on an almost daily basis (Sundgot-Borgen 1994; Nattiv et al. 2007). These factors may lead to the use of extreme weight control methods, disordered eating behaviours and impaired health and performance (Nattiv et al. 2007). Thus, for many athletes who start to diet, the dieting together with weight concerns and the use of extreme weight loss methods will become a focus of their athletic existence and some may be diagnosed with clinical eating disorders (ED) (Sundgot-Borgen 1993; Matejek et al. 1999; Torstveit et al. 2008). Also, some younger athletes may unknowingly slip into an ED as they may be unaware of the energy demand of their increased training loads (e.g., in the transition from junior to senior).

The extreme weight loss methods place athletes at health and injury risk, and there have even been deaths among athletes representing sports characterised by rapid weight reduction and/or extreme dieting. In March 1996, a South Korean judo medallist died of a heart attack probably triggered by an extremely rapid weight loss regime, as he was preparing for the 1996 Atlanta Olympic Games. Furthermore, the deaths of three collegiate wrestlers in 1997 may have been due to the results of extreme dehydration methods to make weight.

[1] BMD values that fall well below the average for the age matched (Z-score) healthy, young female's (Ostopenic definition is stated statistically as 1-2 standard deviations below the average, osteoporosis is stated statistically as >2 standard deviations below the average) (Nattiv et al. 2007).

On the other hand, in sports where a large muscle mass is an important determinant of performance, athletes want to gain weight or lean body mass (LBM) (Walberg-Rankin 2002). These are sports in which performance depends on high absolute muscle strength or power (e.g., hammer throw, shot put, alpine skiing, ice hockey). There is a lack of studies reporting the prevalence of athletes who want to gain weight and the methods most athletes use for gaining weight. However, Hagmar et al. (2008) reported that 26% of the athletes in the Swedish Olympic team (all sports included) answered that they wanted to gain weight or had tried to gain weight during the last 12 months before the Olympics.

Although studies are lacking it is well known that athletes who want to change BM and/or body composition face many challenges and the question of whether the change in BM favours health and/or performance depends on the method and strategy the athlete uses to reach his/her goal. Athletes who want to gain weight are at risk for excessive intake of supplements and drugs, and often have diets high in saturated fat (Walberg-Rankin 2002). Furthermore, most athletes who want to gain weight are striving to avoid a parallel increase in body fat while emphasising muscle growth. Decreasing fat mass (FM) and increasing muscle mass at the same time is a difficult task because a negative energy balance favouring reductions in FM is normally inhibiting increases in muscle mass.

Another challenge is that athletes strive to maintain changes in BM over time, which may result in frequent weight fluctuations, frustrations and unstable performance during the season. Several studies have investigated the effect of acute and rapid weight loss methods in weight class athletes (Webster et al. 1990; Fogelholm et al. 1993; Filaire et al. 2000; Smith et al. 2000, 2001; Hall & Lane 2001; Slater et al. 2005 b; Degoutte et al. 2006; Artioli et al. 2010 b). However, few studies have investigated the effect of gradual weight loss (Fogelholm et al. 1993; Koutedakis et al. 1994; Koral & Dosseville 2009) and none of these studies have investigated the long-term effect of weight loss interventions in athletes. Regarding weight gain strategies, there are only a few studies on acute weight gain (Kreider et al. 1996; Rozenek et al. 2002), but none of them have monitored long-term changes. Furthermore, none of these studies have examined elite athletes. Due to the fact that elite athletes may respond differently from the general population when it comes to weight loss/weight gain interventions, it is difficult to extrapolate the results in the existing studies to elite athletes.

Table 1. *Rules for competition and weigh-in procedures in different weight class sports*

SPORT	COMPETITION	NUMBER OF WEIGHT CATEGORIES IN EACH SPORT	WEIGH-IN PROCEDURES
Wrestling Senior International (Greco-Roman and freestyle)	1 bout = 3x2 minute rounds. Each weight category is contested over one day. ≤ 4 bouts each day of competition. (competition session lasts ≤ 4 hours).	*Male* *Female* 7 7 4*	One weigh-in (30 minute period) on the evening before the tournament/competition starts.
Boxing Amateur	1 bout = 3x3 minute rounds. Competition every second day with 4-5 bouts during the tournament.	*Male* *Female* 11 13 3*	All boxers have weigh-in the morning of the first competition day. During tournaments only those drawn to box have to weigh in on the morning. There are at least 3 hours between weigh-in and start of the competition.
Judo	1 bout = 5 minutes Each weight category is contested over one day. Four to five bouts with minimum 10 minutes between bouts.	*Male* *Female* 8 7	Weigh-in on the morning of the competition (1 hour period). There are at least 2 hours between weigh-in and start of the competition.
Taekwondo	1 bout = 3x3 minute rounds. Each weight category is contested over one day. 5-8 bouts during competition.	*Male* *Female* *7* *7* 4 * 4*	Weigh-in on the evening before competition. One weigh-in at the start of competition.
Lightweight rowing	200 m course. Competition every second day over a period of 7 days.	*Male (Female)* Average weight of crew shall not exceed 70 (57) kg. An individual weight > 72.5 (59) kg is not accepted. Maximum weight for a single sculler is >72.5 (59) kg.	Weigh-in each day and for each event. Weigh-in not less than 1 hour and not more than 2 hours before start of race.

* Olympics

Weight loss strategies in elite athletes

Definitions

Dieting, extreme weight loss methods and the disordered eating continuum

There is a continuum model of disordered eating ranging from energy balance and healthy body image to clinical eating EDs such as anorexia nervosa (AN), bulimia nervosa (BN) and Eating Disorder Not Otherwise Specified (EDNOS) (Drinkwater et al. 2005; Nattiv et al. 2007). For the purpose of this review, relevant terms are defined as follows: **Gradual dieting** means healthy dieting, such as lowering energy intake by a modest number of calories$\cdot$day^{-1} and/or a modest increase in energy expenditure to achieve gradual weight loss. **Rapid dieting** includes use of extreme weight loss methods such as extremely restrictive diets (<125 KJ (30 kcal)$\cdot$kg^{-1} fat-free mass (FFM)[2]$\cdot$day^{-1}), fasting, passive methods (e.g. sauna, hot baths), active dehydration (e.g. exercise in sweat suits), laxatives, diuretics and/or vomiting, often in combination with excessive exercise (Table 2). Athletes often combine several methods to reach the competitive weight (Steen & Brownell 1990; Oppliger et al. 2003; Slater et al. 2005 a). Thus, on this continuum athletes are struggling with body image, weight fluctuation, making weight, eating behaviours and performance issues. **The female athlete triad** refers to the interrelationship between energy availability, menstrual function, and bone mineral density. This triad may have clinical manifestations including EDs, functional hypothalamic amenorrhoea, and osteoporosis (Nattiv et al. 2007). It is important to note that athletes may induce a negative energy balance in an attempt to lose weight or body fat by restricting the caloric intake using abnormal eating behaviours without meeting the criteria for a clinical ED (Drinkwater et al. 2005).

[2] In this thesis LBM (defined as FFM including essential fat (~10% of FM)) will be used. FFM (defined as all fat-free chemicals and tissue including water, muscle, bone, connective tissue and organs) will only be used when referred to definitions or study results that specific use this term.

Table 2. *Definitions of gradual and rapid weight loss*

Gradual weight loss *	Rapid weight loss **
Modestly reduced energy intake	Active or passive dehydration
Modest increase in energy expenditure	Very low energy intake or fasting
Change of E%[3] in diet	Use of laxatives, diuretics, vomiting
Loss of 0.5-1 kg per week	Increased energy expenditure
Duration ≥ 1 week	Duration 12-96 hours

** Based on reduction of FM*
*** Based on body fluid loss*
Modified from Fogelholm et al 1993

Prevalence of gradual and rapid dieting

Although a number of studies have reported suboptimal energy intake among athletes competing in aesthetic and weight-dependent sports (Jonnalagadda et al. 1998; Cupisti et al. 2000; Ziegler et al. 2005), the prevalence of athletes representing aesthetic and weight class sports who are dieting is unknown. Most athletes use a combination of methods, but the weight class athletes most frequently use rapid methods such as reduced energy and fluid intake, fasting, increased training and dehydration (passive and active) (Table 3). Up to 94% of athletes competing in weight class sports report dieting and use of rapid and extreme weight control methods to make weight prior to competition (Table 3).

When researchers study athletes representing leanness sports and aesthetic sports, it is more common to examine disturbed eating behaviour and clinical ED. Available data on the relationship/association between sport participation, use of extreme weight control methods and their effect on health and performance appears inconsistent, varying according to the sport, the athletic performance level, and the methodology used in the studies. Consequently, it is difficult to draw comprehensive conclusions that can be applied to elite aesthetic and leanness as a whole.

[3] The contribution from different macro nutrients compared to total energy intake in percentage (e.g., it is usual to decrease E% from fat in the diet during weight loss, due to the high energy content in high-fat food)

Most studies aiming to investigate the use of extreme weight loss methods and clinical EDs show that athletes are underreporting both the use of such methods and EDs (Nattiv et al. 2007; Sundgot-Borgen & Torstveit et al. 2010). When reviewing studies using clinical evaluation as a method to determine the prevalence of EDs results show a significantly higher prevalence of EDs among both male and female elite athletes representing leanness/weight class sports as compared to elite male and female athletes representing sports with less focus on leanness/weight (Rosendahl et al. 2009; Sundgot-Borgen & Torstveit, 2010). Depending on the EDs included, age group and performance level, the prevalence varies between 40-42% in aesthetic and 30-35% in weight class sports for females and 17-18% in weight class and 22-42% in gravitational sports for male elite athletes. This compares to 5% and 16% in ball game sports and 4% and 17% in technical sports for male and females respectively (Rosendahl et al. 2009; Sundgot-Borgen & Torstveit 2010).

Although most of the research on the triad and its components has been performed exclusively on females, some studies indicate that male athletes also are at risk for these problems. Reduced testosterone levels as a consequence of low percent body fat (Wheeler et al. 1984; Strauss et al. 1985; Karila et al. 2008) and also low BMD (competitive cyclists and long distance runners) have been reported (Hetland et al. 1993; Smathers et al. 2009). In a study on male cyclists, 25% and 9% were diagnosed with osteopenia or osteoporosis, respectively (Smathers et al. 2009). Further research on male athletes is needed to explore the possible association between energy deficiency and low BMD.

Table 3. *The most frequently used weight loss methods among weight class athletes (% of athletes using different methods).*

Study	Method, n, gender and category of athletes regularly losing weight	Age when losing weight began (yr) (mean ± SD)	Weight lost (kg) (mean ± SD)	Sauna/heat room	Rubber suit	Fluid Restriction	Food restriction	Fasting	Laxatives	Diuretics	Spitting	Vomiting	Excessive exercise	Gradual dieting
Steen & Brownell (1990)	Closed-ended questionnaire, male college wrestlers, n=63 (89%).	14.0±2.0	4.4±2.1 * 7.2±3.2 **	78	90	95	93	73	7	3	------	2	------	------
Sundgot-Borgen (1993)	Clinical interview, female elite weight-class athletes, n=13.	------	------	------	------	------	23 +	39 +	23 +	8 +	-----	54 +	69 +	------
Morris & Payne (1996)	Closed-ended questionnaire, male light-weight rowers n=12, female light-weight rowers, n=6.	------	♂ 3.4 * ♀ 2.8 *	63.5	30	71	------	------	------	------	------	------	73	-------
Oppliger et al. (2003)	Closed-ended questionnaire, male college wrestlers, n=741 (84%).	13.7±3.4	5.3±2.8 **	32	6	21	46	8	3 #	3 #	9	2 #	75	80
Alderman et al. (2004)	Structured interview, male NWC wrestlers, n=45.	------	5.3 **	56	49	------	------	------	11	11	------	0	91	------
Slater at al. (2005 a)	Closed-ended questionnaire, male light-weight rowers, n=58 (92%), female light-weight rowers, n=42 (94%).	------	♂ 6.0 ** ♀ 4.5 **	♂ 33 ♀ 58	♂ 41 ♀ 29	♂ 21 ♀ 88	♂ 78 ♀ 94	♂ 7 ♀ 12	♂ 11 ♀ 68	------	------	♂ 0 ♀0	♂ 33 ♀ 53	♂ 59 ♀ 94
Artioli et al. (2010 a)	Closed-ended questionnaire, male judo athletes , n=607 female judo athletes, n=607 (89%). §	12.6±6.1	1.6±1.6 * 4.0±3.1 **	a) 29 b) 55	a) 30 b) 40	a) 29% b) 55%	a) 19 b) 41	a) 12 b) 24	a) 3 b) 8	a) 2 b) 6	a) 19 b) 28	a) 0 b) 2	a) 62 b) 25	a) 18 b) 35

** = Usual weight loss, ** = Most weight lost, # = Once a month or more (defined in one study only), + = Once a week or more (defined in one study only), NWC = National Wrestling Championship, § = Male and female data are merged due to no significant differences between genders, a= Always, b= Sometimes, ------- = Information not available or method not referred to.*

Consequences on performance

The effect of weight loss on performance depends on the athlete's initial percentage of body fat, the magnitude of the weight loss and the strategy used for weight loss and recovery (Webster et al. 1990; Fogelholm et al. 1993, 1994; Koutedakis et al. 1994; Filaire et al. 2000; Smith et al. 2000, 2001; Hall & Lane 2001; Slater et al. 2005 b; Slater 2006; Degoutte et al. 2006; Koral & Dosseville 2009; Artioli et al. 2010 b). Most athletes reduce the amount of strength training in the weight loss period prior to competition in favour of more sport-specific/competition training. Less stimuli for muscle growth combined with negative energy balance is likely to cause a reduction in muscle mass and may therefore impair strength and performance (Koutedakis et al. 1994; Koral & Dosseville 2009).

Rapid weight loss

Most of the studies investigating the effect of extreme weight loss methods have methodological weaknesses such as small samples, undefined performance level, unclear and uncontrolled diet and recovery regimes/strategies and questionable test parameters in regard to specific performance tests (Table 4). Consequently, it is difficult to draw conclusions on the effect of extreme dieting and its effect on performance. Nevertheless, the results indicate that muscle endurance and prolonged aerobic and anaerobic work capacity, as in most combat sports and rowing, are likely to be impaired by rapid weight loss (Table 4).

The extent of the impairment seems to depend on the time from weigh-in to competition and the recovery strategy used. For example, Slater et al. (2005 b, 2006) found minimal impairment of rapid weight loss on 2000m rowing with an aggressive nutritional intervention in the recovery period. However, such an aggressive nutritional intervention may not be applicable for combat athletes due to the characteristics of the sport (e.g., rapid movements) and possible gastrointestinal discomfort with high volume intake. Other studies indicate that a less aggressive nutritional recovery also prevents performance impairment in interval-related performance (Fogelholm 1993; Hall & Lane 2001). Symptoms such as dizziness, hot flashes, nausea, headache and nosebleeds are frequently reported after rapid weight loss in athletes (Alderman et al. 2004) (Table 4).

Table 4. *Rapid and gradual weight loss and the effect on performance.*

Study reference	Methods (% loss of body weight)	Recovery strategy	Performance testing/ Physical indicators of performance	Effect on performance	Comments
Rapid weight loss					
Webster et al. 1990 (male intercollegiate wrestlers, n=7).	Dehydration (4.9%) using exercise in a rubberised sweat suit over 36h.	-------------------	Strength (5 repetitions of chest press, shoulder press, knee flexion and extension), anaerobic power, aerobic peak capacity and lactate threshold.	↓	Impairment in all test parameters. Although athletes had 36h to lose weight, all of the weight loss occurred within 12h before testing.
Horswill et al. 1990 (male wrestlers, n=12).	2 x weight loss (6%) by energy and fluid restriction over 4 days (one with low CHO intake and one with high CHO intake).	------------------	Arm cranking ergometer. 8 bouts of 15s maximal effort intervals with 30s of easy pace between.	→ ↓	Performance maintained with the high CHO diet and impaired with the low CHO diet. Performance decreased more the second time of weight loss.
Burge et al. 1993 (male and female elite light-weight rowers, n=8).	Weight loss (5.2%) by energy and fluid restriction combined with exercise over 24h.	2h recovery period with an intake of 1.5 l water.	Rowing ergometer time trial (2000m).	↓	Performance was impaired by 9%.
Fogelholm et al.1993 (male wrestlers, n=7, and judo athletes, n=3).	Weight loss (6%) by energy and fluid restriction over 2.4 days.	5h recovery period with *ad libitum* intake of food and fluid.	Sprint (30-m run), anaerobic power (1-min Wingate test) and vertical jump height with extra load.	→	Athletes regained 55% of body weight during recovery time.
Filaire et al. 2000 (male judo athletes, n=11).	Weight loss (4.9%) by self-selected energy and fluid restriction over 7 days (≈30% reduction in energy, CHO and fluid intake).	-------------------	Handgrip strength, 30s and 7s jump test.	→ ↓	Performance remained unchanged for left arm strength and 7s jump test but was impaired for right arm strength and 30s jump test.
Smith et al. 2000 (male amateur boxers, n=7).	Dehydration (3.8%) by low-intensity exercise for ≈ 2h in hot environment.	--------------------	Simulated boxing-related task with 3x3 min. rounds with 1 min. rest between on a boxing ergometer.	↓	One athlete improved performance whereas mean reduction in performance was 27% for the other athletes.

Study reference	Methods (% loss of body weight)	Recovery strategy	Performance testing/ Physical indicators of performance	Effect on performance	Comments
Rapid weight loss					
Smith et al. 2001 (male amateur boxers, n=8).	Repeated (2 days between) weight loss (3%) by energy (1000 kcal/day) and fluid restriction (1.0 ml/day).	-----------------	Repeated (2 days between) simulated boxing-related task with 3x3 min. rounds with 1 min. rest between on a boxing ergometer.	→	Performance tended to be lower in both bouts but did not reach statistical significance due to large individual differences.
Hall & Lane 2001 (male amateur boxers, n=16).	Weight loss (5.2%) by energy and fluid restriction over one week (self-selected weight loss strategy).	2 hours recovery with both food and fluid intake (self-selected recovery strategy).	4x2 min. circuit training session with 1 min. recovery between rounds.	→	Athletes failed to reach their subjective expected level of performance after weight loss.
Slater et al. 2005b (male and female competitive rowers, n=17).	Weight loss (4.3%) by energy and fluid restriction over 24h.	Aggressive nutritional recovery strategies in 2h (2.3g/kg CHO, 34mg/kg Na, 28.4ml/kg fluid).	4 rowing ergometer time trials (2000m) separated by 48h in thermoneutral and hot environments.	↓	Performance was impaired by 0.7% during thermoneutral trials and 1.1% during hot trials when trials were merged.
Degoutte et al. 2006 (male judo athletes, n=10).	Weight loss (5%) by self-selected energy and fluid restriction over 7 days.	------------------	Handgrip strength, maximal strength, 30 s rowing task and simulated competition (5x5min bouts).	↓	Energy intake was reduced by 4 MJ per day during weight loss.
Slater et al. 2006 (male and female competitive rowers, n=17).	Weight loss (3.9%) by energy and fluid restriction and increased training load over 24h.	Aggressive nutritional recovery strategies in 2h (2.3g/kg CHO, 34mg/kg Na, 28.4ml/kg fluid).	3 on-water rowing time trials (1800m) separated by 48h.	→	Environmental conditions were cool, showing slight variations. There was a non-significant increase in time of 1.0 seconds.
Artioli et al. 2010b (male judo athletes, n=14).	Weight loss (5%) by self-selected energy and fluid restriction over 7 days, n=7. (control group, n=7).	4h recovery period with *ad libitum* intake of food and fluid. Regained 51% of reduced weight.	Specific judo exercise, number of repeated attacks (10s, 20s, 30s, with 10s rest between), followed by 5min rest and a 5-min judo combat and three bouts of upper-body Wingate test.	→ ↑	Performance remained unchanged in specific judo exercise (number of attacks). Both control and intervention group had a slight improvement in Wingate test.

Study reference	Methods (% loss of body weight)	Recovery strategy	Performance testing/ Physical indicators of performance	Effect on Performance	Comments
Gradual weight loss					
Fogelholm et al. 1993 (male wrestlers, n=7 and judo athletes, n=3).	Weight loss (5%) by energy restriction over 3 weeks.	------------------------	Sprint (30-m run), anaerobic power (1-min Wingate test) and vertical jump height with extra load.	→ ↑	Performance remained unchanged except for the vertical jump which improved by 6-8%.
Koutedakis et al. 1994 (female elite lightweight rowers, n=6).	Weight loss (6%) by energy restriction over 8 weeks.	------------------------	VO2max, respiratory anaerobic threshold, upper body anaerobic peak power and mean power outputs, knee flexor and extensor and isokinetic peak torques.	→ ↓	Performance remained unchanged except for a decrease in respiratory anaerobic threshold and knee flexor. 50% of weight lost as fat-free mass.
Koutedakis et al. 1994 (female elite lightweight rowers, n=6).	Weight loss (7.4%) by energy restriction over 16 weeks.	------------------------	Maximal rowing ergometer test and upper-body Wingate test (VO2max, anaerobic threshold, peak power and mean power outputs) isokinetic knee flexor and extensor.	→ ↑	Improved performance in respiratory anaerobic threshold and knee flexor, VO2max and upper body anaerobic peak power. 50% of weight lost as fat-free mass.
Koral & Dosseville 2009 (male, n=10 and female, n=10 elite judo athletes).	Weight loss (4%) by self-selected energy and fluid restriction over 4 weeks.	------------------------	Countermovement jump, squat jump, 5s repetitions of judo movements, 30s repetition of judo movements, rowing with additional loads.	→ ↓	Performance remained unchanged for squat jump, counter movement jump and judo movement repetitions over 5s while impaired for 30s judo movements.

Considering that most athletes have 2-3 hours to recover after weight-in, the results indicate that the amount of weight lost by the rapid method and the recovery strategy after weight-in is of great importance for performance (Table 4). Although the intention is to lose body water over 1-7 days, it is unavoidable to lose some FM and muscle mass during fasting/extreme low energy intake (Filaire at al. 2001; Artioli et al. 2010).

Gradual weight loss

With regard to gradual weight loss, there are very few studies available. Athletes in the studies of Koutedakis et al. (1994) and Koral & Dosseville (2009) experienced loss of lean tissue as well as FM. However, gradual weight loss seems to be the method with the smallest impairment in performance in these athletes. Interestingly, studies indicate that some athletes may even improve performance during weight loss when using a gradual approach (Fogelholm et al. 1993; Koutedakis et al. 1994).

Consequences on health

Dehydration

In a dehydrated state, plasma volume decreases and peripheral blood flow and sweating rate diminish. This impairs thermoregulatory function and may lead to a series of risks to the athlete's health (Shirreffs et al. 2004). Thus, severe dehydration combined with exercise in rubber suit/sweat suit or sauna, which is a common weight loss method, makes heat dissipation difficult and can even be fatal. With regard to performance, it is recommended to avoid dehydration greater than 2% of BM (Shirreffs et al. 2004).

Inadequate intake of macro- and micronutrients

Very low energy intake and fasting place athletes at risk for inadequate carbohydrate intake as well as intake of essential fatty acids and protein. Reduced carbohydrate intake will result in glycogen depletion, fatigue and inadequate recovery between training sessions (Burke 2004). Further, a reduced protein intake is likely to cause a greater loss of lean tissue during weight loss (Mettler et al. 2009). During weight loss there is also an increased risk for suboptimal intake of calcium, iron and other micronutrients (Heyward et al. 1989; Fogelholm 1993; Filaire 2000). Although this is unlikely to cause problems in the short term, repeated weight loss periods during the season may lead to compromised vitamin and mineral status.

Cognitive function and psychological factors

Dehydration and severe energy restriction will lead to a general feeling of fatigue and are likely to increase perception of effort (Horsewill et al. 1990). Athletes undergoing rapid weight loss have shown an increase in anger, fatigue, tension and anxiety as well as impaired short-term memory (Steen & Brownell 1990; Choma et al. 1998; Filaire et al. 2000; Hall & Lane 2001; Degoutte et al. 2006). Interestingly, some athletes experience this increased anger as performance-enhancing, and thus as an essential part of the pre-competition preparation (Steen & Brownell 1990).

Growth and maturation

Delayed menarche, bone growth retardation and reduced height, weight and body fat have been reported in gymnasts (Weimann et al. 2000). Furthermore, even short-term weight loss may have marked effects on blood biochemistry and hormonal parameters (Karila et al. 2008). This may constitute a special health risk for the adolescent athlete with repeated weight loss during the season. Even though it may take months, studies show that there seems to be a catch-up effect when it comes to growth of bone and lean body mass after a weight loss period in young athletes (Roemmich & Sinning 1997; Caine et al. 2001). However, controlled studies concerning the long-term effect of frequent dieting and weight fluctuation on growth and development are lacking.

Fatigue, injuries and oxidative stress

Heavy training loads combined with low energy intake and/or low carbohydrate intake increase the risk of chronic fatigue, injuries and oxidative stress and may also impair immune function (Burke at al. 2004; Gleeson et al. 2004; Nattive et al. 2007; Yangava et al. 2010), which in the long term can lead to more frequent episodes of injuries/illness for the athlete.

Metabolic changes

Metabolic compensatory responses have been shown in obese persons after weight loss, making weight maintenance more difficult (Weyer at al. 2000; Vogels et al. 2005; King et al. 2007). Leibel et al. (1995) showed that to maintain BM after 10% weight loss, total energy intake had to be reduced by 25 KJ (6 kcal)·kg^{-1} FFM in normal-weight participants. Further, it has been stated that weight-cycling athletes have lower metabolic rate than athletes with no history of weight cycling (Brownell et al. 1987; Steen et al.

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1998). However, longitudinal studies show that metabolic rate decreases during the season but seems to reach the pre-season values after the season, suggesting that the decrease in metabolic rate may not be permanent (Melby et al. 1990). Although these changes may be reversible, it does not eliminate the fact that frequent dieting may have long-term consequences. From practical experience, weight class athletes who have used extreme methods for years, experience that "making weight" becomes increasingly difficult and have to use more and more aggressive/extreme methods to reach their competitive weight. Whether this is a result of metabolic changes or other physiological, biological or psychological factors are unknown.

The risk of disordered eating, hormonal changes and low bone density

For athletes, the stress of constantly denying hunger, being obsessed about food, agonising over body weight, and fearing high body weight is mentally exhausting. Moreover, this preoccupation interferes with the athlete's daily activities as well as his or her training and competitiveness. Dieting athletes may slip into DE, which in turn can lead to a serious ED, disruption of the normal menstrual cycle, and eventually an imbalance in bone remodelling leading to low bone mass, osteopenia or osteoporosis. Although any one of these problems can occur in isolation, the emphasis on weight loss in at-risk individuals can start a cycle in which all three conditions occur in sequence. The female athlete triad has been described elsewhere and I recommend the review by Drinkwater et al. (2005) and Nattiv et al. (2007) for further reading. Longer periods with low energy availability, with or without DE, can impair health and physical performance (Nattiv et al. 2007). Medical complications involve the cardiovascular, endocrine, reproductive, skeletal, gastrointestinal, renal, and central nervous systems (Nattiv et al. 2007).

The consequences of low energy availability, amenorrhoea and imbalance in bone remodelling are more severe for the adolescent athlete since imbalance in bone remodelling hinders high peak bone mass, stature and the development of the reproductive system. Athletes who restrict energy intake, whether inadvertently or intentionally, could be considered at risk for DE. However, it is not necessarily dieting per se that triggers DE or ED, but whether the dieting is guided or not (Sundgot-Borgen & Torstveit 2010). Furthermore, although weight class athletes are considered to be at special risk for developing EDs, there are some data that may indicate that this disturbed eating behaviour and use of extreme weight loss methods only occur in season (Steen &

Brownell 1990; Dale & Landers 1999). ED risk factors considered to be specific to athletes are: perfectionism, experienced pressure to perform, experienced pressure to lose weight leading to restricted eating and/or frequent weight cycling/fluctuation, body dissatisfaction, early start of sport-specific training, injuries, symptoms of overtraining and the impact of coaching behaviour (Forsberg & Locks 2006; Nattive et al. 2007).

Summary

Weight loss is generally motivated by a desire to optimise performance by improving the power to weight ratio, making weight in order to compete in a certain weight category or for aesthetic reasons in sports that emphasise leanness. Due to the negative effects of rapid weight loss and longer periods of restricted energy intake, existing literature recommends a gradual weight loss through moderate energy restriction and promotes a weekly BM loss of 0.5-1 kg (Walberg-Rankin 2002; O´Connor & Caterson 2010). However, the effect of a weekly BM loss of 0.5 vs. 1 kg on body composition and performance in elite athletes has not been examined. Furthermore, the long-term effect on body composition and performance of such interventions has yet to be investigated.

Weight gain strategies in athletes

Prevalence

Muscle mass is an important determinant of performance in sports that depend on high muscle strength or power. To my knowledge, there are no studies that in particular investigate prevalence of weight gain in different sports. Hagmar et al. (2008) reported that 26% of the athletes in the Swedish Olympic team answered that they wanted to gain weight or had tried to gain weight during the last 12 months before the Olympics. All though studies on prevalence are lacking, it is commonly known that many athletes strive to increase muscle mass in a busy training schedule, and that some athletes struggle to increase energy intake sufficiently due to time constraints and practical implications. Thus, for many athletes, diets high in saturated fat and dietary supplements advertised to increase muscle mass may be an easy solution (Walberg-Rankin 2002). Maintenance of muscle mass may also be a challenge. Thus, increasing muscle mass off-season, and thereafter maintaining muscle mass during the season, is an important goal for many athletes (Walberg-Rankin 2002).

Anabolic effect of nutrition

Positive energy balance

My experience indicates that athletes attempting to gain muscle mass emphasise strength training, but fail to focus on nutrition and positive energy balance. The reasons for this might be the practical challenge related to increased energy intake, fear of gaining excess body fat, and/or lack of knowledge. A typical scenario is that athletes manage to increase muscle mass off-season but fail to maintain it during the competitive season, which may lead to impaired performance at the end of the season. This may be due to suboptimal or lack of strength training between competitions, and difficulties in maintaining a sufficient energy intake due to time constraints and practical implications.

The potential for muscle growth depends on an athlete's genetics and resistance-training history (ACSM 2009 b). A positive energy balance alone has been shown to have an important anabolic effect (Forbes 1986), but combining strength training and a positive energy balance results in the most effective gain in muscle mass (Kreider et al. 1996; Rozenek et al. 2002). Studies on sedentary subjects show that LBM contributes 38-46% of the total weight gain associated with excess energy intake (Forbes 1986; Bouchard et al. 1990). Excess energy intake combined with strength training may increase the contribution from changes in LBM to 100% of the total weight gain (Kreider 1996; Rozenek et al. 2002). Since an increase in FM is undesirable for many athletes, the combination of a well-designed strength training programme and an energy-dense diet with adequate protein and carbohydrate, strategically timed protein intake and an overall planned diet is required (Tipton & Wolfe 2004; ACSM 2009 a; ACSM 2009 b).

Rozenek et al. (2002) randomised 73 healthy male subjects into three groups. In addition to their normal diets, Group 1 (CHO/PRO; n=26) consumed a 8402 KJ (2010) kcal, high-protein supplement containing 356 g carbohydrate and 106 g protein. Group 2 (CHO; n=25) consumed a carbohydrate supplement that was isocaloric with CHO/PRO. Group 3 (CTRL; n=22) received no supplement and served as controls. All subjects were placed on a 4-day·week^{-1} strength training programme for 8 weeks. Results showed a significant increase in BM and FFM in CHO/PRO and CHO compared to CTRL with a mean increases in BM of 3.1±3.1 kg and 3.1±2.2 kg, respectively. FFM increased significantly by 2.9±3.4 kg in CHO/PRO and 3.4±2.5 kg in CHO. Performance measured as 1RM in bench press, leg press, and lat pull-down increased significantly in all groups. No significant differences in strength measures were observed among groups following training.

A surplus of ~8360 KJ (~2000 kcal)·day^{-1} can be rather difficult for an athlete with an already high energy intake. The sports nutrition literature suggests that an increase in body mass of 0.25-0.5 kg·week^{-1} should be a realistic goal if the added weight is mainly gain in LBM (Houston 1999; ACSM 2009 b; Slater 2010). It has been suggested that the athlete should have a positive energy balance of 2090-4180 KJ (500-1000 kcal)·day^{-1} to increase LBM (Houston 1999; Walberg-Rankin 2002). However, athletes with a long history of heavy strength training may have less capacity for increasing LBM and strength-related performance (ACSM 2009 b). The excess energy intake in a weight-gain protocol should therefore be considered carefully because greater rates of weight gain are likely to include increments in body fat storage in trained athletes.

To my knowledge, the long-term effect of guided weight gain in elite athletes has not been evaluated. However, it is known that individuals respond differently to the same intervention (Forbes et al. 1986; Bouchard et al. 1990; Dériaz et al. 1995) and studies investigating the long-term effects of weight loss interventions in sedentary overweight participants illustrate the difficulty in maintaining changes in body composition over time (Wing & Phelan 2005).

Protein intake

Most of the studies related to weight gain in athletes are discussing the effects of creatine supplementation, other supplements or protein intakes related to muscle growth. According to the literature, both energy and protein intake are important for increasing muscle mass (Tipton & Wolfe 2004; ACSM 2009 a; Tarnopolsky 2010).

There is a common belief among athletes that high protein diets and supplements are essential for promoting gains in LBM and strength. The literature is, however, somewhat equivocal when it comes to recommendations for protein intake for different athletes. It has been suggested that it is not necessary for physically active individuals to increase their protein intake due to increased efficiency of protein utilization (Hartman et al. 2006; Tarnopolsky et al. 1991). On the other hand, a protein intakes as high as 225% of the current recommended dietary allowance (RDA) ($0.8\ g{\cdot}kg^{-1}$) has been recommended for athletes with high training load due to a higher protein metabolism (Tipton & Wolfe 2004; Tarnopolsky 2010; Tipton & Witard 2007).

The definition of protein requirement is the minimum protein intake that satisfies the metabolic demands and which maintains body composition (Millward 2001). Many athletes and coaches are not interested in protein requirements to maintain body composition; they want to know how much protein they need to promote gains in LBM (accumulate muscle protein). It is likely to think that more protein is required to gain than to maintain LBM. Consequently, many strength athletes have a protein intake that far exceeds the recommendation of $1.2\text{-}1.8\ g{\cdot}kg{\cdot}day^{-1}$ due to the belief that excess intake may increase LBM further (Tarnopolsky 2010). However, exceeding the upper range of protein intake guidelines seems not to be beneficial in terms of increasing LBM, because higher intakes simply increase protein oxidation (Tarnapolsky et al. 1992; Moore et al. 2009). There seems to be a consensus that if athletes are in energy balance or positive energy balance, increased mass and strength are possible on a wide range of protein intakes (Tipton & Wolfe 2004; Tarnopolsky 2010).

Timing of protein intake

The beneficial effect of timing of carbohydrate intake on recovery glycogen re-synthesis is widely studied (Burke 2010). The highest rate of muscle glycogen storage occurs during the first hour after exercise due to activation of glycogen synthase increased insulin sensitivity and permeability of glucose over the cell membrane (Ivy et al. 1988; Richter et al. 1989). Post exercise carbohydrate intake has also a protein sparing effect because it reduces cortisol secretion and increases insulin secretion (Biolo et al. 1999). Several studies have, over the last years, investigated the effect of co-ingestion of carbohydrate and protein before and after strength training to stimulate protein synthesis and thus promote a more anabolic environment (Rassmussen et al. 2000; Esmarch et al. 2001; Tipton et al. 2001, 2004, 2007; Rankin et al. 2004; Moore et al. 2009) (Figure 1).

Some of the first studies indicated that essential amino acids taken before exercise rather than after had an anabolic advantage (Tipton et al. 2001), but this has not been replicated in the latter studies (Rankin et al. 2004; Tipton et al. 2004). There seems to be a consensus that protein should be ingested at a time when muscle protein synthesis is maximal, which is after exercise (Burd et al. 2009; Moore et al. 2009; Hawley et al. 2011). This will stimulate the signalling pathways important for hypertrophy and recovery after intensive exercise (Hawley et al. 2011) (Figure 1), and thereby promote training adaptation. However, since muscle protein syntheses has been shown to be elevated for hours after strength training (Phillips et al. 1997, 1999), there seems to be reasonable to have a frequent intake of meals (including protein) after exercise to maximise the effect.

Type and amount of protein

Intake of essential amino acids seems to be critical in order to reach a positive nitrogen balance after a bout of exercise (Tipton et al. 1999; Børsheim et al. 2002). Thus, proteins of high biological value (high amount of essential amino acids) also stimulate protein synthesis (Tipton et al. 2004). When protein of high biological value (milk) was given post exercise over a 12 week strength training period, greater gains in LBM was reported when compared to subjects consuming an isoenergetic carbohydrate solution (Josse et al. 2010). The acute effect on muscle protein metabolism has also been reported to be more favourable when ingesting milk protein compared to soy protein after a bout of resistance exercise (Wilkinson et al. 2007) Further, dose-response studies indicates that the ingestion of ~20 g of high biological value protein acutely after strength training, maximizes muscle protein synthesis (Moore et al. 2009), and that the combination of carbohydrate and protein results in the most optimal recovery response (Miller et al. 2003). Meal frequency and thus intakes of protein seems to play a role in stimulating muscular hypertrophy and Moore and colleagues (2009) recommends ingestion of protein 5-6 times a day to maximize stimulation of protein synthesis.

Endurance training vs. strength training and its effect on hypertrophy and strength

There are several factors to consider in planning changes in BM and body composition in elite athletes. Firstly, the athlete's weight usually changes "naturally" throughout the season, either from higher to lower weight before important competitions (tuning in the specific competition weight/body composition) or from lower weight to higher weight in the off-season period with greater amounts of training. However, the BM is relatively stable from season to season and such weight changes should be accepted as a part of the training plan and periodisation.

Secondly, some athletes experience difficulties when they plan to perform at their best over a long period of time or when they try to improve several physiological parameters at the same time. For example, when strength and endurance training are performed simultaneously, a potential inhibition of strength development may occur caused by alterations in the adaptive protein synthesis (Nader 2006; Hawley 2009) (Figure 1). There are equivocal results from studies that investigate the effect of concurrent strength training and endurance training on improvements in strength and hypertrophy (Nader 2006; Aagaard & Andersen 2010). A large variation in training status of the participants and differences in design and training methods makes it difficult to draw conclusions.

A limited number of studies report the effect of concurrent endurance and strength training on muscle hypertrophy in particular (Kraemer et al. 1995; Bell et al. 2000). These studies report reduced hypertrophy as a consequence of additional endurance training and more catabolic state/overtraining, low glycogen content and changes in fiber-type transformation are some of the explanatory factors discussed (Kraemer et al. 1995; Bell et al. 2000; Nader 2006; Hawley et al. 2011). The more mechanistically explanation for inhibited effects of endurance training on strength training induced hypertrophy might be less activation of the mammalian target of rapamycin (mTOR) and other important kinases which modulates muscle protein synthesis (Nader 2006). Endurance exercise is associated with signalling mechanisms related to metabolic adaptations, such as the activation of the AMP-activated protein kinase (AMPK) (Nader 2006; Aagaard & Andersen 2010). Activation of AMPK by endurance training may reduce skeletal muscle-protein synthesis by inhibiting mTOR signalling, and may thus limit hypertrophy and strength increases in response to strength training (Figure 1).

Consequently, to manage the overall demands of different components of the sports (e.g., strength, endurance, coordination), the athlete has to periodise the training in micro and macro cycles. This means that the athlete will often plan to peak performance 1-3 times during season and have to accept decreased performance in other periods of the season. This makes it challenging for the athlete who "wants it all" during the entire season. It is also important to have this in mind when planning an intervention for changes in BM and body composition for the athlete so that the sport-specific interference is minimal.

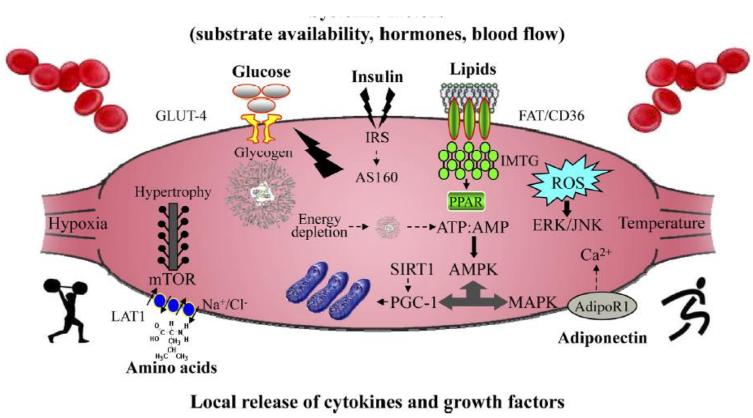

Figure 1. *Some of the contraction-induced signals elicited during and after an acute bout of exercise that are likely to be responsible for many of the long-term (chronic) adaptations as a result of training. These include 1) systemic factors such as an increased blood flow, leading to greater delivery of substrates to muscle and the concomitant alterations in the hormonal milieu to activate receptor-mediated signalling, 2) the release of cytokines and growth factors from muscle that would act to stimulate cell surface receptors and activate intracellular signalling cascades, and 3) muscle contraction (resistance or endurance based) per se. In addition to these, many interdependent factors (both local and systemic) elicit signal transduction in skeletal muscle, including substrate depletion (i.e., glycogen), hypoxia, impaired oxygen flux, leading to increased muscle lactate accumulation and decreased muscle (and blood) pH, and increased muscle temperature. (Hawley et al. 2011).*

Summary

The lack of studies in this area makes it difficult to formulate an evidence-based optimal weight gain strategy for an elite athlete. However, in theory, the quantity of energy intake necessary for optimal gains of muscle mass clearly depends on the individual athlete and training demands. Athletes with a long history of heavy strength training may have less capacity for increasing muscle mass and strength (ACSM 2009 b) and this must be considered when designing optimal nutritional strategies for increasing muscle mass and power during a strength training period. Thus, the increased energy intake in studies performed on the recreational active population or sedate populations may not be optimal for an elite athlete in terms of gaining muscle mass (and not FM). Several strategies are suggested to maximize muscle growth in response to strength training; sufficient energy and protein intake, a high meal frequency and timing of post-exercise recovery meal, all seem to be important factors in this matter. Finally, the specific approaches associated with long-term weight gain have not been identified, and there is a lack of data on long-term changes in body composition overall in the athletic population.

Aim of the studies

We chose to investigate the effect of different weight loss and weight gain strategies by designing two studies. First we designed a study to compare the effect of a weekly BM loss of 0.7% (SR) vs. 1.4 % (FR) (which corresponds to a weekly BM loss of 0.5 vs. 1 kg respectively, in a 70 kg athlete) on changes in body composition and performance. Secondly, we designed a study to examine whether a controlled positive energy balance (~2090 KJ/~500 kcal) through nutritional counselling (NCG) could give a greater increase in LBM and performance than *ad libitum* (ALG) intake during a strength training period. Finally, we looked at the long-term effect of the different interventions.

I) The aim of Paper I was to investigate the effect of a slow weight loss regimen vs. a fast weight loss regimen (a weekly BM loss of 0.7% vs. 1.4 %) on changes in body composition, strength- and power-related performance in elite athletes. The slow and the fast weight loss corresponded to a weekly BM loss of 0.5 vs. 1 kg respectively, in a 70 kg athlete. We hypothesised that the faster weight loss regimen would result in more detrimental effects in both LBM and strength-related performance than the slow weight loss regimen.

II) The aim of Paper II was to compare the long-term effect of a slow weight loss regimen vs. a fast weight loss regimen (a weekly BM loss of 0.7% vs. 1.4 %) on changes in body composition, strength- and power-related performance in elite athletes. We hypothesised that the faster weight loss regimen would result in more detrimental effects in both LBM and strength-related performance and a faster re-gain of weight 6 and 12 months after intervention.

III) The aim of Paper III was to examine whether a controlled positive energy balance through nutritional counselling could give a greater increase in LBM and strength-related performance than an *ad libitum* intake during an 8- to 12-week heavy strength training period. We hypothesised that the athletes in the intervention group, with daily excess energy intake corresponding to ~2090 KJ (~500 kcal), would have greater gain in BM and LBM, and greater strength-related performance enhancement than those in the *ad libitum* group, despite similar strength training stimuli.

IV) The aim of Paper IV was to examine whether a controlled positive energy balance through nutritional counselling has better long term outcomes in body composition than an *ad libitum* intake during an 8- to 12-week heavy strength training period. We hypothesised that the athletes in the guided intervention group would have greater gain in BM and LBM 12 months after intervention than those in the *ad libitum* group.

Methods

Paper I-IV

Participants

Male and female athletes, aged 17-35 (18-35 for weight loss), were recruited by invitation from the Norwegian Olympic Sport Centre when they contacted the centre for assistance with weight loss, or by invitation letters to sport federations (Appendices I-II). For the flow-chart, see Figures 2 and 3. The athletes were informed about the purpose and experimental procedures before written consent was obtained. The study was conducted according to the Declaration of Helsinki and approved by the Data Inspectorate and the Regional Committee for Medical Research Ethics of Southern Norway (Appendices III-IV). Permission to conduct the study was granted by the Norwegian Olympic Committee and the Norwegian Confederation of Sports. The following sports were represented in the weight loss study (Papers I and II): rowing, kayaking, soccer, skating, volleyball, cross country skiing, judo, jujutsu, taekwondo, waterskiing, motocross, cycling, track and field, kickboxing, gymnastics, alpine skiing, ski jumping, freestyle, biathlon and ice hockey. The following sports were represented in the weight gain study (Papers III and IV): rowing, kayaking, soccer, skating, volleyball, taekwondo and ice hockey.

Pre-participation screening

The screening included the Eating Disorder Inventory (EDI-2) (Garner 1991), followed by an interview and medical examination according to the standard for pre-season health evaluation at the Norwegian Olympic Sports Centre. The exclusion criteria were as follows: 1) diseases and conditions known to affect metabolic functions (e.g., hypo-/hyperthyreosis) , 2) use of pharmaceuticals that might affect any of the measurements, 3) presence of one or more of the triad components; DE[4]/ED, menstrual dysfunction and/or low BMD (Nattiv et al. 2007), 4) clinically evident peri-menopausal condition, 5) pregnancy, and 6) FM corresponding to a predicted post-intervention body fat value of less than 5% for males and 12% for females (Fogelholm 1994; Heyward & Wagner

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[4] DE is not a clinical diagnosis, and athletes with DE symptoms do not fulfil all the DSM-IV criteria for a diagnosis.

2004). For possible diagnoses, DSM-IV criteria were used for AN, BN and EDNOS (APA 1994).

Supplementation

The athletes were not allowed to use creatine supplementation during the last 6 weeks prior to inclusion, and they did not take any supplements other than those given by the nutritionist during intervention. A multi-vitamin-mineral supplement (Nycomed, Asker, Norway) and a cod liver oil supplement (Møller's tran, Oslo, Norway) were prescribed to assure sufficient micronutrient intake and essential fat intake during the weight loss intervention (Paper I). Furthermore, if blood samples indicated any other specific micronutrient needs (e.g., iron, Vitamin B12), these vitamins were provided to the athletes and blood levels were thereafter monitored.

Diet registrations

Diet registrations were obtained using a 4-day weighed food record which was analysed by the national food database "Mat På Data" (Version 5.0. LKH, Norway). The athletes' weights were stable during the week of diet registration. The record served as a basis for the development of each athlete's individualised diet plan.

Nutritional counselling

The athletes receiving nutritional counselling had one counselling session$\cdot$week^{-1} during intervention. The counselling was done by an experienced sports nutritionist/physiologist and included basic nutrition, sports physiology and possible adjustments in the dietary plan or weight regimen, depending on progress.

Training

The intervention period started off-season for all athletes in order to be able to add additional training to their schedule and for practical reasons (e.g., travelling and competitions). All athletes continued their sport-specific training schedule. The programme included four strength training sessions$\cdot$week^{-1} to emphasise muscle strength and hypertrophy. The strength training programme was a 2-split periodised programme. Each muscle group was exercised twice a week with two exercises in each session, one main exercise attacking multiple muscle groups (e.g., squat) and one working separately on a specific muscle group (e.g., knee extension) (Appendix 5). Main exercises for leg muscles were clean (whole body), squat, hack squat and dead lift, and main exercises for upper body muscles were bench press, bench pull, rowing, chins, shoulder press and core exercises. In the first four weeks the athletes had a training regimen of 3x8-12 repetition maximum (RM) sets, in the next period 4x6-12RM sets and in the last four weeks 5x6-10RM sets. For the athletes who participated fewer than 12 weeks, the programme was adjusted with shorter periods. The rest period between sets was from 1-3 minutes. Once a week, athletes were supervised during training at the Olympic Sports Centre, to ensure correct training technique and adequate progress. A computerised exercise diary was recorded during the entire intervention period.

Experimental assessments

All tests were conducted by the same test team before and after intervention and the test day was standardised. Athletes were not allowed to perform heavy training 48 hours prior to testing.

Body mass

BM was measured in fasted state with a balance scale (Seca model 708, Seca Ltd., Birmingham, UK) to the nearest 100 g on the morning of the test day between 8-9 am. During the intervention period, athletes used their own scales to monitor BM since their weekly meetings with the nutritionist were at different times of the day and their weight would fluctuate depending on food and liquid intake. They were instructed to weigh themselves without clothes and with empty bladder immediately after waking up and before breakfast.

Body composition

Total BM, FM and total and regional LBM (upper (trunk + arms) and lower (legs)) were measured with dual energy x-ray absorptiometry (DEXA) (GE Medical Systems, Lunar Prodigy, Wisconsin, USA) by a trained technician (Illustration picture 1). The DEXA system was calibrated every day before testing and the test was conducted in a fasted state between 8.30-10.00 am. After BM and height were measured, the athlete was placed on a table and the radiation detector assembly was moved back and forth across the body measured. The measurement took about 15 minutes per athlete. The measurements areas were total body, lumbar spine (L2-L4), femoral neck, Ward's Triangle, trochanter, femoral shaft and total femur in addition to BM, FM, LBM and calculation of fat percentage. For DEXA reproducibility, ten athletes did two repeated measurements within 24 hours, and the coefficient of variation in DEXA Lunar Prodigy total body scan for repeated measurements was 3% for FM and 0.7% for LBM.

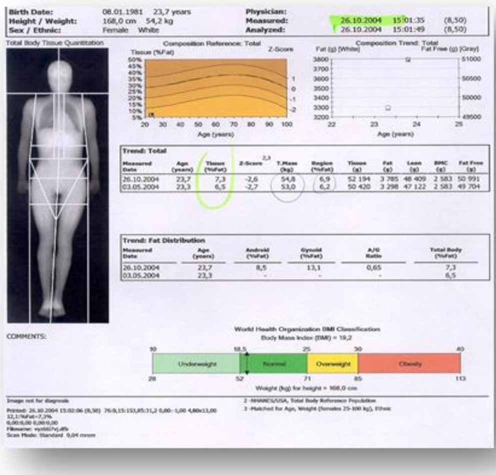

Illustration picture 1. *Visual measure areas of DEXA analysis.*

Performance

Performance was measured by 40 m sprint, counter movement jump (CMJ) and 1RM in bench press, bench pull and squat. Prior to the sprint, CMJ and 1RM strength tests, the athletes performed a standardised warm-up consisting of 15 min low intensity running or cycling.

40 m sprint

After three sub-maximal runs as specific warm-up, the athletes performed three maximal 40 m sprints. The best result was used in the data analysis. The athletes were instructed to stand with one foot on a marker, and time started when the subjects left the marker in the first step. Sprint time was thereafter measured with photocells every 5 m. The photocells were placed at a height of 133 cm.

Counter movement jump

CMJ was performed on a force plate (SG 9, Advanced Mechanical Technology Inc., Newton, MA) and low-pass filtered at 1050 Hz. The CMJ started from a standing position with the hands fixed to the hips. Jump height was calculated from the vertical reaction force impulse during take-off. At each test, the athletes performed three jumps, and the best was used in the data analysis. BM was included in the jump height calculation, and this was measured on the force plate before the first jump at each test.

1 repetition maximum

Maximal strength was measured as 1RM in bench press, bench pull and squat. Prior to the pre-intervention test, familiarisation sessions were conducted with the purpose of instructing the athletes in proper technique and testing procedure. Athletes performed a standardised protocol consisting of three sets with gradually increasing load (40, 75, and 85% of predicted 1RM) and decreasing number of repetitions (10, 7, and 3). The first 1RM attempt was performed with a load approximately 5% below the predicted 1RM load. After each successful attempt, the load was increased by 2–5% until the athletes failed to lift the same load after 2–3 consecutive attempts. There were 3 min rest between each attempt. All strength tests throughout the studies were conducted using the same equipment monitored by an experienced investigator from the test-team.

The athletes performed a **1RM full squat** test. The test started in a standing upright position. The lowest position in the lift, was reached when the centre of rotation in the hip (point A, figure 2), was lower than the top of the knee (point B) (Illustration picture 2). To ensure similar position during all tests, the athletes' squat depth was carefully monitored.

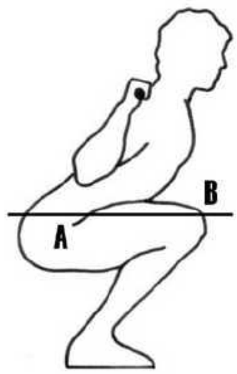

Illustration picture 2. *Illustrate the deepest position of the lift.*

The athletes performed on a standardised barbell **bench press**, where the lift started with straight arms. The barbell was lowered to it touched the chest and raised to straight arms again. The lower back was in touch with the bench at all times during the lift.

The athletes performed **bench pull** with face down on a bench with the arms hanging down holding the bar (Illustration picture 3a). The arms pulled the bar straight up until it touched the bench (Illustration picture 3b). The athletes chin and legs had to be in contact with the bench at all times during the lift.

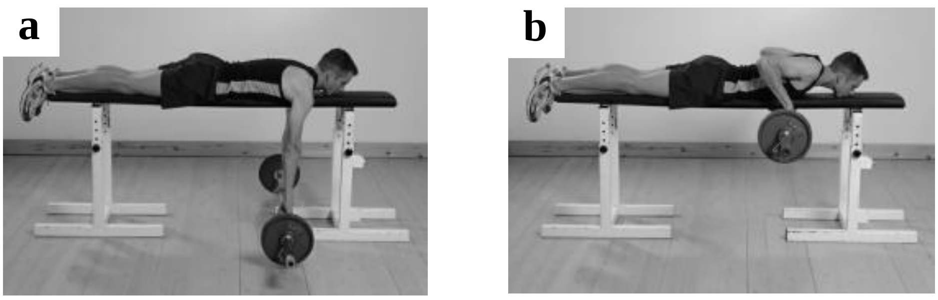

Illustration picture 3 a, b. *The start position (a) and the end position (b) in bench pull.*

Eating disorder inventory

The EDI-2 is a 91-item, 6-point forced-choice self-report measure assessing several behavioural and psychological traits common in anorexia nervosa and bulimia (Garner 1991). The EDI-2 consists of the following 11 subscale scores: drive for thinness, bulimia, body dissatisfaction, ineffectiveness, perfectionism, interpersonal distrust, interceptive awareness, maturity fears, asceticism, impulse regulation, and social insecurity. The athletes in weight loss studies I and II filled out the EDI at pre- and post-testing to assess behavioural and psychological traits.

Statistical analyses

With an expected net difference in change of FM of 6 % for the weight loss study, the minimum sample size for two equally sized groups had to be 29, assuming a SD of FM change equal to 7 % and a significance level of 5 %.

n=2 (1.96 + 1.28)2 x (7/6)2
n= 29

A post hoc analysis on LBM was performed in the weight gain study after 21 and 18 subjects had completed the intervention. We would have had to include 200 subjects for the underlying effect size to reach significance at the 5 % level.

Data are presented as mean±SD for pre- and post-measurements and mean±SE for changes within and between groups. The computer software Graphpad Prism 5.0 (Graphpad Software, San Diego, CA, USA) and SPSS 15 (Chicago, Illinois, USA) were used for statistical analysis. The changes from pre-intervention to 12 months post-intervention within and between groups were analysed with 2-way repeated ANOVA corrected with Bonferroni post hoc test. Pearsons R or Spearmans Rho was performed when appropriate to study correlations between variables. P values below 0.05 were considered statistically significant.

Experimental Design

Papers I and II

The athletes were screened and block randomised to the SR and FR groups (Figure 2). All athletes followed a 4-12 week energy restriction and strength training period. The length of the intervention was determined by the rate of weight loss (SR or FR) and the desired weight loss (minimum 4% of BM). The final weight goal was set by a nutritionist/exercise physiologist based on the results from the body composition measurements that provided the information needed for calculating the minimum fat percentage for each athlete and the athlete's desired weight loss. The length of the intervention period for each subject was dependent on the athlete's weight loss goal and the weekly weight loss rate. For example, a 70 kg athlete who wanted to reduce BM by 5 kg (where the weight loss was appropriate for the calculated minimum fat percentage) would have either a five-week (FR) or ten-week (SR) intervention depending on which intervention group the athlete was randomly allocated to. All athletes in Papers I-IV undertook the same strength training programme, as previously described. After intervention, the athletes received one session of nutrition counselling and exercise counselling within 4 weeks after the post-test in order to stabilise the new BM and body composition. Other than that, there was no counselling or interference with the athletes. They were called in for post-test at 6 and 12 months (Figure 3).

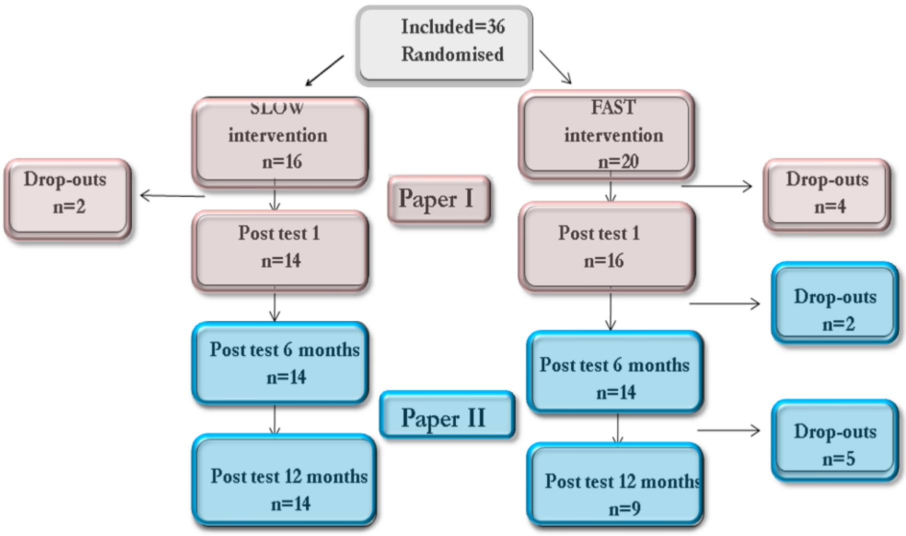

Figure 2. *Flow chart from pre-test to 12 months post-test for the weight loss study.*

Diet intervention

The diet registration served as a basis for the development of each athlete's individualised diet plan promoting weekly BM loss of 0.7% or 1.4%. This was calculated from the assumption that 1g of mixed tissue gives 29 KJ (7 kcal) (McArdle et al. 2000; O´Connor & Caterson 2010) therefore reducing BM by 1 g demands 29 kJ (7 kcal) negative energy balance. For example, a 60 kg athlete in SR had to reduce energy intake by ~ 1756 KJ (~ 420 kcal)·day^{-1} to achieve the weekly weight loss goal of 0.4 kg [(60000 x 0.7% / 7 days x 29 KJ (7 kcal)]. In the diet plans, the aim was to have a daily protein intake corresponding to 1.2-1.8 g·kg^{-1}, a daily carbohydrate intake corresponding to 4-6 g·kg^{-1} and ≥20% fat, with low energy/high nutrient density foods that provided satiety as well as food variety. There were 5-7 daily meals and snacks, and no meal plan below 6270 KJ (1500 kcal)·day^{-1}. All athletes ingested a milk protein-based recovery meal containing carbohydrates (20-40 g) and protein (6-20 g) within 30 minutes after training sessions and a balanced meal within 1-2 hours, in an attempt to optimise recovery.

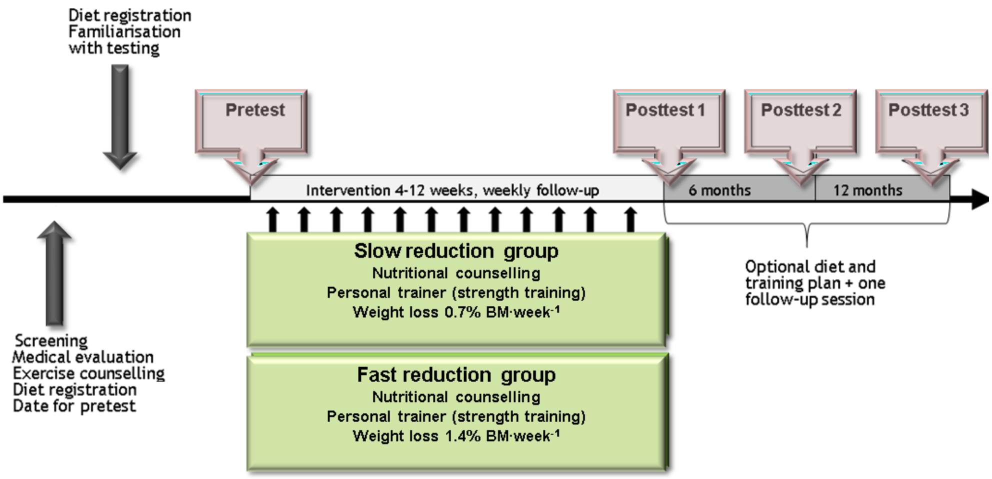

Figure 3. *Design weight loss study.*

Papers III and IV

The athletes were screened and block randomised into NCG and ALG (Figure 4). All athletes followed an 8- to 12-week weight gain period (Figure 5). The length of the intervention period for each subject depended on the athlete's weight gain goal. Athletes in both groups were aiming for a weekly gain of 0.7% of total BM. This corresponds to a weekly weight gain of 0.5 kg in a 70 kg athlete. Thus, if a 70 kg athlete were to increase his/her BM by 5 kg, he/she would need to participate in the intervention for 10 weeks. The athletes in NCG received nutritional counselling once a week during intervention, while the athletes in ALG did not receive any nutrition counselling. The counselling included basic nutrition, sports physiology and possible adjustments in the dietary plan or weight regimen, depending on progress. All athletes had 4 strength training sessions·week^{-1}. After intervention, the athletes received one session of nutrition counselling and exercise counselling within 4 weeks in order to stabilise the new weight and body composition. Other than that, there was no counselling or interference with the athletes. They were called in for post-test at 6 and 12 months (Figure 5).

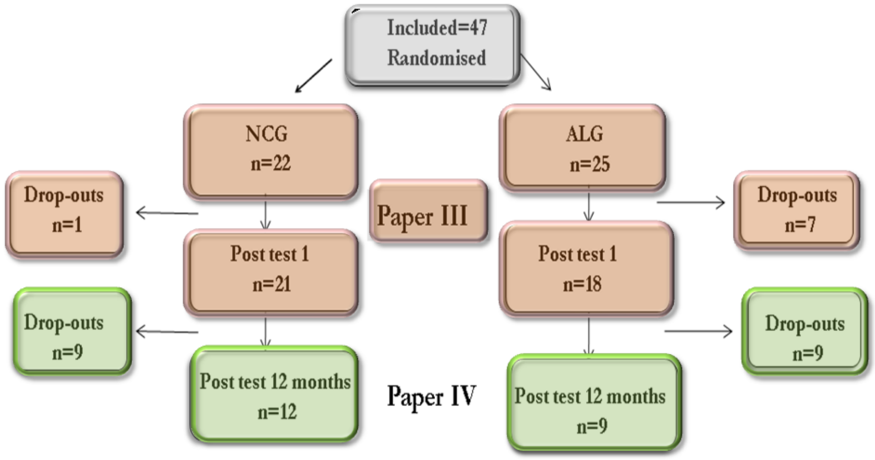

Figure 4. *Flow chart from pre-test to 12 months post-test for the weight gain study.*

Diet intervention

The diet registrations served as a basis for the development of each athlete's individualised diet plan in the NCG, promoting weekly BM gain of 0.7% of total BM. In ALG, 24 hour recall was done mid- and post-test to monitor changes in the nutritional variables during the period. The macronutrient distribution of the total energy intake was designed to have a protein intake corresponding to ≥2 $g \cdot kg \cdot BM^{-1}$, a carbohydrate intake corresponding to 5-7 $g \cdot kg \cdot BM^{-1}$ and 25-30% fat. The focus was on energy- and nutrient-dense foods as well as high food variety and a frequent meal pattern to ensure energy intake every third hour, corresponding to 5-7 meals per day. The dietary plan was tailored to meet each athlete's specific needs and was designed to be as optimal as possible for both health and athletic performance. All NCG athletes ingested a recovery meal containing carbohydrates (40-50 g) and protein of high biological value (15-20 g) within 30 minutes after training sessions, and a balanced meal within 1-2 hours of training to optimise recovery. Athletes in the ALG did not get feedback on their diet registration until they had completed the study. ALG athletes were instructed to eat *ad libitum* during the intervention period, with the goal of gaining 0.7% $BM \cdot week^{-1}$.

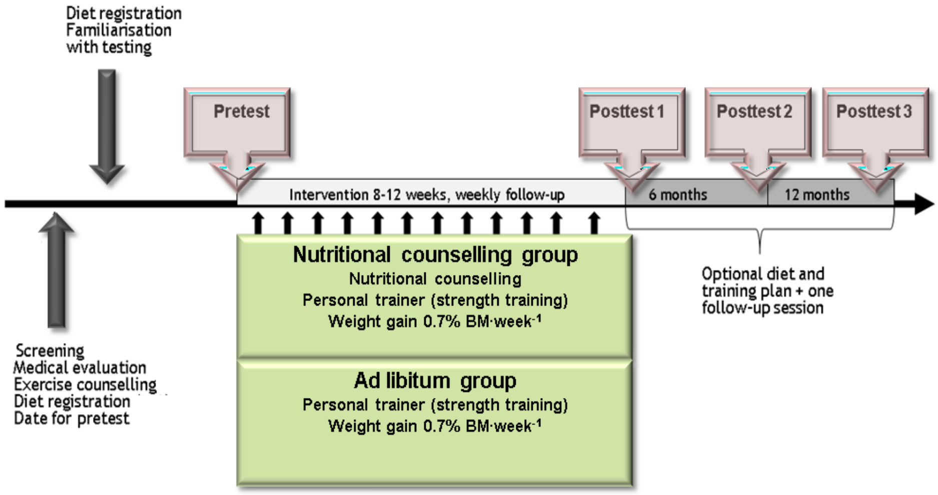

Figure 5. *Design weight gain study.*

Main results of the weight loss study

Paper I

A history of dieting and weight cycling was reported by 53% of the athletes in SR and 45% of the athletes in FR. The mean time spent in intervention for SR and FR was 8.5±2.2 and 5.3±0.9 weeks, respectively. Baseline data are presented in table 5.

Table 5. *Baseline data presented as mean±SD*

	SR		FR	
	Males (n=6)	Females (n=7)	Males (n=5)	Females (n=6)
Age (yrs)	24.9 ± 3.5	22.4 ± 3.1	20.9 ± 4.5	20.7 ± 6.4
Height (cm)	177 ± 11	169 ± 8	179 ± 4	167 ± 1
BM (kg)	78.5 ± 14.1	66.4 ± 8.8	81.9 ± 11.5	68.9 ± 6.7
FM (kg)	13.3 ± 5.0	17.3 ± 4.4	13.3 ± 6.5	21.2 ± 5.2
Total body fat (%)	17 ± 5	27 ± 5	16 ± 3	30 ± 5
LBM (kg)	62.3 ± 10.3	46.3 ± 5.5	65.5 ± 3.3	44.6 ± 3.6
Experience as athletes (yrs)	13 ± 6.4	10.7 ± 4.7	12.6 ± 4.5	13.1 ± 5.1
Training (h•week-1)	15.6 ± 4.5	15.2 ± 3.1	15.2 ± 3.1	13.9 ± 5.3
Strength training last season (h•week-1)	2.8 ± 1.6	2.7 ± 1.6	3.4 ± 1.1	2.1 ± 1.5

BM = Body mass, FM = Fat mass, LBM = Lean body mass

Diet

Baseline energy intake was 10.1±2.6 MJ (2409±622 kcal)·day^{-1} and 10.5±2.2 MJ (2514±518 kcal)·day^{-1} for SR and FR respectively. Energy intake was reduced more in FR (30±4%) than in SR (19±2%) (p=0.003) according to the aim of faster weight loss in FR.

Body composition

BM was reduced significantly by 5.6±0.8% in SR (p<0.001) and 5.5±0.7% in FR (p<0.001) (Figure 6). The average weekly rate of weight loss was significantly slower for SR than FR (0.7±0.4% vs. 1.0±0.4%, p=0.02). FM decreased more in SR than in FR

(31±3% vs. 21±0%, respectively, p=0.02) (Figure 6). Total LBM increased significantly in SR by 2.1±0.4% (p<0.001), whereas it was unchanged in FR (-0.2±0.7%) with significant differences between groups (p<0.01) (Figure 6). The weekly gain in LBM was 0.3±0.0% vs. 0.0±0.1%, (p=0.02) for SR and FR, respectively, and the increase in total LBM in SR was mainly caused by a 3.1±0.8% increase in upper body LBM.

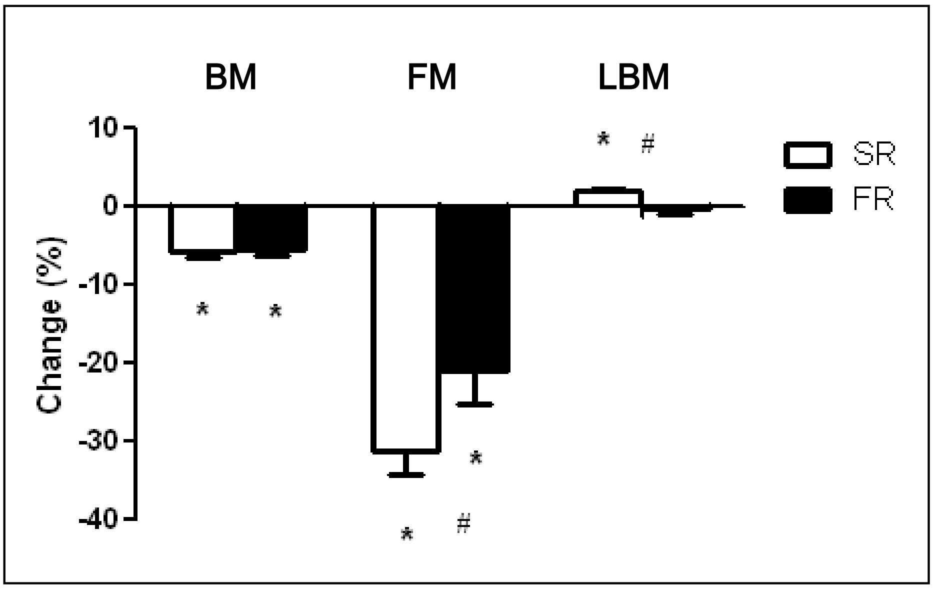

Figure 6. *Changes in body mass (BM), fat mass (FM), and lean body mass (LBM) in the slow rate group (SR) and the fast rate group (FR). Data are presented as mean±SE. * p<0.05 significantly different from pre-intervention, # p<0.05 significant difference between groups.*

Performance

Jumping performance in CMJ improved by 7±3% (p<0.01) in SR, while no significant change was observed in FR (Figure 6). There was no change in 40m sprint performance in any of the groups. 1RM squat improved similarly by 11.9±3.4% (p<0.01) in SR and 8.9±2.3% (p<0.01) in FR (Figure 7). Bench press performance increased more in SR than in FR (13.6±1.1 vs. 6.4±3.3%, respectively, p=0.01) (Figure 7). The performance in bench pull improved by 10.3±3.0% (p=0.001) in SR. The weekly gain in mean relative changes in all 1RM measurements was 1.4±0.7% and 1.3±0.5% for SR and FR, respectively.

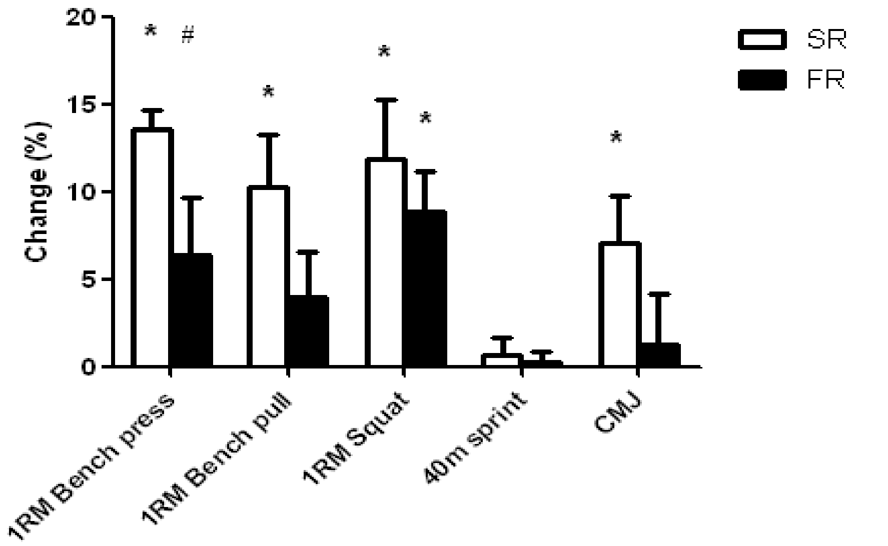

Figure 7. *Changes in 1RM bench press, bench pull and squat, counter movement jump (CMJ) and 40m sprint performance in the slow rate group (SR) and the fast rate group (FR). Data are presented as mean±SE. * p<0.05 significantly different from pre-intervention, # p<0.05 significant difference between groups.*

Eating disorder inventory

There were no significant differences between groups at baseline in any of the EDI subscale scores except for a higher baseline score in drive for thinness in FR, and there were no significant changes in total EDI scores from pre- to post-test in either SR or FR (Table 6).

Table 6. *Changes in EDI scores from pre- to post-test*

	SR (n=11)			FR (n=8)		
	Pre	**Post**	**Change**	**Pre**	**Post**	**Change**
	Mean ± SD	Mean ± SD	Mean ± SE	Mean ± SD	Mean ± SD	Mean ± SE
Total score EDI 2	35.2±16.5	26.2±13.7	9.0±4.5	26.5±11.5	27.6±9.6	1.3±3.3
Drive for thinness	2.1±0.3	2.6±1.1	0.6±1.3	6.0±1.9#	4.1±1.7	1.9±1.8
Body dissatisfaction	3.5±0.1	2.9±0.5	-0.6±1.3	4.5±2.1	4.9±1.2	0.4±1.7

* *Significantly different from pre-intervention*
# *Significant difference between groups*

Compliers versus non-compliers

The defined weekly weight loss goal for SR and FR was 0.7% and 1.4% of BM. All athletes are included in the present results according to the intention-to-treat principle. The mean weekly weight loss rate and standard deviation were 0.7±0.4% of BM·week^{-1} for SR and 1.0±0.4% for FR, with significant differences between groups ($p=0.02$). Three athletes in SR (cut-off values in weekly weight loss rate: 0.5-0.9%) and five athletes in FR (cut-off values in weekly weight loss rate: 1.0-1.6%) did not accomplish their weight loss goal. When noncompliers were removed there were no significant changes in results, but differences between the SR and FR were generally more pronounced. No statistically significant differences in any of the variables were found between compliers and noncompliers.

Paper II

The results of paper II includes data from the intervention period (paper I), however, due to drop-outs in the follow-up, the results are somewhat different due to a smaller population.

A history of dieting and weight cycling was reported by 57% of the athletes in SR and 67% of the athletes in FR. The mean time spent in the intervention for SR and FR was 8.7±2.3 and 5.9±1.1 weeks, respectively. There were no significant differences between groups in any of the baseline measurements. Baseline data are presented in table 7.

Table 7. *Baseline data presented as mean±SD*

	SR		FR	
	Males (n=6)	**Females (n=8)**	**Males (n=3)**	**Females (n=6)**
Age (yrs)	24.9 ± 3.5	22.5 ± 3.1	19.2 ± 1.3	19.6 ± 7.9
Height (cm)	177 ± 11	170 ± 7	177 ± 3	166 ± 5
BM (kg)	78.5 ± 14.1	69.6 ± 7.0	79.6 ± 15.2	66.1 ± 22.4
FM (kg)	13.3 ± 5.0	18.8 ± 5.9	12.5 ± 8.3	19.4 ± 5.6
Total body fat (%)	17 ± 5	29 ± 7	16 ± 7	29 ± 5
LBM (kg)	62.3 ± 10.3	45.9 ± 5.2	65.5 ± 7.5	45.3 ± 3.8
Experience as athletes (yrs)	13 ± 6.4	10.6 ± 4.6	10.7 ± 3.8	13.9 ± 1.6
Training (h•week-1)	15.6 ± 4.5	12.0 ± 2.3	16.3 ± 2.9	14.1 ± 4.5
Strength training last season (h•week-1)	2.8 ± 1.6	2.4 ± 1.7	3.7 ± 1.2	2.0 ± 1.3

BM = Body mass, FM = Fat mass, LBM = Lean body mass

Diet

Energy intake was reduced by 31±5% in FR and 19±5% in SR during the intervention. Two and five athletes from SR and FR respectively reported having followed a maintenance diet plan six months after post-test, 8 and 4 reported having partly followed one and 4 and 0 reported not having followed any diet plan six months after the intervention. Twelve months after intervention, 2 and 4 athletes from SR and FR respectively reported having followed a maintenance diet plan the last six months, 7 and 4 reported having partly followed one and 5 and 1 reported not having followed a diet plan, for SR and FR respectively.

Body composition

BM was reduced by 5.8±0.7% in SR ($p<0.001$) and 5.7±0.9% in FR ($p<0.001$) during intervention (Figure 8). In accordance with the aim of the study, the average weekly rate of weight loss was faster in FR than in SR (1.0±0.5% vs. 0.7±0.4 % respectively, $p=0.02$).

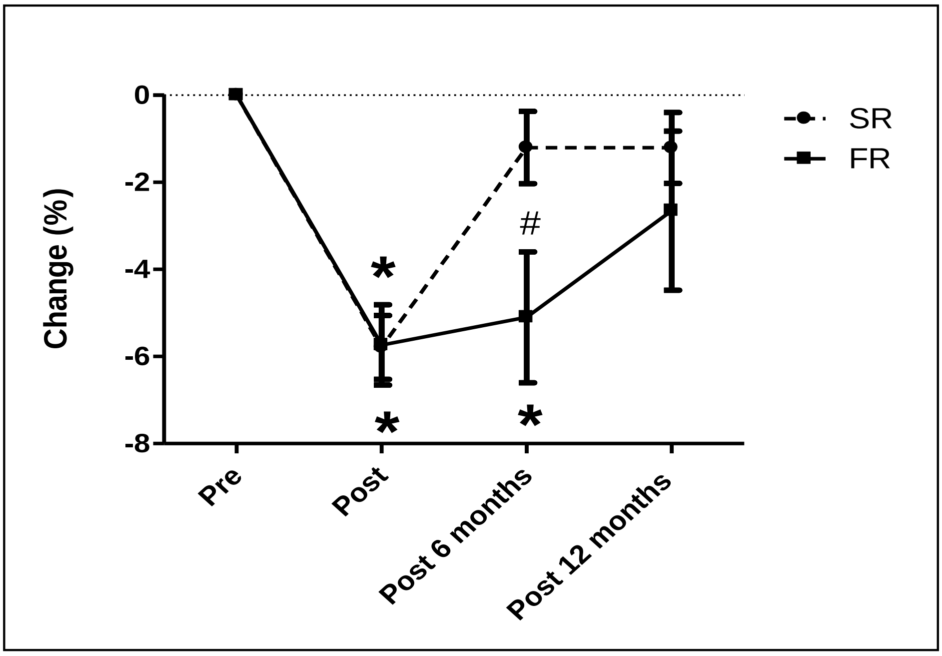

Figure 8. *Changes in body mass (BM) in slow reduction (SR) and fast reduction (FR) groups from pre-test to 12 months post-test. Data are presented as mean±SE. * p<0.05 significantly different from pre-intervention, # p<0.05 significant difference between groups.*

Six months after the intervention, SR had regained 79% of the weight loss, whereas FR had regained 8%, i.e. with a significant difference between groups ($p<0.05$). Twelve months after the intervention, both groups had regained their original BM (Figure 8). Whereas FM tended to decrease more in SR than in FR during intervention (31±3 vs. 23±3%, respectively ($p=0.06$)), SR had regained 90% of the FM 6 months after the intervention and the regain in FM was significantly higher than in FR ($p<0.05$) (Figure 9). Twelve months after the intervention, both groups had regained FM similar to baseline values.

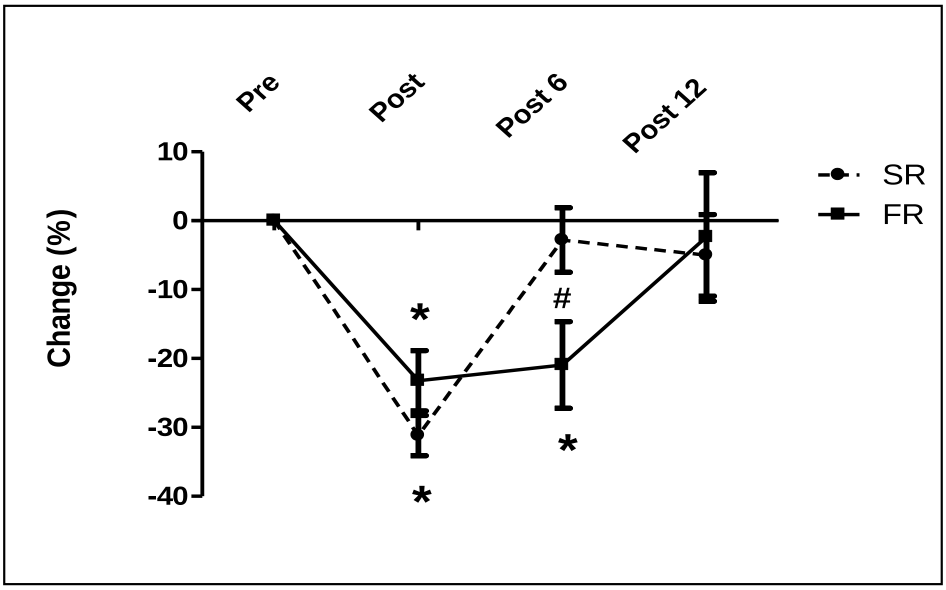

Figure 9. *Changes in fat mass (FM) in slow reduction (SR) and fast reduction (FR) groups from pre-test to 12 months post-test. Data are presented as mean±SE. * p<0.05 significantly different from pre-intervention, # p<0.05 significant difference between groups.*

Total LBM increased by 2.0±0.4% in SR ($p<0.001$) during intervention, but had returned to baseline after 6 and 12 months. LBM did not change significantly in FR during intervention (0.8±1.1%) or after 6 (1.3±0.8%) or 12 months (0.3±0.8%) (Figure 10). There was no significant difference in the change in total LBM between groups at any time.

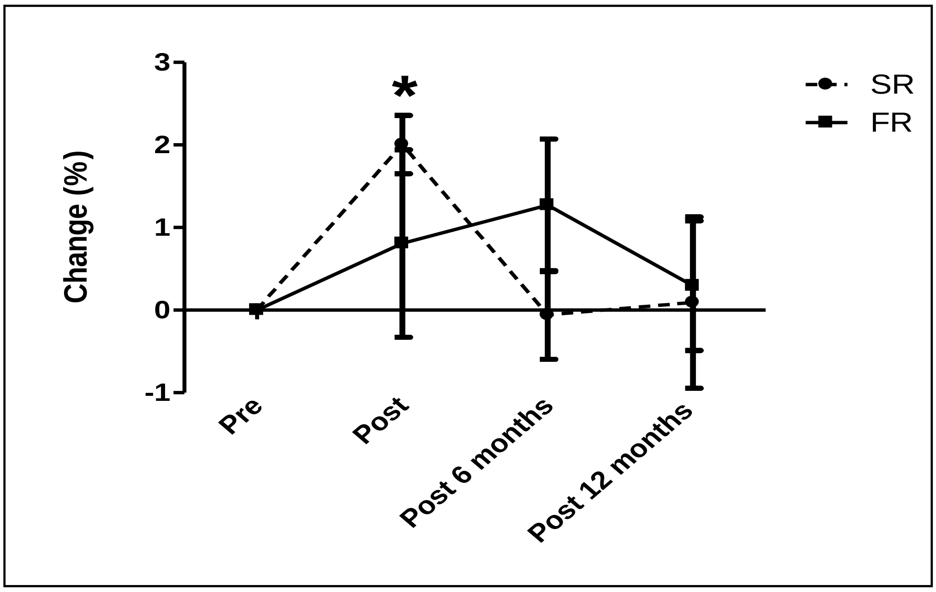

Figure 10. *Changes in lean body mass (LBM) in slow reduction (SR) and fast reduction (FR) groups from pre-test to 12 months post-test. Data are presented as mean±SE. * $p<0.05$ significantly different from pre-intervention, # $p<0.05$ significant difference between groups.*

Training

The athletes reported performing 7.5±0.2 hours·week^{-1} of strength training during intervention. Athletes in SR and FR reported training 15.0±6.0 (range: 3-20 hours) and 14.9±3.1 hours·week^{-1} (range: 10-20 hours) after 6 months, of which 4.7±2.3 and 3.9±1.6 hours were strength training. After 12 months, they reported training 11.9±5.2 (range: 3-20 hours) and 13.3±5.1 hours·week^{-1} (range: 10-20) of which 3.0±1.7 and 3.9±2.0 hours were strength training. The injured athletes reported the lowest amount of training hours.

Performance

Because of small sample sizes due to injuries, the analyses of jumping performance (CMJ) (n=8) and 40m sprint (n=5) are excluded. There were no statistically significant changes in performance in any of the variables in FR at any time. 1RM squat showed a tendency to improve by 15.6±7.5% (p=0.07) in SR but was back to baseline 6 and 12 months after intervention (Figure 11). Bench press performance increased by 17.0±2.6% ($p<0.01$) in SR during intervention, and was still higher than baseline 12 months after intervention (17.7±6.0%, $p=0.01$) (Figure 11). There was no significant change in bench pull performance and there were no significant differences between groups at any time point (Figure 11).

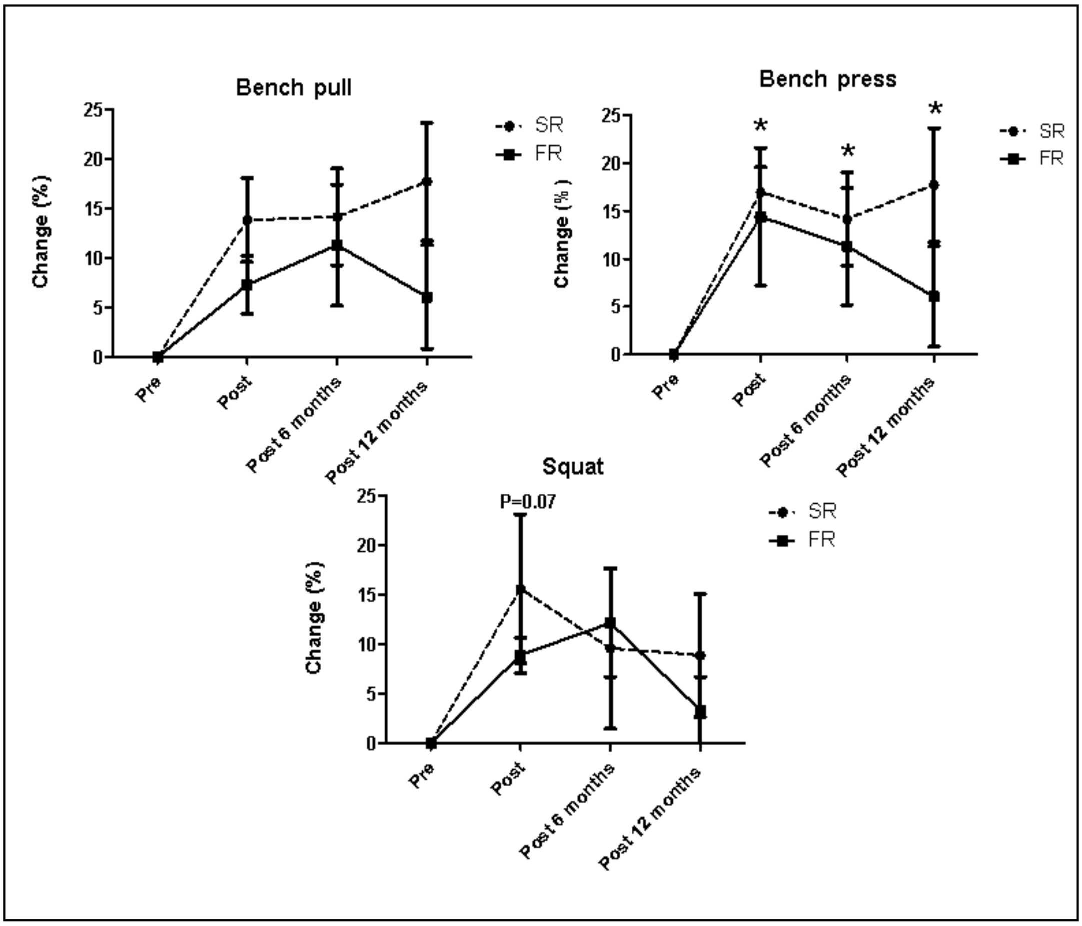

Figure 11. *Changes in 1RM performance in slow reduction (SR) and fast reduction (FR) groups from pre-test to 12 months post-test. Data are presented as mean±SE. * p<0.05 significantly different from pre-intervention, # p<0.05 significant difference between groups.*

Eating disorder inventory

Some of the athletes did not answer all the questions in the EDI questionnaire. Due to the fact that too few in FR (n=3) met the criteria (100% answers) for being evaluated on the EDI, a comparison between FR and SR from pre-intervention to 12 months post-intervention was not performed. There were no significant differences in total EDI score for SR at any time point.

Main results from the weight gain study

Paper III

The mean time spent in intervention was 9.9±1.6 weeks for NCG and 9.9±1.3 weeks for ALG. There were no significant differences between groups in any of the baseline measurements except for the significantly higher FM in ALG. Baseline data are presented in table 8.

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Table 8. *Baseline data presented as mean±SD*

	NCG (n=21)	ALG (n=18)
Age (yrs)	19.1 ± 2.9	19.6 ± 2.7
Height (cm)	179 ± 7.4	180 ± 7.9
BM (kg)	70.7 ± 8.5	74.9 ± 5.7
FM (kg)	7.3 ± 1.6	10.3 ± 3.5 *
Total body fat (%)	11 ± 3	14 ± 5
Experience as athletes (yrs)	11.8 ± 2.8	13.1 ± 3.2
Training (h•week-1)	18.0 ± 5.8	15.2 ± 4.7
Strength training last season (h·week^{-1})	3.8 ± 0.5	3.9 ± 0.3

BM = Body mass, FM = Fat mass, LBM = Lean body mass
** p<0.05 significantly different between groups*

Diet

Energy intake for NCG was higher during intervention than at baseline (15.8±2.5 MJ (3585±600 kcal) vs. 12.7±1.6 MJ (3041±578 Kcal)). Although ALG had the same weight gain goal, energy intake did not change. Consequently, except for protein intake, the intake of macronutrients was higher for NCG than for ALG.

Body composition

BM increased more in NCG than in ALG (3.9±0.6% vs. 1.5±0.4%, p<0.01) (Figure 12). The average weekly rate of weight gain was 0.4±0.1% for NCG and 0.2±0.0% for ALG, with significant differences between groups (p<0.01). FM increased more in NCG than in ALG (15±4% vs. 3±3%, p<0.05) (Figure 12).

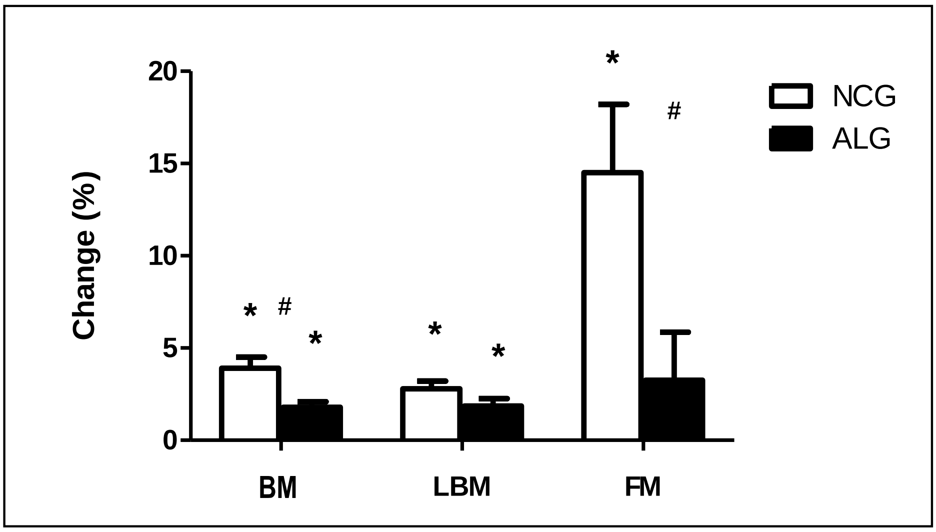

Figure 12. *Changes in body mass (BM), fat mass (FM), and lean body mass (LBM) in the nutritional counselling group (NCG) and the ad libitum group (ALG). Data are presented as mean±SE. * p<0.05 significantly different from pre-intervention, # p<0.05 significant difference between groups.*

Total LBM increased by 2.8±0.4% in NCG (p<0.001) and 1.9±0.4% in ALG (p<0.001) with no significant differences between groups (p=0.1) (Figure 12). The average weekly rate of LBM gain was 0.3±0.1% for NCG and 0.2±0.0% for ALG (p=0.08, comparison between groups). Separating LBM measurements into upper body and leg LBM revealed that NCG had significantly higher gains in leg LBM than ALG (2.5±0.8% vs. 0.2±0.9%, p<0.05).

Performance

No significant change was observed in CMJ in either of the groups (Figure 13). Performance in 40m sprint decreased by 1.2±0.5% (p=0.03) in NCG, but was unchanged in ALG. Strength improved in both NCG and ALG in all three exercises tested (6-12%, Figure 13). There were no significant differences between groups in any of the performance variables. There was a significant correlation between relative increase in BM and changes in 1RM bench press (r=0.46, p=0.003) and 1RM bench pull (r=0.46, p=0.01) (both groups collapsed).

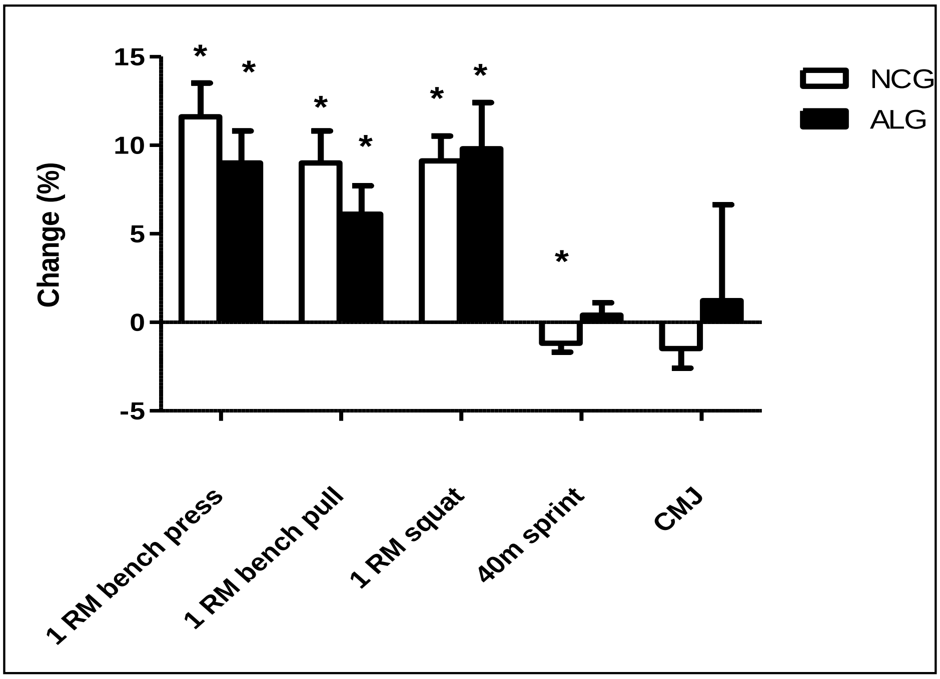

Figure 13. *Changes in 1RM bench press, bench pull, squat, counter movement jump (CMJ) and 40m sprint performance in the nutritional counselling group (NCG) and the ad libitum group (ALG). Data are presented as mean±SE. * p<0.05 significantly different from pre-intervention, # p<0.05 significant difference between groups.*

Compliers versus non-compliers

The predetermined weight gain goal for NCG and ALG was 4.9±0.8 and 5.2±0.9 respectively, with a weekly gain of 0.7% of initial BM, but not all athletes reached their goal. All athletes are included in the present results according to the intention-to treat principle. In NCG, 13 athletes did not accomplish their weight goal (with a cut-off value in weekly weight gain between 0.5 and 1.0%). No significant differences were found between compliers and non-compliers in training hours, baseline values in LBM or strength training experience. Although the ALG athletes did not have any meal plans or nutritional guidance, their goal was also a weekly weight gain of 0.7% of BM. Only one athlete in ALG accomplished his weight gain goal (with a cut-off value between 0.5 and 1.0%). The mean gain in LBM and FM for compliers was 3.7±0.83% and 30.8±3.8% respectively; the figures for non-compliers were 1.9±0.3% and 3.3±2.0.

Paper IV

The results of paper IV includes data from the intervention period (paper III), however, due to drop-outs in the follow-up, the results are somewhat different due to a smaller population.

The mean time spent in intervention was 9.9±1.8 weeks for NCG and 9.8±1.4 weeks for ALG. There were no significant differences between groups in any of the baseline measurements except for the significantly higher FM in ALG. Baseline data are presented in table 9.

Table 9. *Baseline data presented as mean±SD.*

	NIG (n=12)	ALG (n=9)
Age (yrs)	18.5 ± 1.7	19.6 ± 2.7
Height (cm)	178 ± 8	180 ± 7
BM (kg)	67.8 ± 7.4	74.2 ± 5.7 *
LBM (kg)	58.5 ± 2.4	59.2 ± 7.2
FM (kg)	7.2 ± 1.8	9.0 ± 4.4 *
Total body fat (%)	11 ± 4	13 ± 6
Experience as athletes (yrs)	11.2 ± 2.8	14.2 ± 2.4
Training per week (h)	17.7 ± 6.8	16.0 ± 6.0
Strength training last season ($h \cdot week^{-1}$)	3.8 ± 0.5	3.9 ± 0.3

BM = Body masst, FM = Fat mass, LBM = Lean body mass
** p<0.05 significantly different between groups*

Diet

Energy intake for NCG was higher during intervention than at baseline 11.8±4.2 MJ (2821±1010 Kcal) vs. 14.9±3.2 MJ (3562±761 Kcal), but was normalised at the 6 and 12 months tests. Although ALG had the same weight gain goal, energy intake did not change throughout the study. Consequently, the intake of macronutrients was higher for NCG than for ALG during intervention, but no significant differences were seen at 6 and 12 months.

Body composition

The predetermined weight gain goal for NCG and ALG was 4.7±0.8 and 5.1±0.8, respectively, with a weekly gain of 0.7% of initial BM. BM increased more in NCG than ALG during intervention (4.3±0.9% vs. 1.0±0.6%, p=0.01) (Figure 14). After intervention the BM continued to increase in NCG and was significantly higher than in ALG after 6 months (4.2±0.8% vs. 1.1±1.0%, p<0.05) and 12 months (6.0±0.9% vs. 1.8±0.7%, p<0.001), respectively.

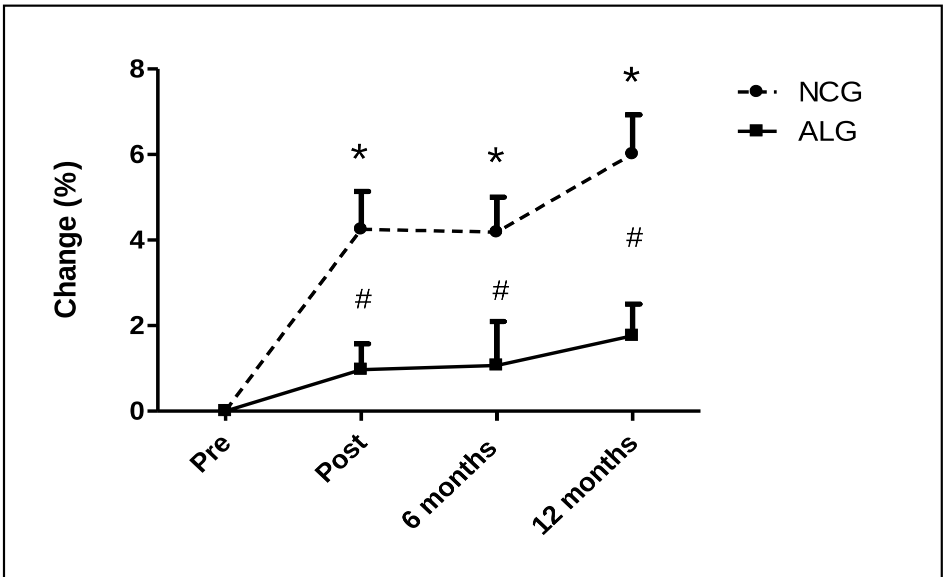

Figure 14. *Changes in body mass (BM) in nutrition intervention group (NCG) and ad libitum group (ALG) from pre-test to 12 months post-test. Data are presented as mean±SE. * p<0.05 significantly different from pre-intervention, # p<0.05 significant difference between groups.*

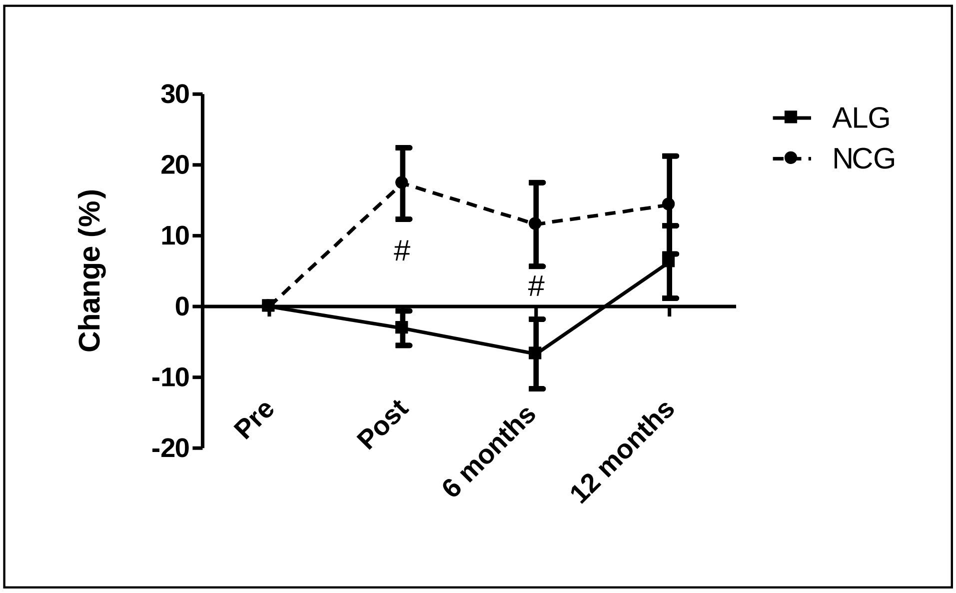

Figure 15. *Changes in fat mass (FM) in nutrition intervention group (NCG) and ad libitum group (ALG) from pre-test to 12 months post-test. Data are presented as mean±SE. * p<0.05 significantly different from pre-intervention, # p<0.05 significant difference between groups.*

A larger increase in fat mass in NCG (17.4±5.1%) than in ALG (5.6±3.1%) was observed during intervention ($p<0.05$) and after 6 months (11.6±5.9% vs.1.8±0.7%, $p<0.05$), but the figures showed little difference after 12 months (14.3±6.9 vs. 8.8±4.4%) (Figure15).

LBM increased in NCG during intervention by 2.8±0.5%, continued to increase after 6 months and was significantly higher than ALG after 12 months (4.4±1.0% vs. 1.1±1.1%, respectively, $p<0.01$) (Figure 16).

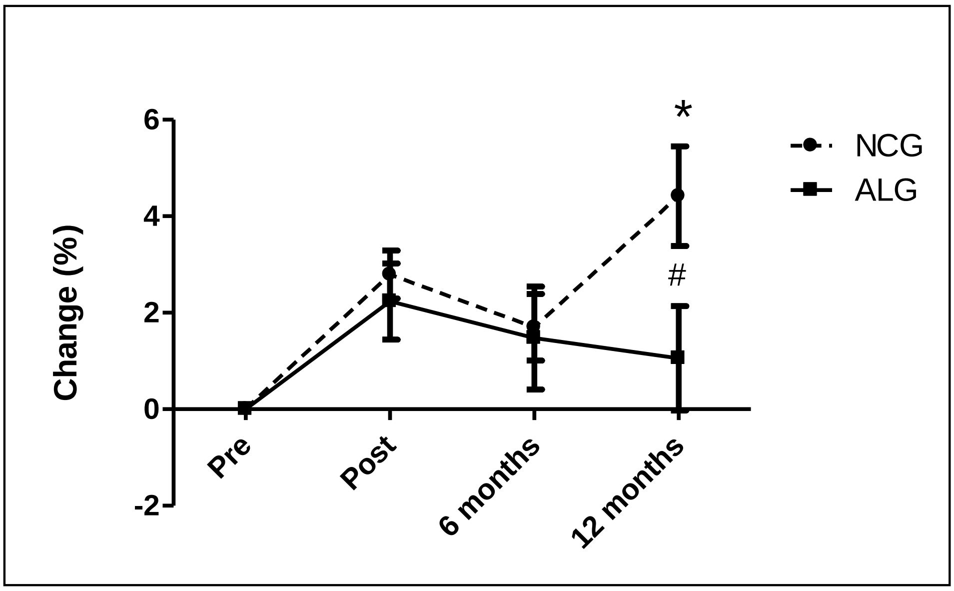

Figure 16. *Changes in lean body mass (LBM) in nutrition intervention group (NCG) and ad libitum group (ALG) from pre-test to 12 months post-test. Data are presented as mean±SE. * $p<0.05$ significantly different from pre-intervention, # $p<0.05$ significant difference between groups.*

Training

Athletes in NCG and ALG reported training 17.7±6.8 h·week^{-1} (range: 12-20 hours) and 16.0±6.0 h·week^{-1} (range: 10-20 hours) and spending 3.8±0.5 h·week^{-1} and 3.9±0.3 h·week^{-1}, respectively, on strength training during the year prior to entering the study. They reported returning to the baseline hours spent on strength training at 6 and 12 months post-intervention. The injured athletes reported the lowest amount of training hours.

Compliers versus non-compliers

The predetermined weight gain goal for NCG and ALG was 4.7±0.8 and 5.1±0.8 respectively, with a weekly gain of 0.7% of initial BM. The long-term goal for athletes in NCG and ALG was to maintain (n=4 vs. n=1) or even increase (n=8 vs. n=8) BM further during season. All athletes are included in the present results according to the intention-to-treat principle. In NCG, 7 athletes (58%) did not accomplish their weight goal (a cut-off value in weekly weight gain at 0.5) during intervention, but all the athletes in NCG managed to maintain or increase BM according to their goal during the 12 months. No significant differences were found between compliers and non-compliers in training hours, baseline values in LBM or strength training experience. Although the ALG athletes did not have any meal plans or nutritional guidance, their goal was also a weekly weight gain of 0.7% of BM. However, no athletes in ALG accomplished their weight gain goal during intervention. After 12 months, 3 (33%) of the athletes in ALG reduced weight while 6 athletes managed to be weight stable or increase BM.

Summary

Papers I and II (weight loss study)

BM was reduced by 5.6±0.8% in SR and 5.5±0.7% in FR during weight loss intervention. FM decreased more in SR than in FR and total LBM increased significantly in SR whereas it was unchanged in FR, showing a significant difference between the groups. Performance increased in every variable in the SR group except for 40m sprint, which was unchanged in both groups. Six months after the intervention, SR had regained most of the weight loss, whereas FR had a relatively stable BM. Twelve months after the intervention, both groups had regained their original weight. Whereas FM tended to decrease more in SR than in FR during intervention, SR had regained most of the FM six months after the intervention.

Twelve months after the intervention, both groups had regained FM similar to baseline values. Total LBM increased in SR during intervention, but had returned to baseline after 6 and 12 months. There were no changes in performance in any of the variables in FR at any time. Bench press performance increased in SR during intervention, and was still higher than baseline 12 months after intervention. There was no significant change in bench pull or squat performance and there were no significant differences between groups at any time point.

Papers III and IV (weight gain study)

BM and FM increased more in NCG than in ALG in the weight gain intervention, whereas there were no significant differences in LBM between groups. Strength (1RM) improved in both NCG and ALG in all three exercises tested, but no significant differences were seen between groups in any of the performance variables. After intervention, BM continued to increase in NCG and was significantly higher than in ALG after 6 and 12 months. FM did not differ between groups after 12 months. LBM continued to increase in NCG after 6 months and was significantly higher than in ALG after 12 months.

Discussion

Design

To be able to carry out a controlled weight loss intervention in the elite athletes' off-season, we had to accept some limitations in the study design. Previous studies and practical experience indicated that weight loss in normal-weight athletes would compromise LBM and thereby potentially also compromise performance. Consequently, because many of the athletes planned to participate in major competitions after intervention, we had to include strength training during intervention to prevent decline in performance. A cleaner approach would be to study weight loss rate with standardised habitual training with no additional stimuli for muscle growth.

Furthermore, different amounts of weight lost during intervention may also be a limiting factor. A cleaner approach would therefore also involve standardising the amount of weight loss for all athletes (e.g., 5% of BM), but due to ethical, practical and health reasons this was not feasible. Further, we wanted to take a practical approach to deciding what we should recommend to our athletes. The combination of strength training and diet was already implemented in our approach towards optimal weight loss strategies. The question was therefore whether there was a difference in changes in body composition at different weight loss rates within the recommended guidelines in the literature.

Diet

Information about subjects' dietary habits before intervention start was collected with a 4-day weighed diet record (3 weekdays and one weekend day). The effect of the meal plan was controlled by weekly measurements of BM and skin fold thickness during intervention (data not shown). However, compared to their high activity level, the reported energy intake was relatively low and this may be due to underreporting, undereating, or both, which are common errors of measurement in self-reported dietary intake (Magkos & Yannakoulia 2003) in both weight loss and weight gain studies. We chose 24-hour recall at the follow-up 6 and 12 months after intervention in order to minimise the burden, to increase compliance and to decrease alteration of the subject's usual intake. However, these data are not presented in Article II due to the fact that they were clearly a result of underreporting and could not be compared with baseline data. Although 17 athletes in the long-term weight loss study reported that they followed or partly followed meal plans with energy intakes close to the meal plan in the weight loss period, they had regained their initial BM after 12 months. Despite the fact that there may be adverse effects in BM regulatory hormones as well as decreased resting energy expenditure from a lower BM (Leibel et al. 1995; Vogels et al. 2005), we find it unlikely that 13 of the athletes had an energy intake below 6.3 MJ (1500 kcal)·day^{-1} after 6 months with no changes in training hours. This strongly implies that these data have a low level of confidence and we chose therefore not to present them. Unfortunately, we did not include the method of doubly labelled water (DLW) in our study due to financial reasons; this would have given us the information we needed to estimate underreporting.

Each athlete had an individualised meal plan based on the reported energy intake and we reduced or increased the energy intake as planned and monitored the response of each athlete. As expected, there were individual differences in response to the planned energy intake. Thus, the meal plan was regulated up or down as a consequence of the intervention of increasing weight by 0.7% of BM·week^{-1} for the NCG or reducing weight by 0.7% or 1.4% of BM·week^{-1} in the weight loss study. Although we increased the planned energy intake for some of the athletes in the weight loss study (n=3) after the first week due to a too rapid weight loss for their intervention goal (possibly due to underreporting at baseline), most of the athletes responded as planned to the reduced energy intake. This might support the suggestion that many of these athletes with frequent weight loss periods during season have a chronically low energy intake, possibly due to metabolic changes.

Metabolic compensatory responses have been shown in obese persons after weight loss (Leibel et al. 1995; King et al. 2007), and it has been stated that weight cycling athletes have lower metabolic rate than athletes with no history of weight cycling (Brownell et al. 1987; Steen et al. 1998). It has also been reported that athletes in sports that emphasise leanness and BM have a surprisingly low energy intake (Jonnalagadda et al. 1998; Cupisti et al. 2000). This is also our practical experience. In the weight loss study we measured basal metabolic rate (BMR) (Douglas bag) in 10 randomly selected athletes and we also calculated BMR with Cunningham (the most representative equation for athletes when LBM is available) before the subjects entered the study (unpublished data). Measured BMR was lower in some athletes than predicted with the Cunningham equation but there were no significant mean differences. Furthermore, the athletes reduced their BMR by 11.5% after weight loss intervention, despite the fact that they did not reduce LBM. Whether this is due to the effect of energy efficiency or other compensatory mechanisms is not clearly understood. However, if a reduction in BM reduces BMR (Leibel et al. 1995) as well as the energy expenditure during exercise per se (Maldonado et al. 2002), the changes in the energy cost of weight change will alter. Thus, a range of metabolic responses including reduced BMR, energy cost of training and daily activity and energy cost associated with weight loss will contribute to the resistance against weight loss.

Body composition

When we compare the weight loss and weight gain studies (Papers I and III), we find some interesting results regarding changes in LBM. The increase in LBM was 1.7 kg and 1 kg for the NCG and SR group, respectively. This corresponds to 2.8% and 2% of total LBM for the NCG and SR group, respectively. Further, the athletes in the SR group had 8.5±2.2 weeks in intervention whereas NCG had 9.9±1.6 weeks for gain. Consequently, the average weekly rate of LBM gain was 0.3±0.1% in NCG and 0.3±0.0% in the SR group. This indicates that the SR athletes actually managed to increase LBM at the same rate as NCG, despite a negative energy balance corresponding to ~2090 KJ (~500 kcal)·day^{-1}.

Importantly, all athletes followed the same strength training programme. The strength training programme implemented in this study was designed to be strenuous, even for experienced athletes, in order to stimulate muscle gain. Possible explanations for the similar results in the NCG and SR groups is that NCG had more experience of strength training and that they had had more strength training included in their sport-specific training before the intervention. Nevertheless, we had expected a greater increase in LBM in NCG during the weight gain period.

One reason why the gain in LBM was not larger in NCG during intervention might be that most of the athletes included endurance and sport-specific training during intervention. Some studies report that hypertrophy is impaired when strength training is combined with endurance training in the same period (Kraemer et al. 1995; Bell et al. 2000). The literature suggests that activation of AMPK by endurance training may reduce the skeletal muscle-protein synthesis response to strength training by inhibiting signalling pathways involved in muscle hypertrophy (Nader 2006; Hawley 2009). Thus, even though the athletes did not combine endurance or sports-specific training with strength training in the same training session (but sometimes on the same day), the amount of endurance training might have reduced the strength training adaptation. On the other hand, some endurance athletes experience improved in endurance performance when strength training is combined with endurance training (Aagaard & Andersen 2010). However, in our studies, endurance performance was not a part of the test battery. Consequently, whether performance in the endurance athletes (e.g., skaters) was positively affected by the strength training added during intervention is not known.

The weight loss group also included endurance and sport-specific training during intervention, so in terms of muscle growth, both groups should have had relatively similar net stimuli. Thus, the impressive positive response in muscle mass in the weight loss group is difficult to explain except by stating that the stimuli for muscle growth have overridden the catabolic processes.

After intervention, LBM continued to increase in NCG and was significantly higher than in ALG after 6 and 12 months. Collectively, the results from changes in LBM during (for SR) and after (for NCG) intervention, might indicate that the meal frequency, timing and distribution of protein may have contributed to a more anabolic environment (Wilkinson et al. 2007; Burd et al. 2009; Moore et al. 2009; Josse et al. 2010; Hawley et al. 2011). Nevertheless, strength training clearly was the most important stimuli for the changes in LBM. For athletes in SR, the frequent meal pattern and timing of protein intake, may have contributed to a less catabolic state. All athletes in NCG reported that they had followed the meal plan to some extent (especially meal frequency and recovery meals) after 6 and 12 months. This persisting change may over time have contributed to greater gains in LBM, especially close to 12 months after intervention, when the basic training period started again for many of the athletes.

Another interesting finding was that for both ALG, which was in energy balance, and the SR group, which was in negative energy balance, the gain in LBM was mainly caused by an increase in upper-body LBM. In contrast, a lower figure of 65% of LBM increase in NCG, which was in a positive energy balance, was due to an increase in lower-body LBM. There may be several explanations for this finding, but it would seem that upper body muscles generally respond better to strength training stimuli than leg muscles (Wernbom et al. 2007). Furthermore, all athletes already had a heavy load on leg muscles in their sport-specific training, which probably reduced the training potential in these muscles. It is however unclear why NCG increased leg LBM more than the ALG and FR groups, other than that the priority of muscle gain seems to be in the upper body when energy availability is relatively low.

Dual energy x-ray absorptiometry (DEXA)

DEXA is considered a valid method for estimating body composition (Lohman et al. 2000) but some issues may be discussed in this connection. Although hydration status has a relatively small effect on body fat percentage values, 5% dehydration results in a change in fat percentage estimate of 1-2.5% (Horber et al. 1992; Lohman et al. 2000). In addition, LBM might have been underestimated in some cases since we did not measure hydration status. Further, it seems that DEXA tends to overestimate changes in FM and fat percentage in elite weight class athletes (standard error of estimation ±1.62%) (Santos et al. 2010). Although no significant difference is found between DEXA and a four-compartment model in estimating mean changes in body composition, there seem to be relatively large individual errors, suggesting that it would be inaccurate for detecting small physiological changes in the elite athlete (Santos et al. 2010). However, it has to be noted that the reference method (four-compartment) tends to underestimate FM (Santos et al. 2010) and that the DEXA hardware used in the study by Santos et al. was a different hardware model (Hologenic) than the one used in our studies.

Variations in total body water due to hormonal changes during the menstrual cycles are well known (Farage et al. 2009). Thus, ideally the female participants should have been tested at the same time in their menstrual cycles. It is however unlikely that total body water will differ to the extent mentioned above (5% of BM) due to hormonal changes during the menstrual cycle, and the practical implications regarding time in the menstrual cycle may therefore be discussed. However, during research, the optimal approach would be to control all variables that might affect the results. In the present study it was impossible to implement testing at the same time in the menstrual cycles of each female athlete due to logistical challenges. To avoid inaccuracies due to stomach contents (overestimated LBM), all the DEXA measurements were performed on fasting subjects and at the same time of the day.

Strength training programme

We hypothesised that hypertrophy strength training would be one of the most important factors for changes in LBM during weight change (ACSM 2009 b). Thus, the training programme implemented for this thesis was a strenuous one, even for the most experienced athlete, in order to ensure that the athletes were getting strong stimuli for muscle growth. Although strength training is the priority for increasing LBM, it is not known if the athletes could have achieved even greater progress with a lower strength training volume.

Oral feedback from the athletes during intervention indicated that the programme may have been too strenuous, since the sessions in the last weeks of progression lasted almost two hours. In addition, the subjects had their sport-specific training during the period although that was reduced to some extent due to the participation in the study. We emphasised a sport-specific approach to the strength training intervention, including some individual exercises in addition to the basic programme to optimise sport-specific adaptations. However, there were several discussions with coaches and athletes prior to participation regarding the effect of the programme. Due to the study design it was impossible to implement totally different training programmes for different athletes with different strength training experience, but it may be debated whether an even more sport-specific programme adjusted to each athlete's level of experience would have produced even better results.

Another interesting approach would be to restrict all endurance and sport-specific training during the weight gain period to see if that improved the results further in terms of muscle growth. However, that was impossible in these studies with the population of elite athletes, who were going to compete shortly after intervention and thus had to maintain sport-specific skills.

Performance testing

It is a challenge to test for sport-specific performance effects. It is relatively easy for the researcher to have full control in the laboratory, but the question always arises as to how applicable and valid results from such tests are for the real performance situation. Because of the heterogeneous group of athletes in this study, we included more general tests of strength- and power-related performance. Nevertheless, the more general impact on physical capacity measured in this study gives important information on how strength and power are affected by the interventions. Also, interesting, although not scientific data, oral feedback from the athletes and placing in competitions indicated that the sport-specific performance outcome showed a positive tendency for both groups of athletes (weight loss and gain) participating in the intervention studies.

It would have been interesting to investigate changes in muscle function by the inclusion of other more basic tests as well. More basic muscle function tests, such as isokinetic or isometric strength tests, are often included in experiments due to more simplistic techniques than the more technical demanding 1RM testing used in our studies. However in our studies we had to choose strictly what measurements to include. The athletes were called in for a whole day, and they had several tests (blood samples, DEXA, psychological/motivational tests, 24-hours recall) before performance testing. Further, most of the athletes were familiar with 1RM testing from years of strength training.

Ethical considerations

The main ethical discussion regarding this project is related to the weight loss study. To allow normal-weight athletes to undergo a weight loss regimen we had created a cohesive team of a sports physician, sports nutritionist, exercise scientist and a psychiatrist. All participants had the standard medical examination for pre-season health evaluation at the Norwegian Olympic Sports Centre before the intervention period and close follow-up during intervention. There was always a medical doctor, psychiatrist, nutritionist and physiotherapist available during and after intervention. If any sign of problems related to eating disorder symptoms was revealed during the weekly consultation, the athlete was evaluated by the eating disorder team at the Olympic Sports Centre. One female athlete was removed from the study due to early signs of ED, and was taken care of by the team. Further, we did not "push" the athletes if they did not reach their weekly weight goal. They received information about how to succeed in terms of reaching their goal, but we were careful about how this information was given to avoid giving the subjects the feeling of being forced to comply with the study.

Finally, we knew that most of the participants in the weight loss study had had several weight loss periods in their athletic career, and that unhealthy weight loss methods had been used. Prior to the PhD project (2005), we gave a questionnaire to the national team athletes in weight category sports to determine the prevalence of athletes who were losing weight and the methods used (Garthe, unpublished data, Report 2005). Seventy-nine% of the male and 86% of the female athletes reported having lost weight before competitions. They usually cut weight by 6-7% of total body weight. The most commonly used methods were dehydration (sweat suits and sauna) and energy restriction, and most athletes used a combination of gradual and rapid methods. Of these athletes, 64% reported that making weight caused significant side effects such as fatigue, nausea, dizziness, headache, vomiting/digestive problems and reduced sex drive. A further 32% reported having started to lose weight before the age of 15. This data is consistent with the literature, which reports frequent use of rapid weight loss methods among weight class athletes (Steen & Brownell 1990; Oppliger et al. 2003; Sundgot-Borgen & Torstveit 2004; Slater et al. 2005; Artioli et al. 2010). Thus, it was important to introduce a different approach to the existing regimens and to present a weight loss study that would possibly have less negative effect on health and performance.

Ethical challenges related to changes in body composition in general

There is a consensus statement that long periods with low energy availability and low fat percentage can impair health and physical performance and disrupt normal sex steroid metabolism (Drinkwater at al. 2005; Nattiv et al. 2007). The Wisconsin Interscholastic Athletic Association implemented a project involving new rules and an educational programme, consistent with ACSM and AMA guidelines, to reduce the use of rapid weight loss and dieting among high school wrestlers (Oppliger et al. 1995). The project included skinfold estimates of body fatness to determine a minimum competitive weight (5%). However, nothing similar has been done in any of the international federations in weight class sports. The literature suggests a lower fat percentage limit, i.e. 5-7% in males and 12% in females (Fogelholm 1994; Heyward & Wagner 2004; O'Connor & Caterson 2010). The theoretical concept of minimal FM is probably based on the amount of essential fat (3% for males and 12% for females) that represents a biologically established limit. This challenges the practical work with the athlete in several ways, as also questioned by Fogelholm (1994): 1) Does it seem correct to set an exact fat percentage limit when it obviously varies greatly among individuals? 2) Is there one critical percentage of body fat which is essential to trigger normal sex steroid metabolism and/or other health and performance variables?

In my experience, some male athletes are genetically lean and can tolerate being as low as 5% whereas others have to work hard to be at 5% and may have a reduced testosterone level at that fat percentage. Further, some female athletes menstruate with a fat percentage of 9 while others experience disruption of the menstrual cycle at 16%. Even though the actual percentage of body fat may be incorrect due to measurement errors, the main point is that there are individual health- and performance-related responses to identical changes in body composition.

Further, the methodological challenges regarding body composition measurements make the question even more complex. When the literature suggests a lower fat percentage limit, it is not reported what method is used to define this theoretical concept (Heyward & Wagner 2004). A detailed discussion about validation of methods to measure body composition is beyond the scope of this thesis, but it is well known that all indirect methods have their challenges (Heyward & Wagner 2004). DEXA, skinfolds (caliper), bioelectrical impedance analysis (BIA) and other methods of estimating body composition have measurement errors, even with standardised procedures. There are also errors related to the equations that convert skin fold measurements to estimated FM and fat%. At this point in time, there is no method that has an error <1%; in fact, most methods have 2-3% error related to the measurements (Heyward & Wagner 2004). This means that an athlete may measure 5% body fat, but actually have 2-8% body fat. Due to this inaccuracy which may influence health and performance, this matter is taken seriously by the International Olympic Committee (IOC) which has set up an ad hoc working group to suggest the optimal fat percentage value for male and female athletes and the most valid method(s) to measure body composition in athletes.

However, it is important to consider a broader evaluation of athletes who want to lose weight. In addition to the objective measurements of body composition, there should be a thorough screening of the athlete including psychological variables, weight history, menstrual history/hormone status, age, level of performance, physical fitness and total work load on the athletes' daily life. Based on this evaluation, the health care personnel will be able to set some limits and recommendations. As an example, if a 15-16 year old athlete wants to lose weight to enhance performance, it may be preferable and healthier to optimise other performance variables (e.g., strength, technique) and have a sound nutrition plan that supports growth and development. Weight loss as a performance variable should be carefully considered, especially when athletes are under 18 years.

Furthermore, close follow-up during and after weight loss may prevent athletes from weight fluctuations and "slipping into" or developing DE/ED. At any signs of DE/ED, the athlete should be referred to a health team with special competence (Drinkwater et al. 2005; Nattive et al. 2007).

Finally, data from body composition measurements should be treated with confidentiality in the same way as other medical data, and measurement of BM and composition should therefore be carried out by competent health care personnel. In addition to this, there is a need for cultural change among athletes, coaches and sports federations related to issues of BM and body composition. Thus, policies and strategies to maintain health and performance during weight loss should be implemented and established within sports federations as well as in teams and sports clubs.

Conclusion

Papers I and II (weight loss study)

The initial aim of a two-fold difference in weight loss rate between the two groups in the weight loss study was not achieved because of a slower weight loss than planned in some athletes in FR, resulting in a weekly weight loss rate corresponding to 1.0 % of BM rather than the planned 1.4%. Nevertheless, total LBM increased significantly more in SR than in FR, and this was accompanied by improved performance in CMJ and all the 1RM tests in SR, whereas there was no significant increase in LBM or improvements in performance except in 1RM squat in FR. Separating into weekly gains in LBM and improvements in strength- and power-related performance, there was still a significant difference between the groups in favour of SR.

More surprisingly, we found that athletes in the fast intervention maintained body composition to a greater extent than those in the slow intervention six months later. However, the slow intervention subjects tended to maintain 1RM performance to a greater extent than those of the fast intervention. The distribution of athletes from different sports may have had the greatest influence on these long-term differences. There were no significant differences between the slow and the fast intervention groups after 12 months, suggesting that several factors other than weight loss rate contribute to maintenance of body composition and performance after weight loss. Therefore, these results indicate that long-term follow-up after intervention is important for an elite athlete in order to maintain changes over time in a busy schedule with competitions, travelling and periods of injuries.

Papers III and IV (weight gain study)

During a strength training period, athletes who received nutritional counselling were more successful in reaching their weight goal than athletes who had an *ad libitum* energy intake. The NCG had significantly higher gains in LBM in legs than ALG, but there were no significant differences between groups in total LBM and performance. We also found that the NCG had significantly higher gains in BM and LBM 12 months after intervention. Thus, athletes who received nutritional counselling during a weight gain period were more successful in reaching their weight goal and in maintaining the positive changes in BM and LBM than athletes who had an *ad libitum* energy intake during the intervention period. However, the results must be interpreted with caution, due to the fact that there was a correlation between age and changes in BM after 12 months and that there were more athletes under 18 years in NCG.

Future research

Future research is warranted regarding the design of optimal strategies for weight loss and weight gain in elite athletes or athletes in general. The following are suggestions for further research:

1. Prevalence: Most studies that investigate weight loss methods among athletes are from the wrestling population. More recently, papers on light-weight rowing, judo and taekwondo have been published. Techniques, methods and frequency of weight making in various sports should be emphasised.

2. Acute weight loss:
   - Controlled intervention studies with performance-specific test protocols.
   - Effect of various techniques and methods for recovery after rapid weight loss.
   - Effects of repeated episodes of weight making on performance in sport-specific protocols.

3. Gradual weight loss:
   - Investigate mechanisms involving metabolic changes and negative energy balance in weight loss studies with or without strength training.

4. Long-term effect on health:
   - Effect of repeated weight loss episodes over years on indexes of health, body composition, nutritional status and growth.
   - Effect of chronic dieting over years on indexes of health, body composition, nutritional status and growth.

5. Overall prevention and organisational factors:
   - Efficacy of various education programmes, information and rule modification on changing weight loss practices.
   - Investigate what, if any, is the optimal fat percentage level for various sports when both health and performance are taken into consideration.

6. Weight gain: Further investigate the optimal surplus diet for elite athletes who want to gain maximal LBM and reveal individual mechanisms and limitations of muscle growth in the strength-trained athlete.

Practical implications of literature presented in the theses, previous studies and practical experience

This chapter is not meant as additional data to the theses or as a part of the theses. It is included more as a practical guideline for the practitioners in this field. This practical guideline is based on existing literature, some of the findings in the studies representing my doctoral work and practical experience from working with athletes for several years. The reason for adding these practical suggestions, is that such guidelines are lacking. Recently, we published an article suggesting these guidelines (Sundgot-Borgen & Garthe 2011). However, instead of just referring to the study, I would like to present some of the guidelines attached to my thesis.

Weight loss

Prevention of unnecessary and unhealthy weight loss

In order to decrease the high number of athletes representing weight class and leanness sports that are dieting and using extreme weight loss methods, there is a need for education among athletes, trainers, coaches and parents. This education should include optimalisation of eating behaviour and energy intake, healthy body image and body composition (Sundgot-Borgen & Garthe 2011)

The athlete's weight and body composition should not be measured unless there are well-founded health and/or performance reasons. In such cases, the coach should take the athlete's initiative seriously and involve professional help. Most of the weight class athletes and those competing in leanness sports are fit and lean, but want to reduce weight to further enhance performance (Marquart & Sobal 1994; Hall & Lane 2001). In such cases the coach and health care team should motivate the athlete to improve strength and power and compete in a higher weight class and avoid putting pressure on an athlete and/or telling an athlete to lose weight. Health care providers should teach the athletes and coaches that weight loss does not necessarily lead to improved athletic performance (Webster et al. 1990; Smith et al. 2000; Slater et al. 2005 b; Burge et al. 1993; Degoutte et al. 2006; Nattive et al. 2007). If the coach is concerned about an athlete's eating behaviour, body image and/or weight or body fat level, the athlete should be referred to a sports nutritionist or health care provider for further evaluation and consultation (Sundgot-Borgen & Torstveit 2010; Nattive et al. 2007).

Further, sports governing organisations and federations should give support to coaches and provide education on health- and performance-enhancing nutrition behaviour, DE/ED and the female athlete triad for coaches and athletes. Each federation should have position statements with guidelines related to optimising nutrition and body composition and reducing harmful weight loss methods.

Guidelines for athletes who want/need to lose weight

Based on research and our practical experience with elite athletes and weight regulations the following recommendations are suggested:

- The weight goal should be based on objective measurements of body composition. Prior to a weight loss intervention, there should be a thorough screening including weight history and weight goal, menstrual history for females, objective measure of BM, FM, LBM and energy/nutritional status, and questions regarding motivation, dietary habits, thoughts and feelings about body image, BM and food (Burke 2007; Nattiv et al. 2007). If there is a history of DE/ED, a more intense and longer follow-up is suggested. Measurements of body composition should be done in private and the results should be explained and discussed with the athlete (Nattiv et al. 2007).

- The weight loss period should be during off-season to avoid interference with competitions and sport-specific training loads, as this may create stress or overload for the athlete as well as not optimal results due to conflicting training stimuli (Nader 2006; Hawley 2009).

- A 4-day (3 weekdays + 1 weekend day) or a 7-day diet registration (using weighed or household measures) should be a basis for the diet plan (Magkos & Yannakoulia 2003; Deakin 2010). Objective measurements of BM and FM should be performed as well as a blood test. If the athlete has a history of amenorrhoea or other indicators of low BMD, an objective measure of BMD is warranted (e.g., DEXA) (Nattiv et al. 2007). If a blood test indicates any specific micronutrient needs (e.g. iron, Vitamin B12), these vitamins should be provided and biochemical changes monitored during the period. A multi-vitamin-mineral supplement and omega-3 fatty acids should be provided during the weight loss period to ensure sufficient micronutrient intake and essential fat intake (Heyward et al. 1989; Fogelholm 1993; Filaire 2000).

- The athlete should consume sufficient energy to avoid menstrual irregularities and aim for a gradual weight loss corresponding to ~0.5 kg per week. To induce a weight loss of 0.5 $kg \cdot week^{-1}$ an energy deficit similar to ~2090 KJ (~500 kcal)$\cdot day^{-1}$ is needed, but there are individual differences. This can be achieved by reduced energy intake, increased energy expenditure, or a combination of the two (O´Connor & Caterson 2010; Walberg-Rankin 2002).

- A sports nutritionist familiar with the demands of the specific sport should plan individual nutritionally adequate diets (Burke 2007). Throughout this process, the role of overall good nutrition practices in optimising performance should be emphasised. The diet plans should aim at a protein intake corresponding to 1.4-2 $g \cdot kg^{-1}$, a carbohydrate intake corresponding to 4-6 $g \cdot kg^{-1}$ and ≥15-20% fat (ACSM 2009 a). The focus should be on low energy/high nutrient density foods that provide satiety as well as food variety and a frequent meal pattern making sure that the athlete is not fatigued during training sessions. There should also be an emphasis on recovery meals containing carbohydrates and protein within 30 minutes of training sessions in an attempt to optimise recovery (ACSM 2009 a; Rassmussen et al. 2000; Esmarch et al. 2001; Tipton et al. 2001, 2004, 2007; Rankin et al. 2004; Moore et al. 2009); these should include dairy food sources to meet RDI of calcium (e.g., milk and yoghurt). In order to avoid extra energy by adding a recovery meal it can be advisable to "time" the meals so that the recovery meal is one of the planned meals during the day.

- It is important that the weight loss does not compromise performance. For most, that means not losing LBM during weight loss. Thus, strength training should be included during the weight loss period. A moderate energy restriction combined with strength training has been shown to alleviate the negative consequences for LBM and performance (Garthe et al. 2011, paper I in the thesis).

- Body fat should be no lower than 5% for males and 12% for females after weight loss (Fogelholm 1994; Heyward & Wagner 2004). However, individual evaluations should be made. Some athletes are genetically disposed to have a lower fat percentage, whereas others do not tolerate being as low without having hormonal disturbances and/or other health- and performance-related impairments.

- Change in body composition should be monitored on a regular basis including a period of at least two months after the weight or body fat percentage goal has been reached, in order to detect any continued or unwarranted losses or weight fluctuations.

- Weight class athletes are encouraged to be no more than ~3% over competition weight and to take no more than 2% in rapid weight loss (depending on time from weigh-in to competition and recovery strategies), in order to avoid large weight fluctuations and impaired performance during season (Burke 2007; Shirreffs et al. 2004).

- Normal-weight athletes under the age of 18 should be discouraged from losing weight (Kiningham & Gorenflo 2001; Artioli et al. 2010 a; Karila et al. 2008).

- For some athletes it can be an advantage, for both health and performance, to gain LBM and move up a weight class. The weight gain period should be controlled and stabilised after the athlete has reached his/her goal.

Weight gain

To help athletes who want to gain weight without using extreme methods such as very high protein diets, diets high in saturated fats or excessive use of supplements, it is advisable to guide them during a weight gain period (Walberg-Rankin 2002; Burke 2007).

Guidelines for athletes who want/need to increase weight

- The weight goal should be based on objective measurements of body composition. Prior to a weight gain intervention, there should be a screening including weight history and weight goal, objective measure of BM, FM and LBM, energy/nutritional status, and questions regarding motivation, dietary habits, thoughts and feelings about body image, BM and food. If there is a history of DE/ED, a more intense and longer follow-up is suggested. Measurements of body composition should be made in private and the results should be explained and discussed with the athlete (Nattive et al. 2007).

- The weight gain period should be during off-season to avoid interference with competitions and sport-specific training loads, as this may create stress or overload for the athlete as well as not optimal results due to conflicting training stimuli (Nader 2006; Hawley 2009).

- A 4-day (3 weekdays + 1 weekend day) or a 7-day diet registration (using weighed or household measures) should be a basis for the diet plan (Magkos & Yannakoulia 2003; Deakin 2010). Objective measurements of BM and FM should be performed as well as a blood test. If the blood test indicates any specific micronutrient needs (e.g., vitamin D), these vitamins should be provided and biochemical changes monitored during the period.

- The athlete should aim for a gradual weight gain corresponding to 0.25-0.5 $kg \cdot week^{-1}$ (Walberg-Rankin; ACSM 2009 b). To induce a weight gain of 0.5 $kg \cdot week^{-1}$, an energy surplus similar to ~2090 (~500 kcal)$\cdot day^{-1}$ is needed, but there are individual differences (paper III from the Thesis). This can be achieved by increased energy intake, decreased energy expenditure, or a combination of the two.

- A sports nutritionist familiar with the demands of the specific sport should plan individual nutritionally adequate diets (Burke 2007). Throughout this process, the role of overall good nutrition practices in optimising performance should be emphasised. The diet plans should aim to have a protein intake corresponding to 1.4-2 $g \cdot kg^{-1}$, a carbohydrate intake corresponding to 5-8 $g \cdot kg^{-1}$ and 25-35% fat (ACSM 2009 a; Tarnopolsky 2010). The focus should be on high energy/nutrient density foods providing variety and a frequent meal pattern to ensure that the athlete is not fatigued during training sessions. There should also be an emphasis on recovery meals containing carbohydrates and protein within 30 minutes after training sessions in an attempt to optimise recovery (ACSM 2009 a; Rassmussen et al. 2000; Esmarch et al. 2001; Tipton et al. 2001, 2004, 2007; Rankin et al. 2004; Moore et al. 2009). Unsaturated fats in the diet (e.g., fish high in fat, olive oil for cooking, nuts/seeds) should also be prioritised.

- It is important that the weight gain does not compromise performance. For most athletes, that means that LBM is the main contributor to the weight gain and that the weight gain is not too rapid. A moderate energy surplus combined with strength training (Kreider et al. 1996; Rozenek et al. 2002) and sport-specific coordination training may help the athlete to adjust gradually to the higher body weight.

- Change in body composition should be monitored on a regular basis to avoid great increases in fat mass affecting both health and performance (Paper III in the Thesis).

- The use of creatine may be helpful in a weight gain period if the athlete responds well (Volek & Rawson 2004). Remember that there is always a risk of contamination and a positive doping test when taking supplements (Maughan 2005).

- To avoid excessive gains in FM, strength training should be emphasised during the period (Kreider et al. 1996; Rozenek et al. 2002). The training programme may be individual and sport-specific, but a relatively high total stress (e.g., hypertrophy training) seems to be an important factor for optimal gains in LBM (ACSM 2009 b).

- Although weight gain in athletes is considered relatively "harmless", it is important that adolescent athletes emphasise good technique and receive guidance during heavy strength training since growth spurt and formation of bones are priorities during that period (Rogol et al. 2000). The adolescent athlete should emphasise good nutritional routines with enough energy to support training. That will make the perfect base for the development of LBM when the growth spurt is over around 17-18 years of age (Rogol et al. 2000).

References

Aagaard P, Andersen JL. Effects of strength training on endurance capacity in top-level endurance athletes. Scand J Med Sci Sports. 2010 Oct;20 Suppl 2:39-47.

Alderman BL, Landers DM, Carlson J, Scott JR. Factors related to rapid weight loss practices among international-style wrestlers. Med Sci Sports Exerc. 2004 Feb;36(2):249-252.

American College of Sports Medicine position stand. Nutrition and athletic performance. Med Sci Sports Exerc. 2009 (a) Mar;41(3):709-731.

American College of Sports Medicine position stand. Progression models in resistance training for healthy adults. Med Sci Sports Exerc. 2009 (b) Mar;41(3):687-708.

American College of Sports Medicine Position stand. Weight Loss in Wrestlers. Med Sci Sports Exerc. 1996 28(2):ix-xii

APA. American Psychiatric Association. Diagnostic and Statistical Manual of Mental Disorders, 4th Ed. Washington, DC: American Psychiatric Association, 1994: 539-550.

Artioli GG, Gualano B, Franchini E, Scagliusi FB, Takesian M, Fuchs M, Lancha AH Jr. Prevalence, magnitude, and methods of rapid weight loss among judo competitors. Med Sci Sports Exerc. 2010 (a) Mar;42(3):436-442.

Artioli GG, Iglesias RT, Franchini E, Gualano B, Kashiwagura DB, Solis MY, Benatti FB, Fuchs M, Lancha Junior AH. Rapid weight loss followed by recovery time does not affect judo-related performance. J Sports Sci. 2010 (b) Jan;28(1):21-32.

Bell GJ, Syrotuik D, Martin TP, Burnham R, Quinney HA. Effect of concurrent strength and endurance training on skeletal muscle properties and hormone concentrations in humans. Eur J Appl Physiol 2000;81:418-427.

Biolo G, Williams BD, Fleming RY, Wolfe RR. Insulin action on muscle protein kinetics and amino acid transport during recovery after resistance exercise. Diabetes 1999;48:949-957.

Brownell KD, Steen SN, Wilmore JH. Weight regulation practices in athletes: analysis of metabolic and health effects. Med Sci Sports Exerc. 1987 6:546-560.

Bouchard C, Tremblay A, Després JP, Nadeau A, Lupien PJ, Thériault G, Dussault J, Moorjani S, Pinault S, Fournier G. The response to long-term overfeeding in identical twins. N Engl J Med. 1990 May;24;322(21):1477-1482.

Burge CM, Carey MF, Payne WR. Rowing performance, fluid balance, and metabolic function following dehydration and rehydration. Med Sci Sports Exerc. 1993 Dec;25(12):1358-1364.

Burd NA, West DW, Moore DR, Atherton PJ, Staples AW, Prior T, Tang JE, Rennie MJ, Baker SK, Phillips SM.Enhanced Amino Acid Sensitivity of Myofibrillar Protein Synthesis Persists for up to 24 h after Resistance Exercise in Young Men. J Nutr. 2011 Apr;141(4):568-73. Epub 2011 Feb 2.

Burke LM, Kiens B, Ivy L. Carbohydrates and fat for training and recovery. J Sports Sci. 2004 22(1):15-30.

Burke L. Nutrition Practical Sports Nutrition 2007. Human Kinetics Australia ISBN -13: 978-0-7360-4695-4.

Burke L. Nutrition for training and recovery after training and competition. In: Burke L, Deakin V Clinical sports nutrition 2010 4th edition McGraw.Hill Australia ISBN 978 0 070 27720 5.

Byrne S, McLean N. Elite athletes: effects of the pressure to be thin. J Sci Med Sport. 2002 Jun;5(2):80-94.

Børsheim E, Tipton KD, Wolf SE, Wolfe RR. Essential amino acids and muscle protein recovery from resistance exercise. Am J Physiol Endocrinol Metab. 2002 Oct;283(4):E648-57.

Caine D, Lewis R, O'Connor P, Howe W, Bass S. Does gymnastics training inhibit growth of females? Clin J Sport Med. 2001 Oct;11(4):260-270. Review.

Choma CW, Sforzo GA, Keller BA. Impact of rapid weight loss on cognitive function in collegiate wrestlers. Med Sci Sports Exerc. 1998 30(4):746-749.

Cupisti A, D'Alessandro C, Castrogiovanni S, Barale A, Morelli E. Nutrition survey in elite rhythmic gymnasts. J Sports Med Phys Fitness. 2000 Dec;40(4):350-355.

Dale KS, Landers DM. Weight control in wrestling: eating disorders or disordered eating? Med Sci Sports Exerc. 1999 Oct;31(10):1382-1389.

Deakin V. Measuring nutritional status of athletes: clinical and research perpectives. In: Burke L, Deakin V Clinical sports nutrition 2010 4th edition McGraw.Hill Australia ISBN 978 0 070 27720 5.

Degoutte F, Jouanel P, Bègue RJ, Colombier M, Lac G, Pequignot JM, Filaire E. Food restriction, performance, biochemical, psychological, and endocrine changes in judo athletes. Int J Sports Med. 2006 Jan;27(1):9-18.

Dériaz O, Tremblay A, Bouchard C. Non linear weight gain with long term overfeeding in man. Obes Res. 1993 May;1(3):179-185.

Drinkwater B, Loucks A, Sherman R, Sundgot-Borgen J and Thompon R. International Olympic Committee Medical Commission Working Group Women in Sport. Position Stand on the Female Athlete Triad. http://multimedia.olympic.org/pdf/ en_report _917.pdf. 2005.

Esmarck B, Andersen JL, Olsen S, Richter EA, Mizuno M, Kjaer M. Timing of postexercise protein intake is important for muscle hypertrophy with resistance training in elderly humans. J Physiol 2001; 535 (Pt 1):301-311.

Farage MA, Neill S, MacLean AB. Physiological changes associated with the menstrual cycle: a review. Obstet Gynecol Surv. 2009 Jan;64(1):58-72.

Filaire EF, Maso F. Degoutte P, Jouanel, Lac G. Food restriction, performance, psychological state and lipid values in judo athletes. Int. J. Sports Med. 2001 22:454-459.

Forbes GB, Brown MR, Welle SL, Lipinski BA. Deliberate overfeeding in women and men: energy cost and composition of the weight gain. Brit J Nutr. 1986 56:1-9.

Fogelholm MG, Koskinen R, Laakso J, Rankinen T, Rukonen I. Gradual and rapid weight loss: effects on nutrition and performance in male athletes. Med Sci Sports Exerc. 1993 25(3):371-377.

Fogelholm, M. Effects of bodyweight reduction on sports performance. Sports Med, 1994 4:249-267.

Forsberg S, Lock J. The relationship between perfectionism, eating disorders and athletes: a review. Minerva Pediatr. 2006 Dec;58(6):525-36.

Garner, D. M. Eating Disorders Inventory-2: Professional Manual. Psychological Assessment Resources Inc: Odessa, FL;1991. p. iv-70.

Garthe I. Vektregulering blant landslagsutøvere i vektklasseidretter i Norge. Rapport 2005, Olympiatoppen.

Gleeson M, Nieman DC, Pedersen BK. Exercise, nutrition and immune function. J Sports Sci. 2004 22(1):115-125.

Hagmar M, Hirchberg AL, Berglund L, Berglund B. Special attention to the weight-control strategies employed by Olympic athletes striving for leanness is required. Clin J Sports Med. 2008 18:5-9.

Hall CJ, Lane AM. Effects of rapid weight loss on mood and performance among amateur boxers. Br J Sports Med. 2001 35:390-395.

Hartman JW, Moore DR, Phillips SM. Resistance training reduces whole-body protein turnover and improves net protein retention in untrained young males. Appl Physiol Nutr Metab. 2006 Oct;31(5):557-64

Hawley JA. Molecular responses to strength and endurance training: are they incompatible? Appl Physiol Nutr Metab. 2009 Jun;34(3):355-61. Review.

Hawley JA, Burke LM, Phillips SM, Spriet LL. Nutritional modulation of training-induced skeletal muscle adaptations. J Appl Physiol. 2011 Mar;110(3):834-45. Epub 2010 Oct 28.

Hetland ML, Haarbo J, Christiansen C. Low bone mass and high bone turnover in male long distance runners. J Clin Endocrinol Metab. 1993 77(3): 770-775.

Heyward VH, Wagner DR. Applied Body Composition Assessment. 2nd edition. Human Kinetics, Champaign IL, USA, 2004.

Heyward VH, Sandoval WM, Colville B. Anthropometric, body composition and nutritional profiles of bodybuilders during training. J Appl Sport Sci Res. 1989;3(2):22-29.

Horber FF, Thomi F, Casez JP, Fonteille J, Jaeger P. Impact of hydration status on body composition as measured by dual energy X-ray absorptiometry in normal volunteers and patients on haemodialysis. Br J Radiol. 1992 Oct;65(778):895-900.

Horswill CA, Hickner RC, Scott JR, Costill DL, Gould D. Weight loss, dietary carbohydrate modifications, and high intensity, physical performance. Med Sci Sports Exerc. 1990 Aug;22(4):470-476.

Houston ME. Gaining weight: The scientific basis of increasing skeletal muscle mass. Can J Appl Physiol. 1999;24(4):305-316.

Ivy JL, Katz AL, Cutler CL, Sherman WM, Coyle EF. Muscle glycogen synthesis after exercise: effect of time of carbohydrate ingestion. J Appl Physiol 1988;64:1480-1485.

Jonnalagadda SS, Bernadot D, Nelson M. Energy and nutrient intakes of the United States National Women's Artistic Gymnastics Team. Int J Sport Nutr. 1998 Dec;8(4):331-344.

Josse AR, Tang JE, Tarnopolsky MA, Phillips SM. Body composition and strength changes in women with milk and resistance exercise. Med Sci Sports Exerc. 2010 Jun;42(6):1122-30.

Karila TA, Sarkkinen P, Marttinen M, Seppälä T, Mero A, Tallroth K. Rapid weight loss decreases serum testosterone. Int J Sports Med. 2008 Nov;29(11):872-877.

King NA, Caudwell P, Hopkins M, Byrne NM, Colley R, Hills AP, Stubbs JR, Blundell JE. Metabolic and behavioural compensatory responses to exercise interventions: barriers to weight loss. Obesity (Silver Spring). 2007 Jun;15(6):1373-1383. Review.

Kiningham RB, Gorenflo DW. Weight loss methods of high school wrestlers. Med Sci Sports Exerc. 2001 May;33(5):810-813.

Koral J, Dosseville F. Combination of gradual and rapid weight loss: effects on physical performance and psychological state of elite judo athletes. J Sports Sci. 2009. Jan15;27(2):115-120.

Koutedakis Y, Pacy PJ, Quevedo RM, Millward DJ, Hesp R, Boreham C, Sharp NCC. The effect of two different periods of weight-reduction on selected performance parameters in elite lightweight oarswomen. Int J Sports Med. 1994 15(8):472-477.

Kreider RB, Klesges R, Harmon K, Grindstaff P, Ramsey L, Bullen D, Wood L, Li Y, Almada A. Effects of ingesting supplements designed to promote lean tissue accretion on body composition during resistance training. Int J Sports Nutr. 1996;6:234-246.

Leibel RL, Rosenbaum M, Hirsch J. Changes in energy expenditure resulting from altered body weight. N Engl J Med. 1995 Mar 9;332(10):621-628.

Lemon PWR Effects of exercise on dietary protein requirements. Int J Sports Nutr 1998;8:426-47.

Lohman TG, Harris M, Teixeira PJ, Weiss L. Assessing body composition and changes in body composition. Another look at dual-energy X-ray absorptiometry. Ann N Y Acad Sci. 2000 May;904:45-54. Review.

Magkos F, Yannakoulia M. Methodology of dietary assessment in athletes: concepts and pitfalls. Curr Opin Clin Nutr Metab Care. 2003 Sep;6(5):539-549. Review.

Matejek NE. Weimann C. Witzel G. Molenkamp S. Schwidergall S, Bohles H. Hypoleptinaemia in patients with anorexia nervosa and in elite gymnasts with anorexia athletica. Int J Sports Med. 1999 20:451-456.

Maldonado, S., Mujika, I., Padilla, S. Influence of body mass and height on the energy cost of running in highly trained middle- and long-distance runners. Int J Sports Med. 2002 23: 268–272.

Marquart LF, Sobal J. Weight loss beliefs, practices and support systems for high school wrestlers. J Adolesc Health. 1994 15:410-415.

Maughan RJ. Contamination of dietary supplements and positive drug tests in sport. J Sports Sci. 2005 Sep;23(9):883-9. Review.

McArdle W, Katch FI, Katch VL Essentials of exercise physiology 2nd edition 2000 Lippincott Williams & Wilkins USA ISBN 0-683-30507-7.

Melby CL, Schmidt WD, Corrigan D. Resting metabolic rate in weight-cycling collegiate wrestlers compared with physically active, noncycling control subjects. Am J Clin Nutr. 1990 52(3):409-414.

Mettler S, Mitchell N, Tipton KD. Increased protein intake reduces lean body mass loss during weight loss in athletes. Med Sci Sports Exerc. 2010 Feb;42(2):326-337.

Miller SL, Tipton KD, Chinkes DL, Wolf SE, Wolfe RR. Independent and combined effects of amino acids and glucose after resistance exercise. Med Sci Sports Exerc. 2003 Mar;35(3):449-55.

Millward DJ. Methodological considerations Proc Nutr Soc 2001;Feb 60(1):3-5.

Moore DR, Robinson MJ, Fry JL, Tang JE, Glover EI, Wilkinson SB, et al. Ingested protein dose response of muscle and albumin protein synthesis after resistance exercise in young men. Am J Clin Nutr. 2009 89;1:161-168.

Morris FL, Payne WR. Seasonal variations in the body composition of lightweight rowers. Br J Sports Med. 1996 Dec;30(4):301-4.

Nader GA. Concurrent Strength and Endurance Training: From Molecules to Man. Med Sci Sports Exerc. 2006 38;11:1965–1970.

Nattiv A, Loucks AB, Manore MM, Sanborn CF, Sundgot-Borgen J, Warren MP. The Female Athlete Triad. Special Communications: Position Stand. Med Sci Sports Exerc. 2007 39(10):1867-82.

O´Connor H, Caterson I. Weight loss and the athlete In: Burke L, Deakin V Clinical sports nutrition 2010 4th edition McGraw.Hill Australia ISBN 978 0 070 27720 5.

Oppliger RA, Harms RD, Herrmann DE, Streich CM, Clark RR. The Wisconsin wrestling minimum weight project: a model for weight control among high school wrestlers. Med Sci Sports Exerc. 1995 Aug;27(8):1220-1224.

Oppliger RA, Steen SA, Scott JR. Weight loss practices of college wrestlers. Int J Sport Nutr Exerc Metab. 2003 Mar;13(1):29-46.

Phillips SM, Tipton KD, Aarsland A, Wolf SE, Wolfe RR. Mixed muscle protein synthesis and breakdown after resistance exercise in humans. Am J Physiol 1997;273:99-107.

Phillips SM, Tipton KD, Ferrando AA, Wolfe RR. Resistance training reduces the acute exercise-induced increase in muscle protein turnover. Am J Physiol 1999;276:E118-E124.

Rankin JW, Goldman LP, Puglisi MJ, Nickols-Richardson SM, Earthman CP, Gwazdauskas FC. Effect of post-exercise supplement consumption on adaptations to resistance training. J Am.Coll.Nutr. 2004; 23 (4):322-330.

Rasmussen BB, Tipton KD, Miller SL, Wolf SE, Wolfe RR. An oral essential amino acid-carbohydrate supplement enhances muscle protein anabolism after resistance exercise. J Appl.Physiol 2000; 88 (2):386-392.

Richter EA, Mikines KJ, Galbo H, Kiens B. Effect of exercise on insulin action in human skeletal muscle. J Appl Physiol 1989;66:876-885.

Roemmich JN, Sinning WE. Weight loss and wrestling training: effects on growth-related hormones. J Appl Phys. 1997 82:1760-1764.

Rogol, A.D., Clark, P.A., Roemmich, J.N. 2000. Growth and pubertal development in children and adolescents: effects of diet and physical activity. Am. J. Clin. Nutr. Aug;72(2):521-8.

Rosendahl J, Bormann B, Aschenbrenner K, Aschenbrenner F, Strauss B. Dieting and disordered eating in German high school athletes and non-athletes. Scand J Med Sci Sports. 2009 Oct;19(5):731-739.

Rozenek R, Ward P, Long S, Garhammer J. Effects of high-calorie supplements on body composition and muscular strength following resistance training. J Sports Med Phys Fitness. 2002 42:340-347.

Santos DA, Silva AM, Matias CN, Fields DA, Heymsfield SB, Sardinha LB. Accuracy of DXA in estimating body composition changes in elite athletes using a four compartment model as the reference method. Nutr Metab. 2010 Mar 22;7:22.

Shirreffs SM., Armstrong LE, Cheuvront SN. Fluid and electrolyte needs for preparation and recovery from training and competition. Carbohydrates and fat for training and recovery. J Sports Sci. 2004 22(1):57-63.

Slater GJ, Rice AJ, Sharpe K, Mujika I, Jenkins D, Hahn AG. Body-mass management of Australian lightweight rowers prior to and during competition. Med Sci Sports Exerc. 2005 (a) May;37(5):860-866.

Slater GJ, Rice AJ, Sharpe K, Tanner R, Jenkins D, Gore CJ, Hahn AG. Impact of acute weight loss and/or thermal stress on rowing ergometer performance. Med Sci Sports Exerc. 2005 (b) Aug;37(8):1387-1394.

Slater GJ, Rice AJ, Tanner R, Sharpe K, Jenkins D, Hahn AG. Impact of two different body mass management strategies on repeat rowing performance. Med Sci Sports Exerc. 2006 Jan;38(1):138-146.

Slater GJ. Protein and amino acid needs for training and bulking up, Practice tips In: Burke L, Deakin V Clinical sports nutrition 2010 4th edition McGraw.Hill Australia ISBN 978 0 070 27720 5.

Smathers AM, Bemben MG, Bemben DA. Bone density comparisons in male competitive road cyclists and untrained controls. Med Sci Sports Exerc. 2009 41(2): 290-296.

Smith M, Dyson R, Hale T, Hamilton M, Kelly J, Wellington P. The effect of restricted energy and fluid intake on simulated amateur boxing performance. Int J Sports Nutr Exerc Metab. 2001 11:238-247.

Steen SN, Brownell KD. Pattern of weight loss and regain in wrestlers: has the tradition changed? Med Sci Sports Exerc. 1990 22 (6):762-768.

Strauss RH, Lanese RR, Malarkey WB. Weight loss in amateur wrestlers and its effect on serum testosterone levels. JAMA. 1985 Dec 20;254(23):3337-3338.

Sundgot-Borgen, J. Prevalence of eating disorders in Elite female athletes. Int J Sports Nutr. 1993 3:29-40.

Sundgot-Borgen, J. Risk and trigger factors for the development of eating disorders in female elite athletes. Med Sci Sports Exerc. 1994 4:414-419.

Sundgot-Borgen J, Torstveit MK. Prevalence of eating disorders in elite athletes is higher than in the general population. Clin J Sport Med. 2004 14:25-32.

Sundgot-Borgen J, Torstveit MK. Aspects of disordered eating continuum in elite high-intensity sports. Scand J Med Sci Sports. 2010 20:112–121.

Sundgot-Borgen J, Garthe I. Elite athletes in aesthetic and Olympic weight-class sports and the challenge of body weight and body composition.J Sports Sci. 2011 Apr 12:1-14. [Epub ahead of print]

Tarnopolsky MA, Atkinson JD, MacDougall BB, Lemon PWR, Schwarcz HP Whole body leucine metabolism during and after resistance exercise in fed humans Med Sci Sports Exerc 1991;23:326-33.

Tarnopolsky MA. Protein and amino acid needs for training and bulking up
In: Burke L, Deakin V Clinical sports nutrition 2010 4th edition McGraw.Hill Australia ISBN 978 0 070 27720 5.

Tipton KD, Gurkin BE, Matin S, Wolfe RR. Nonessential amino acids are not necessary to stimulate net muscle protein synthesis in healthy volunteers. J Nutr Biochem. 1999 Feb;10(2):89-95.

Tipton KD, Rasmussen BB, Miller SL, Wolf SE, Owens-Stovall SK, Petrini BE, Wolfe RR. Timing of amino acid-carbohydrate ingestion alters anabolic response of muscle to resistance exercise. Am.J Physiol Endocrinol.Metab 2001; 281 (2):E197-E206.

Tipton KD, Elliott TA, Cree MG, Wolf SE, Sanford AP, Wolfe RR. Ingestion of casein and whey proteins result in muscle anabolism after resistance exercise. Med.Sci.Sports Exerc. 2004; 36 (12):2073-2081.

Tipton KD, Elliott TA, Cree MG, Aarsland AA, Sanford AP, Wolfe RR. Stimulation of net muscle protein synthesis by whey protein ingestion before and after exercise. Am.J Physiol Endocrinol.Metab 2007; 292 (1):E71-E76.

Tipton KD, Witard OC. Protein requirements and recommendations for athletes: relevance of ivory tower arguments for practical recommendations. Clin.Sports Med 2007; 26 (1):17-36.

Tipton KD, Wolfe RR. Protein and amino acid for athletes. J Sports Sciences. 2004 22:65-79.

Torstveit MK, Sundgot-Borgen J. The female athlete triad: are elite athletes at increased risk? Med Sci Sports Exerc. 2005 (a) 37(2): 184-193.

Torstveit MK, Sundgot-Borgen J. The female athlete triad exists in both elite athletes and controls. Med Sci Sports Exerc. 2005 (b) 37(9):1449-1459.

Torstveit MK, Rosenvinge J, Sundgot-Borgen J. Prevalence of eating disorders and the predictive power of risk factor models in female elite athletes: a controlled study. Scand J Med Sci Sports. 2008: 18(1): 108-118.

Vogels, N., Diepvens, K., Westerterp-Plantenga, M.S. (2005). Predictors of long-term weight maintenance. Obes Res. Dec;13(12):2162-2168.

Volek JS, Rawson ES. Scientific basis and practical aspects of creatine supplementation for athletes. Nutrition. 2004 Jul-Aug;20(7-8):609-14. Review.

Walberg Rankin J. Weight loss and gain in athletes. Curr Sports Med Rep. 2002 4:208-213.

Webster S, Rutt R, Weltman A. Physiological effects of a weight loss regimen practiced by college wrestlers. Med Sci Sports Exerc. 1990 22(2):229-234.

Weimann E, Witzel C, Schwidergall S, Böhles HJ. Peripubertal perturbations in elite gymnasts caused by sport specific training regimes and inadequate nutritional intake. Int J Sports Med. 2000 Apr;21(3):210-215.

Wernbom M, Augustsson J, Thomee R. The influence of frequency, intensity, volume and mode of strength training on whole muscle cross-sectional area in humans. Sports Med. 2007 37(3):225-264.

Weyer C, Pratley RE, Salbe AD, Bogardus C, Ravussin E, Tataranni PA. Energy expenditure, fat oxidation, and body weight regulation: a study of metabolic adaptation to long-term weight change. J Clin Endocrinol Metab. 2000 Mar;85(3):1087-9104.

Wheeler GD, Wall SR, Belcastro AN, Cumming DC. Reduced serum testosterone and prolactin levels in male distance runners. JAMA. 1984 July (27);252(4):514-516.

Wilkinson SB, Tarnopolsky MA, Macdonald MJ, Macdonald JR, Armstrong D, Phillips SM. Consumption of fluid skim milk promotes greater muscle protein accretion after resistance exercise than does consumption of an isonitrogenous and isoenergetic soy-protein beverage. Am J Clin Nutr. 2007 Apr;85(4):1031-40.

Wing RR, Phelan S. Long-term weight loss maintenance. Am J of Clin Nutr. 2005 July;2(1):222-225.

Yanagawa Y, Morimura T, Tsunekawa K, Seki K, Ogiwara T, Kotajima N, Machida T, Matsumoto S, Adachi T, Murakami M. Oxidative stress associated with rapid weight reduction decreases circulating adiponectin concentrations. Endocr J. 2010 57(4):339-345.

Ziegler PJ, Kannan S, Jonnalagadda SS, Krishnakumar A, Taksali SE, Nelson JA. Dietary intake, body image perceptions, and weight concerns of female US International Synchronised Figure Skating Teams. Int J Sport Nutr Exerc Metab. 2005 Oct;15(5):550-555.

OLYMPIATOPPEN

NORGES IDRETTSHØGSKOLE

Forespørsel om deltakelse i forskningsprosjekt for Idrettsutøvere

Vi henvender oss til deg som utøver og spør om du kan tenke deg å være med på en studie i regi av Norges Idrettshøgskole og Olympiatoppen. Hensikten med forskningsprosjektet er å se hvordan den veiledningen som gis på Olympiatoppen når det gjelder ernæring, vektregulering og forstyrret spiseatferd virker.

Bakgrunn
Idrettsutøvere har et økt behov for energi og næringsstoffer. Valg av matvarer, måltidsfrekvens, timing av måltider og restitusjon er viktige faktorer i et treningsregime for å få maksimalt utbytte av utøvers potensial. Dette kan by på flere utfordringer for noen utøvere: energiinntak (kaloriinntak) i forhold til forbruk, tilstrekkelig inntak av makro- og mikronæringsstoffer og planlegging og tilrettelegging av måltider. Ernæringsavdelingen, treningsavdelingen og helseavdelingen på Olympiatoppen har i de siste årene tilbudt veiledning på styrketrening, vektregulering og behandling av utøvere med forstyrret spiseatferd/spiseforstyrrelser. Vi ønsker nå å teste ut effekten av de veiledningsregimene vi tilbyr. Regimene inkluderer kost- og treningsveiledning og vil bli tilrettelagt din idrett i samarbeid med deg og evt. din trener.

Formål
Formålet med denne studien er følgende:
1) Se på effekten av en 24 ukers behandling/veiledning av utøvere med forstyrret spiseatferd/spiseforstyrrelse, menstruasjonsforstyrrelser og redusert beinmasse
2) Se på effekten av 6-12 ukers veiledning på vektreduksjon
3) Se på effekten av 6-12 ukers veiledning på vektøkning

Metode
Utøvere som henvender seg til Olympiatoppens helseavdeling og ernæringsavdeling vil få avtale om tid for en samtale med Professor Jorunn Sundgot-Borgen. I forbindelse med denne samtalen vil det bli klargjort hvilke behov utøveren har og hva han/hun ønsker hjelp til, og utøverne blir således delt inn i: triade, vektreduksjon og vektøkning.

Utøverne blir så randomisert inn i to grupper, veiledning I og veiledning II, der vi ønsker å se på effekten av de ulike veiledningsregimene.

Hvem blir forespurt om å delta?
Juniorer og seniorer (landslagsutøvere – A, B og rekrutter) i utvalgte særforbund som er medlem av Norges Idrettsforbund, samt elever/utøvere ved Norges Toppidrettsgymnas, Wang Toppidrettsgymnas. Primært vil det være utøvere som henvender seg til Olympiatoppens helseavdeling, ernæringsavdeling eller treningsavdeling for følgende veiledning:

1) Vektøkning (vektøkning i form av økt muskelmasse)
2) Vektreduksjon (vektreduksjon i form av tap av fettmasse)
3) Veiledning i forhold til forstyrret spiseadferd/spiseforstyrrelser, menstruasjonsforstyrrelser eller påvist tap av beinmasse

Hva skal du gjøre dersom du blir med?
- En samtale med Jorunn Sundgot-Borgen
- Fylle ut spørreskjema

Målinger som blir gjort i forbindelse med studien

- Måle kroppssammensetning (DXA og kaliper)
- Blodprøve: Østradiol, progesteron, LH, FSH, DHEA, testosteron, kortisol, T3, T4, TSH, IGF-1, jern, B12, kolesterol, HDL, LDL, triglyserider, albumin, kalsium.
- Styrketester
- 4 dagers veid kostregistrering
- Mat og treningsdagbok
- Mental evaluering: EDE, EDI, Contingent self-esteem Scale.

De involverte i prosjektet er underlagt taushetsplikt og prosjektet er meldt til personvernombudet for forskning. Blodprøvene vil bli oppbevart i en biobank uten kommersielle interesser (vurdert av Regional Etisk Komité). Prøvene vil bli lagret i inntil 10 år. Andre forskningsdata vil bli anonymisert i utgangen av 2016. Ansvarlig for biobanken er Professor Jorunn Sundgot-Borgen ved NIH. Dersom utøver/foreldre ønsker å tilbakekalle samtykket, kan dere kreve det biologiske materialet destruert og innsamlede helse- og personopplysninger slettet eller utlevert. Vi startet undersøkelsen i januar 2006 og regner med å avslutte desember 2008.

Det er selvfølgelig frivillig å delta i undersøkelsen og om du ønsker det, kan du trekke seg fra studien uten grunn når du vil. Dersom du vil være med på studien, ber vi deg skrive under på en samtykkeerklæring på neste side. Dersom du er under 18 år skal dine foreldre informeres om studien. De har således mulighet til å nekte deltakelse på vegne av deg (se vedlagt skriv). Dersom du er under 16 år må vi ha dine forelders skriftlige godkjennelse (se vedlagt skriv).

Vi vil samarbeide med trenere og ledere slik at forsøket legges til rette med tanke på å forstyrre sesongen minst mulig. Du vil få mulighet til å gå igjennom en del tester som en vanligvis ikke får anledning til, og det er ikke knyttet risiko eller smerte til noen av testene. Du vil også få en profesjonell vurdering av kostholdet, og nøye oppfølging gjennom den perioden du er med på undersøkelsen. Som forsøksperson er du forsikret gjennom forsøket, slik at de er sikret økonomisk kompensasjon for eventuelle skader eller komplikasjoner.

Olympiatoppens helseavdeling, ernæringsavdeling og treningsavdeling er med i teamet. Prosjektleder for studien er Professor Jorunn Sundgot-Borgen og dr.grad stipendiat Ina Garthe (som for tiden er erstattet av Anu Koivisto) . Medisinsk ansvarlig er Olympiatoppens sjefslege Professor Lars Engebretsen.

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Anu

Med vennlig hilsen

Jorunn Sundgot-Borgen (sign.)	Ina Garthe (sign.)	Jarle Aambø (sign.)
Professor	dr.grad stipendiat	Toppidrettssjef
Norges idrettshøgskole	Norges idrettshøgskole	Olympiatoppen
Olympiatoppen	Olympiatoppen	

Samtykkeerklæring for utøver

Ja, jeg har lest informasjonsskrivet og blitt muntlig informert om studien og vet hva inklusjonen innebærer. Jeg vet at jeg kan trekke meg når som helst underveis, uten grunn. Jeg samtykker herved å delta i studien.

Dato:………….. Sted:……………….

Underskrift utøver

OLYMPIATOPPEN

NORGES IDRETTSHØGSKOLE

Informasjon til særforbund om deltakelse i forskningsprosjekt for Idrettsutøvere

Vi henvender oss til idrettstøvere i utvalgte særforbund for å spør om de kan tenke seg å være med på en studie i regi av Norges Idrettshøgskole og Olympiatoppen. Hensikten med forskningsprosjektet er å se hvordan den veiledningen som gis på Olympiatoppen når det gjelder ernæring, vektregulering og forstyrret spiseatferd virker.

Bakgrunn
Idrettsutøvere har et økt behov for energi og næringsstoffer. Valg av matvarer, måltidsfrekvens, timing av måltider og restitusjon er viktige faktorer i et treningsregime for å få maksimalt utbytte av utøvers potensial. Dette kan by på flere utfordringer for noen utøvere: energiinntak (kaloriinntak) i forhold til forbruk, tilstrekkelig inntak av makro- og mikronæringsstoffer og planlegging og tilrettelegging av måltider. Ernæringsavdelingen og helseavdelingen på Olympiatoppen har i de siste årene tilbudt veiledning på vektregulering og behandling av utøvere med forstyrret spiseatferd/spiseforstyrrelser. Vi ønsker nå å teste ut effekten av de veiledningsregimene vi tilbyr.

Formål
Formålet med denne studien er følgende:

4) Se på effekten av en 24 ukers behandling/veiledning av utøvere med forstyrret spiseatferd/spiseforstyrrelse, menstruasjonsforstyrrelser og redusert beinmasse
5) Se på effekten av 6-12 ukers veiledning på vektregulering (vektøkning, vektreduksjon)
6) Se på effekten av kostoptimalisering

Metode
Utøvere som henvender seg til Olympiatoppens helseavdeling og ernæringsavdeling vil få avtale om tid for en samtale med Professor Jorunn Sundgot-Borgen. I forbindelse med denne samtalen vil det bli klargjort hvilke behov utøveren har og hva han/hun ønsker hjelp til, og utøverne blir således delt inn i: triade, vektreduksjon, vektøkning og kostoptimalisering.

Utøverne blir så randomisert inn i to grupper, veiledning I og veiledning II, der vi ønsker å se på effekten av de ulike veiledningsregimene.

Hvem blir forespurt om å delta?
Juniorer og seniorer (landslagsutøvere – A, B og rekrutter) i utvalgte særforbund som er medlem av Norges Idrettsforbund, samt elever/utøvere ved Norges Toppidrettsgymnas, Wang Toppidrettsgymnas. Primært vil det være utøvere som henvender seg til Olympiatoppens helseavdeling, ernæringsavdeling eller treningsavdeling for følgende veiledning:

1) kostoptimalisering (optimalisering av kostholdet i forhold til din idrett)
2) Vektøkning (vektøkning i form av økt muskelmasse)
3) Vektreduksjon (vektreduksjon i form av tap av fettmasse)
4) Veiledning i forhold til forstyrret spiseadferd/spiseforstyrrelser, menstruasjonsforstyrrelser eller påvist tap av beinmasse

Hva skal de gjøre dersom de blir med?

- En samtale med Jorunn Sundgot-Borgen
- Fylle ut et spørreskjema

Målinger som blir gjort i forbindelse med studien

- Måle kroppssammensetning (DXA og kaliper)
- Blodprøve
- 4 dagers veid kostregistrering
- Mat og treningsdagbok
- Mental evaluering: EDE, EDI, Contingent self-esteem Scale.

De involverte i prosjektet er underlagt taushetsplikt og prosjektet er meldt til personvernombudet for forskning. Blodprøvene vil bli oppbevart i en biobank uten kommersielle interesser (vurdert av Regional Etisk Komite). Prøvene vil bli lagret i inntil 10 år. Ansvarlig for biobanken er Professor Jorunn Sundgot-Borgen ved NIH. Dersom utøver/foreldre ønsker å tilbakekalle samtykket, kan dere kreve det biologiske materialet destruert og innsamlede helse- og personopplysninger slettet eller utlevert.

Vi starter undersøkelsen i løpet av januar 2006.

Det er selvfølgelig frivillig å delta i undersøkelsen og om de ønsker det, kan de trekke seg fra studien uten grunn når de vil. Utøvere under 18 år skal informere sine foreldre om studien. De har således mulighet til å nekte deltakelse på vegne av utøveren. Dersom utøveren er under 16 år må vi ha foreldrenes skriftlige godkjennelse.

Vi vil samarbeide med trenere og ledere slik at forsøket legges til rette med tanke på å forstyrre sesongen minst mulig. Utøverne vil få mulighet til å gå igjennom en del tester som de vanligvis ikke får anledning til, og det er ikke knyttet risiko eller smerte til noen av testene. De vil også få en profesjonell vurdering av kostholdet, og nøye oppfølging gjennom den perioden du er med på undersøkelsen. Som forsøksperson er de forsikret gjennom forsøket, slik at de er sikret økonomisk kompensasjon for eventuelle skader eller komplikasjoner.

Olympiatoppens helseavdeling, ernæringsavdeling og treningsavdeling er med i teamet. Prosjektleder for studien er Professor Jorunn Sundgot-Borgen og stipendiat er Cand.Scient Ina Garthe. Medisinsk ansvarlig er Olympiatoppens sjefslege Professor Lars Engebretsen.

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Med vennlig hilsen

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Deres ref.:
Vår ref.: S-05274

S-05274 ***Hvilken effekt har 12 ukers intervensjon på: 1) idrettsutøvere med en eller flere triadekomponenter; 2) idrettsutøvere som skal regulere kroppsvekt/kroppssammensetning***

Komiteen behandlet søknaden i sitt møte onsdag 28.09.05.

Komiteen har ingen merknader til prosjektsøknaden.

Komiteen har følgende merknad til søknad om opprettelse av forskningsbiobank:

1. **Pkt 3: Stemmer det at prosjektleder er formelt databehandlingsansvarlig? Dette er vanligvis institusjonens øverste leder. Personvernombudet ved institusjonen eller evt. Datatilsynet kan gi mer informasjon om dette**

Komiteen har følgende merknader til informasjonsskrivene (også til særforbund og foreldre) og samtykkeerklæring:

1. **Det skal ikke være nødvendig sende inn beskjed om at foresatte ikke ønsker at deltagelse skal skje.**
2. **Henvendelsen skal holdes i en nøytral form og setninger om at man håper at de som får henvendelsen ser positivt på den og tilsvarende om utenforliggende forhold som knyttet til sesongresultater bes strøket.**
3. **Regional komité for medisinsk forskningsetikk godkjenner ikke men tilrår studier, da den ikke et forvaltningsorgan med vedtakskompetanse**
4. **Dersom studien startet i september, slik det opplyses om til potensielle deltagere, betyr det at komiteen ikke behandler søknaden, fordi mandatet tilsier at igangsatte studier ikke vurderes. Komiteen ber om en avklaring.**
5. **Informasjonsskrivet må tilpasses biobankloven jfr. §11-14 fordi forskningsbiobank opprettes. Ansvarshavende for forskningsbiobanken må oppgis samt at den som ønsker å tilbakekalle samtykket, kan kreve det biologiske materialet destruert og innsamlede helse- og personopplysninger slettet eller utlevert. Adgangen til å tilbakekalle samtykket eller kreve destruksjon, sletting eller utlevering gjelder ikke dersom opplysningene allerede har inngått i vitenskapelige arbeider, jf biobankloven § 14 tredje ledd. (Dersom prøver skal sendes til utlandet, må pasientens tillatelse til dette innhentes, og sosial- og helsedirektoratet må søkes om tillatelse til utføring av prøver). Se også Mal for hva som bør inngå i et informasjonsskriv under Forskerportalen på http://www.etikkom.no/REK/forskerportal/infoskriv.**
6. **Det skal angis hva blodprøvene skal brukes til, da det ikke tillates in blanco fullmakt til forskning på biologiske prøver, jfr. biobankloven.**
7. **Angi destruksjonsdato av biologiske prøver, samt tidspunkt for anonymisering av forskningsdata.**
8. **Angi tidsbruken for de mentale testene (EDE etc).**

UNIVERSITETET I OSLO
Det medisinske fakultet

Side 2 av 2

Vedtak:
"Komiteen ber om revidert informasjonsskriv. Forutsatt at merknadene tas til etterretning, vil komiteen tilrår at prosjektet gjennomføres og at forskningsbiobank opprettes. Komiteen videresender deretter skjema for opprettelse av forskningsbiobank og revidert informasjonsskriv samt komiteens vedtak til Sosial- og helsedirektoratet for endelig behandling av opprettelse av forskningsbiobanken."

Med vennlig hilsen

Annetine Staff
Overlege dr.med.
Leder

Tone Haug
Rådgiver
Sekretær

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Vår dato: 02.06.2006 Vår ref: 14180/SS Deres dato: Deres ref:

TILRÅDING AV BEHANDLING AV PERSONOPPLYSNINGER

Vi viser til melding om behandling av personopplysninger, mottatt 30.01.2006. All nødvendig informasjon om prosjektet forelå i sin helhet 31.05.2006. Meldingen gjelder prosjektet:

14180	*Effekten av 12 ukers intervensjon på 1) triadeutøvere, 2) utøvere som skal regulere vekt*
Behandlingsansvarlig	*Norges idrettshøgskole, ved institusjonens øverste leder*
Daglig ansvarlig	*Ina Garthe*

Personvernombudet har vurdert prosjektet, og finner at behandlingen av personopplysninger vil være regulert av § 7-27 i personopplysningsforskriften. Personvernombudet tilrår at prosjektet gjennomføres.

Personvernombudets tilråding forutsetter at prosjektet gjennomføres i tråd med opplysningene gitt i meldeskjemaet, korrespondanse med ombudet, eventuelle kommentarer samt personopplysningsloven/-helseregisterloven med forskrifter. Behandlingen av personopplysninger kan settes i gang.

Det gjøres oppmerksom på at det skal gis ny melding dersom behandlingen endres i forhold til de opplysninger som ligger til grunn for personvernombudets vurdering. Endringsmeldinger gis via et eget skjema, http://www.nsd.uib.no/personvern/endringsskjema. Det skal også gis melding etter tre år dersom prosjektet fortsatt pågår. Meldinger skal skje skriftlig til ombudet.

Personvernombudet har lagt ut opplysninger om prosjektet i en offentlig database, http://www.nsd.uib.no/personvern/register/

Personvernombudet vil ved prosjektets avslutning, 31.12.2016 rette en henvendelse angående status for behandlingen av personopplysninger.

Vennlig hilsen

Bjørn Henrichsen Synnøve Serigstad

TRENINGSPROGRAM

		Uke 1-3	Uke 4-8	Uke 9-12
Ma	Benkpress	1 x 12.10.8	1 x 12.10.8.6	1 x 10.8.6.6.6
	Liggende roing	1 x 12.10.8	1 x 12.10.8.6	1 x 10.8.6.6.6
	Chins evt. nedtr. nakke	3 x maks	4 x maks	5 x maks
	Pec deck	3 x 12	4 x 10	5 x 8
	Stående opptrekk	3 x 12	4 x 10	5 x 8
	Deltaraise	3 x 12	4 x 10	5 x 8
	Sidel. kroppshev	3 x 12	3 x 10	3 x 8
	Rygg-ups rett rygg	3 x 15	3 x 12	3 x 10
Ti	Styrkevending	2 x 5	3 x 4	4 x 4
	Svikthopp med 0-40 kg	2 x 5	3 x 4	4 x 4
	Knebøy	1 x 12.10.8	1 x 12.10.8.6	1 x 10.8.6.6.6
	Markløft	3 x 10	4 x 8	5 x 5
	Leg extension	3 x 12	4 x 10	5 x 8
	Leg curl	3 x 12	4 x 10	5 x 8
	Dips	3 x maks	4 x maks	5 x maks
	Bicepscurl manual	3 x 12	4 x 10	5 x 8
	Bjørndalen	3 x 15	3 x 12	3 x 10
	Rotary torso	3 x 12	3 x 10	3 x 8
To	Benkpress	1 x 12.10.8	1 x 12.10.8.6	1 x 10.8.6.6.6
	Liggende roing	1 x 12.10.8	1 x 12.10.8.6	1 x 10.8.6.6.6
	Nedtrekk mot bryst	3 x 12	4 x 10	5 x 8
	Flies i kabelapparat	3 x 12	4 x 10	5 x 8
	Stående opptrekk	3 x 12	4 x 10	5 x 8
	Shoulderpress	3 x 12	4 x 10	5 x 8
	Sidel. kroppshev	3 x 12	3 x 10	3 x 8
	Rygg-ups rull opp	3 x 15	3 x 12	3 x 10
Fr	Styrkevending	2 x 5	3 x 4	4 x 4
	Knebøy 90 grader	2 x 6	3 x 6	4 x 6
	Knebøy	1 x 12.10.8	1 x 12.10.8.6	1 x 10.8.6.6.6
	Markløft	3 x 10	4 x 8	5 x 5
	Hack-lift	3 x 12	4 x 10	5 x 8
	Strak mark	3 x 12	4 x 10	5 x 8
	Triceps pushdown	3 x 12	4 x 10	5 x 8
	Bicepscurl Z-stang	3 x 12	4 x 10	5 x 8
	Brutalbenk	3 x maks	3 x maks	3 x maks
	Stå buk rot skive	3 x 12	3 x 12	3 x 12

Paper I-IV

Paper I

International Journal of Sport Nutrition and Exercise Metabolism, 2011, 97-104

Effect of Two Different Weight-Loss Rates on Body Composition and Strength and Power-Related Performance in Elite Athletes

Ina Garthe, Truls Raastad, Per Egil Refsnes, Anu Koivisto, and Jorunn Sundgot-Borgen

When weight loss (WL) is necessary, athletes are advised to accomplish it gradually, at a rate of 0.5–1 kg/wk. However, it is possible that losing 0.5 kg/wk is better than 1 kg/wk in terms of preserving lean body mass (LBM) and performance. The aim of this study was to compare changes in body composition, strength, and power during a weekly body-weight (BW) loss of 0.7% slow reduction (SR) vs. 1.4% fast reduction (FR). We hypothesized that the faster WL regimen would result in more detrimental effects on both LBM and strength-related performance. Twenty-four athletes were randomized to SR (n = 13, 24 ± 3 yr, 71.9 ± 12.7 kg) or FR (n = 11, 22 ± 5 yr, 74.8 ± 11.7 kg). They followed energy-restricted diets promoting the predetermined weekly WL. All athletes included 4 resistance-training sessions/wk in their usual training regimen. The mean times spent in intervention for SR and FR were 8.5 ± 2.2 and 5.3 ± 0.9 wk, respectively ($p < .001$). BW, body composition (DEXA), 1-repetition-maximum (1RM) tests, 40-m sprint, and countermovement jump were measured before and after intervention. Energy intake was reduced by 19% ± 2% and 30% ± 4% in SR and FR, respectively ($p = .003$). BW and fat mass decreased in both SR and FR by 5.6% ± 0.8% and 5.5% ± 0.7% (0.7% ± 0.8% vs. 1.0% ± 0.4%/wk) and 31% ± 3% and 21 ± 4%, respectively. LBM increased in SR by 2.1% ± 0.4% ($p < .001$), whereas it was unchanged in FR (–0.2% ± 0.7%), with significant differences between groups ($p < .01$). In conclusion, data from this study suggest that athletes who want to gain LBM and increase 1RM strength during a WL period combined with strength training should aim for a weekly BW loss of 0.7%.

Keywords: energy restriction, strength training, hypertrophy

Weight loss in athletes is generally motivated by a desire to optimize performance by improving power-to-weight ratio, making weight to compete in a certain weight category, or for aesthetic reasons in leanness sports. Because of the negative effects of rapid weight loss and long periods of restricted energy intake (Hall & Lane, 2001; Koral & Dosseville, 2009; Umeda, Nakaji, Shimoyama,Yamamoto, & Sugawara, 2004), existing literature recommends a gradual weight loss through moderate energy restriction, promoting a weekly weight loss of 0.5–1 kg (Fogelholm, 1994; Rankin, 2002). To induce a weight loss of 0.5–1 kg/wk, an energy deficit corresponding to 500–1,000 kcal/day is needed. This can be achieved by reduced energy intake, increased energy expenditure, or a combination of the two.

However, a decrease in body mass resulting from energy restriction can lead to loss of lean body mass (LBM; Koral & Dosseville, 2009; Koutedakis et al., 1994) and thereby impair performance (Degoutte et al., 2006; Koral & Dosseville, 2009). Strength training in combination with mild energy restriction can preserve LBM during weight-loss periods in overweight sedentary subjects (Kraemer et al., 1999). Therefore, to make weight-loss interventions as effective as possible, we combined energy restriction with strength training to alleviate the expected negative consequences on LBM and performance.

Finally, when the weight-loss goal is fixed, most athletes choose to use the shortest amount of time to reach the goal to avoid extended periods of fatigue. There are probably different implications of reducing daily energy intake by 500 or 1,000 kcal, and a reduction of 1,000 kcal can compromise recovery and impair training adaptations in athletes, especially in those with an already low energy intake (American College of Sports Medicine [ACSM], 2009; Nattiv et al., 2007).

Consequently, the aim of this study was to compare two practical approaches to the recommended weight-loss regimen in the literature. We compared weekly BW losses of 0.7% and 1.4% (i.e., twice the relative weight), which corresponds to weekly weight losses of 0.5 and 1 kg, respectively, in a 70-kg athlete. We hypothesized that the faster weight-loss regimen would result in more detrimental effects on both LBM and strength- and power-related performance.

Garthe, Raastad, and Sundgot-Borgen are with the Norwegian School of Sport Sciences, Oslo, Norway. Garthe, Refsnes, and Koivisto are with the Norwegian Olympic Sports Centre, Oslo, Norway.

Methods

Subjects

Thirty-six elite male and female athletes, age 18–35 years, were recruited, and 30 completed the study. The athletes were recruited by invitation from the Norwegian Olympic Sport Center when they contacted the center to get assistance with weight loss, or by invitation letters to sport federations. The following sports were represented in the study: football, volleyball, cross-country skiing, judo, jujitsu, tae kwon do, waterskiing, motocross, cycling, track and field, kickboxing, gymnastics, alpine skiing, ski jumping, freestyle sports dancing, skating, biathlon, and ice hockey. There were 43% versus 57% and 31% versus 69% men and women in the slow-reduction group (SR) and the fast-reduction group (FR), respectively. The physical and anthropometrical characteristics of the athletes are shown in Table 1.

Six female athletes with repeated weight fluctuations during the last season reported a low energy intake at baseline and therefore had to accomplish their weight goal with an intervention that included increased energy expenditure in addition to the reduced energy intake. They were included in the study because this is a daily practical challenge when working with athletes. However, because of the different intervention with additional energy expenditure included for this subgroup, the statistical analysis, results, and discussion are presented without this subgroup.

The athletes were informed about the purpose and experimental procedures before written consent was obtained. The study was conducted according to the Declaration of Helsinki and approved by the Data Inspectorate and the Regional Ethics Committee of Southern Norway. Permission to conduct the study was provided by the Norwegian Olympic Committee and the Norwegian Confederation of Sports.

Experimental Design

The athletes were screened and block-randomized to the SR and FR groups. All athletes followed a 4- to 12-week energy-restriction and strength-training period. The length of the intervention was determined by the rate of weight loss (SR or FR) and the desired weight loss (minimum 4% of BW). The final weight goal was set by a nutritionist and exercise physiologist based on results from the body-composition measurements that provided the information needed to calculate minimum percentage fat for each athlete and the athlete's desired weight loss. The length of the intervention period for each subject depended on the athlete's weight-loss goal and the weekly weight-loss rate. For example, a 70-kg athlete who wanted to reduce body weight by 5 kg (and the amount of weight loss was appropriate for the calculated minimum percentage fat) would have either a 5- (FR) or 10-week (SR) intervention depending on which intervention group he or she was randomly allocated to.

Preparticipation Screening

Screening included the Eating Disorder Inventory (EDI-2; Garner, 1991), followed by an interview and medical examination according to the standard for preseason health evaluation at the Norwegian Olympic Sports Center. The exclusion criteria were as follows: diseases and conditions known to affect metabolic functions in muscle, use of pharmaceuticals that might affect any of the measurements, and presence of one or more of the triad components—disordered eating/eating disorder, menstrual dysfunction, or low bone-mineral density (Nattiv et al., 2007). For possible diagnoses, *DSM-IV* criteria were used for anorexia nervosa, bulimia nervosa, and eating disorder not otherwise specified (American Psychiatric Association, 1994); clinically evident perimenopausal or postmenopausal condition; pregnancy; and fat mass corresponding to a predicted postintervention body-fat value of less than 5% for men and 12% for women (Fogelholm, 1994; Heyward & Wagner, 2004).

Intervention

Diet. Diet registrations were obtained by a 4-day (3 weekdays + 1 weekend day) weighed-food record that was analyzed by a national food database, "Mat Paa Data" (version 5.0, LKH, Mattilsynet, Norway). The athletes were instructed to make sure they were weight stable during the diet registration. The record served as

Table 1 Baseline Data, *M* ± *SD*

	Slow-Rate Weight Loss		Fast-Rate Weight Loss	
	Men (*n* = 6)	Women (*n* = 7)	Men (*n* = 5)	Women (*n* = 6)
Age (years)	24.9 ± 3.5	22.4 ± 3.1	20.9 ± 4.5	20.7 ± 6.4
Height (cm)	177 ± 11	169 ± 8	179 ± 4	167 ± 1
Body weight (kg)	78.5 ± 14.1	66.4 ± 8.8	81.9 ± 11.5	68.9 ± 6.7
Fat mass (kg)	13.3 ± 5.0	17.3 ± 4.4	13.3 ± 6.5	21.2 ± 5.2
Total body fat (%)	17 ± 5	27 ± 5	16 ± 3	30 ± 5
Lean body mass (kg)	62.3 ± 10.3	46.3 ± 5.5	65.5 ± 3.3	44.6 ± 3.6
Experience as athletes (years)	13 ± 6.4	10.7 ± 4.7	12.6 ± 4.5	13.1 ± 5.1
Training per week (hr)	15.6 ± 4.5	15.2 ± 3.1	15.2 ± 3.1	13.9 ± 5.3
Strength training last season (hr/week)	2.8 ± 1.6	2.7 ± 1.6	3.4 ± 1.1	2.1 ± 1.5

a basis for developing each athlete's individualized diet plan promoting weekly BW loss of 0.7% or 1.4%. This was calculated from the assumption that 1 g of mixed tissue gives 7 kcal. For example, a 60-kg athlete in SR had to reduce energy intake by ~420 kcal/day to achieve the weekly weight-loss goal of 0.4 kg (60,000 × 0.7%/7 days × 7 kcal). In the diet plans, the aim was to have a daily protein intake corresponding to 1.2–1.8 g/kg, a daily carbohydrate intake corresponding to 4–6 g/kg and ≥20% fat, with low-energy/high-nutrient foods that provided satiety, as well as food variety. There were 5–7 daily meals and snacks and no meal plan below 1,500 kcal/day. All athletes ingested a milk-protein-based recovery meal containing carbohydrates (20–40 g) and protein (6–20 g) within 30 min after training sessions and a balanced meal within 1–2 hr, in an attempt to optimize recovery. During implementation of the dietary plan, the athletes were encouraged to use a food scale to ensure correct portion sizes. They were encouraged to drink a minimum of 0.5 L/hr of water during training sessions and ~2 L of fluids during the day. If the athletes were unable to follow the dietary plan during the week, they were instructed to write down any deviations from it.

Supplementation. The athletes were not allowed to have used creatine supplementation during the 6 weeks before the intervention, and they did not take any supplements other than those given by the nutritionist during the intervention. A multivitamin–mineral supplement (Nycomed, Asker, Norway) and a cod liver oil supplement (Møller's tran, Oslo, Norway) were prescribed to ensure sufficient micronutrient intake and essential fat intake during the intervention. Furthermore, if blood samples indicated any other specific micronutrient needs (e.g., iron, vitamin B_{12}), these vitamins were provided to the athletes and blood levels were thereafter monitored.

Nutritional Counseling. The athletes received nutritional counseling once a week during intervention. The counseling included basic nutrition, sports physiology, and possible adjustments in the dietary plan or weight regimen, depending on progress.

Training. The intervention period started off-season for all athletes to be able to add additional training to their schedule and for practical reasons (e.g., traveling and competitions). All athletes continued their sport-specific training schedule (14.6 ± 3.5 hr/week, presented as a mean of the training during the previous year). They included four strength-training sessions per week to emphasize muscle strength and hypertrophy. The strength-training program was a two-split periodized program. Each muscle group was exercised twice a week with two exercises in each session, one main exercise attacking multiple muscle groups (e.g., squat) and one working on a specific muscle group (e.g., knee extension). Main exercises for leg muscles were clean (whole body), squat, hack squat, and dead lift, and main exercises for upper body muscles were bench press, bench pull, rowing, chins, shoulder press, and core exercises. In the first 4 weeks the athletes trained with a 3 × 8–12 repetition-maximum (RM) regimen, the next period with 4 × 6–12RM, and the last 4 weeks with 5 × 6–10RM. For the athletes who participated for less than 12 weeks, the program was adjusted with shorter periods. The rest period between sets was 1–3 min long. Once a week, athletes were supervised during training at the Olympic Sports Center to ensure correct training technique and adequate progress. A computerized exercise diary was recorded during the entire intervention period.

Experimental Assessments

All tests were conducted by the same test team before and after the intervention, and the test day was standardized. Athletes were not allowed to perform heavy training 48 hr before testing.

BW. BW was measured in a fasted state with a balance scale (Seca Model 708, Seca Ltd., Birmingham, UK) to the nearest 100 g on the test day in the morning between 8 and 9 a.m. During the intervention period, athletes used their own scales to monitor BW because their weekly meetings with the nutritionist were at different times during the day, and their weight would fluctuate depending on food and liquid intake. They were instructed to weigh themselves without clothes and with an empty bladder immediately after awaking and before breakfast.

Body Composition. Fat mass, percent body fat, and LBM were measured with dual-energy X-ray absorptiometry (DEXA; GE Medical Systems, Lunar Prodigy, WI) by a trained technician. The DEXA system was calibrated every day before testing, and the test was conducted with the participant in a fasted state between 8:30 and 10:00 a.m. For DEXA reproducibility, 10 athletes did two repeated measurements within 24 hr, and the coefficient of variation in the DEXA Lunar Prodigy total-body scan for repeated measurements was 3% for fat mass and 0.7% for LBM.

Performance. Performance was measured by 40-m sprint, countermovement jump (CMJ), and 1RM of bench press, bench pull, and squat. Before the sprint, CMJ, and 1RM strength tests, the athletes performed a standardized warm-up consisting of 15 min of low-intensity running or cycling. After the general warm-up they performed a more sprint-specific warm-up, followed by three maximal 40-m sprints, and the best result was used in the data analysis. CMJ was performed on an AMTI force platform (SG 9, Advanced Mechanical Technology Inc., Newton, MA), and the best jump of three was used in the data analysis. In the 1RM tests the weight was progressively increased until the athlete could not move it through the full range of motion on at least two attempts.

EDI-2. The EDI-2 is a self-report measure with 91 items, a 6-point forced-choice inventory assessing several behavioral and psychological traits common in anorexia nervosa and bulimia (Garner, 1991). The EDI-2 consists of the following 11 subscales: drive for thinness, bulimia, body dissatisfaction, ineffectiveness, perfectionism, interpersonal distrust, interceptive awareness, maturity fears, asceticism, impulse regulation, and social insecurity. The athletes filled out the EDI before and after testing to assess behavioral and psychological traits.

Statistical Analyses

Data are presented as *M* ± *SD* for pre- and post- measurements and *M* ± *SE* for changes within and between groups. The computer software programs Graphpad Prism 5.0 (CA, SA) and SPSS 15 (Chicago, IL) were used for statistical analysis. The pre- to post- changes within groups were analyzed with paired-samples two-tailed Student's *t* test or Wilcoxon's paired-rank test when appropriate. Between groups, independent two-tailed Student's *t* test and the Mann–Whitney test were used when appropriate. Pearson's *R* or Spearman's rho was performed when appropriate to study correlations between variables. Values of *p* below .05 were considered statistically significant.

Results

A history of dieting and weight cycling was reported by 53% of the athletes in SR and 45% of the athletes in FR. The mean lengths of time spent in intervention for SR and FR were 8.5 ± 2.2 and 5.3 ± 0.9 weeks, respectively. There were no significant differences between groups in any of the baseline measurements (Tables 1, 2 and 3).

Diet

Baseline energy intakes were 2,409 ± 622 and 2,514 ± 518 kcal/day for SR and FR, respectively. Energy intake was reduced more in FR (30% ± 4%) than in SR (19% ± 2%; *p* = .003; Table 2), with the aim of faster weight loss. Although intake of most of the macronutrients was significantly reduced, none of the variables differed between groups (Table 2).

Table 2 Energy and Nutrition Variables Presented as *M* ± *SD* for Diet Registration and Meal Plan and *M* ± *SE* for Change

	Slow-Rate Weight Loss (*n* = 13)			Fast-Rate Weight Loss (*n* = 11)		
	Diet registration	Meal plan	Change	Diet registration	Meal plan	Change
Energy intake (kcal)	2,409 ± 622	1,940 ± 482	–469 ± 61*	2,514 ± 518	1,723 ± 234	–791 ± 113*
Energy (kcal/LBM)	45.6 ± 9.6	36.5 ± 6.5	–9.1 ± 4.2*#	47.8 ± 11.3	33.0 ± 5.2	–15.0 ± 2.2*#
Protein (g/kg BW)	1.6 ± 0.4	1.6 ± 0.4	0.1 ± 0.1*	1.6 ± 0.5	1.4 ± 0.2	–0.2 ± 0.1
Protein (E%)	19.6 ± 6.3	25.2 ± 3.7	7.0 ± 1.3*	18.2 ± 2.9	24.2 ± 3.3	4,5 ± 1.6*
CHO (g/kg BW)	4.1 ± 0.9	3.6 ± 0.7	–0.5 ± 0.2*	4.1 ± 1.1	3.2 ± 0.6	–1.0 ± 0.2*
CHO (E%)	51.0 ± 6.5	54.0 ± 3.3	3.1 ± 1.6	49.3 ± 6.3	55.5 ± 4.4	6.2 ± 1.5*
Fat (E%)	30.0 ± 6.9	20.8 ± 1.1	–9.2 ± 2.1*	31.1 ± 4.0	20.6 ± 2.0	–10.5 ± 1.4*

Note. LBM = lean body mass; BW = body weight; CHO = carbohydrate; E% = percent of total energy intake.

*$p < .05$ significantly different from pre. #$p < .05$ significant difference between groups.

Table 3 Body Composition and Performance Variables Presented as *M* ± *SD* for Pre- and Post- and *M* ± *SE* for Change

	Slow-Rate Weight Loss (*n* = 13)			Fast-Rate Weight Loss (*n* = 11)		
	Pre-	Post-	Change	Pre-	Post-	Change
Body weight (kg)	71.9 ± 12.7	67.8 ± 11.4	–4.2 ± 0.6*	74.8 ± 11.7	70.6 ± 10.6	–4.2 ± 0.6*
Lean body mass (kg)	53.7 ± 11.3	54.7 ± 11.2	1.0 ± 0.2*	54.1 ± 12.1	53.8 ± 11.1	–0.3 ± 0.4#
Fat mass (kg)	15.5 ± 4.9	10.5 ± 3.6	–4.9 ± 0.7*	17.6 ± 6.9	14.4 ± 6.8	–3.2 ± 0.5#*
Countermovement jump (cm)	32.3 ± 6.4	34.3 ± 5.5	2.0 ± 0.7*	31.3 ± 7.6	31.6 ± 7.7	0.3 ± 0.8
40-m sprint (s)	5.76 ± 0.61	5.80 ± 0.65	0.04 ± 0.05	5.99 ± 0.49	5.99 ± 0.44	0.00 ± 0.04
1RM press (kg)	59.2 ± 21.2	66.7 ± 22.3	7.5 ± 0.5*	73.2 ± 33.3	75.5 ± 29.1	2.3 ± 1.7#
1RM pull (kg)	63.5 ± 16.5	69.2 ± 15.8	5.8 ± 1.5*	69.5 ± 19.8	71.4 ± 17.2	1.8 ± 1.7
1RM squat (kg)	97.5 ± 38.3	106.5 ± 34.7	9.0 ± 2.1*	90.0 ± 25.6	97.0 ± 23.9	7.0 ± 1.7*

Note. 1RM = one-repetition-maximum.

*$p < .05$ significantly different from pre. #$p < .05$ significant difference between groups.

Body Composition

BW was reduced by 5.6% ± 0.8% in SR ($p < .001$) and 5.5% ± 0.7% in FR ($p < .001$; Figure 1). The average weekly rates of weight loss for the SR and FR were 0.7% ± 0.4% and 1.0% ± 0.4%, respectively. In accordance with the aim of the study, the rate of weight loss in FR was significantly faster than in SR ($p = .02$). Fat mass decreased more in SR than in FR (31% ± 3% vs. 21% ± 0%, respectively, $p = .02$; Figure 1). Total LBM increased significantly in SR by 2.1% ± 0.4% ($p < .001$), whereas it was unchanged in FR (–0.2% ± 0.7%), with significant differences between groups ($p < .01$; Figure 1). The increase in total LBM in SR was mainly caused by a 3.1% ± 0.8% increase in upper body LBM. The weekly gains in LBM were 0.3% ± 0.0% and 0.0 ± 0.1% ($p = .02$) for SR and FR, respectively.

Body Composition and Gender

Women gained LBM during the intervention, whereas men did not (1.8% ± 0.4% vs. 0.0% ± 0.7%, respectively, $p < .01$). In men, LBM was gained during the intervention in SR (1.7% ± 0.4%, $p < .01$), whereas men in FR tended to reduce LBM (–2.0% ± 1.0%, $p = .1$), with a significant difference between groups ($p < .01$). There were no significant differences between women in SR and FR in any of the body-composition variables.

Performance

Performance in CMJ was improved by 7% ± 3% ($p < .01$) in SR, whereas no significant change was observed in FR (Figure 2). There was no change in 40-m-sprint performance in any of the groups. 1RM squat improved similarly by 11.9% ± 3.4% ($p < .01$) in SR and 8.9% ± 2.3% ($p < .01$) in FR (Figure 2). Bench-press performance increased more in SR than in FR (13.6% ± 1.1% vs. 6.4% ± 3.3%, respectively, $p = .01$; Figure 2). The performance in bench pull improved by 10.3% ± 3.0% ($p = .001$) in the SR and 4.0% ± 2.6% in the FR. Overall change in 1RM for the upper body exercises was higher in SR than in FR (11.4% ± 2.6% vs. 5.2% ± 2.4%, respectively, $p = .03$). The weekly gains in mean relative changes in all 1RM measurements were 1.4% ± 0.7% and 1.3% ± 0.5% for SR and FR, respectively. There were no significant correlations between changes in any of the performance variables, strength-training experience, weight-loss experience, or weekly weight-loss rate and changes in body composition.

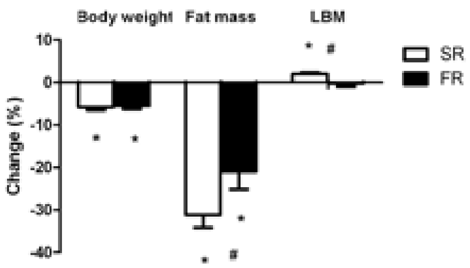

Figure 1 — Changes in body weight, fat mass, and lean body mass (LBM) in the slow-rate weight-loss group (SR) and the fast-rate weight-loss group (FR), *M* ± *SE*. *$p < .05$ significantly different from pre. #$p < .05$ significant difference between groups.

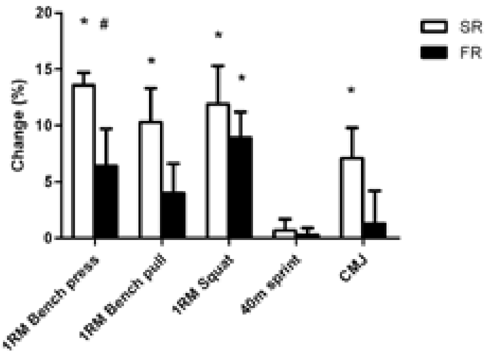

Figure 2 — Changes in one-repetition-maximum (1RM) bench press, bench pull, and squat; 40-m-sprint performance; and countermovement jump (CMJ) in the slow-rate weight-loss group (SR) and the fast-rate weight-loss group (FR), *M* ± *SE*. *$p < .05$ significantly different from pre. #$p < .05$ significant difference between groups.

Performance and Gender

The increase in 1RM squat was higher in women (16.2% ± 2.7%) than in men (4.7% ± 1.5%, $p = .002$). No other significant gender differences were observed for changes in performance tests.

EDI

There were no significant differences between groups at baseline in any of the EDI subscale scores, and there were no significant changes from pre- to posttest in either SR or FR (35.2% ± 16.5% to 26.2% ± 13.7% and 26.5% ± 11.5% to 27.6% ± 9.6%, respectively).

Compliers Versus Noncompliers

The defined weekly weight-loss goals for SR and FR were 0.7% and 1.4% of BW, respectively. All athletes are included in the current results according to the intention-to-treat principle. The mean weekly weight-loss rates and standard deviations were 0.7% ± 0.3% of

BW per week in SR and 1.0% ± 0.5% in FR. Three athletes in SR (cutoff values in weekly weight-loss rate: 0.5–0.9%) and 5 athletes in FR (cutoff values in weekly weight-loss rate: 1.0–1.6%) did not accomplish their weight-loss goals. When noncompliers were removed there were no significant changes in results, but differences between the SR and FR were generally more pronounced. No statistically significant differences in any of the variables were found between compliers and noncompliers.

Discussion

The aim of this study was to compare the effects of 5–6% BW loss at slow and fast rates on changes in body composition and strength- and power-related performance in elite athletes. We hypothesized that the faster weight loss would result in more detrimental effects on both LBM and performance. Surprisingly, LBM increased by 2.1% ± 0.4% in SR, accompanied with improved performance in CMJ and all the 1RM parameters, whereas there was no significant change in LBM or improvements in strength- and power-related performance, except 1RM squat, in FR. Total LBM increased more in SR than in FR, with weekly gains in LBM of 0.3% ± 0.0% and 0.0% ± 0.1% ($p = .02$) for SR and FR, respectively. Consequently, the slower weight-loss intervention had more positive effects on LBM and performance than the faster weight-loss intervention.

Diet

Compared with their high activity level the reported baseline energy intake was relatively low, and this may be a result of underreporting, undereating, or both, which is common in self-reported dietary intake (Magkos & Yannakoulia, 2003). We chose a 4-day weighed-food registration to minimize the burden, improve compliance, and avoid alteration of the subject's usual intake. The possible underreporting during the intervention was controlled for by weekly measurements of BW and sum of skinfolds. The calculated energy deficits for the SR and FR were 469 ± 61 and 845 ± 113 kcal/day, respectively. Because of daily training sessions, no meal plan was set below 1,500 kcal/day. The diet in both groups was a low-fat diet (~20% of total energy intake), and the mean carbohydrate intakes were 3.5 ± 0.7 g/kg (SR) and 3.2 ± 0.6 g/kg (FR), which is less than recommended (ACSM, 2009). The mean protein intakes were 1.6 ± 0.47 and 1.4 ± 0.27 g/kg in SR and FR, respectively, within the recommended protein intake for athletes (ACSM, 2009). Adequate protein intake was considered important to ensure sufficient amino acid supply to muscles and to enhance the anabolic response to strength training, in addition to thermogenic and satiety-inducing effects (ACSM, 2009; Karst, Steiniger, Noack, & Steglich, 1984). The meal plans were based on the dietary registrations and general guidelines for each nutrient, and the athletes took part in making the meal plans. This included choice of foods and drinks and timing of intake. We consider the individual planning crucial for compliance and motivation for the athletes.

Body Composition

LBM increased significantly in SR from pre- to postintervention and increased significantly more in SR than in FR. There were also highly significant differences for men between SR and FR in LBM, even though the sample size was somewhat low (6 vs. 5 athletes). There was no significant difference in weekly hours of strength training the season before entering the study between SR and FR or the men in SR and FR, which could have been a plausible explanation for different changes in LBM.

The first assumption for this difference in LBM changes is the fact that SR spent a significantly longer time in the intervention than FR. The mean amounts of time spent in intervention for SR and FR were 8.5 ± 2.2 and 5.3 ± 0.9 weeks, respectively ($p < .001$). Consequently, athletes in SR performed strength training for ~3 weeks longer than FR. This is likely the most important explanation for the differences in changes in LBM. However, although the athletes in SR had a longer period with energy deficit, they had a smaller restriction in energy intake, and this may also be a contributing factor to the larger increase in LBM. This is supported by the fact that the weekly gain in LBM was significantly higher in the SR group than in the FR group. Consequently, the rate of weight loss seems to be important in addition to the time spent in the intervention.

Note that increased upper body LBM was the major contributor to the increase in total LBM in the SR group. There may be several explanations for this finding, but it seems like upper body muscles generally respond better to strength-training stimuli than leg muscles (Wernbom, Augustsson, & Thomee, 2007). Furthermore, all athletes already had a heavy load on leg muscle in their sport-specific training, which may have reduced the training potential in these muscles. This is also supported by the performance results showing more gain in upper body strength in SR than FR. The increased LBM in SR and maintained LBM in FR during a 5–6% reduction in BW is a controversial result (Koutedakis et al., 1994; Smith et al., 2001; Umeda et al., 2004), because the subjects were normal-weight athletes with a history of high training volume, including strength training.

Studies on gradual weight loss in athletes are sparse, and the methodology is limited because of small sample sizes and different nutritional strategies and measurements of performance and body composition. However, it has been reported that loss of LBM accounts for 30–85% of total weight loss after reducing BW by 4–8% (Koutedakis et al., 1994; Slater, Rice, Jenkins, Gulbin, & Hahn, 2006; Umeda et al., 2004). Furthermore, a curvilinear relationship between initial body-fat content and the proportion of weight loss consisting of LBM is reported (Forbes, 2000). Consequently, weight loss in already lean people will normally compromise LBM even when exercise is incorporated in the weight-loss intervention (Forbes, 2000). Although some studies support this, especially studies that include endurance exercise as the intervention (Kraemer et al., 1999), other studies report a different weight-loss composition in favor of preserving LBM when heavy strength training is added (Kraemer et al., 1999; Stiegler & Cunliffe, 2006). Although the composition of the weight loss varies between studies, most studies report loss of LBM during energy restriction even in obese subjects (Forbes, 2000; Stiegler & Cunliffe, 2006).

In contrast to the suggested curvilinear relationship between initial body-fat content and the proportion of weight loss consisting of LBM, we found no correlations between initial fat mass and changes in LBM. The reason for this may be that the heavy strength training during the intervention stimulated muscle growth and thereby overrode the catabolic effect of negative energy balance on LBM. In a study by Umeda et al. (2004), 38 athletes participated in a 20-day intense training regimen (21 hr/week exercise, including 2 hr/week of strength training) combined with energy restriction. The athletes reduced their BW by 2.8 kg, and loss of fat-free mass contributed to 61% of the total weight loss. Although the intervention was of shorter duration, the weekly weight-loss rate corresponded to 1.2% of BW and thus is comparable with the result in the current study. These results suggest that a certain amount of heavy strength training is critical to preserve or increase LBM during energy restriction in elite athletes.

The relative increase in LBM was significantly greater in women than men. There were no significant differences in total training hours or weekly hours of strength training between men and women the season before entering the study. The fact that women had a higher baseline percent body fat may have contributed to a greater potential for LBM increase in women, as well as other factors such as type of previous strength training.

Strength- and Power-Related Performance

The results of the performance tests support the fact that the duration of the intervention was important for changes in strength- and power-related performance. Study results are equivocal when it comes to performance. Some studies report unchanged or improved performance in certain tests after weight loss in athletes, despite loss of LBM (Smith et al., 2001), whereas other studies report impaired performance (Degoutte at al., 2006; Koral & Dosseville, 2009; Umeda et al., 2004). It is a challenge to measure sport-specific performance and interpret the results, especially if athletes from more than one sport are included. We included athletes from several sports in this study for several reasons. Adequate sample size is one of the limiting factors when elite athletes are included in more challenging intervention studies. Furthermore, it was important for us to include all the athletes that requested weight-loss assistance. Because of the heterogeneous group of athletes in this study, we included more general tests of strength- and power-related performance. Nevertheless, the more general impact on physical capacity measured in this study provides important information on how function is affected by the interventions.

EDI

Because dieting has been considered a risk factor for development of eating disorders (Nattiv et al., 2007; Sundgot-Borgen, 1994), it was expected that the athletes might increase their scores on the drive-for-thinness test (the higher the score, the more symptomatic). Neither SR nor FR increased any of the subscale scores during the intervention period. The lack of increased scores in EDI subscales can probably be explained by the fact that none of the athletes had symptoms of eating disorders at baseline. Furthermore, these athletes were all closely guided during the weight-loss period. It has been stated that in terms of developing eating disorders, it is not necessarily dieting, per se, that triggers an eating disorder but whether or not the athlete is guided during the weight-loss period (Sundgot-Borgen, 1994).

Compliance

Three athletes in SR and 5 in FR did not accomplish their weight-loss goals. Although every athlete was closely followed to reach their final weight goal, we did not put pressure on them in favor of study compliance for ethical reasons. One might also consider whether the noncompliers actually were nonresponders to the intervention because of counterregulatory mechanisms (i.e., reduced metabolism or other mechanisms increasing food efficiency; Brownell, Steen, & Wilmore, 1987).

Experimental Design

To be able to do a controlled weight-loss intervention in elite athletes' off-season, we had to accept some limiting factors in the study design and therefore interpret the results with caution. Studies and practical experience indicated that weight loss in normal-weight athletes would compromise LBM and thereby performance. Because many of the athletes were to participate in major competitions a short time after the intervention, we had to include strength training during the intervention to prevent decline in performance. A cleaner approach would be to look at weight-loss rate with standardized habitual training with no additional stimuli for muscle growth. Different amounts of weight lost during the intervention may also be a limiting factor. A cleaner approach would be to standardize amount of weight loss for all athletes (e.g., 5% of BW), but for ethical and health reasons this was not feasible.

Conclusion

The initial aim of twofold difference in weight-loss rate was not achieved in all the athletes in FR, resulting in a weekly weight-loss rate corresponding to 1.0% of

BW rather than 1.4%. However, total LBM increased significantly more in SR, accompanied by significantly improved performance in CMJ and all the 1RM tests, whereas there was no significant increase in LBM or improvements in performance except in 1RM squat in FR. Separating weekly gains in LBM and improvements in strength- and power-related performance, there was a significant difference between groups in favor of SR. This leads to a general suggestion that athletes who want to gain LBM and increase strength- and power-related performance during a weight-loss period combined with strength training should aim for a weekly weight loss of 0.7% of BW, whereas athletes who only want to keep LBM might increase their weekly weight-loss rate to 1.0–1.4% of BW.

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References

American College of Sports Medicine. (2009). American College of Sports Medicine position stand: Nutrition and athletic performance. *Medicine and Science in Sports and Exercise, 41*(3), 709–731.

American Psychiatric Association. (1994). *Diagnostic and statistical manual of mental disorders: DSM-IV*. Washington, DC: American Psychiatric Association.

Brownell, K.D., Steen, S.N., & Wilmore, J.H. (1987). Weight regulation practices in athletes: Analysis of metabolic and health effects. *Medicine and Science in Sports and Exercise, 19*(6), 546–556.

Degoutte, F., Jouanel, P., Bègue, R.J., Colombier, M., Lac, G., Pequignot, J.M., & Filaire, E. (2006). Food restriction, performance, biochemical, psychological, and endocrine changes in judo athletes. *International Journal of Sports Medicine, 27*(1), 9–18.

Fogelholm, M. (1994). Effects of bodyweight reduction on sports performance. *Sports Medicine (Auckland, N.Z.), 18*(4), 249–267.

Forbes, G.B. (2000). Body fat content influences the body composition response to nutrition and exercise. *Annals of the New York Academy of Sciences, 904,* 359–365.

Garner, D.M. (1991). *Eating Disorders Inventory-2: Professional manual*. Odessa, FL: Psychological Assessment Resources.

Hall, C.J., & Lane, A.M. (2001). Effects of rapid weight loss on mood and performance among amateur boxers. *British Journal of Sports Medicine, 35,* 390–395.

Heyward, V.H., & Wagner, D.R. (2004). *Applied body composition assessment* (2nd ed.). Champaign, IL: Human Kinetics.

Karst, H., Steiniger, J., Noack, R., & Steglich, H.D. (1984). Diet-induced thermogenesis in man: Thermic effects of single proteins, carbohydrates and fats depending on their energy amount. *Annals of Nutrition & Metabolism, 28*(4), 245–252.

Koral, J., & Dosseville, F. (2009). Combination of gradual and rapid weight loss: Effects on physical performance and psychological state of elite judo athletes. *Journal of Sports Sciences, 27*(2), 115–120.

Koutedakis, Y., Pacy, P.J., Quevedo, R.M., Millward, D.J., Hesp, R., Boreham, C., & Sharp, N.C. (1994). The effect of two different periods of weight-reduction on selected performance parameters in elite lightweight oarswomen. *International Journal of Sports Medicine, 15*(8), 472–477.

Kraemer, W.J., Volek, J.S., Clark, K.L., Gordon, S.E., Puhl, S.M., Koziris, L.P., . . . Sebastianelli, W.J. (1999). Influence of exercise training on physiological and performance changes with weight loss in men. *Medicine and Science in Sports and Exercise, 31*(9), 1320–1329.

Magkos, F., & Yannakoulia, M. (2003). Methodology of dietary assessment in athletes: Concepts and pitfalls. *Current Opinion in Clinical Nutrition and Metabolic Care, 6*(5), 539–549 Review.

Nattiv, A., Loucks, A.B., Manore, M.M., Sanborn, C.F., Sundgot-Borgen, J., & Warren, M.P., & American College of Sports Medicine. (2007). American College of Sports Medicine position stand. The female athlete triad. *Medicine and Science in Sports and Exercise, 39*(10), 1867–1882.

Rankin, J.W. (2002). Weight loss and gain in athletes. *Current Sports Medicine Reports, 4,* 208–213.

Slater, G.J., Rice, A.J., Jenkins, D., Gulbin, J., & Hahn, A.G. (2006). Preparation of former heavyweight oarsmen to compete as lightweight rowers over 16 weeks: Three case studies. *International Journal of Sport Nutrition and Exercise Metabolism, 16*(1), 108–121.

Smith, M., Dyson, R., Hale, T., Hamilton, M., Kelly, J., & Wellington, P. (2001). The effect of restricted energy and fluid intake on simulated amateur boxing performance. *International Journal of Sport Nutrition and Exercise Metabolism, 11,* 238–247.

Stiegler, P., & Cunliffe, A. (2006). The role of diet and exercise for the maintenance of fat-free mass and resting metabolic rate during weight loss. *Sports Medicine (Auckland, N.Z.), 36*(3), 239–262.

Sundgot-Borgen, J. (1994). Risk and trigger factors for the development of eating disorders in female elite athletes. *Medicine and Science in Sports and Exercise, 26,* 414–419.

Umeda, T., Nakaji, S., Shimoyama, T.A., Yamamoto, Y., & Sugawara, K. (2004). Adverse effects of energy restriction on changes in immunoglobulins and complements during weight reduction in judoists. *Journal of Sports Medicine and Physical Fitness, 44*(3), 328–334.

Wernbom, M., Augustsson, J., & Thomee, R. (2007). The influence of frequency, intensity, volume and mode of strength training on whole muscle cross-sectional area in humans. *Sports Medicine, 37*(3), 225–264.

Paper II

Long-term effect of weight loss on body composition and performance in elite athletes

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Running title: Weight loss in elite athletes

Abstract

When needed, athletes are recommended to have a gradual weight loss (WL) of 0.5-1 kg·week^{-1} through moderate energy restriction. However, the effect of WL rate on long-term changes in body composition (BC) and performance has not been investigated in elite athletes. PURPOSE: To compare changes in body mass (BM), fat mass (FM), lean body mass (LBM) and performance 6 and 12 months after two different WL interventions promoting loss of 0.7% versus 1.4% of body weight·week^{-1} in elite athletes. METHODS: Twenty-three athletes completed 6 and 12 months post-intervention (slow rate (SR), n=14, 23.5±3.3 yrs, 72.2±12.2 kg and fast rate (FR), n=9, 21.4±4.0 y, 71.6±12.0kg). The athletes had individualized diet plans promoting the predetermined weekly WL during intervention and four strength-training sessions·week^{-1} were included. BM, BC and strength (1RM) were tested baseline, post-intervention and 6 and 12 months after intervention. RESULTS: BM decreased by ~ 6% in both groups during intervention, but were not different from baseline values after 12 months. FM decreased in SR and FR during intervention by 31±3 vs. 23±4% respectively, but were not different from baseline after 12 months. LBM and upper-body strength increased more in SR than in FR (2.0±1.3% vs. 0.8±1.1% and 12±2 vs. 6±2%) during intervention but after 12 months there were no significant differences between groups in BC or performance. CONCLUSION: There were no significant differences between groups after 12 months, suggesting that WL rate is not the most important factor for maintenance of BC and performance after WL intervention in elite athletes.

Keywords: Energy restriction, resistance training, hypertrophy, energy intake

INTRODUCTION

Paragraph 1

Weight loss in elite athletes is generally motivated by a desire to optimize performance by improving power to weight ratio, making weight in order to compete in a certain weight category or due to aesthetic reasons in sports that emphasize leanness. Due to the negative effects of rapid weight loss (e.g., dehydration, fasting) and longer periods of restricted energy intake (Degoutte, Jouanel, Bègue, Colombier, Lac, Pequignot & Filaire. 2006; Fogelholm 1994; Hall & Lane 2001; Koral & Dosseville 2009; Nattiv, Loucks, Manore, Sanborn, Sundgot-Borgen and Warren 2007; Umeda, Nakaji, Shimoyama, Kojima, Yamamoto & Sugawara 2004; Webster, Ruth & Weltman 1990), the extant literature recommends a gradual weight loss through moderate energy restriction promoting a weekly weight loss of 0.5-1 kg (O'Connor & Caterson 2010; Walberg-Rankin 2002). Whereas weight variations during the season are normal for most athletes, weight-cycling and intentional weight loss are considered negative for both performance and body composition, as well as long-term health (Saarni, Rissanen, Sarna, Koskenvuo & Kaprio 2006). Thus, athletes are recommended to reduce weight off-season and to keep close to competition weight during the season (O'Connor & Caterson 2010). However, practical experience indicates that some athletes have to use great effort to maintain a low body mass (BM) during season, and therefore practice repeated weight-loss periods prior to competition. To our knowledge there are no studies on the long-term effect of different weight-loss interventions in athletes, but studies in overweight subjects show that only 20% are able to maintain the changes in body composition after one year (Wing & Phelan 2005).

Paragraph 2

The aim of this study was to compare the long-term effect of two weight-loss regimes recommended in the literature (Walberg-Rankin 2002; O'Connor & Caterson 2010). Thus, we compared the changes in body composition and performance 6 and 12 months after intervention after a weekly BM loss of 0.7% vs. 1.4 %, which corresponded to a weekly BM loss of 0.5 vs. 1.0 in a 70 kg athlete. We hypothesized that athletes in the slower weight-loss regimen would maintain their body composition and physical predictors of performance to a greater extent than athletes in the faster weight-loss regimen.

METHODS

Participants

Paragraph 3

Thirty-six elite athletes, age 18-35 yrs, were recruited: 30 completed the intervention and 23 athletes completed the 6 and 12 month post-intervention tests. The given reasons for drop outs were as follows: The project was too time-consuming (n=2), strength training program interfered with sports specific training techniques (n=1), injury (n=5), unable to meet for testing due to travelling/training out of country (n=3) and retiring from sport (n=1). In addition, one athlete was removed from the study during the intervention because there were early signs of disordered eating (DE) behaviour. The athlete was taken care of by the eating disorder team in the project. The athletes were recruited by invitation from the Norwegian Olympic Sport Centre when they contacted the centre to get assistance with weight loss, or by invitation letters to sport federations. The following sports were represented in the study: football, volleyball, cross country skiing, judo, jujutsu, tae kwondo, waterskiing, motocross, cycling, track and field, kickboxing, gymnastics, alpine skiing, ski jumping, rifle shooting, freestyle, skating, biathlon and ice hockey. In slow reduction (SR) there were 43% males (n=6) and 57% females (n=8), while in fast reduction (FR) there were 33% males (n=3) and 67% females (n=6). The physical and anthropometrical characteristics of the athletes are shown in Table 1.

Paragraph 4

The athletes were fully informed about the purpose of the study and the experimental procedures before written consent was obtained. The study was conducted according to the Declaration of Helsinki and approved by the Data Inspectorate and the Regional Ethics Committee of Southern Norway. Permission to conduct the study was provided by the Norwegian Olympic Committee and the Norwegian Confederation of Sports.

Experimental Design

Paragraph 5

The athletes were screened and block randomized to the SR and FR groups when they contacted the Olympic Sports Centre. All athletes followed a 4-12 week weight-loss intervention with a combination of energy restriction and strength training. The length of the intervention was determined by the rate of weight loss (SR or FR) and the desired weight loss (minimum 4% of BW) for each athlete. The final weight goal was set by the team (nutritionist and exercise physiologist) based on results from the body composition measurements that provided the information needed for calculating minimum fat percentage for each athlete and the athlete’s desired weight loss. For example, a 70 kg athlete set to reduce BM by 5 kg would have either a 5 (1.4% week^{-1}, FR) or 10 (0.7% week^{-1}, SR) week intervention depending on which intervention group the athlete was randomly allocated to. The athletes received nutritional counselling once a week during intervention. The counselling included basic nutrition, sports physiology and possible adjustments in the dietary plan or weight regimen, depending on progress. After intervention, the athletes received one nutrition counseling within 4 weeks and exercise counseling in order to stabilize the new BM and body composition. The athletes were called in 6 and 12 months after intervention to investigate the long-term effect of the different interventions on body composition and performance.

Pre participation screening

Paragraph 6

The screening included the Eating Disorder Inventory (EDI-2) (Garner 1991; Cooper & Fairburn 1987), followed by an interview and medical examination according to the standard for pre-season health evaluation at the Norwegian Olympic Sports Centre. The exclusion criteria were as follows: 1) Diseases and conditions known to affect metabolic functions in muscle, 2) use of pharmaceuticals that might affect any of the measurements, 3) presence of one or more of the triad components; DE/eating disorder (ED), menstrual dysfunction and/or low bone mineral density (BMD), 4) clinically evident peri-menopausal condition, 5) pregnancy, and 6) fat mass (FM) corresponding to a predicted post-intervention body fat value of less than 5% for males and 12% for females (Heyward & Wagner 2004; Fogelholm 1994). For possible diagnoses, DSM-IV criteria were used for anorexia nervosa (AN), bulimia nervosa (BN) and eating disorders not otherwise specified (EDNOS) (APA 1994).

Diet

Paragraph 7

A 4-day diet record was obtained before intervention and 24-hour recall 6 and 12 months after intervention, all of which were analyzed by a national food data base "Mat På Data" (version 5.0. LKH, Mattilsynet, Norway). The record served as a basis for the development of each athlete's individualized diet plan promoting weekly BW loss of 0.7% or 1.4%. The athletes were weight stable during the 4 days they recorded their diets. In the diet plans, the aim was to have a daily protein intake corresponding to 1.2-1.8 $g \cdot kg^{-1}$, a daily carbohydrate intake corresponding to 4-6 $g \cdot kg^{-1}$ and ≥20% fat, with low energy/high nutrient density foods that provided satiety as well as food variety. All diet plans included 5-7 daily meals and snacks, and no meal plan was below 1500 $kcal \cdot day^{-1}$ (four athletes followed a diet plan at exactly 1500 $kcal \cdot day^{-1}$). All athletes ingested a milk-protein based recovery meal containing carbohydrates (20-40g) and protein (6-20g) within 30 minutes of each training session and a balanced meal within 1-2 hours in an attempt to optimize recovery. During implementation of the dietary plan, the athletes used a food scale to ensure correct portion sizes during the 2-3 first weeks. After the 3rd week, the athletes were encouraged to use a food scale if they were uncertain about portion sizes. If the athletes were unable to follow the dietary plan during the week, they were instructed to write down any deviations from the plan.

Paragraph 8

Supplementation

The athletes were not allowed to use creatine supplementation during the last 6 weeks prior to intervention and they did not take any supplements other than those given by the nutritionist during intervention. A multi-vitamin-mineral supplement (Nycomed, Asker, Norway) and a cod liver oil supplement (Møller's tran, Oslo, Norway) were prescribed to assure sufficient micronutrient intake and essential fat intake during intervention. Furthermore, if blood samples indicated any other specific micronutrient needs (e.g., iron, Vitamin B12), these vitamins were provided to the athletes and blood levels were thereafter monitored.

Training

Paragraph 9

The intervention period started off-season for all athletes in order to be able to add additional training to their schedule and for practical reasons (e.g., travelling and competitions). All athletes continued their sport-specific training schedule (14.6±3.5 $h \cdot week^{-1}$, presented as a mean of the training during the previous year). They included four strength training $sessions \cdot week^{-1}$ to emphasize muscle strength and hypertrophy. The strength training program was a 2-split periodized program. Each muscle group was exercised twice a week with two exercises in each session, one main exercise for multiple muscle groups (e.g. squat) and one working more isolated on a specific muscle group (e.g. knee extension). Main exercises for leg muscles were clean (whole body), squat, hack squat and dead lift, and main exercises for upper body muscles were bench press, bench pull (horizontal rowing), rowing, chins, shoulder press and core exercises. In the first four weeks the athletes trained a 3x8-12 repetition maximum (RM) regimen, the next period with 4x6-12RM and the last four weeks with 5x6-10RM. For the athletes who participated less than 12 weeks, the program was adjusted with shorter periods. The rest period between sets was from 1-3 minutes.

Once a week, athletes were supervised during training at the Olympic Sports Centre to ensure correct training technique and adequate progress.

Experimental assessments

Paragraph 10

All tests were conducted by the same test team and the test-day was standardized. Athletes were not allowed to perform heavy training for 48 hours prior to testing.

Body Mass

Paragraph 11

BM was measured in the fasted state with a calibrated scale (Seca mod. 708, Seca Ltd., Birmingham, UK) to the nearest 100 g on the test-day in the morning between 0800-0900. During the intervention period, athletes used their own scales to monitor BW since their weekly meetings with the nutritionist were at different times during the day and the weight would fluctuate depending on food and liquid intake. They were instructed to weigh themselves without clothes and with an empty bladder immediately after waking-up and before breakfast..

Body composition

Paragraph 12

FM and LBM were measured with dual energy x-ray absorptiometry (DEXA) (GE Medical Systems, Lunar Prodigy, Wisconsin, USA) by a trained technician. The DEXA system was calibrated every day before testing and the test was conducted in a fasted state between 0830-1000. For DEXA reproducibility, ten athletes did two repeated measurements within 24 hours, and the coefficient of variation in DEXA Lunar Prodigy total body scan for repeated measurements was 3% for FM and 0.7% for LBM. The athletes wore minimal clothing during DEXA scan (underwear and sports top for females).

Indicators of Performance

Paragraph 13

Performance was measured by 40 m sprint, counter movement jump (CMJ) and 1RM in bench press, bench pull and squat. Prior to the sprint, CMJ and 1RM strength tests, the athletes performed a standardised warm-up consisting of 15 min low intensity running or cycling. After the general warm-up the athletes performed a more sprint specific warm-up, followed by three maximal 40m sprints and the best result was used in the data analysis. CMJ was performed on an AMTI force-platform (SG 9, Advanced Mechanical Technology Inc., Newton, MA, USA), and the best jump out of three was used in the data analysis. For 1RM the weight was progressively increased until the athlete could not move the weight through the full range of motion on at least two attempts.

Eating disorder inventory (EDI)

Paragraph 14

The Eating Disorder Inventory (EDI-2) is a self-report measure with 91-items, 6-point forced-choice inventory assessing several behavioural and psychological patterns common in anorexia nervosa and bulimia nervosa (Garner 1991). The EDI-2 consists of the following 11 subscale scores: drive for thinness (DT), bulimia, body dissatisfaction (BD), ineffectiveness, perfectionism, interpersonal distrust, interceptive awareness, maturity fears, asceticism, impulse regulation, and social insecurity. The EDI is frequently used in both clinical and non-clinical populations to predict risk for development of ED. Hence, the athletes filled out the EDI before and after intervention and 6 and 12 months after intervention to assess behaviours and psychological attributes associated with ED.

Paragraph 15

Statistical analysis

With an expected net difference in change of fat mass of 6 % from baseline to post-intervention test 1, the minimum sample size for two equally sized groups had to be 29, assuming a SD of fat mass change equal to 7 % and a significance level of 5 %. n=2 (1.96 + 1.28)2 x (7/6)2 , n= 29. However, we managed to include only 36 athletes, due to the fact that the athletic population at this level are limited. Although we got significant differences from baseline to post-intervention test 1 (Garthe, Raastad, Refsnes, Koivisto & Sundgot-Borgen 2011), drop outs and multiple t-test (corrected with the Bonferroni *post hoc* test) made the sample sizes too small for some of the 6 and 12 months follow-up tests.

Data are presented as mean±SD for baseline and post-intervention measurements and mean±SE for changes within and between groups. The computer software Graphpad Prism 5.0 (CA, SA) and SPSS 15 (IBM, USA) were used for statistical analyses. Changes from baseline, post-intervention and 6 and 12 month follow-up were analyzed with repeated-measures ANOVAs within groups and two-way repeated-measures ANOVAs between groups. Significant interactions were corrected with the Bonferroni *post hoc* test. P values below 0.05 were considered statistically significant.

RESULTS

Paragraph 16

A history of dieting and weight-cycling was reported by 57% of the athletes in SR and 67% of the athletes in FR. The mean time spent in the intervention for SR and FR was 8.7±2.3 and 5.9±1.1 weeks, respectively. There were no significant differences between groups in any of the baseline measurements (Table 1 and 2).

Diet

Paragraph 17

Energy intake was reduced by 31±5% in FR and 19±5% in SR (Table 2) during the intervention. Although intake of most of the macronutrients was significantly reduced from baseline to post-intervention test, none of the variables differed between groups (Table 2). Maintenance diet plans were reportedly followed for 6 months by athletes from both groups (2 and 5 athletes from SR and FR, respectively). Other athletes (8 and 4, respectively) reported partially following a diet plan. Four athletes in SR and none in FR reported following no diet plan. At 12 months, 2 and 4 athletes from SR and FR respectively, reported to have followed a maintenance diet plan the last six months, 7 and 4 reported to partly follow and 5 and 1 reported not to follow any diet plan for SR and FR respectively.

Body composition

Paragraph 18

BM was reduced by 5.8±0.7% in SR ($p<0.001$) and 5.7±0.9% in FR ($p<0.001$) during intervention (Figure 1). The average weekly rate of weight loss for the SR and FR was 0.7±0.4 % and 1.0±0.4%, respectively. In accordance with the aim of the study, the rate of weight loss in FR was significantly faster than in SR (p=0.02). Six months after the intervention, SR had regained 77% of the BM, whereas FR had regained 14% from post-intervention test (p<0.05). Twelve months after the intervention, both groups had regained their original weight (Figure 1). Whereas FM tended to decrease more in SR than in FR during intervention (31±3 vs. 23±3%, respectively (p=0.06), SR regained 90% of the FM after 6 months and was significantly higher than FR (p<0.05) (Figure 2). Twelve months after the intervention, both groups had regained their original FM. Total LBM increased by 2.0±0.4% in SR (p<0.001) during intervention, but had returned to baseline after 6 and 12 months. LBM did not change significantly in FR during intervention (0.8±1.1%) or after 6 (1.3±0.8%) or 12 months (0.3±0.8%) (Figure 3). There was no significant difference in total LBM between groups at any time.

Performance

Paragraph 19

Because of small sample sizes due to injuries, the analysis of jumping performance (CMJ) (n=8) and 40m sprint (n=5) were excluded. There were no statistically significant changes in performance in any of the variables in FR at any time. 1RM squat tended to improve by 15.6±7.5% (p=0.07) in SR but was back to baseline 6 and 12 months after intervention (Figure 4c). Bench press performance increased by 17.0±2.6% (p<0.01) in SR during intervention and was still higher than baseline 12 months after intervention (17.7±6.0%, p=0.01) (Figure 4b). There was no significant change in bench pull performance and there were no significant differences between groups at any time point (Figure 4a).

Training

Paragraph 20

The athletes reported 7.5±0.2 hours·week^{-1} of strength training during intervention. Athletes in SR reported training 15.0±6.0 hours·week^{-1} after 6 months of which 4.7±2.3 were strength training. FR reported training 14.9±3.1 hours·week^{-1} after 6 months of which 3.9±1.6 hours were strength training. After 12 months, SR reported training 11.9±5.2 hours·week^{-1} of which 3.0±1.7 hours were strength training and FR reported training 13.3±5.1 hours·week^{-1} of which 3.8±2.0 hours were strength training.

Gender

Gender specific analyses for SR and FR were not done due to the small sample size. However, when SR and FR were merged, females tended to gain LBM (2.0±1.8, p=0.06), whereas males LBM was unchanged during intervention (-2.0±1.0) with a significant difference between gender (p=0.03). Further, females had significant improvements in all 1RM parameters, whereas performance parameters were unchanged for males during intervention. No other significant gender differences were observed for changes in performance tests, body composition or subjective feedback during the weekly consultations.

Eating disorder inventory

Paragraph 21

Due to the fact that only three athletes in FR answered all the questions and thereby met the criteria for being evaluated on the EDI, a comparison between FR and SR from baseline to 12 months post-intervention test was not performed. There were no significant differences in Total EDI score for SR at any time point.

DISCUSSION

Paragraph 22

The aim of this study was to compare the long-term effect of 5-6% BM loss with a slow or fast rate on changes in body composition and indicators of physical performance in elite athletes. We hypothesized that the faster weight loss would result in a faster regain of BM and FM 6 and 12 months after intervention. We actually found that the slow intervention resulted in a regain of BM and FM faster than the fast intervention after 6 months, but there were no significant differences between groups after 12 months. We also hypothesized that the slower weight gain would maintain performance to a greater extent after 6 and 12 months. We found that the slower intervention tended to maintain 1RM strength better than the faster intervention after 6 and 12 months, but there were no significant differences between groups at any time point.

Diet

Paragraph 23

We chose a 4-day weighed food record before intervention as a base for the meal plan. We chose a 4-day record (3 weekdays + 1 weekend day) to minimize the burden, to increase compliance and to decrease alteration of the subject's usual intake. Compared to their high activity level the reported energy intake was relatively low and this may be due to underreporting, under-eating, or both, which is a common error of measurement in self reported dietary intake (Magkos & Yannakoulia 2003). Thus, the effect of the meal plan was controlled by weekly measurements of BM and skin fold thickness during intervention. We chose 24-hour recall at the follow-up 6 and 12 months after intervention in order to minimize the burden and to increase compliance. However, these data are not presented in this article due to the fact that it was clearly a result of underreporting and could not be compared with baseline data. Allthough 17 athletes reported that they followed or partly followed meal plans with energy intakes close to meal plan, they had regained their initial BM Despite the fact that there may be adverse effects in BM regulatory hormones as well as decreased resting energy expenditure from a lower BM (Vogels, Diepvens & Westerterp-Plantenga 2005; King et al. 2007), we find it unlikely that 13 of the athletes have a energy intake below 1500 kcal·day^{-1} after 6 months with no changes in training hours. This strongly implies that this data has a low level of confidence and we chose not to present them. The calculated energy deficit during intervention for the SR and FR was 408±84 and 533±179 kcal·day^{-1} respectively. Due to the fact that the athletes performed daily training sessions during intervention, no meal plan was set below 1500 kcal·day^{-1}.

This practice resulted in a slightly different intervention for three of the athletes (1 from SR, 2 from FR). Due to their low baseline energy intake, they had to increase energy expenditure to be able to reach their weekly weight-loss goal. This necessity also may be one reason why there were no significant differences between energy intakes between the two interventions.

Paragraph 24

There were no significant differences between groups in intake of any of the macronutrients at any time (Table 2). Adequate carbohydrate and protein intakes are considered to be among the most important nutritional factors for athletes (Rodriguez, DiMarco & Langley 2009). Thus, the diet during intervention in this study was a low-fat, moderate protein (~20 E%) diet. The mean carbohydrate intake was 3.5±0.7 g·kg^{-1} (SR) and 3.2±0.6 g·kg^{-1}(FR), which is less than recommended (Rodriquez et al. 2009). The mean protein intake was 1.6±0.47 g·kg^{-1} and 1.4±0.27 g·kg^{-1} in SR and FR, respectively, and was within the recommended protein intake for athletes (Rodriquez et al. 2009; Tipton & Wolfe 2004). Adequate protein intake during intervention was considered important to ensure sufficient amino acid supply to muscles and to enhance the anabolic response to strength training, in addition to thermogenic and satiety inducing effects (Karst, Steiniger, Noack & Steglich 1984; Tipton & Wolfe 2004). The meal plans were based on the dietary registrations and general guidelines for each nutrient and the athletes were taking part in making the meal plans.

Body composition and strength performance

Paragraph 25

Both BM and FM showed similar patterns, with significantly reduced values from baseline to post intervention. BM and FM were maintained to a greater extent in FR after 6 months compared to SR. This difference was supported by a tendency towards a more restrictive energy intake in FR (Table 2). One possible explanation for this may be that there were more weight-class athletes in FR than SR (21% vs. 44%). These athletes have an extra motivation for weight maintenance, because they have weigh-ins prior to competitive events as opposed to other athletes who are changing BM and composition for aesthetic or performance-related reasons. Thus, frequent competitions during the 6 months after intervention might be the main reason for keeping a stable weight and body composition for these athletes. In addition, there were 5 drop-outs in FR after intervention (Figure 1), as opposed to none in SR. This may also have influenced the reported weight gain after 6 and 12 months for FR. The given reasons for drop outs were mainly injuries and travelling. However, we do not know if they regained BM quickly after intervention or if increased BM was one of the factors for dropping out.

After 12 months, all parameters were back to baseline values, suggesting that maintenance of new BM and composition was difficult. Maintenance of BM and composition seem to be a multi-factorial issue, including mechanisms that regulate an individual's energy expenditure, body composition, and eating behavior (Vogels et al. 2005). Although athletes in this study maintained or increased LBM during the weight loss period, there may be adverse effects in BM regulatory hormones as well as decreased resting energy expenditure from a lower BM (Leibel et al. 1995). Unfortunately we did not measure resting energy expenditure in all the athletes in this study.

Paragraph 26

For the sedentary overweight population, specific approaches associated with long-term weight loss have been identified (Wing & Phelan 2005). High levels of physical activity (1 hour·day^{-1}), consumption of a low-calorie, low-fat diet, regular breakfast consumption, self-monitoring of weight, and maintenance of a consistent eating pattern across weekdays and weekends seem to be important factors (Wing & Phelan 2005). For elite athletes there may be different approaches due to high training loads, travelling and busy schedules. Most of the athletes reported maintenance of food choices, recovery meals and meal frequency after the intervention. They also reported that they thought they had a higher total energy intake than in the intervention and that they did not monitor BM regularly. Thus, many slowly slipped back to the initial BM. The most commonly reported reasons for not being able to maintain changes in BM and body composition were lack of follow-up and periods of injuries or travelling. It also became apparent that most of the athletes considered that to "voluntarily" keep such a strict diet with a heavy training load was a mental challenge.

Paragraph 27

There were no significant changes in LBM or performance at any time in FR. LBM increased significantly in SR from baseline to post intervention, but was back to baseline after 6 and 12 months. Interestingly, increased LBM in upper body was the major contributor to the increase in total LBM in the SR group during intervention likely contributing to the performance results showing a superior gain in upper body strength in SR compared to FR. Whereas LBM returned to baseline after 6 and 12 months, upper-body strength was maintained in SR, suggesting a complex relationship between training status, LBM and maximal strength. It is a challenge to measure sport-specific performance and interpret the results, especially if athletes from more than one sport are included. We included athletes from several sports in this study due to several reasons. Adequate sample size is one of the limiting factors when elite athletes are included in more challenging intervention studies. Further, it was important for us to include all the athletes who request weight-loss assistance. Because of the heterogeneous group of athletes in this study, we therefore included more general tests of strength and power related performance. Nevertheless, the more general impact on physical capacity measured in this study, gives important information on how function is affected by the interventions.

Paragraph 28

While reporting close to 8 hours·week^{-1} of strength training during the intervention, athletes from SR and FR decreased their time spent in strength training to baseline values after 6 and 12 months (4.7±2.3 vs. 3.9±1.6 and 3.0±1.7 vs. 3.9±2.0 hours·week^{-1}, respectively). Since strength training was a major contributor to the maintenance and gains in LBM during the intervention (Garthe et al. 2011), the reduced stimuli for muscle growth after 6 and 12 months is likely to be the most important factor for the decline in LBM. Since time spent in intervention was ~3 weeks longer for SR, they had a significant greater effect of strength training than FR. Thus, they also had a trend for greater decrease after intervention.

Gender

The relative increase in LBM was significantly greater in females than males. There were no significant differences in total training hours or weekly hours of strength training between males and females the season before entering the study. The fact that females had a higher baseline fat percentage, may have contributed to a greater potential for LBM increase in females as well as other factors such at type of previous strength training.

Eating disorder inventory

Paragraph 29

It is difficult to explain the fact that only a few athletes in FR fulfilled the criteria for being evaluated on the EDI. The EDI questionnaire was voluntary, and it may take close to 45 minutes for some athletes to complete. Although all athletes completed from baseline to post-intervention test and accepted the questionnaire at post-intervention test 6 and 12 months, they may have paid less attention while answering or avoided some of the difficult questions. However, since there were no significant differences in Total EDI score for SR at any time point and the fact that there were no significant differences in Total EDI score for SR from pre to post (Garthe et al. 2011), we speculate that Total EDI score for FR after 6 and 12 months were unchanged.

CONCLUSION

Paragraph 30

Athletes in FR maintained body composition to a greater extent than the SR during the first 6 months and SR tended to maintain 1RM performance to a greater extent than the fast intervention. Distribution of athletes from different sports may have had the greatest influence on these differences. There were no significant difference between the slow and the fast intervention groups after 12 months, suggesting that several factors other than weight-loss rate contribute to maintenance of body composition and performance after weight loss. Long term follow-up after intervention may be more important for an elite athlete in order to maintain changes over time in a busy schedule with competitions, travelling and periods of injuries. The authors would like to emphasize the fact that both "fast" and "slow" interventions were within the recommended weekly weight loss. Further, the "fast" intervention in this study supported a gradual weight loss over several weeks, and consequently can be classified as a slow weight-loss regimen compared to other non healthy regimes practiced by some athletes (e.g., dehydration, fasting, vomiting and use of laxatives).

Practical implications

In practical terms, we recommend that athletes who want to lose 5-6% of BM should combine moderate energy restriction with strength training to achieve gains in LBM and improvements in strength. Both interventions in the present study were within the recommended range of weekly weight loss. There are different weigh-loss methods used for different athletes, as losing weight for weigh-in or losing weight for long-distance running acquire different strategies. Fast weight loss defined as dehydration, fasting, vomiting and use of laxatives should be avoided due to negative effects of health and performance (Nattiv et al. 2007; Degoutte et al. 2006; Hall & Lane 2001; Webster et al. 1990). Before any weight-loss intervention is started, there should be a thorough screening including weight history and weight goal, menstrual history for females, an estimate of body composition and energy status, and questions regarding motivation, dietary habits, thoughts and feelings about body image, BM and food. We also recommend that the weight-loss period is done off-season and that the athlete's health and performance is monitored by health-care professionals during the period. Change in body composition should be monitored on a regular basis together with follow-up from health care professionals after the weight-loss goal has been reached to detect any weight fluctuations and to prevent regain during season. Normal-weight athletes under the age of 18 or an athlete with a previous history of eating disorder should be discouraged to start a weight-loss intervention. Future research in this area should focus on revealing mental and motivational factors in elite athletes during and after weight-loss intervention.

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References

APA. (1994). Diagnostic and statistical manual of mental disorders: DSM-IV. 4th ed. Washington, D.C.: American Psychiatric Association, xi-933.

Cooper, Z., Fairburn, C. (1987). The Eating Disorder Examination: A Semi-structured Interview for the Assessment of the Specific Psychopathology of Eating Disorders. *Int J Eating Dis.* 6:1-8.

Degoutte, F., Jouanel, P., Bègue, R.J., Colombier, M., Lac, G., Pequignot, J.M., Filaire, E. (2006) Food restriction, performance, biochemical, psychological, and endocrine changes in judo athletes. *Int J Sports Med*. Jan;27(1):9-18.

Fogelholm, M. (1994). Effects of bodyweight reduction on sports performance. *Sports Med.* 18(4):249-267.

Garner, D. M.(1991). *Eating Disorders Inventory-2: Professional Manual*. Psychological Assessment Resources Inc: Odessa, FL. p. iv-70

Garthe, I., Raastad, T., Refsnes, P.E., Koivisto, A., Sundgot-Borgen, J. (2011). Effect of two different weight-loss rates on body composition and strength and power related performance in elite athletes. *Int J Sports Nutr Exerc Metab*. April:97-104.

Hall, C.J., Lane, A.M. (2001). Effects of rapid weight loss on mood and performance among amateur boxers. *Br J Sports Med*. 35:390-395.

Heyward, V.H., Wagner, D.R. (2004). Applied Body Composition Assessment. 2nd edition. Human Kinetics, Champaign IL, USA: 159-172

Karst, H., Steiniger, J., Noack, R., Steglich, H.D. (1984). Diet-induced thermogenesis in man: thermic effects of single proteins, carbohydrates and fats depending on their energy amount. Ann Nutr Metab. 28(4):245-52.

Koral, J., Dosseville F. (2009). Combination of gradual and rapid weight loss: effects on physical performance and psychological state of elite judo athletes. *J Sports Sci.* Jan 15;27(2):115-20.

Magkos, F., Yannakoulia, M. (2003). Methodology of dietary assessment in athletes: concepts and pitfalls. *Curr Opin Clin Nutr Metab Care.* Sep;6(5):539-49. Review

Nattiv, A., Loucks, A.B., Manore, M.M., Sanborn, C.F., Sundgot-Borgen, J., Warren, M.P. (2007). The Female Athlete Triad. Special Communications: Position Stand. *Med Sci Sports Exerc.* 39 (10): 1867-82.

O'Connor, H., Caterson, I. (2010). Weight loss and the athlete. In *Clinical sports nutrition*. Burke & Deakin, 4th edition, McGraw-Hill, Australia. ISBN 978 0 070 27720: 116-141.

Rodriguez NR., DiMarco NM., Langley S.; American Dietetic Association; Dietetians of Canada; American College of Sports Medicine. (2009). Position of the American Dietetic Association, Dietitians of Canada, and the American College of Sports Medicine: Nutrition and athletic performance. *Med Sci Sports Exerc*, 41(3), 709-31.

Saarni, S.E., Rissanen, A., Sarna, S., Koskenvuo, M., Kaprio, J. (2006). Weight cycling of athletes and subsequent weight gain in middleage. *Int J Obes*. Nov;30(11):1639-44.

Tipton, K.D., Wolfe, R.R. (2004). Protein and amino acid for athletes. *J Sports Sciences.* 22:65-79.

Umeda, T., Nakaji, S., Shimoyama, T., Kojima, A., Yamamoto, Y., Sugawara, K. (2004). Adverse effects of energy restriction on changes in immunoglobulins and complements during weight reduction in judoists. *J Sports Med Phys Fitness*. Sep;44(3):328-34.

Vogels, N., Diepvens, K., Westerterp-Plantenga, M.S. (2005). Predictors of long-term weight maintenance. *Obes Res.* Dec;13(12):2162-8.

Walberg Rankin, J. (2002). Weight loss and gain in athletes. *Curr Sports Med Rep.* 4:208-213.

Webster, S., Rutt, R., Weltman, A. (1990). Physiological effects of a weight loss regimen practiced by college wrestlers. *Med Sci Sports Exerc.* 22(2):229-234.

Wing, R.R., Phelan, S. (2005). Long-term weight loss maintenance. *Am J of Clin Nutr*, July;2(1):222-225

Figure 1. Flow chard from baseline to 12 months post intervention.

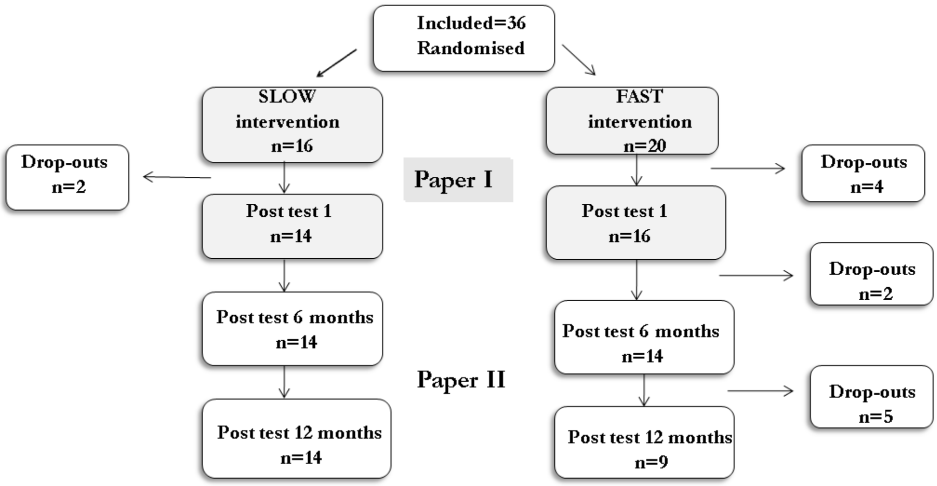
Figure 2. Changes in body mass (BM) in slow reduction (SR) and fast reduction (FR) from baseline to 12 months post intervention (n=14, SR, n=9, FR). Data are presented as mean±SE. * $p<0.05$ significantly different from pre-intervention, $^{\#}$ $p<0.05$ significant difference between groups.

Figure 3. Changes in fat mass (FM) in slow reduction (SR) and fast reduction (FR) from baseline to 12 months post intervention (n=14, SR, n=9, FR). Data are presented as mean±SE. * $p<0.05$ significantly different from pre-intervention, $^{\#}$ $p<0.05$ significant difference between groups.

Figure 4. Changes in lean body mass (LBM) in slow reduction (SR) and fast reduction (FR) from baseline to 12 months post intervention (n=14, SR, n=9, FR). Data are presented as mean±SE. * $p<0.05$ significantly different from pre-intervention, $^{\#}$ $p<0.05$ significant difference between groups.

Figure 5. Changes in 1RM performance in slow reduction (SR) and fast reduction (FR) from baseline to 12 months post intervention (n=14, SR, n=9, FR). Data are presented as mean±SE. * $p<0.05$ significantly different from pre-intervention, $^{\#}$ $p<0.05$ significant difference between groups.

Figure 1



Included=36
Randomised
SLOW
intervention
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FAST
intervention
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Drop-outs
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Paper I
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n=14
Post test 1
n=16
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n=2
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Figure 2

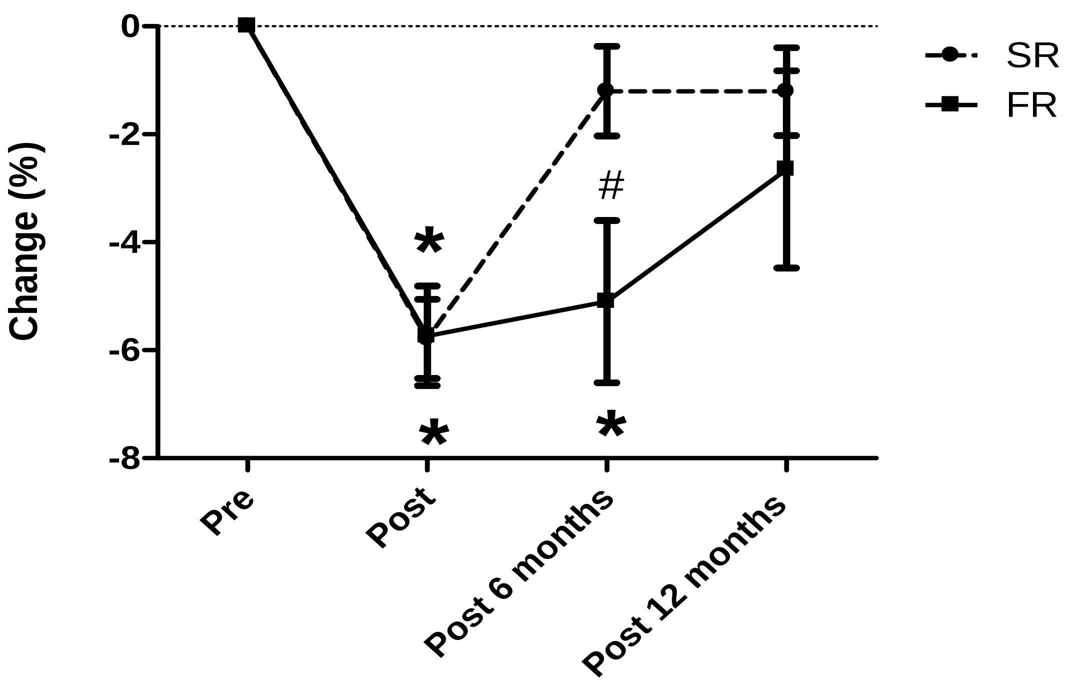


Figure 3

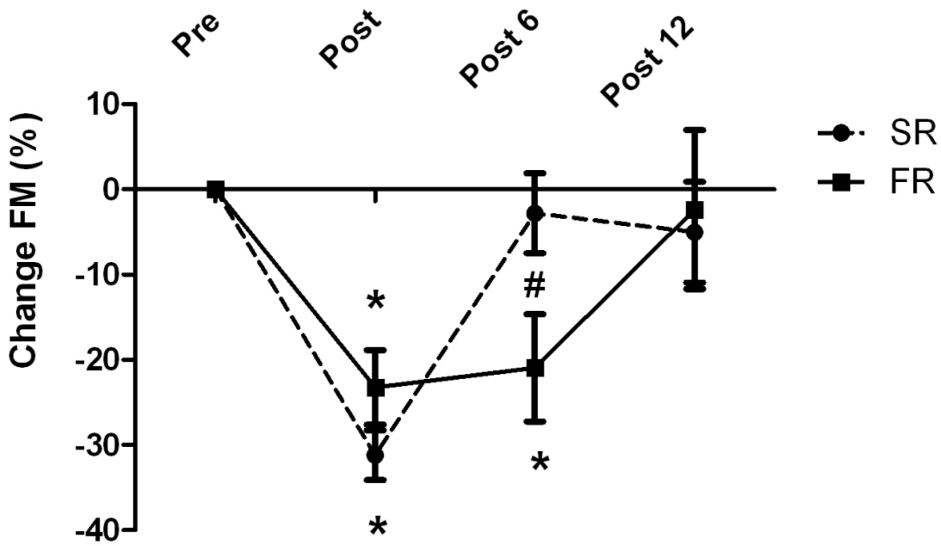


Figure 4

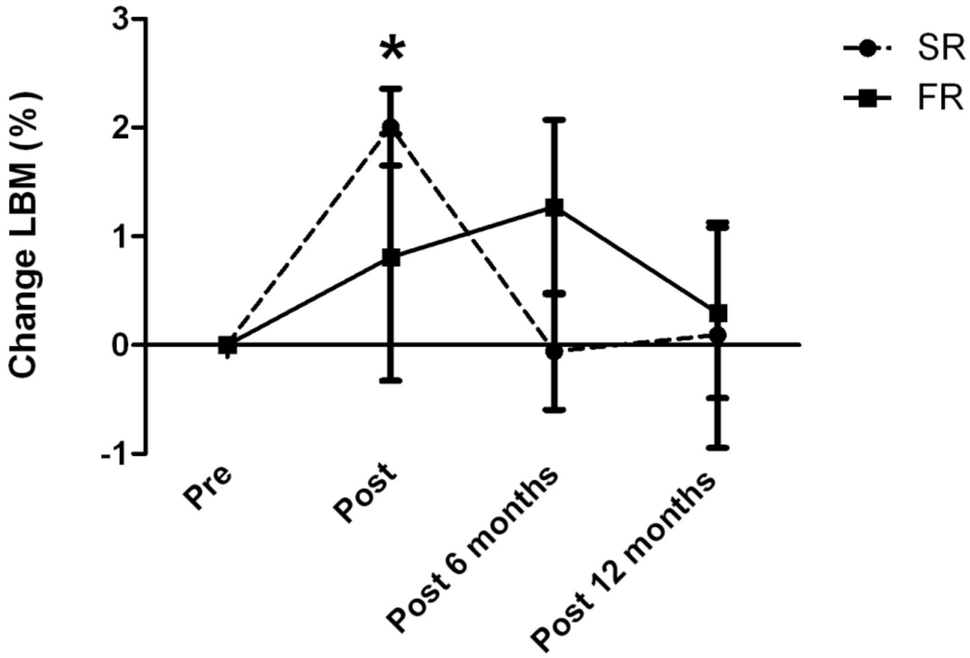
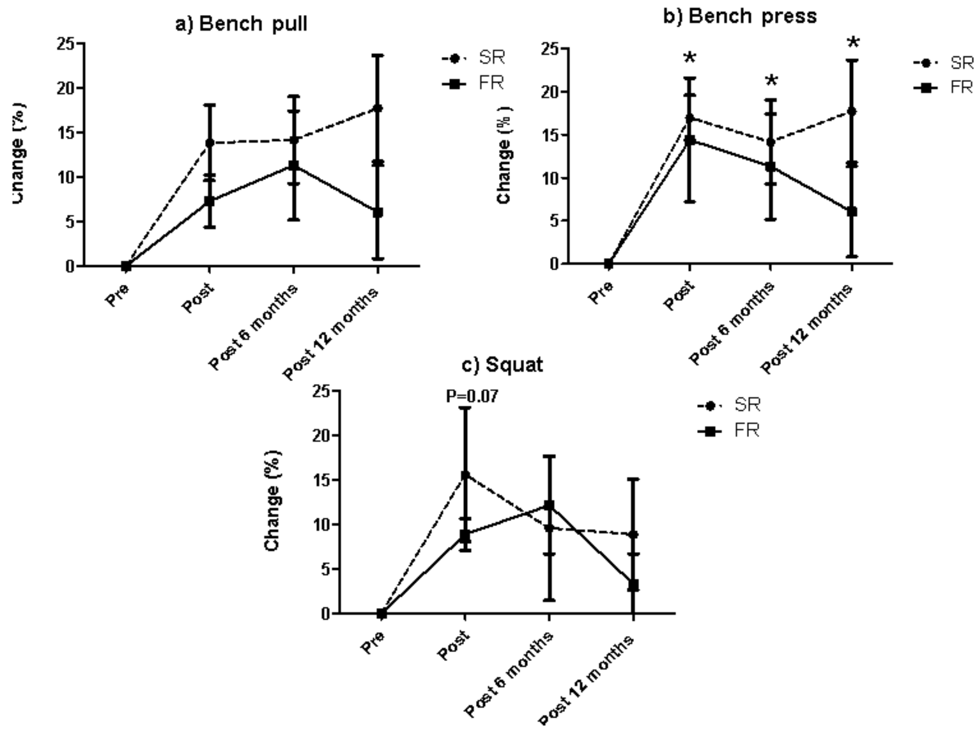


Figure 5



a) Bench pull
Change (%)
SR
FR
Pre
Post
Post 6 months
Post 12 months
b) Bench press
Change (%)
*
SR
FR
c) Squat
P=0.07
Change (%)
SR
FR

Table 1

Table 1. Baseline data presented as mean±SD

	Slow Rate		Fast Rate	
	Males (n=6)	**Females (n=8)**	**Males (n=3)**	**Females (n=6)**
Age (yrs)	24.9 ± 3.5	22.5 ± 3.1	19.2 ± 1.3	19.6 ± 7.9
Height (cm)	177 ± 11	170 ± 7	177 ± 3	166 ± 5
BM (kg)	78.5 ± 14.1	69.6 ± 7.0	79.6 ± 15.2	66.1 ± 22.4
FM (kg)	13.3 ± 5.0	18.8 ± 5.9	12.5 ± 8.3	19.4 ± 5.6
Total body fat (%)	17 ± 5	29 ± 7	16 ± 7	29 ± 5
LBM (kg)	62.3 ± 10.3	45.9 ± 5.2	65.5 ± 7.5	45.3 ± 3.8
Experience as athletes (yrs)	13 ± 6.4	10.6 ± 4.6	10.7 ± 3.8	13.9 ± 1.6
Training per week (h)	15.6 ± 4.5	12.0 ± 2.3	16.3 ± 2.9	14.1 ± 4.5
Strength training last season (h•week-1)	2.8 ± 1.6	2.4 ± 1.7	3.7 ± 1.2	2.0 ± 1.3

BM=body mass, FM=fat mass, LBM=lean body mass

Table 2

Table 2. Energy and nutrition variables presented as mean±SD.

n=14, SR ***n=9, FR***		**(4 days weighed) Food record**	**Meal plan during intervention**
Energy intake (kcal)	SR	2317 ± 689	1909 ± 477 *
	FR	2222 ± 682	1688 ± 229 *
Protein (g/kgBW)	SR	1.4 ± 0.5	1.6 ± 0.4
	FR	1.5 ± 0.6	1.4 ± 0.2
Protein (E%)	SR	18.0 ± 3.0	25.0 ± 3.7 *
	FR	20.0 ± 7.0	24.3 ± 3.5
CHO (g/kgBW)	SR	4.0 ± 1.1	3.5 ± 0.7 *
	FR	3.8 ± 1.3	3.2 ± 0.7
CHO (E%)	SR	51.3 ± 6.3	54.0 ± 3.4 *
	FR	49.0 ± 6.7	56.0 ± 5.0
Fat (E%)	SR	30.1 ± 6.6	20.7 ± 1.1 *
	FR	31.0 ± 3.5	20.3 ± 2.7 *

SR=slow rate reduction, FR=fast rate reduction

* p<0.05 significantly different from pre

# p<0.05 significant difference between groups

Paper III

Effect of nutritional intervention on body composition and performance in elite athletes

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ABSTRACT

Normally, combining strength training with a positive energy intake results in increased lean body mass (LBM) However, most studies are based recreationally active subjects and less is known about optimal weight-gain protocols in elite athletes. The purpose of this study was to evaluate the effect of nutritional guidance in an 8- to 12-week weight-gain period in elite athletes. Thirty-nine elite athletes were randomized to "nutritional counseling group" (NCG, n=21, 19.1±2.9y, 70.9±8.9kg) and "ad libitum group" (ALG, n=18, 19.6±2.7y, 75.0±5.9kg). All athletes continued their sport-specific training and included four strength-training sessions per week. NCG followed a meal plan providing a positive energy balance, while the ALG athletes had an *ad libitum* energy intake. Body weight (BW), body composition (DEXA), and strength (1 RM) were measured pre- and post-intervention. Energy intake was higher in the NCG than in the ALG (3585±601 vs. 2964±884 kcal) and consequently BW increased more in NCG than in ALG (3.9±0.6% vs. 1.5±0.4%). LBM tended to increase more in NCG than in ALG (2.7±0.4% vs. 1.9±0.4%), and fat mass increased more in NCG than in ALG (15±4 vs. 3±3%). All 1RM results improved in both groups (6-12%). Athletes with nutritional guidance increased BW more, but, excess energy intake in a weight-gain protocol should be considered carefully due to undesirable increases in body fat.

Key words: Energy intake, strength training, hypertrophy

INTRODUCTION

Muscle mass is an important determinant of performance in sports that depend on high muscle strength or power. Our experience indicate that athletes attempting to gain weight and lean body mass (LBM) emphasize strength training but fail to focus on nutrition and positive energy balance. The reason for this might be the practical challenge related to increased energy intake, fear of gaining excess body fat, and/or lack of knowledge. Many athletes strive to increase muscle mass in a busy training schedule, and some athletes struggle to increase energy intake sufficiently due to time constraints and practical implications. Thus, for many athletes, diets high in saturated fat and dietary supplements advertised to increase LBM, may be an easy solution (Walberg-Rankin 2002). In addition, the potential for muscle growth depends on an athlete's genetics and resistance training history (ACSM 2009b). A positive energy balance alone has been shown to have an important anabolic effect (Forbes et al. 1986), but combining strength training and a positive energy balance results in the most effective gain in muscle mass (Kreider et al. 1996; Rozenek et al. 2002). Studies on sedentary subjects show that LBM contributes 38-46% of the total weight gain associated with excess energy intake (Bouchard et al. 1990; Forbes et al. 1986). Excess energy intake combined with strength training may increase the contribution from changes in LBM to 100% of the total weight gain (Kreider et al. 1996; Rozenek et al. 2002). Since an increase in fat mass (FM) is undesirable for many athletes the combination of a well-designed strength-training program and an energy dense diet with adequate protein and carbohydrate, strategically timed protein intake and an overall planned diet is required (ACSM 2009a; ACSM 2009b; Tipton & Wolfe 2004; Walberg-Rankin 2002).

Based on the few studies on elite athletes and weight gain, an increase in LBM of maximal 0.25-0.5 kg per week may be realistic (ACSM 2009b; Huston 1999). It has been suggested that the athlete should have a positive energy balance of 500-1000 kcal pr day to increase LBM (Huston 1999; Walberg-Rankin 2002). However, athletes with a long history of heavy strength training may have less capacity for increasing LBM and strength-related performance (ACSM 2009b). The excess energy intake in a weight gain protocol should therefore be considered carefully and individually because greater rates of weight gain are likely to include increments in body fat storage in trained athletes. Therefore, the aim of this study was to examine whether a controlled positive energy balance through nutritional counseling could give a greater increase in LBM and strength-related performance than *ad libitum* intake during an 8- to 12-week heavy strength-training period. We hypothesized that the athletes in the intervention group, with daily excess energy intake corresponding to ~500 kcal, should have greater gain in body weight and LBM, and greater strength-related performance enhancement than the *ad libitum* group, despite similar strength-training stimuli.

METHODS

Subjects

Forty-seven elite athletes (17-31 years) were recruited, and 39 athletes completed the study. An elite athlete was defined as one who qualified for the Norwegian national team at the junior or senior level, or who was a member of a recruiting squad for that team (students at the Norwegian Top-Level Sports College). The given reasons for dropping out were as follows: the project was too time consuming (n=3), strength training program interfered with sport-specific training techniques (n=1), and injury (n=4). The athletes were recruited by invitation from the Department of Sports Nutrition at the Norwegian Olympic Sport Center when they contacted the center to get assistance with weight gain, or by invitation letters to sport federations. The following sports were represented: rowing (n=1), kayaking (n=1), soccer (n=4), volleyball (n=1), tae kwondo (n=1), skating (n=5) and ice hockey (n=26). Ratios of males to females were 91% vs 9% in the nutritional counseling group (NCG) and 92% vs 8% in the ad libitum group (ALG). The physical and anthropometrical characteristics of the athletes are shown in table 1. The secretary general of each sport federation, the national team coach, and the head of the healthcare team for each of the national teams received detailed written information about the aims and procedures of the study. The athletes were informed about the purpose and experimental procedures before written consent was obtained. The study was conducted according to the Declaration of Helsinki and approved by the Data Inspectorate and the Regional Ethic Committee of Southern Norway. Permission to conduct the study was provided by the Norwegian Olympic Committee and the Norwegian Confederation of Sports.

Experimental Design

The athletes were screened and block randomized into NCG and ALG. All athletes followed an 8- to 12-week weight-gain period. The length of the intervention period for each subject depended on the athlete's weight gain goal and length of the off-season period. Athletes in both groups were aiming for a weekly gain of 0.7% of total BW. This corresponds to a weekly weight gain of 0.5 kg in a 70 kg athlete. Thus, if a 70 kg athlete were to increase his/her weight by 5 kg, he/she would participate in the intervention for 10 weeks.

Pre-participation screening

The purpose of the screening was to evaluate whether the athletes met the inclusion criteria. The inclusion criteria were as follows: 1) elite athlete, 2) age 17-35 yrs, and 3) desired weight gain of ≥4% of BW. The main exclusion criteria were as follows: 1) diseases and conditions that are known to affect metabolic functions in muscle, 2) use of pharmaceuticals that may affect any of the measurements, and 3) pregnancy.

The screening was a clinical interview and medical examination according to the standard for pre-season health evaluation at the Norwegian Olympic Sports Center. Athletes were also screened for disordered eating and eating disorders by using the Eating Disorder Inventory (Garner 1991) and medical examination by a sports medicine physician.

Intervention

Diet

Diet registrations were obtained using a 4-day weighed food record (3 weekdays + 1 weekend day) which was analyzed by the national food database "Mat På Data" (version 5.0. LKH, Norway). The athletes' weights were stable during diet registration. The record served as a basis for the development of each athlete's individualized diet plan in the NCG, promoting weekly BW gain of 0.7% of total BW. In ALG, 24 hour recall was done mid- and post test to monitor changes in the nutritional variables during the period. The macronutrient distribution of the total energy intake in the meal plans for NCG was designed to have a protein intake corresponding to 1.4-2.0 $g \cdot kg \cdot BW^{-1}$, a carbohydrate intake corresponding to 5-7 $g \cdot kg \cdot BW^{-1}$ and 25-30% fat (ACSM 2009a; Tipton & Wolfe 2004). The focus was on energy- and nutrient-dense foods as well as high food variety and a frequent meal pattern to ensure energy intake every 3rd hour, corresponding to 5-7 meals per day. The dietary plan was tailored to meet each athlete's specific needs and was designed to be as optimal as possible for both health and athletic performance. All NCG athletes ingested a recovery meal containing carbohydrates (40-50 g) and protein of high biological value (15-20 g) within 30 minutes after training sessions, and a balanced meal within 1-2 hours after training to optimize recovery (ACSM 2009a; Tipton & Wolfe 2004). The athletes were encouraged to use a food scale to ensure correct portion sizes. If the athletes were unable to follow the dietary plan during the week, they were instructed to write down any deviance from the plan. Athletes in the ALG did not get feedback on their diet registration before they had completed the study. ALG athletes were instructed to eat *ad libitum* during the intervention period, with the goal of gaining 0.7% BW·week^{-1}. The athletes were not allowed to use creatine supplements during the last 6 weeks prior to inclusion, and they did not take any supplements other than those given by the nutritionist during intervention (e.g., if blood samples indicated any other specific micronutrient needs, these vitamins or minerals were provided to the athletes and biochemical changes were monitored). Athletes in both groups had free access to sports products such as sports drinks and recovery shakes (30% protein/70%carbohydrate drink) from Maxim (Maxim™, Ishøj, Denmark).

Nutritional counseling

The NCG athletes received nutritional counseling from a sports nutritionist/physiologist once a week for the duration of the intervention. The counseling covered basic nutrition, sports physiology and possible adjustments in the dietary plan or weight regimen, depending on progress. The ALG athletes did not receive any nutritional counseling before or during intervention.

Training

The intervention period started in the off-season for all athletes (during their basic training period) to be able to add additional training to their schedule and to prevent interference with competition and traveling. Because strength training experience is an important variable affecting the expected increase in LBM during a period of heavy strength training (ACSM 2009b), we screened the athletes for their strength training background. The athletes in NCG and ALG reported spending 3.8±0.5 $h \cdot week^{-1}$ and. 3.9±0.3 $h \cdot week^{-1}$, respectively, on strength training during the last year. All athletes continued their sport-specific training schedule (16.7±5.4 $h \cdot week^{-1}$, presented as a mean of the training during the previous year). Four strength training $sessions \cdot week^{-1}$ were included to emphasize muscle strength and hypertrophy. The strength training program was a 2-split periodized program. Each muscle group was exercised twice a week with two exercises in each session, one main exercise attacking multiple muscle groups (e.g. squat) and one working more isolated on a specific muscle group (e.g. knee extension). Main exercises for leg muscles were clean (whole body), squat, hack squat and dead lift, and main exercises for upper body muscles were bench press, bench pull, rowing, chins, shoulder press and core exercises. The athletes followed a 3x8-12 repetition maximum (RM) regimen for the first four weeks, a 4x6-12RM for the next period, and a 5x6-10RM for the final four weeks. For the athletes who participated for fewer than 10 weeks (n=14), the program was adjusted with shorter periods. The rest period between sets lasted 1-3 minutes. Athletes were supervised once per week during training at the Olympic Sports Center to ensure correct technique and adequate progress. A computerized exercise diary was recorded during the entire intervention period, supervised by the personal trainer.

Experimental assessments

All tests were conducted by the same test team at both pre- and post-intervention, and the test day was standardized. Athletes were not allowed to perform heavy training 48 hours prior to testing.

Body weight

BW was measured in fasted state, after emptying the bladder, with a balance scale (Seca mod. 708, Seca Ltd., Birmingham, UK) to the nearest 100 g on the test day in the morning between 8.00-9.00 am. During the intervention period, athletes used their own scales to monitor BW since their weekly meetings with the nutritionist were at different times during the day and the weight fluctuated depending on food and liquid intake. They were instructed to weigh themselves without clothes and with an empty bladder immediately after waking up and before breakfast.

Dual energy X-ray absorptiometry (DEXA)

FM, % body fat and LBM were measured with DEXA (GE Medical Systems, Lunar Prodigy, Wisconsin, USA) by a trained technician. The DEXA system was calibrated everyday before testing and the test was conducted in a fasted state between 8.30-10.00 am. For DEXA reproducibility, ten athletes did two repeated measurements within 24 hours, and the coefficient of variation in DEXA Lunar Prodigy total body scan for repeated measurements was 3% for FM and 0.7% for LBM.

Performance variables

Since the aim of the study was to increase hypertrophy and strength, physical strength and power-related performance indicators were chosen: 40 m sprint time, counter movement jump height (CMJ) and 1RM in bench press, bench pull and squat. Prior to the sprint, CMJ and 1RM strength tests, the athletes performed a standardized warm-up consisting of 15 min low intensity running or cycling. Following the warm-up session, the athletes performed three maximal 40m sprints and the best result was used in the data analysis. CMJ was performed on an AMTI force platform (SG 9, Advanced Mechanical Technology Inc., Newton, MA, USA), and the best of three jumps was used in the data analysis. 1RM was assessed in bench press, bench pull and squat. For 1RM the weight was progressively increased until the athlete could not move the weight through the full range of motion on at least two attempts.

Statistical analyses

Data is presented as mean±SD for pre- and post-intervention measurements and mean±SE for changes within and between groups. The computer software Graphpad Prism 5.0 (CA, USA) and SPSS 15 (Illinois, Chicago, USA) were used for statistical analysis. Pre- to post-intervention changes within groups were analyzed with paired samples two-tailed Student's t-test or Wilcoxon paired rank test when appropriate. Independent two-tailed Student's t-test and Mann-Whitney test were used when appropriate for comparisons between groups. Pearsons R or Spearmans Rho was performed when appropriate to study correlations between variables. P values below 0.05 were considered statistically significant.

RESULTS

The mean time spent in intervention was 9.9±1.6 weeks for NCG and 9.9±1.3 weeks for ALG. There were no significant differences between groups in any of the baseline measurements except for the significantly higher FM in ALG (Table 1, 2 and 3).

Diet

Energy intake for NCG was higher during intervention than at baseline (3585 ± 600 vs. 3041 ± 578) (table 2). Although ALG had the same weight-gain goal, energy intake did not change (Table 2). Consequently, except for protein intake, the intake of macronutrients was higher for NCG than for ALG (Table 2).

Body composition

BW increased more in NCG than in ALG (3.9±0.6% vs. 1.5±0.4%, $p<0.01$, (Figure 1 and Table 3). The average weekly rate of weight gain was 0.4±0.6% for NCG and 0.2±0.0% for ALG ($p<0.01$). FM increased more in NCG than in ALG (15±4% vs. 3±3%, $p<0.05$). Total LBM increased by 2.8±0.4% in NCG ($p<0.001$) and 1.9±0.4% in ALG ($p<0.001$) with no significant differences between groups ($p=0.1$) (Figure 1 and table 3). Separating LBM measurements into upper body and leg LBM revealed that NCG had significantly higher gains in leg LBM than ALG (2.5±0.8% vs. 0.2±0.9%, $p<0.05$) (Table 3). The average weekly rate of LBM gain was 0.3±0.1% for NCG and 0.2±0.0% for ALG ($p=0.08$; between groups comparison).. Because only two females were included in each group, tests for possible gender differences were not performed. When doing the analyses without data from the females, the results did not change significantly.

Indicators of physical performance

No significant change was observed in CMJ in either of the groups (Figure 2 and table 3). Performance in 40m sprint decreased by 1.2±0.5% ($p=0.03$) in NCG, but was unchanged in ALG. Strength improved in both NCG and ALG in all three exercises tested (6-12%, Figure 2 and Table 3). There were no significant differences between groups in any of the performance variables. There was a significant correlation between relative increase in BW and changes in 1RM bench press ($r=0.5$, $p= 0.003$), 1RM bench pull ($r=0.4$, $p=0.01$) and 1RM squat ($r=0.4$, $p=0.02$).

Compliers versus non-compliers

The predetermined weight gain goal for NCG and ALG was 4.9±0.8 and 5.2±0.9, respectively, with a weekly gain of 0.7% of initial body mass, but not all athletes reached their goal. All athletes are included in the present results according to the *intention to treat* principle. In NCG, 13 athletes did not accomplish their weight goal (with a cut-off value in weekly weight gain between 0.5 and 1.0%). No significant differences were found between compliers and non-compliers in training hours, baseline values in LBM, or strength training experience. Although the ALG athletes did not have any meal plans or nutritional guidance, their goal was also a weekly weight gain of 0.7% of BW. Only one athlete in ALG accomplished his weight-gain goal (with a cut-off value between 0.5 and 1.0%). The mean gain in LBM and FM was 3.7±0.83% and 30.8±3.8% for compliers, respectively, and 1.9±0.3% and 3.3±2.0 for non-compliers, respectively.

DISCUSSION

The aim of this study was to compare the effects of nutritional counseling and *ad libitum* energy intake on changes in body composition and performance during a heavy strength training period in elite athletes. We hypothesized that the athletes in NCG would gain more weight and LBM than ALG, and have a greater increase in strength-related performance. Only 38% of the athletes in NCG and 6% in ALG reached their predetermined weight gain goal. In accordance with our hypothesis, athletes in NCG had a greater weight gain than the athletes in ALG and a greater gain in leg LBM. However, the greater total weight gain was mainly due to greater gain in FM and there were no significant differences between NCG and ALG in changes in performance.

Diet

Both underreporting and undereating are common measurement errors in self-reported dietary intake, and have to be taken into consideration (Magkos & Yannakoulia 2003). We chose a 4-day weighed food registration at baseline for all and 24 hours recall mid- and post-test for ALG in order to minimize the burden, improve compliance and to reduce the risk of alteration of the subject's usual intake. The calculated energy surplus for NCG was 544±31 kcal·day^{-1}. The mean carbohydrate intake during intervention was 6.8±1.3 g·kg-1 and 4.5±1.9g·kg^{-1} for NCG and ALG, respectively, and within the recommended carbohydrate intake for athletes (ACSM 2009a). The mean protein intake was 2.4±0.4g·kg^{-1} for NCG and 1.7±0.4 g·kg^{-1} for ALG. Protein intake for NCG was slightly higher than the recommended protein intake for athletes (ACSM 2009a; Tipton & Wolfe 2004). Adequate protein intake was considered important to ensure sufficient amino acid supply to the muscles and to enhance the recovery. Although it was considered beneficial for the athletes to increase their fat intake to increase energy density, and thereby reduce the amount of food consumed, it was important that the athlete had confidence in the meal plan. Thus, the meal plans for NCG were based on the dietary registrations and general guidelines for each nutrient, and the athletes were involved in the development of their own meal plan. This included choice of food and drinks and timing of intakes. We consider personal involvement in planning to be crucial for compliance and motivation for the athletes.

Although NCG athletes were closely monitored, 13 (62%) athletes did not accomplish their weight gain goal (with a cut-off value between 0.5 and 1.0%). Compared with the group allowed *ad libitum* food intake, in which only one athlete (6%) accomplished his weight gain goal, the athletes in NCG were more successful in reaching their weight gain goal. However, we had expected a higher number of athletes in NCG to meet the cut-off value. All athletes had tried to gain weight one or more times earlier in their athletic career. Oral feedback from the athletes in NCG indicated that although they considered the meal plan and nutritional guidance a great help, compared with trying to increase BW by themselves, it was occasionally hard to eat the calculated amount within the tight time schedule. Feedback from athletes in ALG indicated that they found it challenging to increase energy intake, mostly because of practical implications such as planning meals and finding time to eat, but also because of the insecurity about food choice and amount of food for some athletes who tried to avoid gaining excess body fat.

Body composition

The increase in LBM contributed to ~72% of weight gain in NCG, whereas for ALG, body composition changed while BW was relatively stable. Gain in leg LBM was significantly higher in NCG and the gain in LBM in ALG was mainly caused by an increase in upper body LBM. There may be several explanations for this finding, but is seems like upper body muscles generally respond better to strength training stimuli than leg muscles (Wernbom et al. 2007). Furthermore, all athletes already had a heavy load on leg muscles in their sport-specific training, likely reducing the training potential in these muscles. It is unclear why NCG increased leg LBM more than ALG. However, the greater increase in BW in NCG than in ALG put a greater load on leg muscles in all activities involving moving one's BW. Adding this load to the strength training stimulus may therefore have contributed to greater increase in leg LBM in NCG.

The finding that athletes in NCG did not accomplish even greater gains in total LBM despite an energy surplus corresponding to ~500 kcal may have several explanations. First, all athletes had some strength training experience, with power and strength as important factors for their sport-specific performance. Thus, we could not expect large increases in LBM from 8-12 weeks of heavy strength training. As opposed to other weight gain studies that have added extra energy corresponding to 1000-2000 $kcal \cdot day^{-1}$ (Rozenek et al. 2002; Forbes et al 1986; Leibel et al. 1995; Dériaz et al. 1993), we minimized the amount of excess energy. In the study by Rozeneck et al. (2002), untrained subjects gained ~3 kg in 8 weeks, and LBM contributed to almost 100% of the weight gain when they combined strength training and energy surplus corresponding to ~2000 $kcal \cdot day^{-1}$. Because our athletes most likely had used more of their potential for LBM growth due to years of strength training, we decided to add only ~500 kcal·day^{-1}.

Another reason for not accomplishing greater gains in LBM in our study may be that athletes in both groups continued their sport-specific training during intervention. Although the intervention period was completed off-season and the athletes emphasized strength training during the period, some technical and endurance training to maintain sport-specific skills was necessary. When strength and endurance training are performed simultaneously, a potential interference in strength development may occur caused by alterations in the adaptive protein synthesis (Nader 2006). For example, acute resistance exercise induces the activation of mammalian target of rapamycin (mTOR), which modulates muscle protein synthesis (Nader 2006). Endurance exercise, on the other hand, is associated with signalling mechanisms related to metabolic adaptations, such as the activation of the AMP-activated protein kinase (AMPK) (Nader 2006). Thus, activation of AMPK by endurance training may reduce skeletal muscle-protein synthesis by inhibiting mTOR signalling and may thus limit hypertrophy and strength increases in response to strength training.

Two athletes in NCG and two athletes in ALG had slightly different interventions than the other athletes, due to increased endurance training (n=2) and injury/illness (n=2) during the last 3-4 weeks in the intervention. This resulted in a net loss of LBM in these athletes (all other athletes maintained or increased LBM). We decided to include these athletes in the study because they were able to complete the strength training program as described, although they reported fatigue and loss of appetite. Three of these athletes also had a net weight loss during that period. When excluding the four athletes from the analysis, the results did not change significantly for any of the variables.

The increase in FM seen in NCG may be problematic for some athletes during a weight gain period for a variety of reasons, from hindering sport-specific performance to not fitting the stereotype of the lean and muscular athlete. A negative effect of increased fat mass on performance was observed with the reduction in sprint performance in NCG. Our results indicate that experienced strength-trained athletes can only increase LBM to a limited extent. Consequently, an energy surplus has to be individualized to avoid large increases in FM for this group of athletes.

Training

The strength training program implemented in this study was designed as a strenuous program, even for experienced athletes, in order to stimulate muscle gain in all athletes. Although there were no differences between groups in baseline measurements except for FM, it is important to keep in mind that athletes from different sports may have different training regimens and methods. However, when rerunning the analyses with only athletes from ice-hockey (n=26), which was the most represented sport in the study, the results did not change significantly.

Performance

Strength improved in all three tests in both groups, but neither 40m sprint nor counter movement jump performance improved. When weight gain occurs due to increased FM, performance is not expected to increase in anti gravity-related tests such as jumping and sprinting since the excess load as FM is considered “dead weight”. The improvements in strength were smaller in this study than other studies that included subjects with less strength training experience (Kreider et al. 1996; Rozenek et al. 2002). This may be due to the greater strength training experience in our athletes and the concurrent sport-specific training during intervention. A challenge in most studies is to measure sport-specific performance. Because of the heterogeneous group of athletes in this study, we included the more general tests as potential i of sports performance. Nevertheless, the more general impact on physical capacity measured in this study, gives important information on how function is affected by the interventions.

Compliers

It may be discussed whether the non-compliers in NCG were actually non-responders to the intervention due to counter regulatory mechanisms (i.e., increased metabolism or other mechanisms decreasing food efficiency) (Bouchard et al. 1990; Leibel et al. 1995; Weyer et al. 2000). If the athletes were unable to follow the dietary plan during the week, they were instructed to write down any deviance from the plan. However, the athletes might have left out or forgot to report to the nutritionist and there was no other control for food intake during the week than the counseling and weight report. The number of dropouts was 1 in NCG and 7 in ALG. That may have influenced the results in ALG. The reasons for dropping out in ALG were: project was too time consuming (n=3), strength training program interfered with sport-specific training techniques (n=1), and injury (n=3). Even though both groups had weekly follow-up with a personal strength trainer, the NCG received additional follow-up on nutrition, which may have contributed to increased commitment to the project.

CONCLUSION

During a strength training period, athletes who received nutritional counseling were more successful in reaching their weight goal than athletes who had an *ad libitum* energy intake. The NCG had significantly higher gains in LBM in legs than ALG, but there were no significant differences between groups in total LBM and performance. Both BW and FM increased significantly more in NCG than ALG. The excess energy intake in a weight gain protocol should therefore be considered carefully since greater rates of gain are likely to include larger increases in body fat storage in already strength-trained athletes.

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REFERENCES

American College of Sports Medicine position stand (a). (2009). Nutrition and athletic performance. *Medicine and Science in Sports and Exercise*, 41, 709-31.

American College of Sports Medicine position stand (b). (2009). Progression models in resistance training for healthy adults. *Medicine and Science in Sports and Exercise*, 41, 687-708.

Bouchard, C., Tremblay, A., Després, J.P., Nadeau, A., Lupien, P.J., Thériault, G., Dussault, J., Moorjani, S., Pinault, S., & Fournier, G. (1990). The response to long-term overfeeding in identical twins. *New England Journal Medicine,* 24, 1477-82.

Dériaz, O., Tremblay, A., & Bouchard, C. (1993). Non linear weight gain with long term overfeeding in man. *Obesity Research,* 1, 179-85.

Forbes, G.B., Brown, M.R., Welle, S.L., & Lipinski, B.A. (1986). Deliberate overfeeding in women and men: energy cost and composition of the weight gain. *British Journal of Nutrition,* 56, 1-9.

Garner, D. M. (1991). Eating Disorders Inventory-2: Professional Manual. *Psychological Assessment Resources* Inc: Odessa, FL, p. iv-70

Houston, M.E. (1999). Gaining weight: The scientific basis of increasing skeletal muscle mass. *Canadian Journal of Applied Physiology*, 24, 305-316.

Kreider, R.B., Klesges, R., Harmon, K., Grindstaff, P., Ramsey, L., Bullen, D., Wood, L., Li, Y., & Almada, A.(1996). Effects of ingesting supplements designed to promote lean tissue accretion on body composition during resistance training. *International Journal of Sports Nutrition*, 6, 234-246.

Leibel, R.L., Rosenbaum, M., & Hirsch, J. (1995). Changes in energy expenditure resulting from altered body weight. *New England Journal of Medicine*, 9, 621-8.

Magkos, F., & Yannakoulia, M. (2003). Methodology of dietary assessment in athletes: concepts and pitfalls. *Current Opinion in Clinical Nutrition & Metabolic Care*, 6, 539-49. Review.

Nader, G.A. (2006). Concurrent Strength and Endurance Training: From Molecules to Man. Medicine *and Science in Sports and Exercice*, 38,1965–1970.

Rozenek, R., Ward, P., Long, S., & Garhammer, J. (2002). Effects of high-calorie supplements on body composition and muscular strength following resistance training. *Journal of Sports Medicine and Physical Fitness*, 42, 340-347.

Tipton, K.D., & Wolfe, R.R. (2004). Protein and amino acid for athletes. *Journal of Sports Sciences*, 22, 65-79.

Walberg Rankin, J. (2002). Weight loss and gain in athletes. *Current Sports Medicine Report*, 4, 208-213.

Wernbom, M., Augustsson, J., & Thomee, R. (2007). The influence of frequency, intensity, volume and mode of strength training on whole muscle cross-sectional area in humans. *Sports Medicine*, 37, 225-64.

Weyer, C., Pratley, R.E., Salbe, A.D., Bogardus, C., Ravussin, E., & Tataranni, P.A. (2000). Energy expenditure, fat oxidation, and body weight regulation: a study of metabolic adaptation to long-term weight change. *Journal of Clinical Endocrinal Metabolism,* 85, 1087-94.

Figure Captions

Figure 1. Changes in body weight (BW), fat mass (FM), and lean body mass (LBM) in the nutritional counseling group (NCG) and the ad libitum group (ALG). Data are presented as mean±SE. * $p<0.05$ significantly different from pre-intervention, # $p<0.05$ significant difference between groups.

Figure 2. Changes in 1RM bench press, bench pull, squat, counter movement jump (CMJ) and 40m sprint performance in the nutritional counseling group (NCG) and the ad libitum group (ALG). Data are presented as mean±SE. * $p<0.05$ significantly different from pre-intervention, # $p<0.05$ significant difference between groups.

Figure 1.

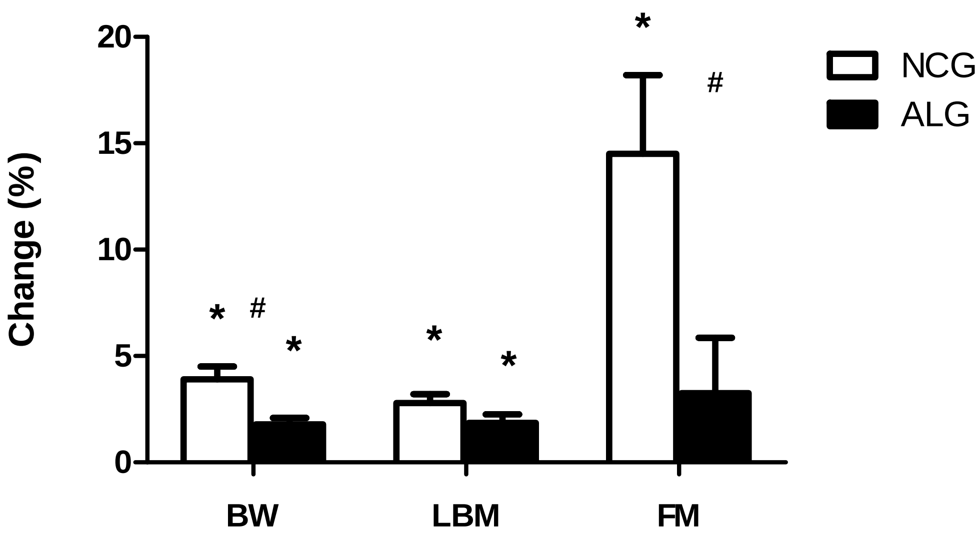

Figure 2.

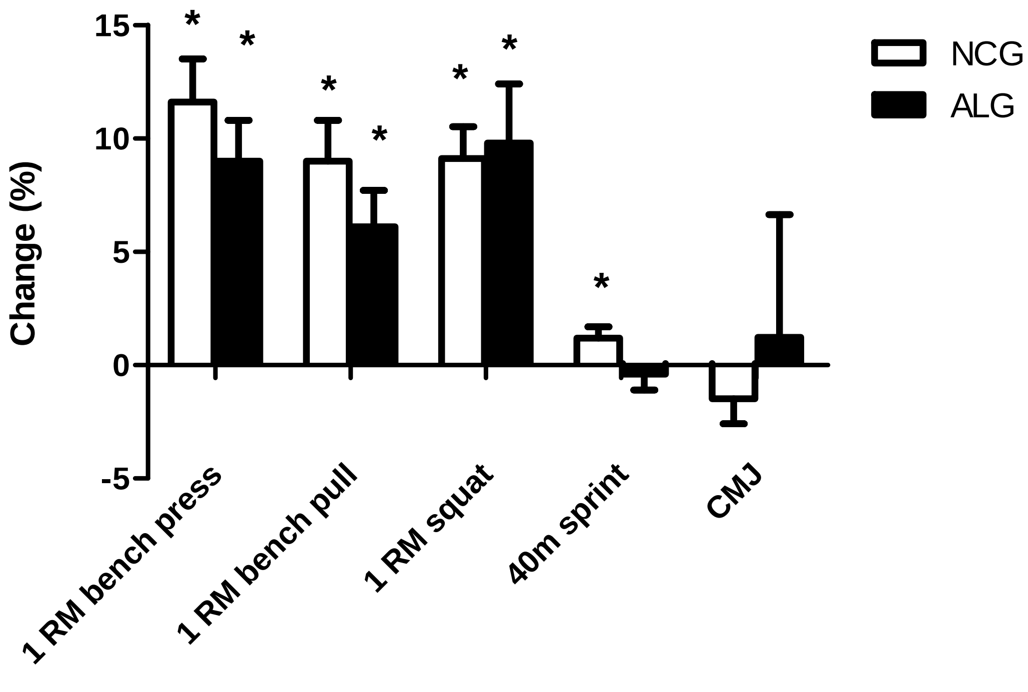
NCG
ALG
Change (%)
15
10
5
0
-5
1 RM bench press
1 RM bench pull
1 RM squat
40m sprint
CMJ

Table 1. Physical and anthropometrical characteristics of athletes presented as mean±SD

	NCG (n=21)	ALG (n=18)
Age (yrs)	19.1 ± 2.9	19.6 ± 2.7
Height (cm)	179 ± 7.4	180 ± 7.9
BW (kg)	70.7 ± 8.5	74.9 ± 5.7
FM (kg)	7.3 ± 1.6	10.3 ± 3.5 *
Total body fat (%)	11 ± 3	14 ± 5
Experience as athletes (yrs)	11.8 ± 2.8	13.1 ± 3.2
Training per week (h)	18.0 ± 5.8	15.2 ± 4.7
Strength training last season (h·week^{-1})	3.8 ± 0.5	3.9 ± 0.3

* $p<0.05$ significantly different between groups

Table 2. Energy and nutrition variables presented as mean±SD for pre- and post-intervention and mean±SE for change.

	NCG			ALG		
	Diet registration	Meal plan during intervention	Change	Diet registration	24-h recall during intervention	Change
Energy intake (kcal)	3041 ± 578	3585 ± 600	544 ± 31*	3032 ± 771	2964 ± 884	128 ± 418 #
Protein (g/kgBW)	1.8 ± 0.4	2.4 ± 0.4	0.6 ± 0.1*	1.7 ± 0.5	1.7 ± 0.4	0.03 ± 0.2 #
Protein (E%)	17.4 ± 3.4	19.6 ± 1.4	2.3 ± 0.2*	17.4 ± 3.2	18.5 ± 3.5	1.2 ± 0.7
CHO (g/kgBW)	5.4 ± 1.1	6.8 ± 1.3	1.4 ± 0.8*	5.4 ± 1.7	4.5 ± 1.9	0.73 ± 1.3 #
CHO (E%)	52.2 ± 6.5	55.1 ± 4.0	3.0 ± 1.4	52.2 ± 10.3	47.4 ± 6.1	5.0 ± 2.4 #
Fat (E%)	29.8 ± 5.8	25.0 ± 3.8	4.8 ± 1.4*	30.0 ± 9.2	34.1 ± 3.8	3.8 ± 2.3 #

* $p<0.05$ significantly different within groups
# $p<0.05$ significantly different between groups

Table 3. Body composition and performance variables presented as mean±SD for pre- and post-intervention and mean±SE for change.

	NCG			ALG		
	Pre	Post	Change	Pre	Post	Change
BW (kg)	70.7 ± 8.5	73.4 ± 8.4	2.7 ± 0.4 *	74.9 ± 5.2	76.1 ± 5.5	1.2 ± 0.3 * #
LBM total (kg)	61.2 ± 8.7	62.9 ± 8.9	1.7 ± 0.3 *	62.0 ± 6.3	63.1 ± 6.6	1.2 ± 0.3 *
LBM leg (kg)	21.2 ± 0.7	21.7 ± 0.7	0.5 ± 0.2 *	21.5 ± 0.7	21.5 ± 0.7	0.0 ± 0.2
LBM upper body (kg)	35.9 ± 1.2	37.0 ± 1.2	1.1 ± 0.2 *	36.4 ± 0.9	37.5 ± 1.0	1.1 ± 0.2
FM (kg)	7.3 ± 1.6 #	8.4 ± 2.1	1.1 ± 0.3 *	10.3 ± 3.5	10.5 ± 3.5	0.2 ± 0.3 #
CMJ (cm)	38.7 ± 6.2	36.2 ± 10.7	0.63 ± 0.5	37.8 ± 5.9	38.2 ± 19.8	0.43 ± 1.3
40m sprint (s)	5.28 ± 2.20	5.39 ± 0.27	0.07 ± 0.03*	5.09 ± 1.39	5.05 ± 1.37	0.02 ± 0.04
1RM bench press (kg)	77.4 ± 21.2	85.2 ± 21.3	7.9 ± 1.0 *	82.2 ± 18.3	90.1 ± 18.4	6.9 ± 14 *
1RM bench pull (kg)	69.3 ± 14.3	78.8 ± 13.6	5.5 ± 0.8 *	71.9 ± 21.8	76.1 ± 22.7	4.2 ± 1.9 *
1RM squat (kg)	114.5 ± 26.6	121.9 ± 25.5	9.6 ± 1.5 *	117.9 ± 30.3	128.5 ± 32.0	10.7 ± 2.5 *

* p<0.05 significant change from pre-intervention

# p<0.05 significantly different between groups

Paper IV

Long-term effect of nutritional counseling during weight gain in elite athletes

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Running title: Weight gain in elite athletes

ABSTRACT

Lean body mass (LBM) is important in power-related sports. In athletes with heavy training loads and competitions, it may be difficult to increase and maintain LBM during season. **Aim:** To evaluate the long-term effects on body composition after an 8-12 week weight-gain period with or without nutritional guidance. **Methods:** Twenty-one elite athletes where randomized into “nutritional counseling group” (NCG, n=12, 18.5±1.7yrs, 67.8±7.4kg) and “ad libitum” group (ALG, n=9, 19.6±2.7yrs, 74.2±5.7kg). NCG followed a meal plan providing a surplus of 506±84 kcal·day^{-1}, whereas ALG had an *ad libitum* energy intake (EI) during the strength training (4 sessionss·week^{-1}) intervention. Body weight (BW) and body composition was measured pre, post, 6 and 12 months after intervention. **Results:** EI in NCG was normalized after 12 months, whereas EI in ALG was unchanged during and after intervention. BW increased more in NCG than ALG during intervention (4.3±0.9% vs.1.0±0.6%) and after 12 months (6.0±0.9% vs.1.8±0.7%). LBM increased in NCG during intervention (2.8±0.5%) and after 12 months (4.4±1.0%), whereas LBM in ALG was unchanged. **Conclusion:** NCG managed to maintain and further increase BW and LBM after the intervention period. Hence, the focus on nutritional guidance in addition to strength training seems to be preferable to obtain long-term effect of weight gain in athletes.

Keywords: Energy intake, strength training, hypertrophy, lean body mass

INTRODUCTION

Paragraph Number 1

Muscle mass is an important determinant of performance in sports that depend on high muscle strength or power. Thus, increasing and thereafter maintaining lean body mass (LBM) off-season and during season is an important goal for many athletes (Walberg-Rankin 2000). However, many athletes strive to increase and even to maintain muscle mass in a busy training schedule. A typical scenario is that athletes manages to increase LBM off-season but fail to maintain LBM during the competitive season, which may lead to impaired performance at the end of the season. This may be due to suboptimal or lack of strength training between competitions, and difficulties in maintaining a sufficient energy intake due to time constraints and practical implications.

Paragraph Number 2

There are few studies of elite athletes and weight gain and to our knowledge no study that has evaluated the long-term effect of guided weight gain in elite athletes. It is known that positive energy balance in combination with strength training is effective in terms of gaining muscle mass (Rozenek et al. 2002; Kreider et al. 1995). However, athletes with a long history of heavy strength training may have less capacity for increasing LBM and improve strength-related performance (ACSM 2009b). In addition, the potential for muscle growth depends on an athlete’s genetics and resistance training history (ACSM 2009b). Individuals respond different to the same intervention (Bouchard et al 1990; Dériaz et al 1995; Forbes et al. 1986) and studies done on long-term effect of weight loss interventions in sedentary overweight participants illustrate the difficulty in maintaining changes in body composition over time (Wing & Phelan 2005). For the sedentary overweight population, specific approaches associated with long-term weight loss have been identified, whereas high levels of physical activity (1 hours·day^{-1}), eating a low-calorie, low-fat diet, eating breakfast regularly, self-monitoring weight, and maintaining a consistent eating pattern across weekdays and weekends have also been identified as important factors (Wing and Phelan 2005). To our knowledge, such factors are not identified in long-term weight gain and there is a lack of data on long term changes in body composition overall in the athletic population.

Paragraph Number 3

Therefore, the aim of this study was to examine whether a controlled positive energy balance through nutritional counseling would have better long term outcomes in body composition than *ad libitum intake* during an 8- to 12-week heavy strength training period. We hypothesized that the athletes in the guided intervention group should have greater gain in body weight and LBM 12 months after intervention than the *ad libitum* group.

Paragraph Number 4

METHODS

Participants

Forty-seven elite athletes (17-31 years) were recruited, 39 athletes completed the intervention and 21 athletes completed the 6 and 12 months follow-up test. An elite athlete was defined as one who qualified for the Norwegian national team at the junior or senior level, or who was a member of a recruiting squad for that team (students at the Norwegian Top-Level Sports College). The given reasons for dropping out were as follows: the project was too time consuming (n=3), strength training program interfered with sport-specific training techniques (n=1), athletes had moved to play for other clubs or hockey leagues (n=10), not accessible (n=2) and injury (n=10) (Figure 1). The athletes were recruited by invitation from the Department of Sports Nutrition at the Norwegian Olympic Sport Center when they contacted the center to get assistance with weight gain, or by invitation letters to sport federations. The following sports were represented in the final sample: rowing (n=1), kayaking (n=1), soccer (n=4), volleyball (n=1), tae kwondo (n=1), skating (n=4) and ice hockey (n=9). Ratios of males to females were 83% vs 17% in the nutritional counseling group (NCG) and 78% vs 22% in the ad libitum group (ALG). The physical and anthropometrical characteristics of the athletes are shown in table 1. The secretary general of each sport federation, the national team coach, and the head of the healthcare team for each of the national teams received detailed written information about the aims and procedures of the study. The athletes were fully informed about the purpose and experimental procedures before written consent was obtained. The study was conducted according to the Declaration of Helsinki and approved by the Data Inspectorate and the Regional Ethic Committee of Southern Norway. Permission to conduct the study was provided by the Norwegian Olympic Committee and the Norwegian Confederation of Sports.

Paragraph Number 5

Experimental Design

The athletes were screened and block randomized into NCG and ALG. All athletes followed an 8- to 12-week weight-gain period. The length of the intervention period for each subject depended on the athlete’s weight gain goal. Athletes in both groups were aiming for a weekly gain of 0.7% of total BW. This corresponds to a weekly weight gain of 0.5 kg in a 70 kg athlete. Thus, if a 70 kg athlete were to increase his/her weight by 5 kg, he/she would participate in the intervention for 10 weeks. Further, the athletes wanted the weight gain to be a result of increased LBM and to avoid large gains in fat mass (FM). The athletes in NCG received nutritional counselling once a week during intervention, while the athletes in ALG did not receive any nutrition counselling. The counselling included basic nutrition, sports physiology and possible adjustments in the dietary plan or weight regimen, depending on progress. All athletes had 4 strength-training sessions·week^{-1}. After the intervention period, the athletes received one nutrition counseling and exercise counseling in order to stabilize the new weight and body composition.

Paragraph Number 6

Pre-participation screening

The purpose of the screening was to evaluate whether the athletes met the inclusion criteria. The inclusion criteria were as follows: 1) elite athlete, 2) age 17-35 yrs, and 3) desired weight gain of ≥4% of BW. The main exclusion criteria were as follows: 1) diseases and conditions that are known to affect metabolic functions in muscle, 2) use of pharmaceuticals that may affect any of the measurements, and 3) pregnancy.

Paragraph Number 7

The screening was a clinical interview and medical examination according to the standard for pre-season health evaluation at the Norwegian Olympic Sports Center. Athletes were also screened for disordered eating and eating disorders by using the Eating Disorder Examination (Garner et al. 1991) and medical examination by a sports medicine physician. Athletes under the age of 18 were screened by an orthopedic doctor and evaluated to make sure that skeletal growth was terminated.

Paragraph Number 8

Intervention

Diet

Diet registrations were obtained using a 4-day weighed food record which was analyzed by the national food database “Mat På Data” (version 5.0. LKH, Norway). The athletes’ weights were stable during the week of diet registration. The record served as a basis for the development of each athlete’s individualized diet plan in the NCG, promoting weekly BW gain of 0.7% of total BW. In ALG, 24 hour recall was done mid- and post test to monitor changes in the nutritional variables during the period. The macronutrient distribution of the total energy intake was designed to have a protein intake corresponding to ≥2 $g \cdot kg \cdot BW^{-1}$, a carbohydrate intake corresponding to 5-7 $g \cdot kg \cdot BW^{-1}$ and 25-30% fat. The focus was on energy- and nutrient-dense foods as well as high food variety and a frequent meal pattern to ensure energy intake every 3^{rd} hour, corresponding to 5-7 meals per day. The dietary plan was tailored to meet each athlete’s specific needs and was designed to be as optimal as possible for both health and athletic performance. All NCG athletes ingested a recovery meal containing carbohydrates (40-50 g) and protein of high biological value (15-20 g) within 30 minutes after training sessions, and a balanced meal within 1-2 hours after training to optimize recovery (ACSM 2009a; Tipton & Wolfe 2004). The athletes were encouraged to use a food scale to ensure correct portion sizes. If the athletes were unable to follow the dietary plan during the week, they were instructed to write down any deviance from the plan. Athletes in the ALG did not get feedback on their diet registration before they had completed the intervention. ALG athletes were instructed to eat *ad libitum* during the intervention period, with the goal of gaining

0.7% BW·week^{-1}. All the athletes received one nutritional counselling within the first month after intervention in order to establish weight maintenance.

Paragraph Number 9

The athletes were not allowed to use creatine supplements during the last 6 weeks prior to inclusion, and they did not take any supplements other than those given by the nutritionist during intervention (e.g., if blood samples indicated any other specific micronutrient needs, these vitamins or minerals were provided to the athletes and biochemical changes were monitored). Athletes in both groups had free access to sports products such as sports drinks and recovery shakes (30% protein/70%carbohydrate drink) from Maxim (Maxim^{TM}, Ishøj, Denmark). There were no supplement restrictions after intervention.

Paragraph Number 10

Nutritional counseling

The NCG athletes received nutritional counseling once a week for the duration of the intervention. The counseling covered basic nutrition, sports physiology and possible adjustments in the dietary plan or weight regimen, depending on progress. The ALG athletes did not receive any nutritional counseling before or during intervention.

Paragraph Number 11

Training

The intervention period started in the off-season for all athletes (during their basic training period) to be able to add additional training to their schedule and to prevent interference with competition and traveling. All athletes continued their sport-specific training schedule (16.7±5.4 h·week^{-1}, presented as a mean of the training during the previous year). In addition, four strength training sessions·week^{-1} were included to emphasize muscle strength and hypertrophy. The strength training program was a 2-split periodized program. Each muscle group was exercised twice a week with two exercises, a main exercise and one for the isolation of the specific muscle group. The athletes followed a 3x8-12 repetition maximum (RM) regimen for the first four weeks, a 4x6-12RM for the next period, and a 5x6-10RM for the final four weeks. For the athletes who participated for fewer than 10 weeks (n=14), the program was adjusted with shorter periods. The rest period between sets lasted 1-3 minutes. Athletes were supervised once per week during training at the Olympic Sports Center to ensure correct technique and adequate progress. A computerized exercise diary was recorded during the entire intervention period, supervised by the personal trainer. After intervention, athletes trained as usual with no interference from the study. Because strength training experience is an important variable affecting the expected increase in LBM during a period of heavy strength training (ACSM 2009b), we screened the athletes for their strength training background.

Paragraph Number 12

Experimental assessments

All tests were conducted by the same test team at both pre- and post-intervention, and the test day was standardized. Athletes were not allowed to perform heavy training 48 hours prior testing.

Body weight

BW was measured in fasted state, after emptying the bladder, with a balance scale (Seca mod. 708, Seca Ltd., Birmingham, UK) to the nearest 100 g on the test day in the morning between 8.00-9.00 am. During the intervention period, athletes used their own scales to monitor BW since their weekly meetings with the nutritionist were at different times during the day and the weight fluctuates depending on food and liquid intake. They were instructed to weigh themselves without clothes and with an empty bladder immediately after waking up and before breakfast.

Dual energy X-ray absorptiometry (DEXA)

Fat mass, % body fat and LBM were measured with DEXA (GE Medical Systems, Lunar Prodigy, Wisconsin, USA) by a trained technician. The DEXA system was calibrated at the day of testing and the test was conducted in a fasted state between 8.30-10.00 am. The coefficient of variation in DEXA Lunar Prodigy total body scan for repeated measurements was 3% for FM and 0.7% for LBM.

Paragraph Number 13

Statistical analyses

Data is presented as mean±SD for pre and post measurements and mean±SE for changes within and between groups. The computer software Graphpad Prism 5.0 (CA, SA) and SPSS 15 (IBM, USA) were used for statistical analyse. The pre to post 12 months changes were analyzed with repeated ANOVAs within groups and two-way repeated ANOVAs between groups. Significant interactions were corrected with the Bonferroni *post hoc* test. P values below 0.05 were considered statistically significant.

RESULTS

Paragraph Number 14

The mean time spent in intervention was 9.9±1.8 weeks for NCG and 9.8±1.4 weeks for ALG. There were no significant differences between groups in any of the baseline measurements except for the significantly higher FM in ALG (Table 1 and 2).

Diet

Energy intake for NCG was higher during intervention than at baseline (2821±1010 vs. 3562 ± 761), but was normalized at 6 and 12 months test (table 2). Although ALG had the same weight-gain goal, energy intake did not change throughout the study (Table 2). Consequently, the intake of macronutrients was higher for NCG than for ALG during intervention, but no significant differences were seen at 6 and 12 months test (Table 2).

Paragraph Number 15

Body composition

The predetermined weight gain goal for NCG and ALG was 4.7±0.8 and 5.1±0.8, respectively, with a weekly gain of 0.7% of initial body mass. BW increased more in NCG than ALG during intervention (4.3±0.9% vs.1.0±0.6%, $p=0.01$) (Figure 2). After intervention the BM continued to increase in NCG and was significantly higher than ALG after 6 and 12 months. A larger increase in fat mass in NCG (17.4±5.1%) than in ALG (5.6±3.1%) was observed during intervention ($p<0.05$) and after 6 months, but was not different after 12 months (Figure 3). LBM increased in NCG during intervention by 2.8±0.5%, continued to increase after 6 months and were significantly higher than ALG after 12 months (Figure 4). When looking at the distribution of LBM gains, 67% of the increase during intervention was due to gain in upper body. From 6-12 months the increase in LBM was only contributed by gain in legs. Only two females were included in each group and therefore, tests for possible gender differences were not performed. Excluding the female athletes from the analyses did not change the results significantly.

Paragraph Number 16

Training

Athletes in NCG and ALG reported training 17.7±6.8 h·week^{-1} and 16.0±6.0 h·week^{-1} and spending 3.8±0.5 h·week^{-1} and 3.9±0.3 h·week^{-1}, respectively, on strength training during the last year before entering the study. They reported spending between 6-7 h·week^{-1} on strength training during intervention, and reported that they went back to baseline hours spent in strength training at 6 months. At 12 months test they reported spending 4.3±1.7 h·week^{-1} in strength training.

Paragraph Number 17

Compliers versus non-compliers

The predetermined weight gain goal for NCG and ALG was 4.7±0.8 and 5.1±0.8, respectively, with a weekly gain of 0.7% of initial body mass. The long-term goal for athletes in NCG and ALG was to maintain (n=4 vs. n=1) or even increase (n=8 vs. n=8) BW further during season, respectively. All athletes are included in the present results according to the *intention to treat* principle. In NCG, 7 athletes (58%) did not accomplish their weight goal (with a cut-off value in weekly weight gain at 0.5) during intervention, but all the athletes in NCG managed to maintain or increase BW according to their goal during the 12 months. No significant differences were found between compliers and non-compliers in training hours, baseline values in LBM, or strength training experience. Although the ALG athletes did not have any meal plans or nutritional guidance, their goal was also a weekly weight gain of 0.7% of BW. However, no athletes in ALG accomplished their weight gain goal during intervention. After 12 months 3 (33%) of the athletes in ALG reduced weight while 6 athletes managed to be weight stable or increase BW.

DISCUSSION

Paragraph Number 18

The aim of this study was to compare the effects of nutritional counseling and *ad libitum* energy intake on changes in body composition and performance 6 and 12 months after a heavy strength training period in elite athletes. We hypothesized that the athletes in NCG would maintain BW and LBM to a greater extend than ALG 6 and 12 months after intervention. In accordance with our hypothesis, athletes in NCG had significantly higher BW and LBM compared to ALG after 12 months.

Paragraph Number 19

Diet

Both underreporting and undereating are common measurement errors in self-reported dietary intake, and have to be taken into consideration (Magkos & Yannakoulia 2003). We chose a 4-day weighed food registration in order to minimize the burden, poor compliance and alteration of the subject's usual intake. The calculated energy surplus in the diet plan for NCG was 506±84 kcal·day^{-1}. The mean carbohydrate intake during intervention was 7.2±1.5 g·kg^{-1} and 5.0±2.3 g·kg^{-1} for NCG and ALG, respectively, and within the recommended carbohydrate intake for athletes (ACSM 2009 a). The mean protein intake was 2.5±0.4g·kg^{-1} for NCG and 1.8±0.3 g·kg^{-1} for ALG. Protein intake for NCG was slightly higher than the recommended protein intake for athletes (ACSM 2009 a; Tipton & Wolfe 2004). Adequate protein intake was considered important to ensure sufficient amino acid supply to the muscles and to enhance the recovery. The meal plans for NCG during intervention were based on the dietary registrations and general guidelines for each nutrient, and the athletes were involved in the development of their own meal plan. This included choice of food and drinks and timing of intakes. We consider individual involvement in planning to be crucial for compliance and motivation for the athletes during intervention and to make it easier to follow after intervention to prevent weight loss. If the athletes were unable to follow the dietary plan during the week, they were instructed to write down any deviance from the plan. This was discussed during the weekly counseling sessions. There was no other control for food intake during the week than the counseling and weight report during intervention.

Paragraph Number 20

Although NCG athletes were closely monitored, 7 athletes did not accomplish their weight-gain goal during intervention. However, all athletes in NCG managed to maintain or increase BW 12 months after intervention and were more successful compared to ALG, in which no athlete accomplished the weight gain goal during intervention and only 6 athletes managed to be weight stable or increase BW after 12 months. All athletes had tried to gain weight one or more times earlier in their athletic career and reported that weight gain and especially maintaining the weight during season was a challenge. It is important to recognize the genetic factors and the challenges associated with the individual metabolic response to overfeeding, making weight gain more difficult for some individuals (Bouchard et al. 1990; Leibel et al. 1995; Weyer et al. 2000). Oral feedback from the athletes in NCG indicated that they considered the meal plan and nutritional guidance as very helpful during intervention and that the maintenance meal plan helped them to continue the process after intervention. All athletes in NCG reported that they had followed the meal plan to some extend (e.g. meal frequency, recovery meals, food choices) after 6 and 12 months. Feedback from athletes in ALG indicated that they found it challenging to increase energy intake, mostly because of practical implications such as planning meals and finding time to eat, but also because of the insecurity about food choice and amount of food for some athletes who tried to avoid gaining excess body fat both during and after intervention.

Paragraph Number 21

Body composition

The increase in LBM contributed to ~57% of weight gain in NCG, whereas for ALG, body composition changed while BW was relatively stable during intervention. It has been suggested that an increase in body mass of 0.25-0.5 kg per week should be a realistic goal if the added weight is due to gain in LBM (ACSM 2009 b; Houston 1999; Rozenek et al. 2002). Further, it has been suggested that the athlete should have a positive energy balance of 500-1000 kcal pr day to reach this goal (Houston 1999; Walberg-Rankin 2002). However, there is a question whether this is realistic in elite athletes. The finding that athletes in NCG did not accomplish even greater gains in total LBM despite an energy surplus corresponding to ~500 kcal may have several explanations. First, all athletes had some strength training experience, with power and strength as important factors for their sport-specific performance. Thus, we could not expect large increases in LBM from 8-12 weeks of heavy strength training. Another reason for not accomplishing greater gains in LBM in our study may be that athletes in both groups continued their sport-specific training during intervention. Although the intervention period was completed off-season, and the athletes emphasized strength training during the period, some technical and endurance training to maintain sport-specific skills was necessary. Combining strength training with endurance training can suppress some of the strength training adaptation, for example, limiting changes in skeletal muscle cross-sectional area (Hawley 2009).

Paragraph Number 22

The relatively large increase in FM seen in NCG after intervention may be problematic for some athletes during a weight-gain period for a variety of reasons, from hindering sport-specific performance to not fitting the stereotype of the lean and muscular athlete. Our results indicate that experienced strength-trained athletes can only increase LBM to a limited extent and that a short period of energy surplus in these athletes may cause gains in LBM. The data indicates that it is easier to increase LBM without increasing FM when the weight gain period is of longer duration. The athletes in NCG managed to further increase BW and LBM, while fat mass decreased. That is remarkable since the athletes trained less strength training and had more sports specific training and competitions during the 6 and 12 months after intervention. Although there were no significant differences between the mean ages in the two groups, there were more young athletes in NCG than AL (7 vs. 3 athletes under the age of 18, respectively), which may have influenced the results. Athletes under the age of 18 were screened by an orthopedic doctor and evaluated to make sure that skeletal growth was terminated. About 50% of adult body weight is gained during adolescence and peak weight velocity occurs at about the same time as peak height velocity (Rogol et al. 2000). However, the rate of weight gain decelerates in a manner similar to height velocity during the later stages of pubertal development (Rogol et al. 2000), so it is uncertain how much of the changes seen in the 10 athletes from age 17 to 18 years are due to biological growth during the 12 month period. Further, we found a significant correlation between age and weight gain at the 12 months post test ($r=-0.45$, $p=0.04$). This indicates that the great discrepancy in the results in weight gain between groups may partly be explained by the higher number of young athletes in NCG. However, during the first 6 months of the season with frequent competitions, both groups followed the same trend and tended to slightly reduce LBM. After 6 months, athletes in NCG started to increase LBM whereas ALG continued the decrease. This indicates that age is not the only explanation for the discrepancy between groups. If that had been the case, LBM would probably have followed a different pattern in NCG than ALG the first 6 months. Feedback from athletes indicates that they initiated an "intervention" period as learned during the study intervention as the competitive season started to diminish. It is interesting to see that athletes in NCG managed to increase LBM significantly during the 6 months without other nutritional guidance than what they received during intervention. It is also interesting to see that 100% of the LBM gained in NCG the last six months were due to gains in LBM in the lower body (legs) and not upper body as seen during intervention. The athletes did not report any specific changes in strength training program the last 6 months, but all athletes from NCG reported that they partly followed the intervention meal plan.

Paragraph Number 23

Compliers

Compared to the group allowed *ad libitum* food intake, in which none of the athletes accomplished their weight gain goal, the athletes in NCG were more successful in reaching their weight gain goal. However, we had expected a higher number of athletes in NCG to succeed. It may be discussed whether the non-compliers in NCG were actually non-responders to the intervention due to counter regulatory mechanisms (i.e., increased metabolism or other mechanisms decreasing food efficiency) (Bouchard et al. 1990; Leibel et al. 1995; Weyer et al. 2000). The number of dropouts was 10 in NCG and 16 in ALG. Even though both groups had weekly follow-up with a personal strength trainer during intervention, the NCG received additional follow-up on nutrition during intervention, which may have contributed to increased commitment to the project during and after intervention.

Paragraph Number 24

CONCLUSION

We found that the NCG had significantly higher gains in BW and LBM 12 months after intervention. Thus, athletes who received nutritional counseling during a weight-gain period were more successful in reaching their weight goal and to maintain the positive changes in BW and LBM, than athletes who had an *ad libitum* energy intake during the intervention period. However, the results must be interpret with caution, do to the fact that there were a correlation between age and changes in BW after 12 months and that there were more athletes under 18 years in NCG.

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REFERENCES

American College of Sports Medicine position stand a. 2009. Nutrition and athletic performance. Med. Sci. Sports. Exerc. Mar;41(3):709-31.

American College of Sports Medicine position stand b. 2009. Progression models in resistance training for healthy adults. Med. Sci. Sports. Exerc. Mar;41(3):687-708.

Bouchard, C., Tremblay, A., Després, J.P., Nadeau, A., Lupien, P.J., Thériault, G., Dussault, J., Moorjani, S., Pinault, S., Fournier, G. 1990. The response to long-term overfeeding in identical twins. N. Engl. J. Med. May 24;322(21):1477-82.

Dériaz, O., Tremblay, A., Bouchard, C. 1993. Non linear weight gain with long term overfeeding in man. Obes. Res. May;1(3):179-85.

Forbes, G.B., Brown, M.R., Welle, S.L., Lipinski, B.A. 1986. Deliberate overfeeding in women and men: energy cost and composition of the weight gain. Brit. J. Nutr. 56:1-9.

Garner, D.M. 1991-. Eating Disorders Inventory-2: Professional Manual. Psychological Assessment Resources Inc: Odessa, FL;. p. iv-70

Houston, M.E. 1999. Gaining weight: The scientific basis of increasing skeletal muscle mass. Can. J. Appl. Physiol. 24(4):305-316.

Hawley, J.A. 2009. Molecular responses to strength and endurance training: are they incompatible? Appl. Physiol. Nutr. Metab. Jun;34(3):355-61.

Kreider, R.B., Klesges, R., Harmon, K., Grindstaff, P., Ramsey, L., Bullen, D., Wood, L., Li, Y., Almada, A. 1996. Effects of ingesting supplements designed to promote lean tissue accretion on body composition during resistance training. Int. J. Sports. Nutr. 6:234-246.

Leibel, R.L., Rosenbaum, M., Hirsch, J. 1995. Changes in energy expenditure resulting from altered body weight. N. Engl. J. Med. Mar. 9;332(10):621-8.

Magkos, F., Yannakoulia, M. 2003. Methodology of dietary assessment in athletes: concepts and pitfalls. Curr. Opin. Clin. Nutr. Metab. Care. Sep;6(5):539-49. Review

Rogol, A.D., Clark, P.A., Roemmich, J.N. 2000. Growth and pubertal development in children and adolescents: effects of diet and physical activity. Am. J. Clin. Nutr. Aug;72(2):521-8.

Rozenek, R., Ward, P., Long, S., Garhammer, J. 2002. Effects of high-calorie supplements on body composition and muscular strength following resistance training. J. Sports. Med. Phys. Fitness. 42:340-347.

Tipton, K.D., Wolfe, R.R. 2004. Protein and amino acid for athletes. J. Sports. Sciences. 22:65-79.

Walberg Rankin, J. 2002. Weight loss and gain in athletes. Curr. Sports. Med. Rep. 4:208-213.

Weyer, C., Pratley, R.E., Salbe, A.D., Bogardus, C., Ravussin, E., Tataranni, P.A. 2000 Energy expenditure, fat oxidation, and body weight regulation: a study of metabolic adaptation to long-term weight change. J. Clin. Endocrinol. Metab. Mar;85(3):1087-94.

Wing, R.R., Phelan, S. 2005. Long-term weight loss maintenance. Am. J. Clin. Nutr. July;2(1):222-225

Figure captions

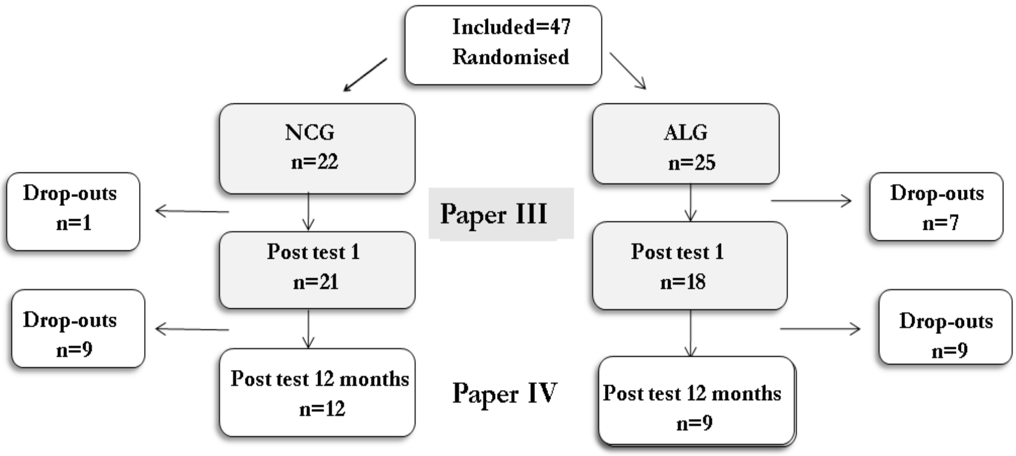
Figure 1. Flow chard over participants.

Figure 2. Changes in body weight (BW) in nutrition counseling group (NCG) and *ad libitum* group (ALG) from pre to post 12 months. Data are presented as mean±SE. * $p<0.05$ significantly different from pre-intervention, # $p<0.05$ significant difference between groups.

Figure 3. Changes in fat mass (FM) in nutrition counseling group (NCG) and *ad libitum* group (ALG) from pre to post 12 months. Data are presented as mean±SE. * $p<0.05$ significantly different from pre-intervention, # $p<0.05$ significant difference between groups.

Figure 4. Changes in lean body mass (LBM) in nutrition counseling group (NCG) and *ad libitum* group (ALG) from pre to post 12 months. Data are presented as mean±SE. * $p<0.05$ significantly different from pre-intervention, # $p<0.05$ significant difference between groups.

Figure 1.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Randomised
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ALG
n=25
Drop-outs
n=1
Paper III
Drop-outs
n=7
Post test 1
n=21
Post test 1
n=18
Drop-outs
n=9
Drop-outs
n=9
Post test 12 months
n=12
Paper IV
Post test 12 months
n=9

Figure 2.

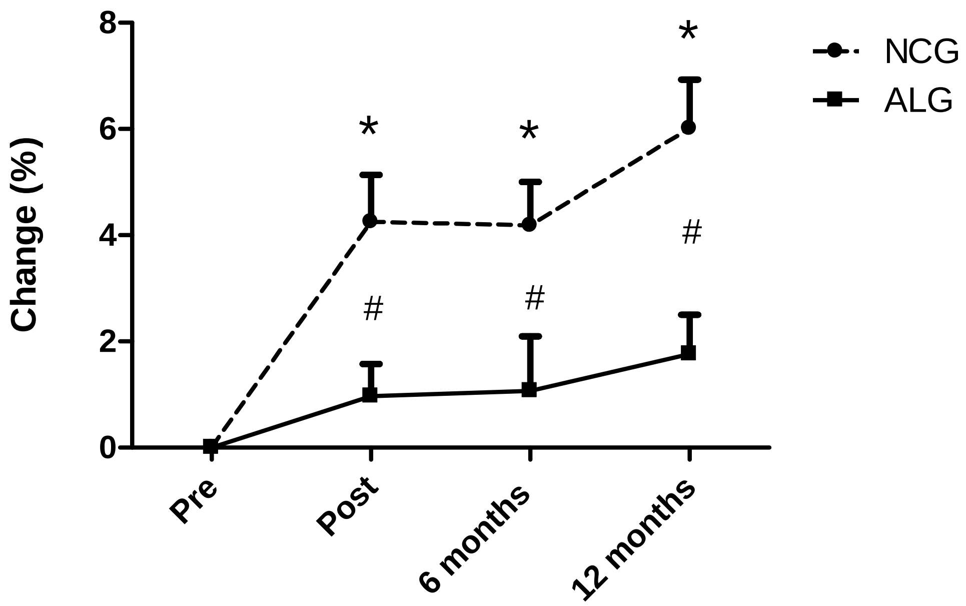

Figure 3.

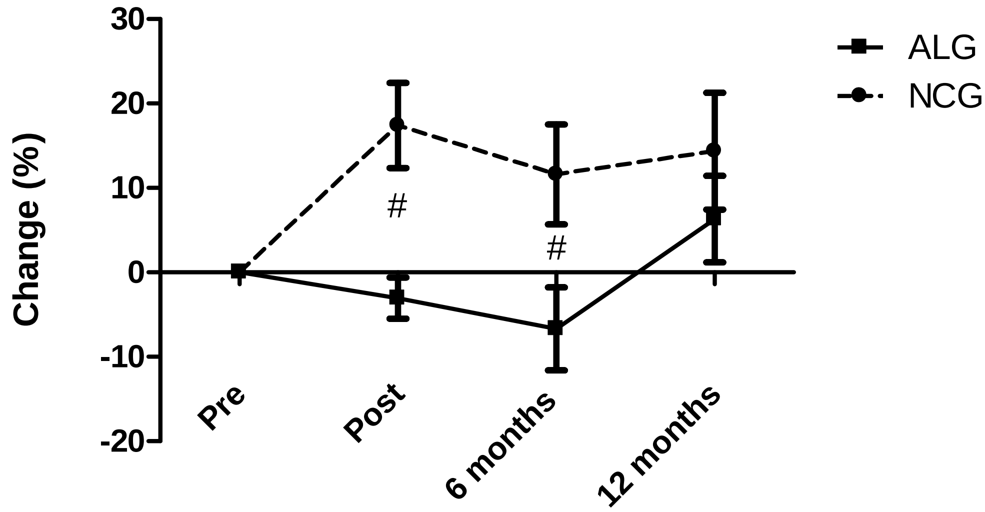

Figure 4.

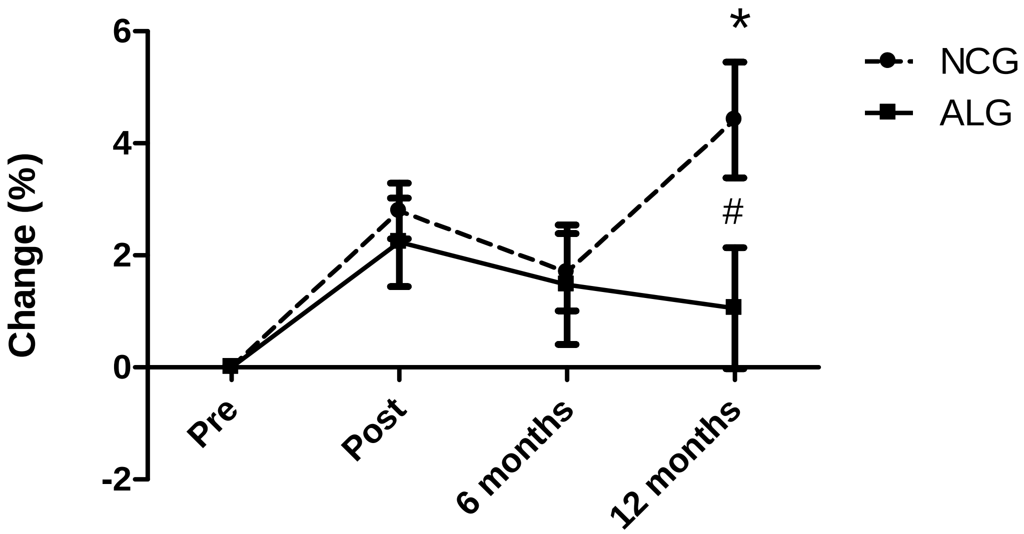

Table 1. Baseline data presented as mean±SD

	NIG (n=12)	ALG (n=9)
Age (yrs)	18.5 ± 1.7	19.6 ± 2.7
Height (cm)	178 ± 8	180 ± 7
BW (kg)	67.8 ± 7.4	74.2 ± 5.7 *
LBM (kg)	58.5 ± 2.4	59.2 ± 7.2
FM (kg)	7.2 ± 1.8	9.0 ± 4.4 *
Total body fat (%)	11 ± 4	13 ± 6
Experience as athletes (yrs)	11.2 ± 2.8	14.2 ± 2.4
Training per week (h)	17.7 ± 6.8	16.0 ± 6.0
Strength training last season ($h \cdot week^{-1}$)	3.8 ± 0.5	3.9 ± 0.3

* = significantly different within groups
# = significantly different between groups

Table 2. Energy and nutrition variables presented as mean±SD.

	NCG			
	Diet registration	**Meal plan**	**6 months**	**12 months**
Energy intake (kcal)	2821 ± 1010	3562 ± 561 *	2838 ± 761	2723 ± 982
Protein (g/kgBW)	1.7 ± 0.7	2.5 ± 0.43 *	1.7 ± 0.4	1.6 ± 0.5
CHO (g/kgBW)	5.3 ± 1.8	7.2 ± 1.5 *	4.7 ± 0.8	4.9 ± 1.3
Fat (E%)	29.2 ± 9.8	23.5 ± 2.8 *	33.4 ± 5.9	28.2 ± 5.3
	ALG			
	Diet registration	**24h recall**	**6 months**	**12 months**
Energy intake (kcal)	2864 ± 640	3258 ± 229	3038 ± 1070	3047 ± 972
Protein (g/kgBW)	1.6 ± 0.5	1.8 ± 0.3 #	1.8 ± 0.6	1.7 ± 0.4
CHO (g/kgBW)	5.3 ± 1.3	5.0 ± 2.3 #	5.1 ± 2.0	5.3 ± 1.4
Fat (E%)	30.0 ± 8.9	34.4 ± 3.8 #	29.8 ± 2.6	27.6 ± 4.7

* = significantly different within groups
# = significantly different between groups

ERRATA

1) Page IX: abbreviation CMJ/1RM in parenthesis.
2) Page 18, l 10: removed "lean body mass".
3) Page 20, l 5 & 22: CHO replaced with carbohydrate.
4) Page21, l8: Body weight replaced with BM.
5) Figure design: body weight replaced with BM.
6) Page 29 l 12: added sentence:" .....three sub-maximal runs as specific warm-up".
7) Page 29 l 16: The following sentence has been changed from: "The athletes were instructed to stand with one foot on a marker, and time started when the subjects touched a mechanical switch (placed 88 cm from the marker) in the first step. Sprint time was thereafter measured with photocells every 10m."

   to:

   "The athletes were instructed to stand with one foot on a marker, and time started when the subjects left the marker in the first step. Sprint time was thereafter measured with photocells every 5m."
8) Page 30, l 11: The following sentence was deleted: " Strength tests were always preceded by a 10-min warm-up on a cycle ergometer".
9) Added "et al." to Kreider 1996.