HOMAWLO : HOW TO MAINTAIN WEIGHT LOSS ?

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HOMAWLO: How to maintain weight loss?

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Prof. Edith Hummler

To Alice and Jane,

my wonderful daughters
my sources of inspiration

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LIST OF ABBREVIATIONS

AgRP	Agouti-related peptide
AT	Adaptive thermogenesis
BMI	Body mass index
CCK	Cholecystokinin
GLP-1	Glucagon-like peptide 1
HOMAWLO	How to maintain weight loss
NPY	Neuropeptide Y
NWCR	National weight control registry
POMC	Pro-opiomelanocortin
REE	Resting energy expenditure
TEF	Thermic effect of food
VLCD	Very low caloric diet
WLM	Weight loss maintenance
WLoMs	Weight loss maintainers

SUMMARY: What does it take to maintain weight loss?

Weight loss maintenance (WLM) is the weak link in the battle against obesity. Surveys suggest that in the general population, 20% of the initially overweight persons having intentionally lost weight are able to maintain it. Understanding how these "successful losers" manage their weight could help devise efficient WLM interventions. National registries collect the characteristics of weight loss maintainers (WLoMs: previously overweight or obese persons with a weight loss of ≥10% maintained for ≥1 year). The most frequent self-reported strategies are very low energy and fat intake, and high levels of exercise. However, a closer look at the data suggests that the reported intake might be underestimated, since it is similar to the measured resting energy expenditure, and also that physical activity only just reaches normal recommendations. The particularities of WLM thus remain elusive, and while several studies compare WLoMs to weight regainers, none has yet compared WLoMs to persons with a long-term normal, stable weight.

Our HOMAWLO (HOw to MAintain Weight LOss) study and its mixed-method design aimed at gaining a more comprehensive view on WLM by comparing 16 WLoMs and 16 matched Controls with a lifetime normal, stable weight. Their diet, physical activity, eating behaviors, strategies and experiences were assessed by questionnaires and in-depth interviews. The major result was the supplementary burden of WLM, revealed by WLoMs' specific and rigid strategies, their tendency toward more vigorous exercise, their higher scores on eating disorders scales, and a discourse revealing constant worries about eating and weight. Despite all their efforts, their energy and nutrient intake were similar to those of the Controls.

In the meantime, recent publications of large WLM-intervention studies showed disappointing long-term results, with a difference of a few kilos at best between the "intensive" and the "control" groups. This led us to the hypothesis that an excessive drop in resting energy expenditure (REE), mostly described shortly after weight loss, might increase the drive to eat and thus partly explain the burden experienced by our participants. Moreover, coping with food cravings might be more difficult for those with high impulsivity levels, contributing to their higher restraint and disinhibition scores. Only a longitudinal study could verify these hypotheses, and we designed this and assessed its feasibility. We measured dietary intake, body composition, REE, physical activity, impulsivity, weight maintenance strategies and eating disorders among the 50% of initial participants who agreed to follow-up. Our pilot showed good feasibility. There was no evidence for systematically low REE among WLoMs, but our data suggested individual patterns of physiology and behavioral characteristics that should be further explored longitudinally, and taken into account when devising WLM interventions.

RESUME

Le maintien de la perte de poids (MPP) est le maillon faible dans la lutte contre l'obésité. Des enquêtes populationnelles suggèrent une prévalence de 20% de MPP, et une meilleure compréhension des stratégies qui y sont associées pourrait contribuer à l'efficience d'interventions de MPP. Plusieurs registres nationaux collectent les caractéristiques de *WLoMs* (Weight loss maintainers, des personnes initialement en surpoids ou obèses ayant maintenu une perte d'au moins 10% pendant au moins 1 an). Les stratégies le plus fréquemment mentionnées par les participant-e-s sont des apports énergétiques et lipidiques très faibles, et des niveaux élevés d'activité physique. Toutefois, une analyse détaillée de ces données montre qu'elles sous-estiment probablement leurs apports nutritionnels, similaires à la dépense énergétique de repos, et que leur activité physique atteint simplement les recommandations pour la population générale. Dès lors, les particularités du MPP restent indéfinies, d'autant que les études comparent le plus souvent les WLoMs avec des personnes ayant repris du poids, mais pas avec des sujets de poids normal stable.

Notre étude HOMAWLO (HOw to MAintain Weight LOss), de méthode mixte, avait pour but de décrire de manière plus globale le MPP, en comparant 16 WLoMs et 16 Contrôles appariés (de poids normal stable). Leur alimentation, activité physique, comportements alimentaires, stratégies et leur vécu ont été investigués par questionnaires et interviews approfondies. Le résultat principal était le fardeau accru lié au MPP par rapport au maintien d'un poids normal stable. Ce fardeau était lié à des stratégies très spécifiques et rigides, à une fréquence accrue d'activité physique vigoureuse, à des scores plus élevés sur des échelles de comportements alimentaires, et à un discours révélateur d'un souci constant concernant l'alimentation et le poids.

Dans l'intervalle, la publication récente de résultats d'études d'intervention suscitait la déception : à long terme, l'effet des interventions « intensives » n'étaient que de quelques kilos. Ceci nous a conduits à investiguer l'hypothèse d'un déclin accru de la dépense énergétique de repos (DER), jusqu'alors décrite immédiatement après la perte de poids, et qui, s'il persistait durant le MPP, pourrait contribuer à expliquer les difficultés des WLoMs. De plus, le niveau d'impulsivité pourrait rendre plus difficile le contrôle des prises alimentaires. En vue d'une étude longitudinale permettant de vérifier ces hypothèses, nous avons mené une étude de faisabilité, dans laquelle nous avons mesuré les apports alimentaires, la composition corporelle, la DER, l'activité physique, l'impulsivité, les stratégies de MPP et les comportements alimentaires auprès des participant-e-s à HOMAWLO ayant accepté le suivi (50%). Le pilote a démontré une bonne faisabilité. La DER ne semblait pas systématiquement plus basse chez les WLoMs, mais les résultats suggéraient des patterns individuels qui devront être investigués et pris en compte lors du développement d'interventions de MPP.

1. INTRODUCTION

Obesity has been defined as a health problem as early as in the fifth century BC by Hippocrates. However, it is only recently that its prevalence has risen dramatically, reaching 600 million adults worldwide in 2014 (1). This increase, of more than 200% since 1980, markedly affects the mortality risk, especially among younger adults (2-4). A thorough analysis by Olshansky et al. predicted a decrease of life-expectancy in the American population, leading to the conclusion that *"Unless effective population-level interventions to reduce obesity are developed, the steady rise in life expectancy observed in the modern era may soon come to an end and the youth of today may, on average, live less healthy and possibly even shorter lives than their parents"* (5). As of today, despite decades of research and thousands of scientific publications contributing to our understanding of obesity and its biological, psychological and social components, despite our awareness of the threat represented by this disease in terms of public health and health care costs, despite individual determination, specialized care and the design of numerous diets, lifestyle interventions and even pharmaceutical treatments, the obesity epidemic is gaining speed.

However, next to the alarming reports about the worldwide rise of body weight, there is evidence that weight gain is not ineluctable, and that intentional weight loss is not always doomed to fail. Our goal, with this work, is to describe weight loss resistance and weight loss maintenance and to provide original data illustrating the interactions of some biological and behavioral components influencing the individual fight against weight gain and obesity.

1.1. Weight loss resistance

In the short term (6 months), state-of-the-art weight loss programs consisting of comprehensive, multicomponent lifestyle interventions result in 5 to 10 kg of weight loss on average (6-9). The studies reaching more spectacular results report high attrition rates, which restrict the applicability of their findings to unselected patients (10-12). Several well conducted trials have shown that isocaloric diets with various proportions of proteins, carbohydrates or lipids are equally efficient (7,

8, 13-15), and that the variable most strongly related to success is the intensity of the intervention, notably the number of sessions attended (9, 16). These are usually far greater than what is common in usual care (7, 15), which lessens the generalizability of published results. Once weight loss is initiated, average body mass generally falls sharply during the first six months, before climbing back (6). The initial rate of weight loss (16, 17) and the satisfaction with the new weight (18) positively predict the long term outcome, but on average, the sustained weight loss over four years reaches a mere 3 to 4 kg (6, 19-21). This is close to the definition of weight stability (22) and even though an average weight loss of 5% has been associated with better health determinants in groups of obese persons, it is far from matching the expectancies of overweight individuals.

This resistance to weight loss has been observed already in 1959 by Stunkard, a pioneer in the treatment of obesity. At that time, the prevalence of obesity in the United States of America was only 12% (it has more than doubled since), and Stunkard, in this seminal paper based on his clinical observations, wrote that among 100 persons, only 2 had stabilized their weight loss two years after the initiation of their obesity treatment (23) leading him to state that *"We can acknowledge that treatment for obesity is a terribly difficult business, one in which our experts achieve only modest success, and the rest of us, even less"* (23).

Stunkard's observations have been followed by numerous studies with similar conclusions, leading to a pessimistic vision of the treatment of obesity, as stated for example by Crawford et al., more than 40 years later: *"(…) most people will be unable to avoid weight gain and very few will manage to lose weight.*" (19). Results such as these may have contributed to the negative stereotyping of obesity in the medical profession. In a survey among 600 general practitioners, Foster et al. have shown that these physicians had very negative views on patients suffering from obesity, and mostly felt unable to help them lose weight (24). They also felt that their patients suffering from obesity would reach a normal weight if they were sufficiently motivated (24). Weight bias has also been reported in large proportions of medical students (25). This appraisal of obesity, considered as a motivation problem,

has been largely internalized by the affected persons, who blame themselves and their supposed lack of willpower for being overweight (26).

This “blame the victim” attitude seems to persist despite the scientific knowledge provided by research on biological determinants of weight gain and weight loss resistance. Indeed, numerous studies on the neurobiology of appetite have made clear that the pathways controlling food intake, although designed to maintain a generally stable weight, are unable to cope with the constant stimuli and exposure to palatable food[1] (27-33). Under normal conditions, several processes interact in order to keep body weight within a predetermined range, which is largely controlled by genetic factors. This quasi-homeostatic system contributes to weight’s stability despite day-to-day fluctuations of dietary intake and energy expenditure (31, 32). The central nervous system is a major player in this regulation, especially the hypothalamus, which is the target of neuropeptides and hormones involved in the regulation of appetite. Some of these substances are orexigenic, such as the neuropeptide Y (NPY) and the agouti-related peptide (AgRP), or the gut-released hormone grehlin. Others are anorexigenic, such as pro-opiomelanocortin (POMC), the gut-released cholecystokinin (CCK) and glucagon-like peptide-1 (GLP-1), or the hormone leptin, synthesized in the adipocytes. When energy stores are sufficient, or when food is consumed, satiety signals act in order to prevent further intake (30, 32). Conversely, when weight loss occurs, an efficient counter-regulation process decreases or delays the release of satiating hormones and increases the orexigenic substances, favoring the restoration of initial weight (34-36).

This physiological steady-state can, however, be overridden by signals from other brain systems, particularly the cortico-limbic system and the so-called “reward pathways” (32, 37). These signals, related to the dopaminergic, opioidergic and cannabinoid brain systems, are involved in the hedonic process at work when food intake is driven by pleasure rather than necessity. It has been suggested that the regulation system is insufficiently powered to cope with an environment which provides a

[1] Social determinants also play a large role but will not be discussed here.

high availability of energy dense, palatable foods (32, 33). It is probable that some individuals are more susceptible than others to the reward signals (37), in part because the cortico-limbic areas are also concerned with learning and memory, mood and emotion (27, 29, 38). Also, it has been hypothesized that some persons with obesity might have a less efficient reward system (blunted dopaminergic response to food consumption), necessitating a higher food intake to activate the reward signal (39).

The many biological systems involved in the complex regulation of food intake are elegantly displayed by MacLean in Figure 1 (33). Our work will focus on resting energy expenditure and body composition, and will not address the endocrine, neural or bacterial factors.

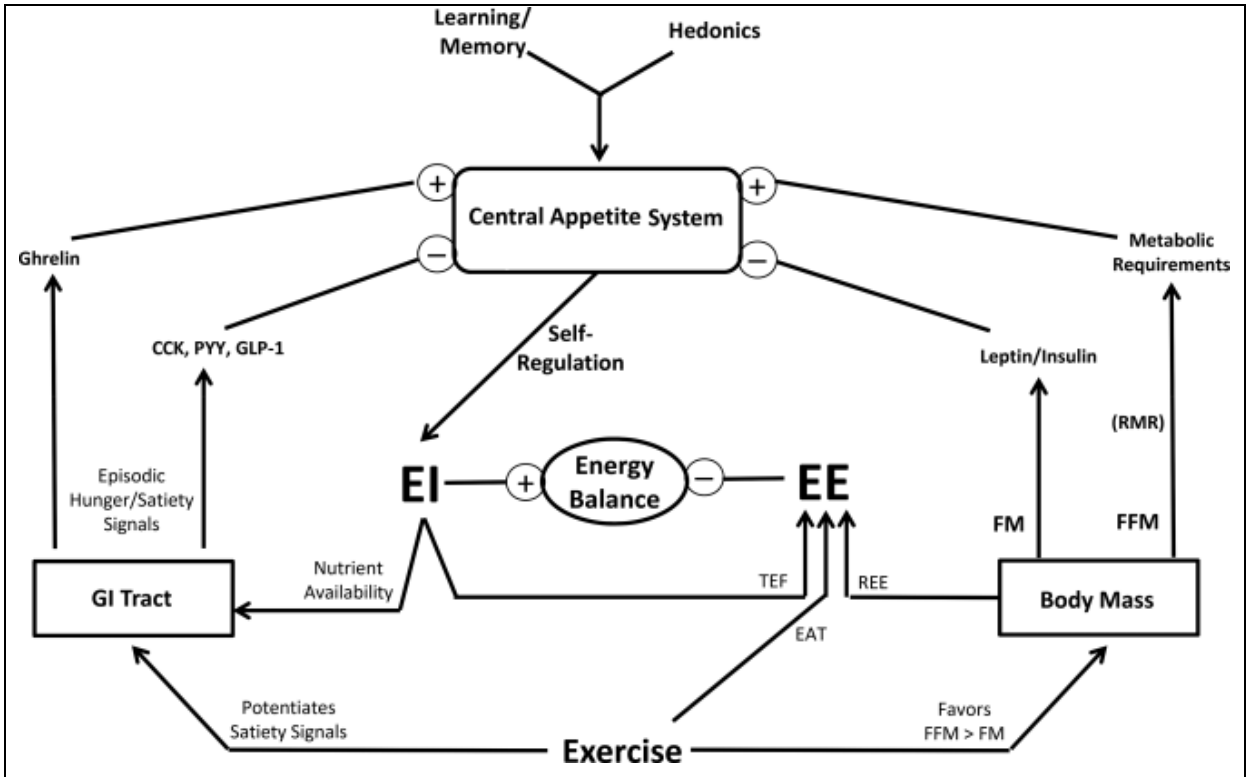

Figure 1: Biological inputs of appetite regulation.

The key biological effectors of appetite are placed in the context of the energy balance relationship (energy intake, EI; expended energy, EE; thermic effect of food, TEF; exercise activity thermogenesis, EAT; resting energy expenditure, REE; resting metabolic rate, RMR). Separate effects of fat-free mass (FFM) and fat mass (FM) denote stimulatory and inhibitory inputs, respectively. The gut provides

feedback through neural and endocrine paths that involve the episodic hunger and satiety signals coincident to nutrient availability and the prandial state. These biological inputs operate in a neural architecture established early in life that dictates food preferences. Exercise may influence appetite through its impact on these biological inputs, but its overall impact is variable and complicated by compensatory eating behaviors. The built-in redundancies, complexities, and individual variability, with each aspect of food preference and these feedback systems, which are rooted in the underlying genetics, establish a daunting biological complexity to the nature of appetite control.

Reproduced with permission, MacLean et al. p. S9 (33).

Despite the understanding that obesity is the consequence of an intertwined set of determinants, and even though comprehensive guidelines for the treatment of this condition have been published (8, 40, 41), the prevalence of obesity is still rising. Moreover, the apparently poor odds of success do not prevent individuals from attempting to lose weight, irrespective of their current corpulence: in the UK, 39% of the population reported actively trying to lose weight in 1997, a rate that increased to 47% in 2013 (42). A systematic review including 72 studies published in 2016 (including more than 1 million subjects) has shown that 42% of the general population worldwide seeks to lose weight, and 23% actively tries not to gain weight (43). Among persons with overweight or obesity, these rates are even higher, with at least 70% trying to lose weight in France (44) and between 44 to 65% in the United States (45). In Switzerland, 30% of the persons with normal weight, and 70% to 80% of people with overweight or obesity want to lose weight, but only 13% are following a diet (46). Are people unaware of the low odds of successful weight? Or do they believe in the heavily marketed "super-diets" promising slimming waistlines? The fact is that the persons following weight loss diets often undergo a succession of weight loss and regain phases, the so-called weight cycling, which has raised the concern of an increased health risk compared to stable overweight or obesity (47, 48). The risk related to weight cycling has been challenged by methodological limitations, such as the lack of a

standard definition, the variability of the included population, and the lack of distinction between deliberate and unintentional weight loss (49, 50).

Weight cycling has also led to the assumption that weight loss diets could be responsible for ultimate weight gain, because several studies have shown an association between the number of diets and a higher body mass index (51, 52). Moreover, a longitudinal study among more than 1'660 pairs of twins led by Pietilainen (53) has shown that, in monozygotic pairs, the dieting twin weighed more than their non-dieting counterpart (BMI was 0.4 higher). In dizygotic pairs, the difference was 1.7 points of BMI at the age of 16, and 2.2 at the age of 25. Another prospective study has shown increased odds of become obese after following diets among 8'824 Australian adults participating in a national survey (21). The odds ratio of suffering from obesity was 1.9 for those who had followed a weight loss diet during the past year compared to those who did not. The odds ratio was 2.9 for those who had followed more than one diet and 3.2 for those who were still on a diet (21). Several authors have argued that this co-occurrence of dieting and weight gain does not prove that the first is a causal factor of the second (54-56). To them, it only shows that people prone to weight gain are more inclined to follow weight loss diets, and that dieting is merely a proxy for weight gain vulnerability. The controversy is ongoing, and for now there are no data ascertaining that obese-prone persons would have gained less weight without dieting than after trying several weight loss diets. Some results even suggest that several attempts are necessary to achieve weight loss (57-60). For example, among 54 women having successfully achieved 10% weight loss, only 16% were attempting weight loss for the first time, and 18% had tried at least 5 times. Those who had attempted more often had not a lower one-year success rate than the others (58).

In summary, current lifestyle treatments seem unable to counter the biological regulation favoring weight gain in an obesogenic environment. Unfortunately, most studies report the average weight loss, whereas considering the proportions of persons able to lose at least 5% or 10% weight would give a more comprehensive picture of the treatment results. Also, it might be useful to explore the

characteristics associated with weight loss maintenance, instead of focusing on weight loss resistance and weight regain.

1.2. Weight loss maintenance: from clinical observations to national registries

The prevalence of weight loss maintenance is hard to estimate, because many data are drawn from clinical settings and thus not representative of the general population. In 1994, Brownell and Rodin wrote about the selection bias affecting most studies on weight loss, which included patients of specialized consultations for obesity and eating disorders, and who were presenting several comorbidities and great difficulties to lose weight (61). A few years later, Bartlett et al. tried to answer the question whether *"the prevalence of successful weight loss and maintenance was higher in the general community than in the research clinic"* with a systematic review (62). They qualified the methodological quality of the included studies as very poor and they could not perform the planned meta-analysis. They included 8 studies, reporting rates of "self-cure" between 9% and 43% in the general population. The definitions of obesity and weight loss maintenance varied between the studies (loss of 5kg, 10 kg, 5%, 10%, 15% or 2 BMI units, sustained for 6 month or 1 year). Only three studies had large population-based samples (62). This attempt was followed by a survey in a small, but representative sample of the US population (n=474) (63). Among the 145 persons who reported an intentional weight loss of at least 10% of their maximum weight, 69 (47.6%) had maintained it for at least one year. When considering only those with an initial body mass index ≥27, the rate of one-year weight loss maintainers was 20.6% (and 11% maintained weight loss for over five years). The authors prudently concluded that *"[they] reject the notion that weight loss maintenance is impossible, while [they] acknowledge that [it] is difficult"* (63). Several other surveys have taken place since then (64-66); their characteristics and results are summarized in Table 1 (Appendix I). By then, interest in weight loss maintenance was ignited and had led to the founding of what would become the largest provider of publications on weight loss maintenance: the National Weight Control Registry (NWCR) (http://www.nwcr.ws/). This ongoing cohort study includes "successful weight losers" who fill questionnaires annually. In Europe, several registries have also

been started, recruiting persons successful at maintaining weight loss according to various definitions (Table 2, Appendix I). Although these registries are not designed to provide a prevalence of weight loss maintenance, they confirm Brownell and Rodin's assumption: the maintenance of weight loss is higher in populations presenting a variety of characteristics than in clinical populations.

1.3. Factors of weight loss maintenance: observational studies

The registries, together with other observational studies, provide useful knowledge on the main factors related to weight loss maintenance (WLM). The variety of methods used to collect the data (most often self-reported) provides a somewhat fragmented view on possible determinants of WLM, but also illustrates their complexity and their variety. Quantitative and qualitative designs complement each other and give a wider insight of the personal characteristics and experiences related to WLM. Some studies include a control group (either of normal weight or with overweight), affording a different perspective on the results.

Dietary intake and physical activity

The earliest publications from the NWCR reported very low energy intake (1'400 kcal/day on average), low fat intake (24% of energy) and high levels of physical activity (2'834 kcal/week) as the main recipe for successful WLM (67, 68). Subsequent analyses of the growing cohort have repeatedly reported these figures, implying why WLM was hard to sustain.

Energy intake might have been underestimated however, because it matches the resting energy expenditure of 1'450 kcal/day measured in a subsample of the NWCR (n=40) (69). Data from the National Portuguese registry showed that the dietary intake of persons with WLM was within the normal range (2'200 kcal/day from which 33% from fat) (70).

An objective measure of physical activity using accelerometry in a subgroup of NWCR showed results similar to those of the questionnaire, but it also showed that the levels of physical activity were not higher than in a group of normal weight controls (71, 72). These measures also revealed a high variability among the groups: whereas 90% of the NWCR participants reported using physical activity

as a WLM strategy, 25% of them spent less than 1'000 kcal/week and 15% less than 500 kcal/week (73). The NWCR participants were more often found in the sedentary or the very active groups, while the normal weight controls more often reported regular and moderate activity (71). The Portuguese registry found that their participants simply reached the recommendations to stay healthy: 78% reported > 150 minutes/week (a little over 20 minutes per day) of moderate to vigorous physical activity (50% reported at least 35 minutes/day).

So it seems that dietary intake and physical activity associated with WLM are within the recommendations for the normal population. This does not mean that they are easy to achieve. In a survey, Sciamanna et al. (74) have asked more than 1000 participants about their strategies for weight loss and for WLM, instead of asking them to choose among a list. It appeared that numerous strategies were used to reach the usual reported "eating less calories" or "practice physical activity". Moreover, WLM strategies were often different from those for weight loss. Among 18 practices associated with weight loss, only 10 were also associated with WLM, and four practices were associated with WLM but not with weight loss (74).

Strategies for WLM

Several qualitative and quantitative studies have shown that a number of practical strategies are necessary to control intake, such as limiting portion sizes (74-76), avoiding fast food restaurants (19, 77, 78), avoiding fat in the diet (74, 77, 79), sticking to the weight loss diet (80), controlling food intake (81), increasing fruits and vegetables (70, 74, 78), limiting carbohydrates, candy or soft-drinks (74, 78, 82). To increase physical activity, the most frequent strategies were making time and prioritizing (77, 83), sticking to a plan or a routine (74, 75, 79, 84) and watching less television (85).

Two other strategies have been very consistently reported by successful weight loss maintainers: self-weighing (57, 74, 76-78, 86-91) and consuming breakfast (70, 77, 92, 93). It is difficult to evaluate the contribution of these practices to weight loss maintenance, because most studies lack a control group. However, a longitudinal analysis of the NWCR data shows that weight regain was associated

with the decrease of both physical activity and self-weighing, and with the increase of fat intake (94). A few cross-sectional (mostly qualitative) studies included groups of weight regainers for comparison, and reported the lack of weighing or the absence of adequate reaction to weight regain (79, 81, 89, 95), the lack of physical activity (77, 84, 90) and the absence of breakfast[2] (93) as reasons for weight regain.

The long term maintenance of WLM strategies is accompanied by high restraint and low disinhibition, as shown by the data of the NWCR (57, 96-98). High levels of self-control and restraint have also been reported by other studies (91, 99-101). Over time, the increase of disinhibition has been associated with weight regain (102, 103). Whereas motivation in itself does not seem to be a factor of success (i.e. persons who regain weight are similarly motivated as those who maintain weight loss) (83), problem solving, positive self-talk and coping skills (81, 89, 90, 95), self-rewarding and goal-oriented thinking (74) were reported as favoring WLM.

Another determinant of success is the quality of social support, as shown by Karfopoulou et al. in their Greek cohort (104). From their results, it appeared that participants with sustained weight loss maintenance (n=289) had quantitatively less social support than those who regained weight (n=122), but of different quality. The weight loss maintainers received more compliments, whereas the regainers received more advice. The entourage of the maintainers participated more often in the changes, when that of the regainers provided encouragements. The support towards the maintainers was associated with less energy intake (assessed with 24 hour diary), which was not the case for the regainers. In several qualitative studies, support and accountability were also identified as success factors (75, 84, 105, 106).

In summary, weight loss maintenance is the result of a large set of dietary and behavioral strategies, as well as psychological and social factors. Because these strategies seem to vary from one individual to another, they probably need to be tailored individually. Nevertheless, some are ubiquitous in the

[2] In men only, and with a conservative definition (first eating episode consumed at home).

aforementioned observational studies and should not be overlooked when designing an intervention for weight loss maintenance.

1.4. Weight loss maintenance interventions

The reviews aiming at identifying successful WLM interventions are mostly inconclusive, principally because the trials rarely differentiated the phase of weight loss from that of maintenance, and also because the interventions were insufficiently described (107-111). Other limitations include high attrition rates, short duration, or the absence of a control group (111-113). Three reviews provide useful conclusions: Lee et al. (114) showed that technology-based interventions did better in preventing weight regain compared to no intervention at all, but not as well as personal contact, which, moreover, had lower attrition. Personal contact with a professional was also identified as a critical component in a meta-analysis on the effect of extended care on WLM (115) and in another, earlier review (116) which, besides, showed small but significant effects of physical activity programs and problem solving skills.

In the absence of a recent review encompassing various interventions for WLM (117)[3], we analyzed the literature reporting on controlled trials where the participants were randomized after their initial weight loss. The duration of the WLM interventions ranged from 6 to 30 months, with or without a follow-up after the end of the intervention (also from 6 to 30 months). The number of participants ranged from 40 to several hundreds, with attrition rates that increased with longer follow-ups.

We found two types of studies: the single component trials where one or two constituents of the intervention were manipulated and compared (the content, such as foods, nutrients, types of exercise, or the mode of delivery, such as type of support, procedures, number of contacts), and the large multicomponent trials.

[3] A Cochrane review started in 2009 has been withdrawn in 2015, before it could be finished. We could not find any information about the reason.

Single component trials: diet & exercise

We found 11 studies that manipulated participants' diet (n=9) or physical activity (n=2) (Table 3, Appendix I). All the interventions reached the goal of weight stabilization or even additional weight loss, but the differences between the interventions were small and rarely statistically significant. Regarding diet, prepackages meals did no better than normal food when similar counselling was given to all groups (118); drinking 5 dl of water before each meal did not improve weight maintenance when it was added to a program including daily weighing, step counting and encouragement to eat more fruits and vegetable (119); adding a component of reducing energy density to an intensive cognitive behavioral therapy did not improve the results (120); fiber supplementation had no additional effect (121). Regarding physical activity, exercising for 45 minutes three times a week was useful for WLM when added to of a low fat, ad libitum diet with weekly group meetings and monitoring, but there was no difference whether the exercise consisted in walking or resistance training (122), and adding 180 minutes of exercise to biweekly group sessions with a therapist did not improve WLM (123).

Two studies manipulating protein content showed statistically significant results, but with a very small effect size (124) or for a short duration only (125). The first study was a large European study (the Diogenes study) including more than 900 participants, and comparing ad libitum diets with various contents in proteins and glycemic index foods (124). The diets with high protein content were associated with less weight regain, but even if the difference between groups was statistically significant ($p<0.005$), it was in fact inferior to 1 kg after 26 weeks. The second study also showed a significant effect of an increased intake of protein (30 g/day in one drink). Both groups (total n=120) received intensive support (monthly visits and counselling by a dietician) but at the end of the 6 months, the supplemented group had regained 20% of their weight, versus 55% in the control group ($p<0.05$). The average weight loss was 6.7 kg and 3.8 kg, but as these data include the initial weight loss (4 weeks of very low caloric diet), it is not possible to assess the effectiveness of the supplementation on the WLM alone (125).

On the other hand, some interventions showed promising results despite not reaching statistical significance: for example, in a trial including 334 persons (126), those consuming a very low caloric diet in response to weight regain of 3 kg seemed to have a higher chance of 2 year WLM, compared to those who consumed such a diet on a fixed, intermittent basis (2 weeks of VLCD every third month): the prevalence of WLM was 62% vs 44% (NS), suggesting that tailoring the intervention might be useful (126). This was also suggested by a trial conducted by Fogelholm et al. (127), who compared medium with high levels of walking (1'000 kcal vs 2'000 kcal per week) and with no walking (control). Over the 10 months of the intervention, the group with the medium intensity seemed to regain less weight (-0.7 kg) than the higher intensity (+0.2 kg SD 0.9) or the controls (+1.7 kg SD 0.8) (NS). This apparent paradox (gaining more weight with higher levels of exercise) was related to the fact that the adherence was much better in the medium intensity group, stressing the fact that the intervention has to be adapted to the possibilities of the target group. Finally, a study by Toubro et al. (128) suggested that after an eight week very low caloric diet, eating an ad libitum, balanced diet might be more effective than a reduced energy diet for 1 year WLM (+0.3 kg vs +4.1 kg $p = 0.08$) with the same support otherwise.

In summary, there is no evidence that a particular dietary component or a specific exercise regimen, other than respecting energy needs and practicing at least 45 minutes of physical activity three times a week, improves WLM.

Single component trials: intervention techniques & support

When compared to the results of a control group (with minimal or no intervention), any intervention seemed to be better than none (123, 129-136), but only if the intensity of the intervention was considerable: for example, Simpson et al. compared intensive intervention, less intensive intervention, and none (with similar content) in 170 persons who had previously lost at least 5% of weight (137). The "intensive" intervention consisted in 6 individual sessions + 9 phone calls over one

year, which corresponds to a standard follow-up in Switzerland[4] and might not have been enough to have an effect, as the 2.8 kg average difference between the intensive group and the controls did not reach statistical significance (95% CI -6.1 - +0.5). It seems that the minimal intensity of effective interventions is higher than in usual care: weekly reminders by email + monthly personalized emails for at least 6 months (134), or monthly visits + phone contacts for 12 months (135). However, there does not seem to be a linear correlation between the intensity of the support and WLM. For example, a very intensive, coach-led approach gave similar results to a behavioral intervention with dietary information over the phone: both groups had less than 1 kg weight regain during the 1-year WLM phase, whereas a control group receiving cognitive behavioral therapy regained 6 kg (p=0.06) (138). Similarly, group counselling (bimonthly for 6 months and then monthly for another 6 month) was as good as peer-support and monthly phone calls (139), and adding phone calls to face-to-face contacts did not improve the outcome (140). This shows that "more" is not always better.

Beside their intensity, the content and mode of delivery of the interventions have an impact on their effectiveness. For example, self-monitoring, which has been repeatedly reported as an important factor of WLM in observational studies, has been assessed by Wing et al. (136). They randomized 314 participants (who had lost an average of 19 kg over the past two years) into three arms: a control group, who received a quarterly newsletter, and two intervention groups focusing on weekly self-weighing and self-regulation: one group received telephone and face-to-face advice related to the amplitude of weight change, the other group received the same advice through a website or by email. Over the 18 months of follow-up, the internet-intervention group regained 4.7 kg, similar to the control group (+4.9 kg, NS), whereas the face-to-face group regained 2.5 kg (P=0.05 with control group). From this study, self-monitoring seemed useful when accompanied by a personal counselling interaction. Another study showed that adding monitoring to a 3 months WLM intervention based on cognitive behavioral therapy did not improve the results after 18 months of follow-up (120). So, it seems that self-monitoring is not effective *per se*, but can be a useful complement to counselling.

[4] In Switzerland, insurers reimburse 6 dietetic consultations per year, renewable once.

An interesting study showed that an intervention could end up in different results depending on whether the focus was on exercise or on weight (141). After an initial 6 months weight loss phase, 67 patients were randomized into two WLM interventions, both of which provided bimonthly group sessions, a fixed caloric amount and 150 minutes of walking per day. In one group, the sessions were devoted to exercising and discussing exercise-focused strategies (including friendly competitions and prizes when goals were met). In the other group, the focus was on weight and the sessions were devoted to discuss participants' difficulties. In the exercise-focused group, 22% of the participants adhered to the caloric objective, vs 44% in the weight-focused group ($p<0.1$). On average, participants in the weight-focused group maintained 91% of their weight loss, vs 54% in the exercise-focused group ($p<0.01$). From these results, it seems that focusing too much on physical activity might contribute to forget dietary intake constraints.

Building the WLM components into the initial weight loss intervention seemed promising in a trial by Kiernan et al. (142): 267 participants were randomized to receive one of two interventions: "Maintenance first" (8 weeks of weight stabilization skills, followed by 20 weeks of weight loss intervention) or "Weight loss first" (20 weeks of weight loss, followed by 8 weeks of problem solving skills). Both resulted in approximately 9% of weight loss at the end of the intervention, but the weight regain over the subsequent year was only 1.4 kg in the Maintenance first group, versus 3.3 kg in the Weight loss first group ($p=0.001$).

Addressing WLM issues in a way that is tailored to participants' needs seems important. In a one-year WLM intervention study, Perri et al. (131) compared relapse-prevention training (didactic lectures about specific maintenance skills) and a problem-solving approach (therapist-led group discussion about weight management issues from the participants). The problem-solving group had the best results (-10.8 kg SD 8.7 vs -5.9 kg SD 6.4). A ≥10% weight loss was maintained by 35% of the problem-solving group, 21% of the relapse-prevention group, and 6% of the control group.

Multicomponent trials

We identified the published results of three large randomized controlled trials that compared multicomponent WLM interventions with usual care: the Weight Loss Maintenance Trial (143-145), the Keep it Off Trial (146, 147) and the Maintain Study (148, 149).

The Weight Loss Maintenance Trial (143) is the longest WLM intervention (5 years so far). After a 6 month weight loss program (balanced diet and exercise), 1'032 participants were randomized into three groups for a 30 months intervention: Personal Contact, Interactive Technology, or Self-Directed (=control group). Participants in the Personal Contact group had monthly contact with an interventionist over the phone (5 to 15 minutes) as well as an individual face-to-face contact (45 to 60 minutes) every 4th month. Those in the Interactive Technology group were encouraged to regularly use an interactive website, with reminders (email and phone) when they failed to log on. Both interventions incorporated constructs such as problem-solving, relapse prevention and support, as well as features associated with sustained behavior change such as self-monitoring, accountability, and motivational interviewing. The control group received printed guidelines and met briefly with a professional at the 12-month assessment visit (143). During the 30 months of WLM intervention, about 50% of the lost weight (5 kg) was regained (144). Compared to the control group after 18 months, the Personal Contact group regained 1.8 kg less ($p<0.001$) and the Interactive Technology group regained 1.1 kg less ($p<0.005$). Compared to the control group after 24 months, the Personal Contact group regained 2 kg less ($p<0.001$) and the Interactive Technology group regained 0.9 kg less ($p<0.05$). After 30 months, only the Personal Contact group did better than the control group, regaining 1.5 kg less (0.001). The differences in weight regain between the two intervention groups were statistically significant at months 24 and 30 (mean difference: 1.1 and 1.2 kg, $p<0.01$). From these results, it appears that personal contact, although limited in frequency and duration, provided a modest benefit, whereas the advantage of interactive technology was not sustained over

time (144). The trial was pursued for 30 more months (145), and the participants of the Personal Contact group (N=196) were randomized to no further intervention or continued intervention. The initial control group was also followed (N=218). This additional intervention did not provide supplementary benefit in terms of weight regain (difference in weight regain 0.6 kg, 95% CI -1.4 to 2.7, p=0.55) (145).

The Keep it Off Trial (146) is a phone-based intervention designed to promote WLM. More than 400 patients who had previously lost at least 10% weight were randomized into a guided or a self-directed weight maintenance program. The guided program included a 10 session course book which was worked through during 10 biweekly phone coaching calls, followed by less frequent calls over the course of the intervention. Participants were encouraged to monitor dietary intake and weight, and to engage in physical activity. Participants received individualized advice based on (self-reported) weight charts. Extra support was provided when weight-regain occurred. The self-directed group received the 10 session course book and a monitoring logbook, as well as two phone calls. The odds for 24 month weight maintenance were better in the guided group (OR 1.37, 95%CI 0.97 to 2.03), but the effect size was small: weight regain was 0.8 kg (SD 6) vs 2.4 kg (SD 7) after one year, 2 kg (SD 7) vs 3.8 kg (SD 7) after 18 months, and 3 kg (SD 8) vs 4.8 kg (SD 8) after two years. The 1.8 kg weight difference at 18 months was statistically significant (p=0.028) (147).

The Maintain study (148) compared the efficacy of a 42-week intervention followed by 14 weeks without contact with a usual care program among patients who had lost at least 4 kg in a preliminary weight loss program. The intervention addressed maintenance skills, self-monitoring, physical activity, obtaining social support and relapse prevention, and offered group visits and phone calls. The frequency of contact was reduced over the course of the intervention. Participants were instructed to reach out to their dietician if a 1.4 kg regain occurred, in order to address difficulties. The usual care program mimicked the typical patient experience of no further intervention after participating in the weight loss program.

Weight regain was lower in the intervention group than in the usual care group (0.75 kg vs 2.4 kg, p=0.04). At the end of the 56 weeks, those in the intervention group had regained, on average, 15% of their weight loss, versus 42% in the usual care group (149).

Two other trials (16, 150) were not "purely" WLM trials, in the sense that the participants were randomized before weight loss, which makes the assessment of effectiveness difficult. We nevertheless decided to include them in this analysis, because the interventions were designed with a focus on WLM, and because the results distinguished between the WL and the WLM phases.

Jeffery et al. (150) based their program on the hypothesis that boredom is an important factor of noncompliance and relapse after weight loss. Their "Maintenance-Tailored Treatment" promoted different behavioral prescriptions in distinct units alternated with periods without intervention, whereas the control group (Standard Behavioral Treatment) consisted of typical recommendations for behavior change that remained constant over time. Over 200 participants were recruited in the community, randomized and followed for 18 months (6 months weight loss and 12 months WLM). The weight loss phase consisted in the same number of sessions in both groups, but with different content and organization. The Maintenance-Tailored Treatment emphasized variety, with six 8-week units with a particular topic and specific goals for each unit. Between the units, participants were given a 4-week break, with no further instructions than to use their own judgement. The Maintenance-Tailored Treatment was less effective than the Standard Treatment during weight loss (-5.7 kg vs -7.4 kg, $p<0.02$), but more effective for WLM: weight change during the first 6 months of WLM was similar in both groups (-2.4 kg vs -3.3 kg, non-significant), but during the subsequent 6 months, the Maintenance-Tailored group maintained their weight, whereas the Standard Treatment group regained 1.4 kg ($p<0.01$). Additionally, those in the Maintenance-Tailored group completed their home assignments better, reported higher self-efficacy and their perceived reinforcement from weight loss was higher. The small difference between

groups was partly attributed to the strong results of the Standard group, which were better than expected. Nevertheless, the proposed treatment shows promising results (150).

The Look Ahead trial (16) is a long-term lifestyle intervention trial that was designed to compare a very intensive intervention with a standard program in people with type 2 diabetes. Over 5'000 patients have been randomized before weight loss and followed for more than eight years. The intensive intervention offered an individual dietary plan tailored for a 7-10% weight loss, group and individual meetings, monitoring and physical activity recommendations for the first year. From the second year, the program focused on WLM and included monthly individual sessions as well as phone calls and emails. From the fifth year, phone calls and emails stopped, but monthly group meetings led by dieticians, psychologists and exercise specialists took place. The usual care intervention offered three group sessions per year during 4 years, and one yearly session from year five. The patients who asked for more help were referred to a primary care practitioner who would recommend any relevant intervention. Weight loss was greater in the intensive group at each time point, but both groups regained weight after the end of year one. After 8 years of follow up, the intensive group displayed an average of 5% weight loss, vs 2% in the standard group, but 27% of the intensive group had lost at least 10% of weight, vs 17% in the standard group. The major factor predicting WLM was the capacity of losing weight during the first year (16).

In summary, although most interventions usually reached their goal of improving WLM compared to no intervention or standard treatment, their effect size was usually small (1 to 3 kg on average) and their impact declined over time. It has to be noted that all the large trials were conducted in the US, which obesogenic environment cannot be equated to the situation in Europe. Therefore, the generalizability of the results is limited. Finally, although no "magic bullet" emerges, these studies show that several components (personal contact with a well-trained professional, problem solving skills and theory-driven diversified contents) can promote WLM.

1.5. What makes weight loss maintenance difficult?

As shown above, even the most comprehensive and longstanding programs bring very modest results. These WLM programs, similarly to weight loss interventions, target the two modifiable components of the energy balance: nutritional intake and physical activity. Despite a wide array of techniques intended to improve compliance, the average weight maintenance is low, and the large individual variability suggests that other factors are involved, such as resting energy expenditure, body composition and thermic effect of foods.

Resting energy expenditure and adaptive thermogenesis

When weight loss occurs, the energy needs of the body are reduced, sometimes beyond the predictions based on body composition changes. This excessive drop is called “adaptive thermogenesis” (AT) and has been considered as a factor compromising WLM in the context of obesity (151-153). However, its impact on weight regain has been rated as “exaggerated” by several authors (27, 154-156). AT was first described by Taylor & Keys. in their famous “Minnesota Experiment” of semi-starvation and refeeding ((157), cited by Dulloo (158)): in this study, the intake of 32 lean young men was restrained to half of their requirements for 6 months, leading to a 24% weight loss. AT was estimated at ≈200 kcal/day, representing 35% of the reduction in resting energy expenditure (REE), and was not explained by the loss in fat-free mass (reported by Müller et al. (159)). In this case, AT was a consequence of life-threatening weight loss, and its occurrence in the context of obesity needed confirmation. The studies summarized below show discrepant results, and both the level of AT and its persistence are subject to debate.

The study by Schwartz et al. (160) suggests the existence of AT in the context of weight loss. In this meta-analysis, including 71 weight-loss studies (1’450 initially overweight or obese subjects), they compared measured REE with the values predicted before and after weight loss by the Harris and Benedict formula. At baseline, the measured REE was slightly lower than predicted (-13.2 ±149.4 kcal/day), a difference that increased significantly after weight loss (-58.8 ±134.6 kcal/day, $p<0.01$).

This could mean that during the process of weight loss, the real energy expenditure moves away from the predicted numbers, with the limit that the Harris and Benedict formula, however robust, is not a very precise way to predict individual REE (161).

In order to quantify AT in weight reduced individuals, Camps et al. (152) compared measured and predicted REE at baseline, after 8 weeks of a very-low-energy diet, and 1 year after baseline (n=91). REE was measured by indirect calorimetry and predicted with the Westerterp equation, which takes fat free mass and fat mass into account (162). The patients lost 10 kg during the 8 weeks of energy restriction and regained 4 kg during follow-up. The ratios between measured and predicted REE decreased significantly from 1.004 ±0.08 at baseline to 0.963 ±0.07 ($P<0.01$) at 8 weeks and 0.984 ±0.068 ($P<0.05$) at one year, suggesting that AT developed during weight loss and was sustained for 44 weeks. Measured REE was 4% lower than the predicted value at 8 weeks, and 2% lower at 1 year. The correlation between AT and weight loss suggested that AT disappeared with weight recovery. The authors noted large variability as a limitation of the study (152).

To explore if AT persisted during WLM, Rosenbaum et al. (163) retrospectively compared 7 trios with matched sex and weight. Each trio was composed of two persons with reduced weight (one after recent -5 to 8 weeks- weight loss and the other with >1 year WLM), and of one stable-weight control. On average, the estimated AT (calculated as the difference between observed 24-h REE and that predicted on the basis of regression equations including body composition) was 161 kcal (±58) in the recent weight loss group, 143 kcal (±55) in the sustained weight loss group, and 40 (±54) in the stable weight control group. The authors concluded that weight loss was accompanied by a sustained decline in energy expenditure, regardless of the duration of WLM (163).

However, other studies have put into question the importance of AT. Redman et al. (164) randomized 48 healthy, overweight subjects into 4 groups: caloric reduction (25% of requirements), caloric reduction + exercise (total of 25% requirement), severe caloric restriction (<900 kcal/day) and a weight stable control group. State of the art measurements were performed (doubly labeled water,

metabolic chamber and DXA) and the results showed, at 3 months, a transient AT in both dietary restriction groups, but not in the restriction + exercise group. In another study, persons who had lost >40 kg through either surgery (N=13) or a diet (N=13) were compared. AT was higher in the diet group than the surgery group (419 kcal, ±169 vs 201 kcal ± 182, $p<0.05$), but was nonexistent after 12 months despite continuing weight loss (165).

These discrepancies can be related to differences in study populations or methodologies and will be discussed later. Nevertheless, it seems that AT could represent a metabolic hurdle on the way to WLM.

Body composition and weight regain

Because fat free mass is the main determinant of REE, its maintenance during weight loss seems beneficial. Evidence shows that fat free mass can be spared during weight loss when initial fat mass is high (166, 167). However, it has been suggested that weight regain favors fat mass which is less favorable and might render successive weight loss more difficult. This phenomenon has been described in lean adults by Dulloo et al. based on the data from the Minnesota trial, implying that weight loss, and more specifically the loss of fat free mass, would trigger a drive to eat persisting until fat free mass reaches baseline values, even though weight and fat mass have already been recovered (158, 168). This “fat overshooting” phenomenon has not been demonstrated in overweight or obesity, although several studies have shown that during weight regain after weight loss, the rates of fat mass regain were higher than that of fat free mass (169, 170). However, the assessment of body composition usually lacks precision and the observed differences encompass the measurement error (171). Bosy Westphal et al., in a study comparing body composition after weight regain (n=27) with that after stabilized weight loss (n=20) have shown that weight cycling did not negatively affect body composition assessed by MRI (172).

While it is not established that weight regain increases the proportion of fat mass in obese adults, it might be surmised that initial body composition could play a role in the risk of weight regain.

Thermic effect of food

Another factor that could affect WLM is the energy expenditure related to dietary intake, called the thermic effect of food (TEF) and corresponding to 5 to 15% of energy intake. It seems that some individuals have a very stable metabolic efficiency, whereas others present adaptations that oppose weight change, for example by converting excessive energy intake into heat (diet induced thermogenesis). It has been suggested that thermogenesis is blunted in a post-obesity state compared to persons with lifetime normal weight (173). Whether the type of weight loss diet affects this component of energy expenditure is unclear, because of the great individual variability of results (174). A low fat diet could reduce TEF compared to a very-low-caloric diet (175) and a ketogenic diet might slightly increase it, but the difference is at the limit of detection and, in the case of the ketogenic diet, its impact was detrimental to body composition (176).

In summary, the adverse effects of the changes of REE, body composition and postprandial thermogenesis after weight loss seem inconsistent. It is however necessary to better understand how these parameters affect weight loss maintenance in order to develop adequate, helpful programs for people who struggle with their weight.

1.6. Research question

As seen in the above introduction, the question is not “Is weight loss maintenance possible?” but “Why is weight loss maintenance attained by some, and not by others?” Indeed, while encouraging numbers of WLM prevalence demonstrate that a large minority can durably overcome overweight or obesity, the results of the intervention studies are puzzling: the recipes provided by successful weight losers do not seem to be applicable by just everyone. Could the experience of weight loss maintainers be explored further, in order to better understand what WLM entails? Are the determinants of weight maintenance different after weight loss, versus a lifetime stability at a healthy corpulence? The following chapters will address these questions by reporting the HOMAWLO (HOw to MAintain Weight LOss) study.

1.7. Aims and outline of the HOMAWLO study

Our goal was to assess a large array of determinants related with weight maintenance among persons who had previously lost weight, and to compare the results with a control group with a lifetime, stable normal weight. HOMAWLO was intended as an exploratory study supporting a subsequent grant proposal for a larger study.

In the first study, our goal was to assess dietary intake, daily eating patterns, physical activity and eating behaviors, and to explore strategies and perceptions of the experience of weight maintenance in two groups: one of individuals with WLM, and one of individuals with a lifetime, stable normal weight considered as a control group. We used a snowball procedure, a nonprobability sampling method where the study subjects recruit the participants across a variety of contexts, in order to avoid selection bias. The weight loss maintainers (WLoMs) (n=16) had lost ≥10% of their initial weight (initial BMI ≥25) and maintained the loss for ≥1 year. The Controls (n=16) had a lifetime normal, stable weight, and were matched for sex, age and socioeconomic status. Diet, physical activity and eating behaviors were assessed with validated questionnaires (177-180). Strategies, experiences and perceptions of weight maintenance were explored during a qualitative semi-structured interview (181).

In the second study, we explored weight monitoring and the role of self-weighing in the process of weight maintenance. This behavior, although repeatedly reported as an important component of WLM, might have negative consequences on psychological health, which makes it difficult to advise self-weighing as a safe component of WLM (182). Our objectives were to determine if self-weighing was used as a weight maintenance strategy, and to assess the behavioral and psychological consequences of self-weighing among WLoMs and normal weight controls. To that end, we performed a qualitative analysis of the discourse of the HOMAWLO participants.

The third was an exploratory study to assess the feasibility of a large scale, longitudinal study and to develop the hypothesis of adaptive thermogenesis as an obstacle for WLM. Our objectives were to

test the measurements body composition, resting energy expenditure, diet, physical activity and impulsivity, and to quantify the difference in resting energy expenditure between WLoMs and Controls. In order to estimate the attrition rate for a cohort study, we contacted the participants of the initial study for a follow-up. We set up a laboratory to test the procedures and the measurements and initiated collaborations with the EPFL and the University of Geneva for the data analyses. We developed a questionnaire assessing the weight maintenance strategies, based on the initial study. Diet was assessed with a 5-day food diary and eating disorders with validated questionnaires (179, 183).

2. RESULTS

The results of the HOMAWLO study, as well as the authors' contributions, are summarized hereunder. The full articles and manuscripts can be found at the end of the present document and in Appendixes II, III and IV.

2.1. What are the weight maintenance specificities among persons who have lost weight compared to persons with a lifetime normal, stable weight?

In this mixed-method, cross-sectional study, we compared 16 Weight Loss Maintainers (WLoMs) with 16 matched Controls recruited in the community through a snowball procedure. First, we found that although WLoMs consumed different types of food (more protein sources, low fat foods and artificially sweetened beverages) than Controls, their energy and nutrient intakes were similar. Second, both groups engaged in more than 1 hour of daily physical activity on average, but more WLoMs reported vigorous activity (53% vs 19%), and Controls were more often sedentary (38% vs 6%). Third, WLoMs' scores on the eating behavior subscales "restraint" and "disinhibition" were significantly higher than the Controls'. Fourth, the qualitative data showed that both groups relied on a large array of strategies to maintain weight, but that this process was more burdensome for WLoMs, who maintained a constant vigilance and an effortful control over their behaviors, whereas Controls were more confident and displayed a more relaxed attitude. In summary, despite similar nutritional intake, WLoMs experienced an additional burden maintaining weight loss compared to keeping a stable normal weight.

This study has been presented at several scientific conferences (184-187) and was published in Obesity Facts (Appendix II (188)). M. Kruseman designed the study, searched for funding and performed the data collection together with I. Carrard. M. Kruseman trained and supervised N. Schmutz who assisted with data collection. M. Kruseman analyzed the data and wrote the manuscript with the collaboration of I. Carrard.

2.2. Is self-weighing an advisable weight loss maintenance strategy?

This study was a secondary analysis of the one presented above, and focused on the role of self-weighing in the process of weight maintenance. The main result was that weight monitoring was central to weight control in both groups, but that the way it was performed and the responses to its results differed between WLoMs and Controls. First, WLoMs weighed themselves more frequently than Controls (3.3 ±1.5 vs. 1.2±1.4 on a scale ranging between 0=never to 6=several times a day). Second, WLoMs felt unable to assess their weight change without stepping on the scale, whereas the Control group was able to "feel" their weight very precisely. Third, both groups took action when their weight went up, but the modalities were different: the Controls went back to their habitual eating and exercising behaviors, whereas the WLoMs compensated drastically by relying on severe dieting strategies. Fourth, self-weighing triggered lower self-esteem, negative affects and even paradoxical effects (e.g. the "permission" to eat more when weight goes down) in a subgroup of WLoMs.

This study has been published in Appetite (Appendix III (189)). M. Kruseman designed the study, searched for funding and performed the data collection together with I. Carrard. M. Kruseman trained and supervised N. Schmutz who assisted with data collection. M. Kruseman participated in the analysis of this data set and the writing of the manuscript in collaboration with I. Carrard.

2.3. To what extent is resting energy expenditure involved in the resistance to weight loss maintenance? An exploratory study.

This exploratory study aimed at assessing the feasibility of a longitudinal study, and the participants of the initial study reported above were requested to take part in a follow-up, three years after the initial inclusion. We set up a laboratory for the measurements of resting energy expenditure (REE), body composition, physical activity and impulsivity, developed an electronic tool to improve data collection of food consumption (190) and initiated collaborations with the EPFL and the University of Geneva for the data analyses. Half of the participants accepted the follow-up (n=18), with geographic

distance being the main predictor for declining. The process proved to be very well feasible. Although the results should be considered with caution because of the small sample size, the following observations can be made: first, four participants of the WLoM group (50%) gained >5kg, and two of these reached >90% of their maximum weight (Regainers). Second, there was no evidence that REE dropped below expected values among WLoMs, and the predictive formulas tended to underestimate REE both in Maintainers and Regainers. Third, the comprehensive and multidimensional assessment of physical activity showed the variability of walking patterns, and notably the numerous short walking episodes reflecting personal preferences or capabilities. Fourth, although Maintainers were more severe than Controls in their weight maintenance strategies and especially food choices, they often abandoned self-weighing (50%) and food planning (50%), whereas they listed strategies that are not useful for weight maintenance, such as eating more nuts and organic food.

The results of this study were presented at the European Congress on Obesity (191). The manuscript (Appendix IV) was reviewed by L. Tappy. It will not be published because of the exploratory character of the study. M. Kruseman designed the study, searched for funding and performed the data collection with the collaboration of I. Carrard. M. Kruseman trained and supervised A. Aebi who assisted with data collection. M. Kruseman analyzed the data and wrote the manuscript with the collaboration of I. Carrard. M. Kruseman was involved in the project developing and validating an electronic tool for recording food consumption. This study was published in Nutrients (190).

2.4. Conclusion

In summary, the initial HOMAWLO study showed that maintaining weight loss necessitated more efforts than keeping a normal stable weight, despite similar energetic and nutritional intake. These efforts were reflected in the strategies followed by WLoMs, but also in the higher psychological burden. The follow-up study suggested that this was not related to a systematic, abnormal drop in REE.

3. DISCUSSION

WLM is related to a large number of intertwined determinants and the goal of the HOMAWLO study was to explore how maintaining weight loss was similar to, but also different from, keeping a normal stable weight. Our results showed that the participants maintaining weight loss "struggled" more than the persons who spontaneously maintained a normal weight: the WLoMs followed more rigid weight maintenance strategies (including specific food choices), they scored higher on both eating restraint and disinhibition scales, they monitored their body weight more closely, and they reported experiencing a higher burden. Meanwhile, the energy and nutritional intakes were similar in both groups. Our results also show heterogeneity among the WLoMs, with a large group oscillating between high vigilance and loss of control over eating, a smaller group exerting high levels of control and physical activity without experiencing loss of control, and another small group on the verge of eating disorders, struggling with alternating waves of restraint and binge eating, and whose self-esteem was negatively affected by self-weighing.

These data suggest several hurdles on the way to WLM, which different individuals experience and cope with in different ways. The first hurdle may be lack of knowledge about adequate dietary intake and portion sizes, and might contribute to explain why WLoMs consumed similar amounts of energy while choosing more "diet foods" and being more vigilant than Controls. The second hurdle could be that some, if not most, WLoMs have to cope with hard-to-resist food cravings, which would explain the high restraint and disinhibition scores. The third could be what is called "adaptive thermogenesis", an excessive drop in resting energy expenditure after weight loss; this could contribute to the higher burden and explain the more frequent adoption of vigorous exercise levels observed in our group of WLoMs.

3.1. Purposeful food choices, but to what effect?

The higher intake of protein sources, low fat foods and artificially sweetened products among WLoMs may reflect habits acquired during the weight loss process (192, 193). Proteins are favored in

most weight loss diets, although their impact on weight loss maintenance has not yet been proven (194, 195). Low fat diets have been widely promoted for several decades and the consumption of low-fat products is a common feature among successful weight losers (67, 196, 197), as is that of artificially sweetened drinks (82). In our study, these purposeful food choices did not result in a significantly lower energy or nutritional intake. One possible explanation is that despite the satiating effect of proteins (usually assessed after pre-loads on visual analog scales) (195, 198, 199), their increased consumption during covertly manipulated meals had no influence on daily energy intake (200). Likewise, protein supplements did not improve WLM outcomes after 6 months compared to a placebo, despite a reduction of hunger sensation (201), suggesting that the desire to eat overrules satiety even after the weight loss phase (198). As described in our introduction, the biological systems involved in appetite control are not always capable of coping with the various stimuli triggering food intake. At least two other phenomena could be involved in the discrepancy between the eating strategies and the actual intake observed in our study: portion-distortion, and halo-effect. Portion-distortion implies that WLoMs did not adjust their personal norms for portion size to their new weight and requirements (202), as is frequently the case among persons with higher body weight (203). The “halo-effect” (204) leads to the overconsumption of food items identified as “good” or “healthy” (205, 206) and is illustrated in our follow-up study by the fact that 50% of the WLoMs mentioned eating more nuts and organic foods as strategies for WLM. The belief that the composition of the diet (the quality), rather than the quantity, has an effect on weight is common although not evidence-based (207, 208).

The impact of an intervention focusing on participants’ ability to match their dietary intake to their physiological needs should be evaluated: addressing portion-distortion and translating nutritional needs into actual foods (taking energy-density into account) might be helpful for persons trying to maintain weight loss (209-211). However, for this to be effective, the psychological aspects of eating behaviors observed in our study should also be addressed.

3.2. Control over eating and its loss

"Restraint" and "Disinhibition" as components of eating behavior are two sides of the same coin. In our study, most WLoMs scored significantly higher than Controls on these subscales, like the participants in both the German and the Portuguese WLM registries (91, 212). "Restraint" reflects the intention to restrict, eliminate or favor specific foods either by *rigid* or *flexible* control over eating behavior. "Disinhibition" signals the tendency to lose control over eating and is reinforced by *rigid* control (213). In our study, the co-occurrence of these opposite tendencies suggests that the WLoMs exerted *rigid* rather than *flexible* control over eating, which was consistent with the observed intake discussed above. The WLoMs' higher scores on Restraint and Disinhibition subscales were also consistent with the qualitative data on attitudes and experiences. Indeed, although WLoMs and Controls reported quite similar strategies for maintaining weight, the WLoMs applied strict rules and expressed a constant vigilance, whereas the Controls were more relaxed and trusted their ability to regulate their intake. For example, weight monitoring was reported as an important strategy by both groups, but the WLoMs used the scale regularly whereas the Control group "felt" their weight; then, when their weight went up, the WLoMs compensated drastically by relying on severe dieting strategies, whereas the Controls went back to their habitual eating and exercising behaviors. Research shows that normal-weight persons seem able to spontaneously adjust their intake when energy-dense snacks are added to their diet (214). This might not be the case for the WLoMs, or at least not for all of them: in a small but well-controlled overfeeding study in which the energetic load was increased progressively with intermittent ad libitum periods, the participants displayed large individual variation in the ad libitum intervals, suggesting that there were "compensators" (able to spontaneously reduce their intake in response to overfeeding) and "non-compensators" (174). Poor regulation of intake has been related to several biological determinants: the circulating mediators of appetite (198, 215), the microbiome (216), and maybe even osteocytes (at least in rats) (217), none of which can be influenced by therapies available today. As a result, persons who are not able to spontaneously adjust their intake to their needs have to rely on cognitive control to limit their food

intake. Inhibitory control, or response inhibition, is a cognitive process leading to the inhibition of an automatic behavior. Impulsivity (and particularly two of its facets, urgency and reward sensitivity (218)) opposes inhibitory control, wearing out the self-control necessary to resist eating (37, 219, 220). Two approaches have shown promising results on eating behaviors: mindful eating and inhibitory control training. Mindful eating, which has been associated with a lower risk of overweight in a large French population sample (221), promotes the balance between nutritional needs, physiological sensations and pleasure and might favor *flexible* over *rigid* control in relation to eating behavior (213, 222-224). Inhibitory control training targets automatic processes over responses to food with computerized tasks, during which participants are trained to associate particular stimuli (e.g. certain food items) with inhibitory motor responses (225, 226).

Although these approaches could be helpful to those who struggle with inhibitory control (227) and might lessen the burden expressed by the WLoMs, another factor might increase the drive to eat: the process called adaptive thermogenesis. Unlike the other biological determinants mentioned earlier, this might be a modifiable factor (notably by physical activity) and therefore it is presented in more detail below.

3.3. Adaptive thermogenesis and body composition

As discussed in the introduction section, a large body of literature has spread the assumption that adaptive thermogenesis (AT), or the excessive drop in REE after weight loss, contributes to the low rate of WLM. Therefore, in our initial HOMAWLO study, the higher level of effort necessary to maintain weight loss compared to keeping a normal weight, including the higher level of physical activity, has led us to hypothesize that AT might play a role. In our follow-up study however, we found no evidence of AT, although we have to consider the results with great caution because of the small sample and the cross-sectional design. What we did find, however, was a large variability in the results, similar to what has been reported in the literature (152, 228, 229). Also, when assessing the published data on REE after weight loss, we identified large discrepancies between studies in the

amplitude of AT. These discrepancies can be explained by the differences between the instruments used to assess REE or between the study populations. But they might also be related to the fact that historically, the concept of AT was developed while disregarding several physiological aspects of body composition. The method of calculation for AT is the comparison, after weight loss has occurred, of measured and predicted REE. Most regression equations predict REE from the amount of fat free mass, because this explains 60-80% of the variance of REE (230, 231). The predicted value is normalized for body composition with a regression equation which includes, most of the time, age, sex and baseline body composition. However, this approach is based on statistical rules rather than on physiology, and overlooks three important aspects of the physiology of weight loss: the non-linearity of body composition changes during weight loss, the metabolic cost of fat mass, and the heterogeneity of fat free mass.

First, the normalized equations predicting REE assume a linear reduction of 25-30% of fat free mass during weight loss in obese populations (166, 167, 232). However, the range of change in body composition is considerable: during a weight loss intervention in which 59 women with overweight or obesity dieted on 1'000 kcal for 14 weeks, the range of lost weight as fat free mass ranged from 2 to 49% (average 13%) (233). The composition of lost weight depends on the initial body composition (the higher the fat mass at baseline, the more fat mass is lost (166, 171)), but is not linear over time, with relatively more loss of fat free mass during the early stages of weight loss, followed by larger loss of fat mass afterwards (167, 234). Adding an exercise program to a weight loss diet might contribute to a larger relative loss of fat mass (235, 236). Also, the fat free mass after weight loss might be "overhydrated" and consists of relatively less body cell mass than in matched stable weight individuals (237).

Second, although fat free mass is the largest predictor of REE, fat mass has also an impact. Moreover, its metabolic cost varies with its proportion: using a database of more than 1306 women, Bosy-Westphal et al. analyzed the relative contribution of fat mass on the variance of REE (238). They showed that the metabolic rate of fat mass increased between ≤10% up to 40% of fat mass, but that

it was drastically reduced when fat mass reached >40%, concluding that the normalizing equations developed in persons with very high initial fat mass are likely to overestimate the expected REE, and therefore overestimate AT (238).

Third, the REE equations are based on a body composition model of two compartments, fat mass and fat free mass, notwithstanding the heterogeneity of the latter: while organs represent only 5-6% of total body weight, they contribute to more than 80% of REE (239, 240) while muscle and bone mass have low specific resting metabolic rates. A study applying magnetic resonance imaging and specific tissue metabolic rates (229) to 43 women during a weight loss diet suggests that the relatively higher losses of organ mass occurring during obesity treatment could explain the important drop in REE (229, 241). When the organ-weight is included in the normalization equations, AT is dramatically reduced and represents only around 50 kcal/day (229, 231). This could explain the tremendously high AT calculated in a group of 16 "competitive weight losers" who lost around 58 kg over 30 weeks (242): the adjustment equation, based on initial body composition, did not take into account the loss of organ mass and the estimated AT was 275 (±207) kcal/day after 30 weeks, and 499 (±207) kcal/day after six years (242), which has been considered overrated (243).

Nevertheless, when taking into account correction factors for the loss of organ mass, the most prudent estimations of AT show an unexplained reduction in REE of 50 kcal/day which, although much lower than previous estimations, is not trivial and could play a role in the difficulties faced during the WLM process (173, 229). Therefore, the maintenance (or even increase) of energetically costly fat free mass during weight loss is considered a desirable goal, especially for those who experience a large drop in REE.

The challenge of optimizing body composition

To reach this goal of fat free mass maintenance, increased protein intake and physical activity are usually promoted, but average results are clinically close to insignificant. When combined with a low energy diet, physical activity did not change the maintenance of fat free mass compared to diet alone

in a randomized controlled trial (244). In another study, there was no difference in fat free mass whether weight loss was achieved by exercise or by a diet, although the participants in the exercise group lost significantly more fat mass than those in the diet group (235, 236). Also, the type of exercise seems to have no specific impact on body composition during weight loss (245). Likewise, the impact of higher protein intake on fat free mass maintenance seems minor. Parr et al. (246) have shown that increasing protein intake during a weight loss intervention consisting of a combination of energy intake reduction (250 kcal) and energy expenditure increase (≈250 kcal/day) had no impact on body composition. In a proof of concept trial involving a hypoenergetic diet (40% reduction) and physical training for 6 days/week during 4 weeks, the diet with the higher protein content (2.4 vs 1.2 g/kg/day) resulted in a slight increase of lean body mass (1.2±1 vs 0.1±1 kg; $P<0.05$) and greater loss of fat mass (4.8±1.6 vs 3.5±1.4; $P<0.05$), but the lipid consumption was twice as low in the high protein group (38±6 vs 86±13) and could partially explain the results (247). Finally, the maintenance or increase of fat free mass after weight loss is not only difficult, but might even be counter-productive. Indeed, a series of experiments led by Blundell et al. (248, 249) showed a correlation between fat free mass (but not fat mass) and energetic intake, suggesting a physiological drive in favor of the maintenance of fat free mass.

However, individual variations are large and could explain the seemingly trivial average results reported in the literature. Because fat free mass truly affect REE, and cannot be estimated with BMI (250), it seems interesting to assess body composition and adjust energy flux individually in order to improve WLM.

The two-sided effect of physical activity

As seen above, physical activity does not seem to contribute greatly to the maintenance of fat free mass during weight loss. However, it increases the loss of fat mass (235, 236) and is assumed to increase energy expenditure. Although exercise has been repeatedly cited as the main WLM strategy among the participants of the NWCR, most interventions have failed to show any significant impact,

and exercise most often has to be accompanied by other lifestyle measures to be effective (251, 252). This might be because sufficient levels are difficult to maintain for people who were initially sedentary: Schoeller et al. proposed 80 minutes/day of moderate exercise or 35 minutes/day of vigorous exercise to minimize weight regain (253) which has been confirmed in a review by Donnelly et al. suggesting that more than 250 minutes per week of "moderate to vigorous" activity were necessary to improve WLM (254). These levels can be difficult to reach and maintain. Another explanation for the disappointing effect of exercise on WLM might be related to the fact that training, as well as weight loss, reduces the metabolic cost of physical activity (173, 255) meaning that during long-term WLM the expended energy of physical activity tends to slow down, diminishing its effectiveness. Additionally, two forms of compensation could interfere with the effect of physical activity on WLM: increased energy intake and decreased spontaneous movement. The first form of compensation, i.e. the response in energy intake to increased physical activity, shows large variability in a review by Blundell et al. (256). After two to five days of increased exercise the intake was unchanged in 65% of the studies, increased in 19% and decreased in 16%. In another, more recent review, Thomas et al. showed that among thin people the (ad libitum) intake in response to increased physical activity was different according to the dose of exercise, with higher intake accompanying high doses of aerobic exercise (257). It seems that marked differences in energy intake exist between those who can tolerate exercise-induced energy deficit, and those who cannot (258). The second form of compensation, the modification of spontaneous movement (or non-exercise activities, also called fidgeting) in response to increased volitional activities, is subtle and hard to assess (259). These activities can represent between 8 to 15% of daily expenditure (173, 260) and are reduced in response to high levels of physical activity, attenuating the effect on energy balance (261). This concept has been further developed and described as the "constrained model" by Pontzer et al., who elegantly demonstrated that total energy expenditure reaches a plateau at a certain level of physical activity (262). As with REE modifications, the authors stress the large individual variability of energy expenditure (262) and compensation (258, 263). Therefore, the high levels of physical activity

found in successful WLM (67, 73, 264) as well as in our participants, might reflect a “self-selection bias”. The low-compensators (or good responders to physical activity) could be over-represented in these studies which do not include random sample but rather self-selected successful WLM.

In summary, increased exercise should be implemented for its beneficial effects on physical and mental health, but necessitates adequate guidance to optimize its weight-related outcomes.

3.4. Limits and strengths

Our studies have several limitations. First, the assessment of dietary intake is prone to bias, whichever the method used (265). The FFQ used in our first study relies on memory, necessitates the ability to synthesize usual portions and frequencies of consumption, and does not allow detailed assessment of quantities (265, 266). The food diaries used in the follow-up provide more precise data, but the self-assessed quantities might be underestimated (267, 268). However, the comparison between groups is valuable. Nevertheless, methods permitting more accurate and precise assessment of intake are very much needed (266) and we are currently developing an electronic tool to that effect (190). Second, the sample size is a limitation for the interpretation of the quantitative data (whereas it is a very large sample with regard to the qualitative data). However, the originality of our approach gives our data a unique value in suggesting directions for future research. The main strengths of this study are the complementarity of the quantitative and qualitative methods, the recruitment in the community avoiding selection bias, and the consideration of WLM from several angles, nutritional, behavioral and physiological.

3.5. Perspectives

Our work, while contributing to the current knowledge about WLM, also offers several perspectives. The individual variability of the major determinants of WLM, the fact that even the most comprehensive and intensive WLM interventions yield disappointing results, the inadequacy of the dietary intake in spite of burdensome efforts to control food choices and eating behavior show that we must tie basic research with clinical interventions if we are to respond better to the factors

impairing WLM. As suggested by the NIH working group (269), one of the most important issues is the individual variability. Our hypothesis is that multi-component interventions might be counter-productive because, instead of focusing on personalized strategies, they increase the burden by addressing too many factors at once. To do justice to the diversity of the target population, we propose defining the patterns of the main determinants involved in WLM and tailoring the strategies accordingly.

More specifically, a longitudinal study could assess whether circumscribed weight maintenance strategies defined according to the participants' patterns of individual characteristics (REE, body composition, dietary and activity skills, and psychological profile related to eating behaviors) is more effective than a program including all of the usual components of WLM interventions. Technology already offers some helpful tools for interventions and monitoring (270, 271) and the longitudinal design would also permit to document related parameters such as the microbiome, total energy expenditure and hormones related to appetite and weight control.

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APPENDICES

Appendix I: Table 1, Table 2, Table 3

Appendix II: Article "Long-term weight maintenance strategies are experienced as a burden by persons who have lost weight compared to persons with a lifetime normal, stable weight."

Appendix III: Article: " Qualitative analysis of the role of self-weighing as a strategy of weight control for weight-loss maintainers in comparison with a normal, stable weight group"

Appendix IV: Manuscript: What happens with weight loss maintenance? An exploratory study on body composition, resting energy expenditure, dietary intake and physical activity

APPENDIX I

Table 1. Estimations of the prevalence of weight loss maintenance (WLM) in various populations (chronological order of publication)

Authors (Reference)	Year	Country	Population	Methods	Definition of WLM	Results
McGuire et al. (63)	1999	USA	Representative population sample, 57% participation rate. Inclusion criteria: initial BMI ≥27. N=228	Telephone survey. Self-reported data.	Intentional loss of ≥10% of maximum weight (if = BMI ≥27) maintained ≥1 year.	WLM: 20.6%.
Weiss et al. (64)	2007	USA	Data from NHANES[1] 1999-2002, 83% participation rate. Inclusion criteria: ≤90% of maximum weight, 1 year before the study. N=1'310.	Individual interviews at participants' home. Self-reported data.	Stable weight within 5% during the subsequent year.	WLM: 58.9%. Continued weight loss (>5%): 7.6%. Weight regain (>5%): 33.5%.
De Zwaan et al. (65)	2008	Germany	Random population sample of 2'095 adults. Inclusion criteria: BMI >25 at maximum weight. N=610. Adjustments for underestimation of self-reported weight and overestimation of height (based on general	Phone survey. Self-reported data.	Intentional loss of ≥10% of maximum weight maintained ≥1 year.	WLM: 17.7% (1 year). ≥5 year-WLM: 8%. Among 223 with initial BMI>30: 29.7% (1 year-WLM) and 11.7% (≥5 year-WLM).

			population data). Attrition rate 10%.			
Kraschnewski et al. (66)	2010	USA	Data from NHANES[1] 1999-2006. Inclusion criteria: BMI ≥25 at maximum weight. N=14'306.	Self-reported data.	Loss of ≥10% of maximum weight and maintained ≥1 year.	WLM: 17.3%. WLM lost 15% of maximum weight: 8.5%. WLM lost 20% of maximum weight: 4.4%. 69% reported intentional weight loss.

[1] National Health and Nutrition Examination Survey

Table 2. Summary of national registries on weight loss maintenance (WLM) (chronological order of publication)

Name and primary reference	Country	Definition of WLM	Recruitment, N included	Methods	Remarks
National Weight Control Registry, started in 1994 (67). http://www.nwcr.ws/default.htm	USA	Maintenance of ≥13.6 kg (30 lb) for ≥1year. (In 2001, mention of weight loss of 10% (57). Self-reported weight, height, weight change. Documentation of weight loss (photos or external testimonies).	Prospective recruitment via the internet, media, mailings to weight loss programs, articles in health newsletters and magazines. No compensation. >10'000 adults so far. An adolescent weight control registry has been started.	**Questionnaires** Demography, weight, height, weight history, weight loss methods and trigger events, weight maintenance strategies, self-weighing frequency, previous weight-loss attempts, psychological health, eating behaviors/disorders. Dietary intake (food frequency questionnaire) and physical activity (Paffenbarger questionnaire). **Measures** In subsamples: Resting energy expenditure (69), Accelerometry (71, 72), Sleep quality (272).	Around 40 publications so far.
Portuguese weight control registry, started in 2008 (70). http://panosr.fmh.ulisboa.pt/rncp	Portugal	Intentional weight loss of ≥5 kg and maintained ≥1 year (independent of initial weight).	Recruitment through local and national media, social media. N=388 (from which 225 completed in-person assessments). Participants with	**Questionnaires** Demography, weight, height, weight history, weight loss and maintenance strategies, dietary habits. Dietary intake (food frequency questionnaire) and physical	Average weight loss 18.3 kg (18.7% of initial weight). Average duration maintenance 28 months.

			various initial BMI (10% normal BMI, 24% overweight, 66% obesity).	activity (Paffenbarger questionnaire). **Measures** Weight and height (57% of sample). Accelerometry (in a subsample, size unknown).	
German weight loss registry, started in 2009 (91)	Germany	Intentional weight loss of ≥10% of maximum weight, maintained for ≥1 year.	Volunteer sample. N=494.	**Questionnaires** Demography, weight, height, weight history, eating habits, weighing history, eating behaviors and disorders, depression.	Has been stopped after 3 years due to lack of public funding.
MedWeight study, started in 2012 (273) http://medweight.hua.gr/en/index.php	Greece	Intentional loss of ≥10% of maximum weight (if maximum BMI >25) and maintained ≥1 year.	Inclusion of adults with BMI ≥25, recruitment via social media and local press. Follow-up of weight loss maintainers and regainers (weight ≥95% of max). Exclusion if weight between 90-95% of max). No compensation. N=361 (73% WLM).	**Questionnaires** Medical history, weight, height, weight history, weight loss methods, lifestyle habits, social support, psychological assessment. Physical activity (International physical activity questionnaire). **Telephone interview** Two 24-h dietary recalls.	One year follow-up with questionnaires. Supported by the Coca-Cola Foundation.
Finnish weight control registry, started in 2012 (274)	Finland	Intentional loss of ≥10% of maximum	Articles and advertisement in	**Questionnaires**	

		weight (if maximum BMI ≥30) and maintained ≥2 years.	national media, flyers in health care centers and hospitals. N=158.	Demography, general health and lifestyle, weight, height, weight history, previous weight loss attempts, personality, changes in diet, motivation, eating habits, physical activity, weighing practices.	

Table 3. Description of dietary or exercise intervention studies for weight loss maintenance; randomization occurred after weight loss (alphabetical order)

Reference	Population	WL-Phase	WLM-Phase	Intervention(s)	Control	Results Intervention	Results Control	Conclusion
Agras 1996 (118)	194 women (10% attrition)	12 weeks VLCD*	9 months + 9 months follow-up	Prepackaged meals According to food plan vs. weight	Regular food According to food plan vs. weight	-8.2 kg (SD 12.3) vs. -8.6 kg (SD 11.4)	-6 kg (SD 11.1) vs. -2.8 (SD 18.3) kg	Weight change includes WL phase. No group difference.
Akers 2012 (119)	N=40	12 weeks	12 months	Record daily weight and steps, fruit&vegetable intake. + 5 dl water before meals	Record daily weight and steps, fruit& vegetable intake.	-1kg	-2kg	No group difference
Borg 2002 (122)	90 men (9% attrition)	2 months VLCD*	6 months +23 months follow-up	Ad libitum low fat diet, weekly group sessions, food and exercise diaries + 45 minutes exercise 3x/week: Walking vs Resistance training	Ad libitum low fat diet, weekly group sessions, food and exercise diaries	During WLM, adjusted mean difference to controls: Walking: +0.3 kg (95% CI -2.2 to 2.8). Resistance training -1.3 (95% CI -3.8 to 1.1).		At 23 months, 47.5% of all participants regained >10% of lost weight. No group difference.
Fogelholm 1999 (127)	82 women (2% attrition)	12 weeks VLCD*	10 months	Low-fat diet, 1 group session/week, pedometers, monthly information on healthy diet. + Walking :	Low-fat diet, 1 group session/week, pedometers, monthly information on healthy diet.	-0.7 kg (SD 1) vs +0.2 kg (SD 0.9). Adherence to exercise negatively	+1.7 kg (SD 0.8).	No group difference.

				1000kcal/week vs 2000kcal/week		correlated with weight regain		
Lantz 2003 (126)	334 (65% attrition)	16 weeks VLCD*	2 years	VLCD on a regular intermittent basis.	VLCD if weight regain ≥3kg.	-6.2% (SD 9.5) (44% maintained 5% WL).	-7.7% (SD 8.4) (62% maintained 5% WL).	Weight change includes WL phase. No group difference.
				2 sessions/months for 6 months, then 1x/month				
Larsen 2010 (124)	938 (38% attrition)	Weight loss diet to reach -11 kg	26 weeks	AD Libitum diets 1. Low prot-low GI 2. Low prot-high GI 3. High prot-Low GI 4. High prot-High GI	Control (n=114)	Difference weight regain: - High vs Low Protein: 0.93 kg - Low vs High GI: 0.95 kg		< 1kg difference between groups (p<0.005).
Lejeune 2005 (125)	120 (6% attrition)	4 weeks VLCD*	6 months	1 counselling /month with dietician + 30g protein/day	1 counselling /month with dietician	-6.7 kg (+20% weight regain)	-3.8 kg (+55% weight regain)	Weight change includes WL phase. P<0.05.
Lowe 2008 (120)	103 women	Meal replacement -7.6 kg	14 weeks +18 months follow-up	Cognitive behavioral therapy with monitoring. + Energy density	Cognitive behavioral therapy with or without monitoring.	-1.9% (SD 7.7) 6 months weight change.	+0.24% (SD 5.4) vs 0.04% (SD 5.3) 6 months weight change.	No difference at 18 months (regain after 6 months).
Pasman 1997 (121)	39 women (20% attrition)	2 months VLCD*	14 months	No dietary restrictions, no physical activity advice. Assessment with 3 days food diary, 3	No dietary restrictions, no physical activity advice. Assessment	65% (SD 65) to 123% (SD 63) weight regain.	61% (SD 66) weight regain.	No group difference.

				times during intervention. + 10 g fiber	with 3 days food diary, 3 times during intervention			
Perri 1988 (123)	123 (26% attrition)	1 year	1 year	1. Therapist (2 group sessions/months) 2. Intervention 1 + Social support (peer support & incentives) 3. Intervention 1 + 180 minutes exercise/week 4. Interventions 1 + 2 + 3	Control	1: -11.4 kg (SD 12) 2: -8.4 kg (SD 7.5) 3: -9.1 kg (SD 6.4) 4: -13.5 kg (15.2) On average, 83% of WL maintained.	-3.6 kg (SD 6.2) On average, 33% of WL maintained.	Weight change includes WL phase. No group difference.
Toubro 1997 (128)	37 women (8% attrition)	8 weeks VLCD	1 year	Ad Libitum diet : 55% CHO, 20-25% Fat, booklet. Group sessions : 2-3x/months 6 months, then 1x/month	Reduced energy diet (1875 kcal), card system.	+ 0,3 kg (95% CI -3 to 3.6).	+ 4.1 kg (95% CI 1.2 to 6.9).	During WLM phase. P=0.08 for group difference.

* VLCD : very low caloric diet

APPENDIX II

Long-term weight maintenance strategies are experienced as a burden by persons who have lost weight compared to persons with a lifetime normal, stable weight.

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M. Kruseman designed the study, searched for funding and performed the data collection together with I. Carrard. M. Kruseman trained and supervised N. Schmutz who assisted with data collection. M. Kruseman analyzed the data and wrote the manuscript in collaboration with I. Carrard.

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Original Article

Long-Term Weight Maintenance Strategies Are Experienced as a Burden by Persons Who Have Lost Weight Compared to Persons with a lifetime Normal, Stable Weight

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Keywords
Obesity · Weight loss maintenance · Dietary intake · Perception

Abstract
Objective: To assess dietary intake, eating patterns, physical activity and eating behaviors, and to explore strategies and perceptions of the experience of weight maintenance in weight loss maintainers (weight loss maintenance (WLM) ≥ 10% weight loss maintained for ≥1 year) and in matched controls with a lifetime stable normal weight. ***Methods:*** Volunteers (32) were recruited by a snowball procedure in this cross-sectional, mixed-methods study. Diet, physical activity, and eating behaviors were assessed with validated questionnaires. Strategies and experiences were investigated during interviews. Descriptive coding, thematic analysis (qualitative data) as well as descriptive analysis and t-tests (quantitative data) were performed. ***Results:*** Both groups had similar energy and macronutrient consumption. Those in the WLM group reported higher levels of exercise and scored higher on several dimensions of eating disorders. Four themes – 'food choices,' 'quantities and portion control,' 'physical activity', and 'burden' – emerged from the qualitative data. Both groups used similar weight maintenance strategies, but those in the WLM group experienced a higher burden, expressing effortful control which contrasted with the control group's confidence in their internal cues. ***Conclusion:*** Our results show an additional burden related with maintaining weight loss compared to keeping a stable normal weight. They provide evidence to devise interventions that will address the difficulty of regulating intake.

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Introduction

Treating obesity is a challenge, mostly because of the difficulty in maintaining weight loss beyond 1 year [1, 2]. Whereas numerous weight loss interventions have been evaluated and compared, resulting in evidence-based guidelines [3, 4], the process of successful weight loss maintenance (WLM) is still elusive [5, 6]. Despite a growing body of research on this topic, the effective components of WLM interventions are difficult to identify [7, 8]. One reason is that the population of interest is hard to reach, in part because of its small size [9, 10], but also because many people lose weight successfully outside structured programs [11] and therefore are difficult to identify and approach.

However, several studies have included 'weight loss maintainers', usually defined as persons who have intentionally lost at least 10% of their initial body weight and kept it off for at least one year [12]. One major ongoing study is the US-based National Weight Control Registry (NWCR), which started in 1994 and has regularly published on self-reported weight maintenance strategies [13–15], characteristics associated with WLM [16, 17] and the risk factors of weight regain [18, 19]. In this cohort, the most frequently self-reported strategies of WLM include consuming low-energy and low-fat diets, eating breakfast regularly, following consistent eating patterns, monitoring weight and food intake, and engaging in at least 1 h of daily physical activity [12, 13, 19]. Likewise, European-based WLM registries have reported decreased energy intake [20], low carbohydrate consumption and regular physical activity [21] as successful strategies. Overall, these studies suggest that a low-energy diet and high levels of physical activity are necessary for WLM. However, these factors were rarely measured precisely or, when they were, gave inconsistent results. For example, Phelan et al. [22] showed low average energy intake in the NWCR (1,379 ± 573 kcal, approximately 19 kcal/kg), but energy intake in the Portuguese Weight Control Registry were in the normal range (2,199 ± 840 kcal, approximately 30 kcal/kg) [21]. Levels of physical activity did not explain this discrepancy (>60 min/day vs. approximatively 40 min/day). Other studies that included assessment of physical activity indicate great variability of results [21, 23], suggesting that the amount of physical activity necessary to maintain weight loss is highly individual [21]. Another issue is the absence of comparisons with a reference group presenting a stable normal weight. Comparisons have been made with the general populations in some studies [13, 24, 25], but these included overweight persons not seeking weight loss. While weight loss maintainers have reported dietary restraint and physical activity as their main strategies, it is not well known whether they eat less and move more than individuals with stable normal weight.

Nevertheless, sustaining WLM strategies might have high costs, notably on eating behaviors: the German and the Portuguese Weight Control Registries both showed an over-preoccupation with shape and weight in persons having maintained weight loss compared to the general population (which included overweight persons who did not seek weight loss). They also identified more binge eating and compensatory behaviors than in the general population [24, 25]. In an analysis of 10-year prospective data from the NWCR, Thomas et al. [19] found that higher dietary restraint (i.e., the degree of conscious control applied to regulate eating behavior) and lower disinhibition (i.e., the tendency toward loss of control in eating) seemed necessary to maintain weight loss. Taken together, these data suggest that high levels of control and vigilance, constant monitoring, and discipline are necessary for WLM. On the other hand, qualitative studies assessing perceptions and representations on WLM provide contrasting findings, showing that persons who were able to maintain their weight loss put emphasis on 'lifestyle change rather than being on a diet' [26], moved away from the 'dieting mentality', and reported a 'more relaxed, "no worries approach"'. They 'avoided banning foods from their diet' [27] and mentioned experiencing a 'shift towards a new self' and 'rede-

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fining themselves' [28]. It is striking that results from studies with different approaches seem inconsistent: Quantitative studies imply a possible burden of WLM related to controlled dietary intake and monitoring of body weight, whereas qualitative studies describe a more flexible approach and relaxed attitude. This apparent contradiction could be related to the fact that these factors have been studied distinctly in various samples of weight loss maintainers recruited in different, single settings.

Therefore, a more comprehensive examination would be useful to better understand what WLM entails, and to target specific needs when designing WLM interventions. Our goal was to assess dietary intake, daily eating patterns, physical activity and eating behaviors, and to explore strategies and perceptions of the experience of weight maintenance in two groups: one group of individuals with WLM, and one group of individuals with a lifetime, stable normal weight considered as a control group.

Material and Methods

We used a mixed-method design with quantitative tools to assess dietary intake, physical activity, and eating behaviors as well as a qualitative methodology to explore daily eating patterns, strategies, and experiences of weight maintenance. This was an exploratory study in which the data were intended to support a grant proposal for a larger investigation. The study protocol was approved by the Cantonal Ethics Committee on Research.

Recruitment Strategy

With the goal of describing weight maintenance across a variety of situations, we used a snowball procedure to sample at least 15 participants per group, as opposed to recruiting in one or two settings, which could lead to selection bias. Power was not calculated a priori because this was an exploratory study; so we wanted to include as many participants as possible with the funding available. We recruited the first participants by word of mouth through the investigators' networks. Each participant was asked to think of someone they knew who could also be eligible, either in the WLM or the control group.

The inclusion criteria to participate in the WLM group were initial BMI ≥ 25 kg/m^2 and intentional weight loss of at least 10% of initial weight, maintained for at least 12 months, excluding bariatric surgery. The controls' inclusion criteria were BMI between 18.5 and 24.9 kg/m^2 and adult lifetime stable weight of ±5 kg, apart from pregnancies. The participants in both groups had to live or work in the French-speaking part of Switzerland and were matched by sex, age, and socioeconomic status.

Procedures

The participants were included after a screening interview performed by phone. They self-reported weight and height, and those in the WLM group provided pictures (similarly as in the NWCR) by email or social media to ascertain self-reported weight change. When no pictures were available, testimonies of caregivers (e.g., physicians, dieticians) were accepted. The study goals and procedures were explained, and a 2-hour appointment was arranged, which took place at either our office or the participant's home. The meeting started with the formal information about the study and the informed consent being signed, after which an audio-recorded semi-structured interview was performed. At the end of the interview, a set of 17 questionnaires was given to the participant to be filled out at home, together with a pre-stamped envelope. Data from four questionnaires were used in this study. If the questionnaires were not returned after 7 days, a reminder was sent by email. If the questionnaires were still not returned, up to two phone calls were made. All of the questionnaires were entered manually into pre-coded databases (double entry). Individual feedback was mailed to each participant, together with a department store voucher worth CHF 20.00 (approximately equivalent to EUR 18.00) as compensation for their participation.

Measures

A short questionnaire was used to collect sociodemographic data on sex, age, country of origin, family status, education [29], profession, and income [30]. These data were used to describe our study population and to match the participants in both groups.

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Dietary Intake

The Food Frequency Questionnaire (FFQ) [31] is a 97-item questionnaire used to self-report dietary intake; it has been developed and validated in the Geneva population and widely used in the French-speaking part of Switzerland for research and surveys [32]. The food items contributing substantially to the nutritional intake of a representative sample of the population of the State of Geneva (providing at least 90% of the calories, proteins, carbohydrates, total fat, dietary cholesterol, alcohol, vitamin D, and retinol consumed by the population) are part of the FFQ. The questionnaire assesses the respondent's diet during the previous month by asking the respondent to choose the frequency of consumption for each food item (never during the last 4 weeks, once a month, 2–3 times per month, 1–2 times per week, 3–4 times per week, once a day, twice or more per day) and to estimate the portion they consumed (smaller, equal, or larger than the displayed reference portion). Eight food groups were defined (protein sources, starches, fats, low fat, vegetables, fruits, sugar and sweets, artificially sweetened), and daily portions were summed up to calculate the respondent's average consumption of each food group. Average daily intakes of calories, proteins, carbohydrates, total fat, and alcohol were calculated with the food composition table developed for the FFQ [31].

Daily Eating Patterns

Usual frequencies of daily eating occasions and nibbling during the last month were assessed during the interviews. Meals and snacks were defined as any structured food intake (including lunches, dinners, and snacks). Breakfast was defined as any caloric intake within 1 h following awakening. Nibbling was defined as irregular, unplanned intake without a clear start or ending.

Physical Activity

The Global Physical Activity Questionnaire (GPAC) [33] is a 16-item questionnaire that is used in more than 100 countries and was developed by the World Health Organization to assess the intensity, frequency and duration of physical activity related to the professional, transport and leisure domains during a typical week. These parameters are combined in a standardized SPSS routine to classify subjects according to three levels of physical activity:

- *Vigorous:* intense physical activity reaching at least 1,500 MET-min/week, at least 3 days a week OR moderate to intense physical activity reaching at least 3,000 MET-min/week.
- *Moderate:* at least 20 mins of intense physical activity at least 3 days a week OR at least 30 mins of moderate physical activity or walking, at least 5 days a week OR at least 5 days/week of walking or moderate to intense physical activity, reaching at least 600 MET-min/week.
- *Sedentary:* none of the above criteria are reached [33].

Eating Behaviors

The Three-Factor Eating Questionnaire (TFEQ) [34] is a 51-item questionnaire initially developed to evaluate eating behaviors among persons suffering from obesity. Three scores can be calculated, corresponding to the subscales of 'restraint' (21 items), 'disinhibition' (16 items) and 'hunger' (14 items). Higher scores indicate higher levels of 'restraint', 'disinhibition' and 'hunger', but no cut-off points are defined. The French version of the questionnaire has been validated [35]. For the purpose of our study and similarly to the NWCR [19], we used the 'restraint' and 'disinhibition' subscales.

Strategies and Experiences

One of the investigators (one psychologist and two dieticians) conducted individual semi-structured interviews with each participant during one-on-one sessions lasting between 1 and 2 h. An interview guide with open-ended questions (previously tested among 5 persons who met the WLM criteria and were not part of this study), was used to cover weight changes over time, successful weight loss (WLM group only), weight maintenance (strategies, rules, or habits that helped them to manage their weight, difficulties they experienced in maintaining their weight), and how they anticipated the future. The interview guide included questions such as: 'Tell me about how you eat to maintain your body weight.'; 'What helps you to maintain your weight? What makes it difficult or hinders you?'; 'Could you describe what you consider as rules in your diet?'.

Data Analyses

Quantitative data were analyzed with SPSS (version 22.0, 2013, IBM Corp. Armonk, NY, USA). The descriptive results were expressed as frequencies (n; %) or means ± SD after checking for normality of distribution. Comparisons of continuous variables were made for descriptive purposes. As data distribution was

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normal, the comparisons between groups were tested with t-tests. No categorical comparisons were carried out because of the insufficient number of subjects per cell. Energy intake is expressed as total kilocalories and as kilocalories per kilogram of body weight. Macronutrient and alcohol intakes are expressed as grams per day and as a percentage of total energy intake.

The interviews were transcribed verbatim. Two investigators performed the descriptive coding [36] of the interview transcripts using MaxQDA software (version 11, 1989–2014; VERBI Software-Consult-Sozialforschung GmbH, Berlin, Germany). First, the strategies reported by the participants were listed and summarized into main codes to count how many participants used each of them. Second, the interviews were coded to reflect the participants' experiences with minimal interpretations. Both principal investigators coded the first two interviews together to reach a good level of concordance. Memos were created for each code definition. Then, each investigator coded half of the dataset and checked the codes of the other half. When needed, the codes or code definitions were clarified or modified by consensus. Finally, all of the codes were reviewed and grouped into main themes. Emblematic citations were extracted and reproduced in the results section, with the participant's gender and age in brackets.

Results

Sample Characteristics

Between June and December 2013, we included 36 volunteers (18 in each group) through 14 different contacts. Two participants in the WLM group did not return the questionnaires, and the data of 2 controls were excluded because their dietary intakes seemed unrealistic (7 kcal/kg and 110 kcal/kg body weight per day). The remaining 32 participants (20 women, 12 men) were Caucasian and mostly Swiss (n = 25; 78%) or from a nearby European country (n = 7; 22%). Most lived in Geneva or its suburbs (n = 20; 62%). The others lived either in small cities (n = 5; 16%) or in the countryside (n = 7; 22%), up to 150 km away from Geneva.

The respondents in the WLM group had higher BMI than the controls (25.5 ± 2.9 vs. 21.0 ± 1.9; $p < 0.001$) but all had lost at least 10% of their weight (range 12–35%). Table 1 displays detailed characteristics of the participants.

Dietary Intake, Daily Eating Patterns, Physical Activity, and Eating Behaviors

Among the eight food groups defined in the FFQ, foods that belonged to the 'protein sources' and 'low fat' groups were consumed significantly more often among the participants in the WLM group than among those in the control group, whereas 'sugar and sweets' were almost equally consumed among both groups. Artificially sweetened products were exclusively consumed by participants from the WLM group. The groups' energy and nutrient intakes were similar when adjusted for body weight (table 2).

The WLM group did not exhibit any specific daily eating pattern in terms of meal frequencies or nibbling in comparison with the controls (table 2).

The GPAC questionnaire showed that participants of both groups engaged, on average, in more than 1 h of daily physical activity (WLM group 96 ± 67; control group 66 ± 42 min). Eight participants in the WLM group (53%) and 3 (19%) in the control group reported a vigorous level of physical activity, whereas 1 (6%) and 6 (38%) were considered sedentary, respectively (table 2).

The participants in the WLM group had higher scores in the 'restraint' and 'disinhibition' subscales of the TFEQ than the controls, reflecting conscious effort to restrict food intake and more overeating and loss of control (table 2).

Strategies and Experiences

Four major themes emerged from the qualitative data: 'food choices', 'quantities and portion control', 'physical activity' and 'burden'. The latter was only found in the WLM group.

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Table 1. Participant characteristics with WLM compared to stable normal-weight controls (N = 16 in each group: 6 men and 10 women)

	WLM	Controls
Male/female ratio (n)	6/10	6/10
Age, years	38.1 ± 7.9	39.4 ± 10.0
Weight history		
Current weight, kg*	74.5 ± 11.8	62.5 ± 10.0
BMI, kg/m^2*	25.5 ± 2.9	21.0 ± 1.9
Weight loss, kg	25.2 ± 11.7	–
Years of weight maintenance, years	3.5 ± 3.1	–
Family status (n;%)		
Living alone (vs. married or partnership)	8 (50%)	4 (25%)
Children yes	10 (62.5%)	10 (62.5%)
Education level		
Upper Secondary	10 (62.5%)	6 (37.5%)
Tertiary (university or equivalent)	6 (37.5%)	10 (62.5%)
Employement category		
Executive	4 (25%)	4 (25%)
Employee	10 (62.5%)	10 (62.5%)
Self-employed	1 (6%)	1 (6%)
Income categories (monthly)		
<5,000 CHF	3 (19%)	2 (12.5%)
5,000–9,499 CHF	6 (37.5%)	8 (50%)
≥ 9,500 CHF	3 (19%)	5 (31%)
Refused to answer	4 (25%)	1 (6%)

*p < 0.005 (t-test).

Food Choices

Participants in both groups referred to conscious food choices intended to maintain their weight, like trying to eat plenty of fruits and vegetables (10 in the WLM group (63%); 11 in the control group (69%)) and cutting down on fats (14 in the WLM group (88%); 11 in the control group (69%)) and snacks (13 in the WLM group (81% ; 7 in the control group (44%)). Participants in the WLM group mentioned choosing protein-rich food items more often (10 in the WLM group (63%); 1 in the control group (6%)), avoiding carbohydrates (13 in the WLM group (81%); 3 in the control group (19%)) and using artificially sweetened products (6 in the WLM group (38%); 0 in the control group). Sub-themes emerged from the discourse of the respondents according to their group: *'rules'* in the WLM group and *'habits'* in the control group.

Rules versus Habits

When talking about their food choices, women and men in the WLM group referred to effortful cognitive control with precise rules about which foods they could eat and which they had to avoid: *'(...) Every Thursday you eat, until the end of your life, proteins. Every Thursday is protein day'* (woman, 42). They often used definite terms like *'banning,' 'never eating'* and *'forbidden'.* Emblematic quotes include: *'Chocolate bars? I abolished those!'* (man, 46), *'(...) I cut out all soft drinks, ice-tea, I banned all that from my diet' (man, 37), 'For now, I don't eat carbohydrates. My idea is not to eat any at all, ever'* (woman, 48). On the contrary, the controls referred to their food choices as healthy habits or personal preferences. The purposeful

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Table 2. Dietary intake, eating patterns, physical activity and eating behaviors (mean ± SD) of 16 participants with WLM and 16 stable normal-weight controls

	WLM	Control	p value (t-test)
Food group intake, g			
Protein sources	396 ± 287	223 ± 107	0.037
Starches	205 ± 92	239 ± 98	0.348
Fats	114 ± 57	125 ± 60	0.592
Sugar and sweets	243 ± 321	224 ± 178	0.845
Low fat	89 ± 79	38 ± 34	0.029
Artificially sweetened	234 ± 45	0	0.093
Vegetables	135 ± 69	131 ± 72	0.904
Fruits	340 ± 408	252 ± 152	0.451
Energy intake			
Total energy intake	1,704 ± 671	1,592 ± 423	0.577
Weight adjusted energy intake, kcal/kg	23.1 ± 8.7	25.4 ± 5.0	0.356
Protein intake, g/kg	1.14 ± 0.54	0.96 ± 0.27	0.263
Protein intake, % TEI	20 ± 4.1	16 ± 2.4	0.002
Carbohydrates intake, g	185.2 ± 89.9	174.4 ± 48.5	0.674
Carbohydrates intake, % TEI	44 ± 10.4	47 ± 5.8	0.397
Lipid intake, g	65.9 ± 27.7	63.4 ± 22.1	0.780
Lipid intake, % TEI	36 ± 6.9	38 ± 5.6	0.516
Alcohol intake, g	5.35 ± 5.6	11.98 ± 14.4	0.102
Eating patterns, n (%)			
No breakfast	4 (25%)	5 (31%)	
2–3 structured meals/snacks	7 (44%)	9 (56%)	
4–6 structured meals/snacks	8 (50%)	7 (44%)	
Daily nibbling	6 (38%)	4 (25%)	
No defined eating pattern	1 (6%)	0	
Physical activity level, n (%)			
Sedentary	1 (6%)	6 (38%)	
Moderate	6 (40%)	7 (44%)	
Vigorous	8 (53%)	3 (19%)	
TFEQ Subscales scores			
Restraint	10.5 ± 5.1	5.1 ± 3.6	0.002
Disinhibition	7.6 ± 3.2	4.4 ± 2.7	0.005

avoidance of food groups was uncommon and seemed to be merely a default choice among the controls, who considered it to be '*natural*' and '*not really an effort*'. They also refuted the term 'rules' and referred to pleasure and taste when describing their food choices: *'When I was a kid I didn't like vegetables too much, but now I really like them, so it's easy'* (man, 28). *'I don't drink soft drinks, but it's not a big effort as I don't like them so much'* (woman, 43). *'It's like fried food, I am not attracted to fried food (…) so it's pretty easy, I just don't want to eat that stuff. (…)'* (woman, 43).

Quantities and Portion Control

Among the participants, 21 spontaneously mentioned the quantities of food they consumed and their portion size control, including 9 from the WLM group (56%) and 12 from the control group (75%). Again, sub-themes emerged that were more specifically related to each group: '*vigilance'* (WLM group) and *'confidence*' (control group).

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Vigilance versus Confidence

Those in the WLM group expressed constant vigilance and intention to adjust their intake. They described difficulties with controlling quantities of particularly palatable food, despite applying strategies like buying single-portion packages and using smaller plates. *'Each thing that enters my mouth, I'm thinking, how many calories is this gonna be, what on earth can I eat tonight to compensate, or tomorrow?'* (woman, 44). *'Over the week, I eat a certain amount of [Weight Watcher] points, I'm like a walking calculator'* (woman, 30). They also referred to the quantities they used to eat before their weight loss: *'Compared to 6 years ago, it's a drastic reduction'* (man, 27). They strove to acquire the ability to regulate quantities more easily: *'I'd like to learn how to enjoy eating those nice things, how to manage the quantity and frequencies'* (woman, 29). Those in the control group considered internal cues to be sufficient for regulating their intake and determining when their consumption was excessive, and they expressed confidence that the quantities they consumed would balance out naturally over their next few meals: *'I don't need to control things, I mean… not mentally. There is, for me, a physical regulation. (…). I sort of trust it'* (woman, 29). The respondents in the control group also referred to cognitive control but did not experience it as an effort: *'No excess. A constant attention, but without giving yourself a headache'* (man, 51).

Physical Activity

Almost all of the participants (15 in the WL group (94%); 13 in the control group (81%)) mentioned sports or physical activity as a strategy for weight maintenance. Sub-themes were: *'scheduled changes'* (WLM group) and *'pleasurable habits'* (control group).

Scheduled Changes versus Pleasurable Habits

In the WLM group, current physical activity was different from what participants were used to before weight loss, and they had established some structure (days and/or duration): *'I practice much more sports than before, at least twice a week, 2 h each time'* (woman, 42). *'Every Tuesday, I play badminton; and on Fridays, I started running'* (man, 46). On the other hand, most of the controls had always practiced physical activity and sports: *'Oh yes, I practice sports. I always did, but I do not have one activity in particular, I enjoy the variety'* (woman, 45). Among the controls, physical activity was also more often inserted into their daily lives: *'[I have] no parking close to work. So I ride my bicycle. I have no other option, even when I'm tired or if it snows or rains. It's just like that'* (woman, 45). In the WLM group, the participants did not mention particularly liking or disliking physical activity, whereas the controls often qualified their activities as a pleasure : *'It's true. I love sports, I think I couldn't live without them'* (man, 28). *'I like running. I like swimming. I often go to the gym. I'd say when I have free time I give priority to physical activity'* (woman, 52).

Burden

'Burden', already discernible within the previous themes in terms of attention, emerged as a theme in and of itself among the WLM group. To them, 'burden' referred to the following issues: the hardship of maintaining their weight – *'I'm full of good intentions, but in practice, it is always difficult to stick to them. I often have difficulty holding on'* (woman, 29); the anxiety of gaining weight again – *'I feel anxious about regaining my weight, about returning to my old ways, about letting myself go completely and reaching more than 100 kg again. If I weighed over 100 kg again, I think I'd go crazy'* (man, 37); and the loneliness and unfairness of their situation – *'I'd like to be one of those persons who can eat everything and never gain one gram'* (woman, 44), *'The comments, they can have an annoying side, because you get the feeling of not being understood; the feeling that people do not realize what it represents [to maintain weight loss]'* (woman, 30) and *'You have the feeling you have to control everything, unlike someone who*

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has no weight problems, who doesn't have to go to too much trouble' (man, 31). The importance of self-control for self-esteem also appeared: *'What is also difficult is to have done all that and not have the image you were expecting, because in my head, after having lost all that weight, I should have been perfect, but no'* (woman, 30). Such concerns were not found in the control group.

Discussion

In this study, we used a mixed-method approach to assess dietary intake, daily eating patterns, physical activity and eating behaviors, and to explore strategies and perceptions related to the experience of weight maintenance among persons who have lost weight and individuals with a lifetime stable normal weight. Our main finding is that, despite purposeful food choices, those in the WLM group had similar nutritional intake than normal weight controls. Our second finding is that the reported weight maintenance strategies are not specific to WLM, but are also used to maintain a lifetime normal weight. However, the implementation of these strategies by individuals in the WLM group necessitated burdensome stratagems and higher vigilance.

The quantitative data on dietary intake reflected the WLM group's preferences for protein sources and low-fat preparations. They also consumed artificially sweetened foods, whereas controls did not. This reflects a conscious effort to choose 'weight loss diet foods', which might have been acquired during the weight loss process [37, 38]. These different food choices did not result in measurably lower energy intake or different nutrient intake when compared to the normal-weight controls, and this might indicate that the individuals in the WLM group needed these strategies to avoid excessive consumption of fats and sugar. It is also possible that, while avoiding the food items they perceived as unhealthy or fattening, they ate more of the other foods, increasing the total nutrient and energy intake. In this case, care-givers should make sure that persons trying to maintain weight loss have accurate knowledge about dietary needs, nutritional value of foods, and adequate portion sizes, as this could help them choosing from a larger variety of foods and preparations. A more detailed analysis of their food intake, by food diary for example, would give more information on this matter.

Daily eating patterns varied widely within the groups and did not reveal any specificity associated with WLM. This was also true for the consumption or avoidance of breakfast, unlike what has been shown in the NWCR [15] and tends to show that individuals have to find their own eating rhythm that allows them to maintain their weight, as has been suggested by others [25, 39].

The participants in both groups considered physical activity to be necessary for weight maintenance and dedicated a considerable amount of time to it. Those in the WLM group were more likely to engage in higher-intensity physical activity and for a longer duration than the controls. This result might indicate a vulnerability to weight gain in the WLM group. This is also suggested by the NWCR data, in which those with the highest physical activity reported more dietary strategies to maintain their weight loss [23]. It is possible that after weight loss, some individuals struggle with lower resting energy expenditure, which has been documented during or shortly after weight loss [40, 41]. A recent publication suggests that this phenomenon persists even after several years of weight loss [42], but these data should be confirmed and compared with the resting energy expenditure of a control group with stable normal weight. In this pilot study, we were not able to measure resting energy expenditure. This, together with the assessment of body composition, should be done in the future among WLM and normal-weight controls, in order to assess whether the struggle to maintain weight loss is related to a lower metabolism.

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The WLM group scored higher on the scales evaluating eating behaviors, similarly as in two European registries [24, 25]. The higher scores obtained on the 'restraint' scales reflects the intention to restrict or favor the intake of particular food groups, and are consistent with the results of dietary intake. 'Restraint' can manifest itself as a *rigid control* in relation to an eating behavior, which is characterized by a dichotomous, all-or-nothing approach to eating and dieting, and entails that some foods are excluded from the diet or by a *flexible control* in relation to an eating behavior, which is described as a more graduated approach to eating and dieting, in which all types of food can be eaten but with a control on the quantity [43]. High rigid control on eating behavior has been related with high 'disinhibition' scores [43] which was also observed in our WLM group. The fact that these behaviors reinforce each other, imprisoning the individual in a vicious circle [43], might explain why similar energy intake was observed in the WLM and the control groups in our study, despite high 'restraint'. Therefore, the ability to exert flexible control might be a desirable goal and could be encouraged in the WLM group. The concept of mindful eating, which promotes eating in a manner that balances individual nutritional needs, hunger, satiety, appetite, and pleasure has shown encouraging preliminary findings [44–46]. It could be a helpful approach, but should be carefully evaluated in the long term, because any alteration in the WLM strategies could also result in undesirable outcomes.

The qualitative data give more insight into what it means to maintain weight loss in the long run. The discourse of the WLM group reflected an effortful control and a constant vigilance, whereas the normal-weight controls expressed a more relaxed attitude. However, the control group also paid attention to their intake and food choices, similarly to what has been shown by others [47–49]. This was also true for physical activity, as those in the WLM group scheduled specific activities, whereas those in the control group were more active on a daily basis. Finally, the fear of regaining weight and the fact that weight loss maintainers did not always feel understood in their struggle should be taken into account when devising WLM interventions. It is possible that developing long-term support, for example in the form of peer-groups, might alleviate the burden experienced by persons maintaining weight loss, as suggested by Hindle et al. [27].

This study has some limitations. Most importantly, the dietary measure is prone to bias because it relies on memory and necessitates the ability to estimate monthly frequencies and portions [50]. The rather low energy intake in our sample indicate an underestimation of the intakes, as is usually the case with food frequency questionnaires [50]. Therefore, the absolute results of dietary intake should be considered with great caution. However, as the FFQ was used in both groups, the comparison of their intakes can be valuable. Moreover, as underreporting has been related to weight loss history and dietary restraint [51, 52], the WLM group might have underestimated their intake to a larger extent than the controls. In this case, the real energy intake might be higher in the WLM group than in the controls, which would stress the importance of addressing 'restraint' and 'disinhibition' in this group. Another limitation is the higher BMI of the WLM group, which could have contributed to their sense of burden by increasing the desire to lose more weight.

The sample size is a limitation with regard to the quantitative data, and the power is insufficient to relate subgroups characteristics and strategies. Also, the comparisons should be considered with caution. However, the number of participants was large compared to other qualitative studies about WLM, and limited generalizability is normally the case in qualitative studies [36].

Among the strengths of this study is the complementarity of the quantitative and qualitative methods used. Another forte is the snowball procedure we used for recruiting in the community, which allowed for a heterogeneous sample, including men, and provided rich data. Other strengths include matching the individuals of each group, asking for proof of WLM and using validated questionnaires.

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Conclusion

This study shows that there is an additional burden to maintaining weight loss compared to keeping a stable normal weight over time. Both necessitate self-control and conscious choices, but, even after t3.5 years, weight loss maintainers endure a high level of vigilance to stick to their strategies, whereas persons with a lifetime stable normal weight display a more relaxed attitude and the ability to adjust their intake more intuitively. In spite of these unequal efforts, energy and nutrient intakes do not differ between groups. Long-term changes in resting energy expenditure after WLM are unknown and should be explored. Research should also focus on the long-term effect of various interventions on the burden of WLM, such as promoting mindful eating, increasing the ability to choose appropriate portions from a variety of foods instead of rigidly selecting/avoiding certain types of food, and providing long-term support.

Disclosure Statement

The authors declare having no conflict of interest.

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APPENDIX III

Qualitative analysis of the role of self-weighing as a strategy of weight control for weight-loss maintainers in comparison with a normal, stable weight group.

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M. Kruseman designed the study, searched for funding and performed the data collection together with I. Carrard. M. Kruseman trained and supervised N. Schmutz who assisted with data collection. M. Kruseman participated in the analysis of this data set and the writing of the manuscript in collaboration with I. Carrard.

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Qualitative analysis of the role of self-weighing as a strategy of weight control for weight-loss maintainers in comparison with a normal, stable weight group

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Abstract

Self-weighing seems to have a primary role in weight-loss maintenance. The use of this strategy may help correct even slight weight regain and contribute to long-term weight stability. However, self-weighing has also been associated with negative psychological health consequences in specific subgroups. This study aimed to explore the use and the behavioral and psychological consequences of self-weighing in a group of weight-loss maintainers (WLoMs). We chose a qualitative design to conduct this investigation. Eighteen WLoMs were interviewed and compared to a matched comparison group of 18 participants with a lifelong normal stable weight (NSW). Analyses showed that most WLoMs needed regular self-weighing to be aware of their weight. The weight displayed on the scale helped WLoMs sustain the continuous efforts needed to maintain weight loss and also at times triggered corrective actions that were sometimes drastic. Weight changes generated both negative and positive affect among WLoMs, who could experience anxiety because of self-weighing or have their self-esteem impaired in the case of weight gain. In comparison, the NSW group rarely used self-weighing. They relied on a conscious way of living to control their weight and needed fewer strategies. NSW participants simply went back to their routine when they felt a slight increase in their weight, without experiencing consequences on their mood or self-esteem. Regular self-weighing as a component of weight-loss maintenance should be encouraged to help WLoMs regulate their food and physical activity, provided that potential consequences on psychological well-being, including self-esteem, are screened and addressed when needed.

Keywords: weight-loss maintenance; self-weighing; psychological well-being; body weight; behavioral strategies

1. Introduction

Weight-loss maintenance is a major issue in the treatment of obesity. Behavioral interventions involving diet and physical activity have been reported to be only moderately effective in slowing weight regain after weight loss (Dombrowski, Knittle, Avenell, Araujo-Soares, & Sniehotta, 2014), and research is needed to design effective interventions (MacLean et al., 2015). A way of improving our knowledge on weight-loss maintenance is to observe successful individuals. In the community, it has been reported that, among previously overweight or obese persons who lost at least 10% of their weight, around 20% succeeded in maintaining the loss for at least one year (de Zwaan et al., 2008; McGuire, Wing, & Hill, 1999). This number might increase if we could transfer the know-how of those who succeeded to those who tend to regain weight.

After long being criticized as being responsible for the increase in disordered eating, self-weighing has attracted the interest of researchers as a weight-control strategy (Pacanowski, Bertz, & Levitsky, 2014). Weight monitoring belongs to the strategies of weight-loss maintenance identified by the National Weight Control Registry (NWCR), which has been enrolling successful weight-loss maintainers for twenty years. This study identified the core weight-loss maintenance strategies as being the consumption of a low-calorie low-fat diet, the maintenance of high levels of physical activity and the consistent self-monitoring of weight (Butryn, Phelan, Hill, & Wing, 2007; Thomas, Bond, Phelan, Hill, & Wing, 2014). A reduction in the use of any of these strategies, including self-weighing, turned out to be predictive of weight regain several years later (Thomas et al., 2014). Using semi-structured interviews, qualitative studies carried out with individuals successful with weight-loss maintenance also underlined the importance of self-weighing, together with a healthy, balanced eating approach including regular meals, increased levels of physical activity and social support (Hindle & Carpenter, 2011). Self-monitoring of weight and behavior was also a theme that distinguished those who maintained weight loss from those who had regained weight, combined with adopting a long-term approach, setting realistic weight goals, having a routine and being organized, avoiding food deprivation and coping with lapses (McKee, Ntoumanis, & Smith, 2013).

Regular self-weighing has been examined in literature reviews and is associated with greater weight loss or prevention of weight regain (Pacanowski et al., 2014; Vanwormer, French, Pereira, & Welsh, 2008; Zheng et al., 2015). A higher weighing frequency was also associated with greater weight loss or less weight gain at 24-month follow-up in two large trials conducted in the community (Linde, Jeffery, French, Pronk, & Boyle, 2005). Interventions based on self-weighing and feedback were successfully evaluated for weight-gain prevention of college students (Bertz, Pacanowski, & Levitsky, 2015; Levitsky, Garay, Nausbaum, Neighbors, & Dellavalle, 2006), leading to the postulate that self-weighing might prevent age-related weight gain.

In spite of these studies, self-weighing use is still in debate because the consequences of frequent self-weighing on psychological health have been questioned (Dionne & Yeudall, 2005). Positive correlations have been found between self-weighing and disordered eating, body dissatisfaction or depressive symptoms, and weight gain among adolescents and young adults (Neumark-Sztainer, van den Berg, Hannan, & Story, 2006; Pacanowski, Loth, Hannan, Linde, & Neumark-Sztainer, 2015; Quick, Larson, Eisenberg, Hannan, & Neumark-Sztainer, 2012). A review of 20 studies that examined psychological effects of self-weighing showed that many of the studies reported a negative relationship between self-weighing and affect (4/10), self-esteem (3/4), body evaluation (4/10) and eating behaviors or cognitions (6/13), particularly for certain subgroups, such as women or young adults (Pacanowski, Linde, & Neumark-Sztainer, 2015). A recent meta-analysis also highlighted that the effect of self-weighing might be adverse for particular individuals, such as younger samples or normal-weight individuals, or in certain situations, such as when self-weighing was not part of an intervention (Benn, Webb, Chang, & Harkin, 2016). The benefits and the potential adverse effects of self-weighing have to be described more thoroughly to help health care professionals give correct and relevant advice.

The importance of self-monitoring to adjust one's behavior is based on the theory of self-regulation (Bandura, 1998). Recording one's behavior and then comparing the actual state with the desired state would prompt self-corrective adjustments to achieve one's goal through a discrepancy-reducing feedback loop (Carver & Scheier, 1982). Self-monitoring is one of the "ingredients" identified in the corpus of techniques used in behavior-change interventions (Abraham & Michie, 2008) that target healthy eating and physical activity,

smoking cessation (Michie, Hyder, Walia, & West, 2011) or control of alcohol consumption (Michie et al., 2012).

Regarding weight management, keeping track of one's weight would enable the adjustment of the behaviors involved in its control, food consumption and physical activity (Boutelle, 2006). The complementarity of other weight-management components was confirmed by studies that searched to determine the unique effect of self-weighing (Madigan, Jolly, Lewis, Aveyard, & Daley, 2014; Mahoney, 1974). They concluded that there was a lack of evidence to recommend self-weighing as an intervention without any other behavioral component.

The first randomized controlled study showing that daily self-weighing was an effective tool for the prevention of weight regain was conducted with participants who had lost at least 10% of their body weight during the prior 2 years (Wing, Tate, Gorin, Raynor, & Fava, 2006). The study, which was aimed specifically at weight-loss maintenance, also provided the participants with feedback and intervention aiming at self-regulation. A softer procedure designed to encourage and facilitate weekly self-weighing as a maintenance intervention after a weight-loss program that proposed recording weight on a card, together with two telephone calls without specific advice on weight management, also showed promising results (Madigan, Aveyard, et al., 2014).

These studies have highlighted the key role of self-weighing in weight-loss maintenance in the presence of additional tools, such as weight record-keeping, reinforcement, feedback or counseling, but they have provided no information about how weight-loss maintainers converted self-weighing into a successful strategy. A better understanding of the processes that underpin the successful effect of self-weighing on weight in observational studies could help optimize its use in interventions. The goal of the present study was to explore the use and the consequences of self-weighing in weight-loss maintenance. In order to identify the specificities related to weight-loss maintenance, we compared two groups, one composed of participants successful at maintaining weight loss and one composed of participants who had always had a normal, stable weight. We wanted to address three questions:

- Was self-weighing used as a weight maintenance strategy?
- What were the behavioral consequences of self-weighing?
- What were the psychological consequences of self-weighing?

In order to collect data on processes, we conducted face-to-face interviews of weight-loss maintainers (WLoMs) and of individuals with a lifelong normal stable weight (NSW), and we proceeded to descriptive qualitative analyses. We referred to the consolidated criteria for reporting qualitative research (COREQ) to report our study (Tong, Sainsbury, & Craig, 2007).

2. Material and methods

2.1 Population

We recruited two groups of 18 participants in the community, from June 2013 to January 2014, through snowball sampling. The sample size of 18 participants per group was defined a priori for the exploratory study. The first WLoM participants were recruited through the professional and personal networks of the investigators. After each interview, participants were asked whether they could think of someone in their environment who could be a comparison participant and whether they knew other people who had also lost and maintained weight loss. Both samples were recruited this way.

The inclusion criteria used for the WLoM group were those of the NWCR (Wing & Hill, 2001), with intentional weight loss of at least 10% and maintenance for at least one year. Participants were required to have been overweight (BMI≥25) for a minimum of one year before the loss, excluding pregnancy. Women who had given birth and who had breast fed should have stopped for at least one year. Exclusion criteria were bariatric surgery or severe somatic or psychiatric conditions. Self-weighing was not an inclusion criterion.

The inclusion criterion to be involved in the NSW comparison group was to have had a normal weight (18.5 ≤BMI≤24.9) during adulthood, which was stable within a range of 5 kilos. Exclusion criteria were severe somatic or psychiatric conditions.

Groups were paired on gender, age and socio-economic status. The data used in this study were part of an exploratory study on weight-loss maintenance. Results on dietary intake will be published elsewhere (in preparation).

2.2 Procedure

After first contact by phone to check the main inclusion and exclusion criteria, an appointment was arranged with an interviewer. During this appointment, participants

received complete information on the study and signed an informed consent prior to proceeding with the interview. It was explained to participants of both groups that we were interested in individuals successful at weight-loss maintenance so that those who regain weight could be better supported. The inclusion of a normal stable group was explained by saying that we wanted to understand which processes were specific to weight-loss maintenance in comparison with normal weight control. The weight loss of WLoMs was attested by pictures before and after the loss, as done in the NWCR (Klem, Wing, McGuire, Seagle, & Hill, 1997). Interviews were audio-recorded, and no field notes were taken. Participants were seen once for one to two hours. The meeting took place either at the participant's home or at our office; we made sure that the place was quiet. Only the interviewer and the participant were present during the interview. At the end of the interview, the participants received paper questionnaires that they had to mail back with a pre-stamped envelope. In the present paper, only data from the socio-demographic questionnaire were used. The participants received by mail a general report on the study results at the end of the trial, together with a gift voucher of 20 Swiss francs. We did not ask them to correct the transcripts. The protocol was approved by the Cantonal Ethics Committee on Research (Geneva, Switzerland).

2.3 Measures

Interviews: Semi-structured interviews were conducted by one of three female interviewers, two dietitians and one psychologist (including the two authors IC and MK). One of the dietitians and the psychologist (the authors) were experienced, with a Master's in Public Health for the dietitian, a PhD in Psychology for the psychologist and more than 10 years of clinical and research experience in the field of obesity and disordered eating for both of them. The second dietitian had more recently graduated, had experience in treating patients who were overweight or obese, and worked under the authors' supervision. A grid with the main questions helped the interviewers address all the topics to cover. This grid was slightly adjusted after the first interviews, in accordance with unplanned items that had emerged. The data collected concerned weight history, including weight loss and weight regain episodes if any, reasons for weight gain or weight stability. The data on participants' current weight, weight loss and weight-loss maintenance duration were retrieved from this part of the interviews. WLoMs were questioned on the methods used the last time they lost weight.

All participants were asked about strategies, rules or habits that, according to them, had ensured weight management either after weight loss (for WLoMs) or during their whole life (for the NSW group). In addition to open questions on strategies, specific questions were focused on self-weighing frequency ("How frequently do you weigh yourself?", "Why?" "And before losing weight how frequently did you weigh yourself?" and "At what frequency will you continue?") and perceived consequences ("What happens when the weight displayed on the scale increases/decreases?").

Self-weighing frequency: Participants' answers were classified according to the following categories used in previous studies (LaRose et al., 2014; Wing et al., 2006): 0: never weigh myself; 1: less than once/month; 2: less than once/week; 3: one time/week; 4: several times/week; 5: one time/day; 6: several times/day.

Socio-demographic questionnaire: Data on participants' age, gender, origin, marital status, education level, profession and income level were collected with this questionnaire.

2.4 Analysis

The interviews of the 36 participants were anonymized and integrally transcribed verbatim. In order to describe the processes as reported by the participants with the least interpretation, we based our analysis on qualitative description as characterized by Sandelowski, which entails "low-inference" interpretation (Sandelowski, 2000). Sandelowski explained that qualitative description does not require a conceptual interpretation of data. The output of the analysis should be "a comprehensive summary of an event in the everyday terms of those events […], an accurate accounting of events that most people (including researchers and participants) observing the same event would agree is accurate" (p. 336).

The quantitative analyses were conducted with SPSS (version 22). They included descriptive analyses of participants' characteristics and differences between groups. Comparisons between groups were calculated with chi-square for nominal variables and t-tests for quantitative variables. Calculations involving self-weighing frequency were cross-checked with non-parametric analyses that gave similar results.

The interviews were coded by IC and MK with MaxQDA (version 11). To ensure standardization of the codes, two interviews were first coded by both of them together.

Then, the two authors coded half of the interviews separately according to a list of codes. Several a priori codes were defined similarly for both groups. They were descriptive, mainly determined from the strategies for weight management mentioned in the literature (e.g. planning, weight self-monitoring). The list was then enriched with codes that emerged during the process of coding and that were more specifically related to the three research questions on the use of self-weighing and self-weighing's behavioral and psychological consequences. A logbook described the list of codes and what they included or not, together with rules of coding. Each modification was discussed and when a new code was introduced, all interviews were re-examined. Each coder reviewed the interviews coded by the other; several iterations were needed. No new codes emerged in the last interviews, indicating that we had reached data saturation.

3. Results

3.1 Sample characteristics

The WLoM group's mean age was 39.3 ± 8.2 years old, and that of the NSW group was 39.4 ± 10.1. Each group comprised 11 women (61.1%) and 7 men (38.9%). The WLoM group's mean BMI was significantly higher than the NSW group's BMI (25.8 ± 3.0 vs 21.3 ± 2.1, $t_{(34)}$=-5.2, p<.001).

Most participants came from Switzerland (n = 26, 72.2%), with no difference in nationality between WLoMs and NSW participants (χ^2 = 0.6, p=0.711). No differences emerged regarding marital status of the two groups ($\chi^2_{(3)}$ = 5.9, p=0.117) or education level ($\chi^2_{(5)}$ = 3.3, p=0.647). The majority of participants were professionally active (n=17 WLoMs (94.4%), and n=16 NSW participants (88.9%)) and income categories were similar between the two groups ($\chi^2_{(7)}$ = 5.7, p=0.580).

WLoMs had lost a mean of 25.2 ± 11.1 kg and had maintained the loss for a mean of 3.9 ± 3.6 years. To lose weight, most WLoMs had resorted to popular weight-loss programs that they had applied by themselves or customized. These weight-loss programs favored proteins, a balanced diet or were a home-made mix. A few participants used the help of a dietitian or a health care professional who gave various prescriptions regarding self-weighing during the weight-loss phase, from "weigh yourself each day" to "once a month when we

meet." Two WLoMs were seeing a health care professional for their weight maintenance but had received no prescription regarding self-weighing for weight-loss maintenance.

3.2 Frequency of self-weighing

WLoMs' mean frequency of self-weighing was 3.3 ± 1.5 on the scale that ranged from 0 "never" to 6 "several times a day". This result represents a frequency of self-weighing between once a week and several times a week. NSW group's median frequency was 1.2 ± 1.4, which represents self-weighing less than once a month. No participants reported self-weighing several times per day. Proportions of each group's participants by frequency of self-weighing are displayed in Figure 1.

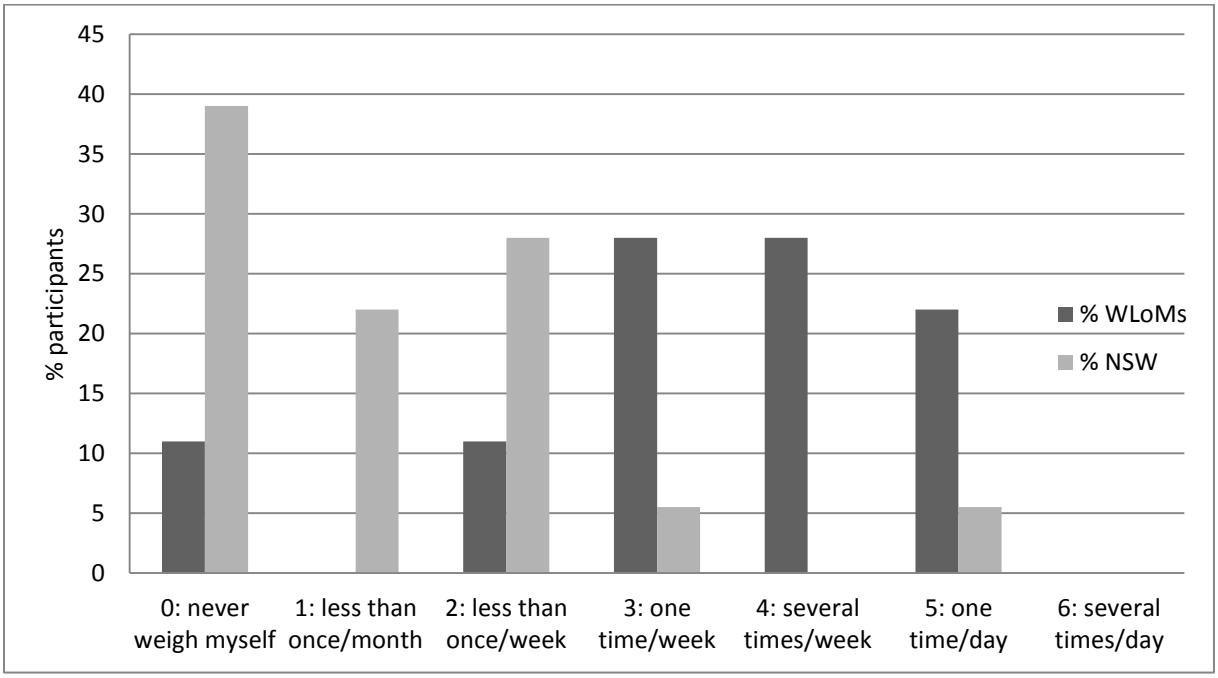

Fig.1 Percentages of WLoMs and NSW participants in each category of self-weighing frequency (WLoMs: Weight-loss maintainers group; NSW: Normal, stable weight comparison group).

The difference of self-weighing frequency between the groups was statistically significant ($t_{(34)}$=-4.3, p<.001), meaning that the WLoMs used self-weighing more frequently than NSW participants.

3.3 Qualitative description

Data description is structured according to the three questions explored in this study.

- Was self-weighing used as a weight maintenance strategy?
- What were the behavioral consequences of self-weighing?
- What were the psychological consequences of self-weighing?

Regarding **the use of self-weighing as a weight maintenance strategy**, self-weighing was not spontaneously mentioned as a strategy, but when we came on the topic during the interview, "stepping on the scale" was considered as a safety measure by the group of WLoMs. Two WLoMs mentioned that they were relying on their clothes and one of them on his performance when biking. Whereas most WLoMs said self-weighing was helping them to monitor their weight, most NSW participants said they never used a scale or very rarely did so.

When WLoMs were asked if they used to weigh themselves before weight loss, most of them answered negatively, ("definitely not"), meaning that at that time they did not want to know how much they weighed. They got into the habit of self-weighing during weight loss. Without the scale as a reference, they had no idea of their weight: "*I can gain four to five kilos. I won't know it. I only see it on the scale*" (WLoM, Woman, 47).

WLoMs continued self-weighing during weight maintenance and said that they would go on that way. The result of self-weighing was considered to be either encouraging, when their weight was stable or decreasing, or providing a warning sign, when their weight was increasing. The scale informed them of whether they had properly managed their week/day or not, which was the trigger for action when weight was increasing: "*When I see the scale, either it's encouraging, or I think 'Ouch, I have to pull myself together'*"(WLoM, Woman, 29).

Self-weighing was seen as routine on the part of the WLoMs: "*I weigh myself every other morning; it has really become a habit now*" (WLoM, Man, 52). But for others, self-weighing was painful, and they would have liked to avoid it. Some had tried to, but observed that they had gained weight. One woman noticed that continuous self-weighing during weight-loss maintenance was the difference between this successful weight loss and the previous ones, after which she had regained weight.

Apart from triggering action when their weight had increased, self-weighing also appeared to have a role in itself among WLoMs, contributing to awareness and vigilance, like a

safeguard: "*It helps me to weigh myself once a week. I like to keep track of where I am. It stays here a little [showing her head]. It's a kind of control, for sure*" (WLoM, Woman, 42).

On the contrary, NSW participants could "feel" their weight—some of them even with accuracy close to 500 grams—whereas not one WLoM mentioned such an internal benchmark. NSW participants relied on clothes or on their reflection in the mirror as a reference: "*I don't need to weigh myself to know how much I weigh. I weigh myself once in a while. I know how much I weigh within 500g even if [my weight] has changed*" (NSW participant, Woman, 45).

Then, regarding **the behavioral consequences of self-weighing** or of feeling one's weight, we identified patterns of behaviors intended to manage weight that resulted from weight awareness and classified them into three categories. The first category assembled strategies used when participants were accepting the weight they either felt or saw on the scale and was called "Conscious living." In the second and third categories were collected strategies used when participants wanted to modify their weight; they were called "Drastic compensation" and "Keep calm and go back to your routine."

The category called "Conscious living" concerned patterns used when individuals' weight was perceived as stable. Participants of both groups kept at their usual weight-management strategies, which were mostly about planning and organizing mindfully.

All participants, WLoMs and NSW participants, mentioned being careful not to keep stocks of tempting foods at home, giving away the chocolate they received in excess, planning before buying groceries or organizing themselves to prepare meals in advance so as not to be dependent on take-out. Physical activity required some arrangements with work and family for WLoMs and the NSW group. Overall, both groups anticipated and organized themselves to move and eat in a balanced way.

But besides these similarities in "Conscious living" for WLoMs and NSW participants, differences between groups could also be noticed. Most WLoMs were more stringent: "*It is necessary to put constraints in the diet because you cannot expect success without making an effort. You have to be consistent*" (WLoM, Woman, 47). They had developed an arsenal of proactive strategies in relation to the pitfalls of their environment. They suggested

restaurants if their friends wanted to go to places where nothing suited them or asked the waiter to swap the starches for vegetables; they warned their family that they would not eat anything when invited for birthdays or holidays. Overall, WLoMs were constantly watchful regarding their diet and/or their physical activity, even when their weight was stable.

NSW participants reported fewer controlled strategies. Some of them explained that they were able to know in advance how much to eat in order to have enough until the next meal or to be able to put the right quantity on their plate to have "enough but not too much": "*I don't eat big portions. Generally, I help myself so that there are no leftovers on my plate. If I want more, I can take a second plate*" (NSW participant, Woman, 49). WLoMs never mentioned such knowledge. Finishing one's plate was mentioned as a common habit among the NSW group and WLoMs, but the latter were not able to help themselves the adequate quantities and ended up overeating.

The category "Drastic compensation" assembled extreme strategies used to rectify weight increases. They were used by most WLoMs. When weight increased on the scale, they turned to the method they had used for weight loss and re-applied the principles that had worked previously. These rules were often radical, such as one day of consuming exclusively protein, two-three days of low-fat cottage cheese and bouillon, or eating more vegetables and (almost) no carbohydrates. Some said that constant attention was needed and that they knew it would be the case for the rest of their lives. Others even spoke in terms of punishment. Most WLoMs fluctuated between usual strategies and restrictive phases, during which they went on a strict diet: "*I know that during 2-3 days, I will only eat vegetables and proteins, with some fruits*" (WLoM, Woman, 42); "*I try to be vigilant and to react quickly. One and a half kilo [gained], and I don't feel pretty anymore. I go back to my weight-loss program*" (WLoM, Woman, 45).

Finally, the category "Keep calm and go back to your routine" gathered strategies mainly used by NSW participants when they felt they had gained some weight. They knew that at certain times, such as Christmas or holidays, they would gain a little weight and that they would lose it when they went back to their habits. After they ate calorie-rich foods during a certain time, either they would pay more attention to their diet and do more physical activity for a while or they would feel uncomfortable rather rapidly and would not continue

eating that way. NSW participants seemed to counterbalance in a natural way, without having to plan restrictive days or apply specific control strategies. Processes seemed automated compared to WLoMs who had to instill constant attention to manage their behavior: "*If I eat too much greasy, heavy stuff, naturally I rebalance. But even without an effort, it's spontaneous. I feel it was too much and I … it just rebalances"* (NSW participant, Woman, 43); "*It is a sweet balance during the holidays. We eat one main meal, and for the rest we eat sandwiches. It's a kind of balance*" (NSW participant, Man, 35).

When it comes to **psychological consequences of self-weighing**, first, WLoMs judged negatively their "dependency" on self-weighing. Weighing too frequently left them worried that it would become overwhelming and "drive them crazy": "*I don't want to weigh myself every day, but I know it helps me*" (WLoM, Woman, 45). Frequent self-weighing was also discouraged by health care providers: "*During the first three years, I got on the scale twice a day, in the morning and in the evening, to be sure. And then my dietitian slapped me on the wrist, so I continued only in the morning*" (WLoM, Woman, 44). WLoMs felt worried about giving too much attention to their weight, but on the other hand they also reported that missing the "self-weighing session" could be associated with anxiety: "*Every morning I get on my scale. Every morning. I am worse than a girl. The day I leave my house and I realize that I have forgotten, I panic all day*" (WLoM, Man, 37).

Secondly, among WLoMs, the weight displayed on the scale was more than just information on how they had dealt with food and physical activity during the previous days. It provoked consequences for their mood, their body image, and for some of them, on their self-esteem. Weight loss was related to happiness and weight gain with anxiety, guilt, sadness, anger and self-blaming among WLoMs: "*The lighter I am on the scale, the better I feel. If my weight goes up, I spend the whole day thinking about it*" (WLoM, Woman, 44). They were sensitive to the variations of the scale that could switch on an internal alarm as if regaining a little was similar to gaining back all the lost kilos: "*I am very attached to my body image, which affects my mood a lot, I mean. If my weight increases, it makes me sad. I don't want to go out anymore. It's a bit as if gaining 2-3kg meant I regained all my weight! As soon as it's going up, I say oh no, that's dreadful! I'm not tolerant at all with myself over that. And when it [the weight] goes down, it has a slight euphoric effect! I go back to my weight-loss program when it goes up*" (WLoM, Woman, 30). Insecurity regarding their success and anxiety of regaining

weight was revealed through their interaction with the scale. No participants reported what happened to their mood when their weight was stable.

Paradoxical effects were also mentioned, such as thoughts of eating more when the weight was lower than expected: "*I am happy when my weight goes down and unhappy when it goes up. When it goes down I think, 'Cool, you can take two more macaroons," but I shouldn't think that way because it will stop going down*" (WLoM, Woman, 28).

In comparison, the NSW participants who weighed themselves reported no implications of the result of self-weighing on their mood. They were not surprised by the results that appeared on the scale. Their emotions and their self-esteem were independent of the result shown on the scale. NSW participants were satisfied with their weight but would not have liked gaining weight. They reported that they would feel unsatisfied if they gained 5 to 10 kilos and would react to avoid more weight gain: "*I don't know how I would feel if I gained weight, but I am sure that I would react*" (NSW participant, Man, 47).

Discussion

In this paper, we analyzed interviews of individuals who had maintained weight loss and others who had always kept a normal stable weight in order to explore and compare how self-weighing was used as a strategy of weight maintenance as well as the behavioral and psychological consequences of self-weighing.

Most participants in the WLoM group used self-weighing more frequently than the NSW participants. The strategy of self-weighing was part of WLoMs' life as it helped them to keep the course and adjust their dietary intake and physical activity. Without the help of the scale, they were unable to identify any weight gain, even, for some of them, after several years of weight-loss maintenance. This is in accordance with data from the NWCR showing that discontinuing self-monitoring of weight was associated with weight regain (Thomas et al., 2014). WLoMs had acquired this strategy during weight loss and were still relying on it, whether it was a trouble-free routine or a painful moment. In comparison, individuals who had had a lifelong normal stable weight seemed to rely on internal points of reference. They knew rather precisely the variations of their weight without needing a scale.

The behavioral consequences of self-weighing—or of feeling one's weight for participants who did not rely on self-weighing—entailed adapted strategies according to weight change. Even though participants of both groups went on as usual when their weight remained stable, the "usual" differed between the WLoMs and the NSW group. All participants reported that they needed planning and organization. However, WLoMs had developed more tactics, needed constant attention and resorted to more stringent behaviors than NSW participants who relied on internal knowledge. Also, when their weight increased, WLoMs could resort to quite extreme behaviors to return to their weight, whereas NSW participants went back to their routine. Weight management differed between WLoMs and people with a lifelong normal stable weight in terms of vigilance and energy devoted to it, even after several years of weight-loss maintenance.

The WLoMs did not rely on self-weighing as a single measure as it was interrelated with behavioral strategies, but it was a necessary condition to guide one's behaviors. This observation is consistent with studies that found an effect of self-weighing when used in a self-regulatory program (Wing et al., 2006). However, WLoMs were capable of giving themselves feedback and adjusting their behavior without needing professional advice. Self-weighing seems a necessary step allowing the behavioral components of personal health strategies to work. It instills the drive to react or the motivation to go on with the strategies, as illustrated by the WLoMs who expressed a "dependency" to self-weighing and acknowledged that stopping the use of the scale had led to weight regain. This constant use of strategies was also reported by the quantitative studies on the NWCR data (Butryn et al., 2007; Thomas et al., 2014) and in qualitative studies (Hindle & Carpenter, 2011).

The consequences of self-weighing on mood were also different across groups. For most WLoMs, weight increase triggered negative emotions such as anger and guilt. In the present case, it seems that these emotions of anger or guilt were helping WLoMs to initiate corrective actions. If we refer to the model of self-regulation proposed by Carver and Scheier (1982; 2011), negative affect can be seen as the "error signal" that results from the comparison between the current and desired states. This error signal indicates a discrepancy between the observed and expected weight, leading the persons to make more efforts to reach their goal. Furthermore, the increase in positive affect is a sign that weight is less than planned and that the person outperformed, leading the individuals to decrease their efforts.

That can be paralleled to what we observed among the WLoMs of our study, who were alternating between usual and drastic corrective strategies. In comparison, the process of self-regulation of NSW participants was much smoother and seemed mostly automatic, requiring less attention. It implied neither self-weighing nor strong corrective actions, and it was not causing notable variations in their emotional state.

However, some WLoMs also reported anxiety towards self-weighing or that their self-esteem was negatively affected when their weight increased on the scale. This negative impact of self-weighing on psychological well-being corroborates results observed in adolescents and young adults (Benn et al., 2016; Pacanowski, Linde, et al., 2015; Pacanowski, Loth, et al., 2015; Quick et al., 2012) and shows that despite the number on the scale certainly ensuring that actions will be taken in case of weight regain, some WLoMs had difficulties keeping a healthy concern for weight maintenance without adverse effect.

The negative effect that self-weighing can cause on certain WLoMs' self-esteem should be examined in a longitudinal study, as it may impact the person's sense of self-efficacy or add a supplementary cost to the constant vigilance already needed for weight-loss maintenance. WLoMs may be then discouraged to continue using this strategy, thus precipitating weight regain. Moreover, the overvaluation of shape and weight for self-esteem is a core feature of eating disorders (Fairburn, 2008). Before recommending self-weighing as a strategy for weight-loss maintenance, disordered eating should be checked in persons experiencing this association between weight and self-esteem.

These findings underline that weight-loss maintenance can be attained through behaviors that are disseminated along a continuum of healthy and extreme strategies. Drastic behaviors can suit certain WLoMs and enable them to achieve weight-loss maintenance. Even though they are not usually recommended, they can be tolerated, as long as adverse effects on psychological health are screened and taken care of.

This study shows that self-weighing is used by many individuals as a successful strategy for weight-loss maintenance. Even if self-weighing has been most of the time described as a necessary strategy for weight-loss maintenance in the literature (Butryn et al., 2007), a qualitative study also described WLoMs that did not rely on this strategy (Metzgar, Preston, Miller, & Nickols-Richardson, 2015). Instead they reported that social support that helped

them to stay motivated, planning ahead, being mindful and aware of one's food choices, learning about nutrition and portion control, and being physically active were facilitators of weight loss and weight-loss maintenance. This shows that other pathways can be taken to reach weight-loss maintenance, which could be recommended for those who experience adverse effects from self-weighing.

The inclusion of a heterogeneous sample composed of men and women that had used different weight-loss methods provided rich data and can be seen as a strength. These results cannot be generalized on a statistical basis; instead, they can only be generalized only on a theoretical basis. One has to keep in mind the specificities of the sample, as most of the individuals interviewed in this study had chosen to lose and maintain weight on their own, with no or little help from professionals. They had used various weight-loss methods and relied on strategies of weight-loss maintenance that they had developed by themselves. Self-weighing was suitable for most of them to help them maintain their weight loss. The literature has shown that this strategy was privileged for many persons from the community, similar to our sample, but also that there were other options, such as relying on internal cues that could be learned during a weight-loss program. Two WLoMs in our study also mentioned relying on their clothes, similarly to several participants of the control group. Identifying the determinants predicting who can benefit the most from which strategy would be valuable for the design of a tailored weight-loss maintenance program.

Finally, it must be noted that the comparison group enrolled in this study was hard to recruit. We demanded a lifetime stable weight within a range of 5 kg, whereas the normal population seems to gain weight during its lifespan (Droyvold et al., 2006). We probably included participants who had particular abilities to monitor their weight with internal cues and who had acquired good knowledge of their functioning. A recent study showed that the importance of the environment can be more or less "obesogenic" and potentiate or neutralize unhealthy eating habits (Lindvall et al., 2015). If the context continues favoring weight gain increasingly, more people might have to resort to strategies to preserve a stable weight—and self-weighing may be one way.

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APPENDIX IV

What happens with weight loss maintenance? An exploratory study on body composition, resting energy expenditure, dietary intake and physical activity

Manuscript

The results of this study will be presented at the European Congress on Obesity. The manuscript will not be published because of the exploratory character of the study. M. Kruseman designed the study, searched for funding and performed the data collection with the collaboration of I. Carrard. M. Kruseman trained and supervised A. Aebi who assisted with data collection. M. Kruseman analyzed the data and wrote the manuscript in collaboration with I. Carrard. The manuscript was reviewed by Prof. L. Tappy.

What happens with weight loss maintenance? An exploratory study on body composition, resting energy expenditure, dietary intake and physical activity.

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Abstract

Weight loss maintenance (WLM) necessitates greater efforts than keeping a normal weight. This might be related with a lower than expected resting energy expenditure (REE) after weight loss, referred to as "adaptive thermogenesis" (AT). If AT persists overtime, it would force persons with weight loss maintenance to adopt more drastic strategies than normal weight controls in order to avoid weight regain. A longitudinal study would be necessary to assess to what extent AT is related to weight loss maintenance, and if this relation is mediated by factors such as impulsivity, which is an important component in the response to food stimuli. The goal of this pilot study was to assess the feasibility of such a cohort study by testing the methods measuring REE, body composition, impulsivity, diet and physical activity, and to provide an estimate of the difference in REE between weight loss maintainers and normal weight controls.

Introduction

In the initial phase of our pilot study on How to Maintain Weight Loss (HOMAWLO), we found that the weight loss maintenance (WLM) group ended up consuming amounts of energy and micronutrients similar to those of the control group (with lifetime normal stable weight), in spite of stronger cognitive control over their food choices and a higher vigilance towards the quantities they ate (1). Our results also seemed to indicate that the WLM group used exercise to regulate their weight more than the controls did. These observations might be related to the imprecision of our measurements, which relied on a food frequency questionnaire (2) and the Global physical activity questionnaire (3). But they can also be seen in light of the results of the National weight control registry, which show that among weight loss maintainers, those reporting more dietary control were also reporting the highest physical activity (4). This could suggest that, after weight loss, some individuals struggle with a lower than expected resting energy expenditure (REE), a phenomenon referred to as "adaptive thermogenesis" (AT), which forces them to use more drastic strategies to avoid regaining weight. Although the effect of AT on weight regain has been called "overrated" by some (5-8), it has been widely described as a response to undereating or to dietary changes (9-21). AT has mostly been documented during or shortly after weight loss (9, 22) and has rarely been investigated in long term weight loss maintainers; to our knowledge, only one recent publication suggests the persistence of AT several years after losing weight (12).

Based on our initial results and the literature published on AT, we hypothesized that the subjects with lower than expected REE would have to adopt more weight maintenance strategies, and apply them with greater rigor, than those who have a higher REE. A related hypothesis was that impulsivity, an important component in the response to food stimuli (23-26), would play a role in the ability to sustain these strategies. A longitudinal study would be necessary to assess to what extent adaptive thermogenesis and impulsivity are related, individually or in combination, to weight loss maintenance. Individuals of various corpulence and weight trajectories would be followed during their weight loss process and the subsequent weight maintenance or regain phases. The primary

outcomes would be weight differences (between follow-up and maximum weight, and between follow-up and baseline). The main determinants would be REE, AT and selected facets of impulsivity. Body composition, physical activity, dietary intake, weight maintenance strategies and eating disorders would be taken into account.

The goal of the exploratory study reported here was to test the methods and evaluate the feasibility of such a cohort study.

Methods

This exploratory follow-up study took place between February and November 2017, 3 years after the initial inclusion in HOMAWLO, at the Laboratory of the Department of Nutrition and dietetics (School of Health Sciences, Geneva, Switzerland). It was approved by the Cantonal Ethics Committee on Research.

Procedures

All the participants of the HOMAWLO study received a letter explaining the goals and procedures of this exploratory study, and inviting them to contact us. A reminder was mailed after 2 weeks. After 2 more weeks, the participants who had not reached out were contacted by email (twice) and telephone (up to 3 messages if the person could not be reached). Each participant who accepted the follow-up received a written confirmation with the instructions regarding the 2½ hour-assessments. Upon arrival at the laboratory, each participant received the formal information and signed the consent form, and underwent the calorimetry and the anthropometric measurements, then received breakfast. The results were not shared with the participants. After breakfast, they were interviewed about their perceived difficulties and opportunities related to weight maintenance, and completed two computerized tasks assessing two dimensions related to impulsivity and relevant for weight maintenance: inhibitory control of automatic responses, and decision making (27, 28). Then they were instructed about the questionnaires and the food diary to be filled at home, and about the use of the accelerometer (ActiGraph). They were given pre-stamped envelopes for returning the

documents and the accelerometer. Before leaving, they received a 45.- Swiss francs voucher for a department store, as compensation for their participation. Their travel expenses were reimbursed. Individual results and feedback were sent to each participant upon reception of their documents and instrument.

Measurements

The participants' height was measured to a 0.1 cm precision with a calibrated stadiometer (SECA, Germany) and they were weighed on the 0.01 precision scale linked to the Bod Pod (described below). Their current weight was measured to calculate weight change since inclusion. An increase or decrease of ≥5 kg was considered as weight change. Participants initially included as Weight Loss Maintainers were classified as "Regainers" if their weight had reached > 90% of their former maximum weight.

Body composition was assessed by densitometry (body weight divided by body volume), using an air-displacement plethysmograph (Bod Pod, Cosmed, Italy). After calibration of the device, the participant, wearing a tight swimsuit and a swim cap, sat in the measurement chamber while body volume was assessed (two repeated measurements, averaged). The thoracic lung volume, estimated by the software, was subtracted. The Bod Pod software was used to calculate the percent fat mass (Siri's equation), and fat free mass (weight minus fat mass).

REE was assessed by indirect calorimetry using a ventilated hood system (Quark RMR, Cosmed, Italy). The measurements were performed in the morning, after an overnight fast. Calibration was performed shortly before each measurement. The participants had been awake between 30 minutes and 2 hours, had been fasting for at least 10 hours, had refrained from any activity between awakening and the measurement, and had not performed strenuous exercise the day before the measurement. The participant lay down on a hospital bed with a canopy covering their head for 30 minutes. Noise and lighting were minimized during the measurement. The first 10 minutes were used to stabilize the reading and discarded; only the last 20 minutes were recorded in the database. Data

on the volumes of oxygen (VO2) and carbon dioxide (VCO2) were collected every 20 seconds and converted to REE. Predicted REE was calculated with three different formulas, the Mifflin-St-Jeor (29), the Harris-Benedict (30) and the Owen (31, 32) formulas; these three calculated REE's were compared to the measured values to assess to what degree each over- or underestimated the REE for a given group of subjects.

Physical activity was assessed by interview and with an accelerometer. During the interview, each participant provided detailed information about the exercise they performed every week, including type and intensity of exercise, duration in minutes per session, and number of sessions per week. Each activity was converted into metabolic equivalents or MET (33), which were used to calculate a physical activity level added to a daily life activity factor of 1.2. (PAL) (34). Additionally, the participants were given an accelerometer (ActiGraph, Florida, USA) to wear on their right hip for 5 consecutive days at all times except while showering, bathing or sleeping. They were also asked to keep a paper log of the wear-time of the accelerometer and the time and duration of activities other than walking, to provide correct attributions of the non-wear-time vs rest-time to the files. The raw data of the ActiGraph were processed to extract the durations (endurance) and cadence (performance) of walking episodes.

Dietary intake was assessed with a five-day food diary. The participants were instructed to write down all food and drink consumed during 5 consecutive days and nights, in as much detail as possible. Nutritional intake was calculated with the Prodi software (Prodi 6.6, Nutri-Science GmbH, Germany). Total energy intake was calculated in kcal and kcal per kg of body weight. Protein, carbohydrate, fat and alcohol intakes were calculated in grams per kg of body weight and in % of total energy intake.

Strategies for weight maintenance were assessed with a questionnaire developed on the basis of the initial HOMAWLO study results. The questionnaire provided a list of 29 food items and 19 behaviors, and the participants had to state their avoidance or adoption of each weight-maintenance strategy

on a 4 point scale. They could also add foods or behaviors to the list. Strategies were considered individually and in categories. Five categories were computed: Control of eating context (8 strategies, e.g. I avoid eating in restaurants, I avoid eating in front of the TV, I avoid the presence of fat foods or sweets), Control of intake (8 strategies, e.g. I avoid nibbling, I avoid second servings, I have breakfast), Planning (2 strategies: I organize my menus in advance, I eat regularly during the day), Monitoring (4 strategies, e.g. I weigh myself, I keep track of what I eat), and the strategy of practicing Physical activity.

Impulsivity was assessed with two computerized tasks. We used the Iowa Gambling Task (35) to evaluate participants' decision making, and we used a food-specific stop-signal task (36) specifically designed for the study to evaluate inhibitory control. These assessments took place in order to test their feasibility and usability, and their results are outside the scope of this paper.

Eating behaviors were assessed with the Eating Disorder Examination-Questionnaire (EDE-Q (37)) and the Three-Factor Eating Questionnaire (TFEQ (38)). The EDE-Q is a 28-item questionnaire that assesses core dimensions of eating disorders. Four subscales can be computed: Restraint, Eating concern, Weight concern and Shape concern, as well as a total score. The assessment, based on the past 28 days, is carried out on seven-point frequency or severity scales. The TFEQ is a 51-item questionnaire that evaluates eating behaviors in obesity. It yields one score for each of the three subscales of Restraint (21 items, e.g. "When I have eaten my quota of calories, I am usually good about not eating any more"), Disinhibition (16 items, e.g. "If I'm with someone who's eating heartily, I usually eat too much") and Hunger (14 items, e.g. "I'm often so hungry that I often eat between meals"). Higher scores indicate higher levels of Restraint, Disinhibition and Hunger, but no cut-off points are defined.

The experience of the participant as to what each found easy or difficult about weight maintenance was assessed in an open ended interview lasting 10 to 15 minutes.

Analysis

All quantitative data were analyzed descriptively (mean, standard deviation for continuous variables, frequencies and percent for categorial variables). Because of the small number of observations, Kruskal-Wallis tests were used for comparisons of continuous variables between three groups: Maintainers, Regainers and Controls. When relevant, categorial variables were compared between Maintainers and Controls with Chi^2 tests. Spearman correlations were performed for continuous variables. The qualitative data were analyzed following descriptive thematic analysis procedures (39).

Results

Of the 36 initial participants, 18 (10 Controls, 8 WLM) agreed to the follow-up visit. Among the 18 who did not (8 Controls, 10 WLM), twelve never answered at all, four stated that they were not interested, one was pregnant and one reported a disorder involving frequent hypoglycemia, which was incompatible with the fasting necessary for the calorimetry. Seven of the nine initial participants who lived more than one hour away from Geneva did not take part in the follow-up. Table 1 displays the characteristics of the 36 participants to the initial study, according to agreement to their follow-up.

Table 1: Characteristics of the participants at inclusion in the initial study (n=36).

	Agreed to follow-up (n= 18)	Declined to follow-up (n=18)
WLM/Control ratio (n)	8:10	10:8
Male/Female ratio (n)	9:9	5:13
Age in years (mean±SD)	44 (±9.7)	41 (±8.5)
Living >60 minutes from the laboratory (n)	2 (11%)	7 (39%)
Initial weight characteristics (mean±SD)		
Body Mass Index at inclusion (kg/m^2)	23 (±2.6)	24 (±4.1)
Initial weight loss (kg)	22 (±10)	28 (±12)
Years of weight maintenance at inclusion	4 (±4)	4 (±3.4)
Family status (n;%)		
Living alone (vs married or partnership)	9 (50%)	6 (33%)
Children yes	9 (50%)	12 (67%)
Education level[a] (n;%)		
Tertiary (University or equivalent)	9 (50%)	6 (33%)
Employement category (n;%)		

Executive	5 (28%)	4 (22%)
Employee	9 (50%)	11 (61%)
Monthly income[b]*(n;%)*		
< 5'000 CHF	3 (17%)	4 (22%)
5'000 – 9'499 CHF	6 (33%)	9 (50%)
≥ 9'500 CHF	6 (33%)	3 (17%)

[a] According to the International Standard Classification of education [(40)].

[b] According to the distribution of salaries in Geneva [(41)].

Weight change since initial study

Of the eight participants initially included as WLM, two regained weight up to > 90% of their former maximum and were classified as Regainers. Of the other six, initially classified as Maintainers (weighing ≤90% of maximum weight), two regained more than 5 kg. Among the Controls, one participant gained 10 kg, one lost 10 kg (the first related to a sudden stop, the second to an increase of training), while the other eight were weight-stable.

Body composition and resting energy expenditure

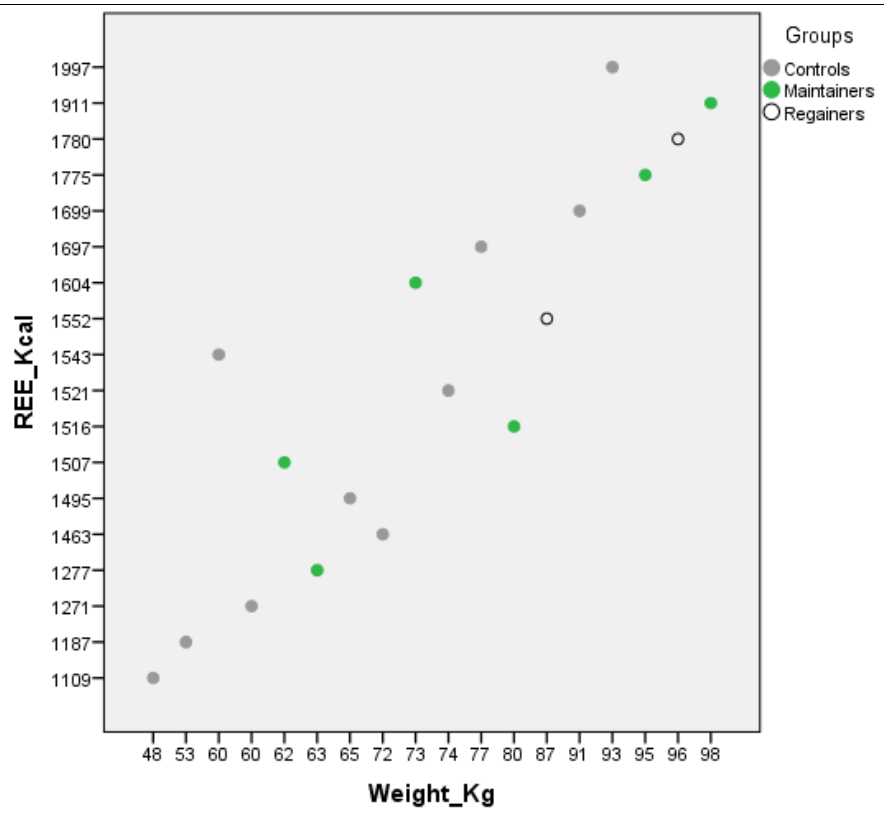
The averaged results for each group are presented in Table 2. The proportion of fat mass was highest among Regainers, and higher in Maintainers than in Controls. Fat free mass was similar and within the normal range in all groups (Table 2). The REE per kilo of body weight was lower in Regainers than Maintainers and Controls whereas it was similar across groups when considered in kcal/kilo of fat free mass (Table 2 and Figure 1). The ratio of measured/predicted REE varied according to the formula that was used, and measured values were higher than predicted in Maintainers and Regainers. This difference was statistically significant when the Owen formula, which takes fat free mass into account was used (Table 2). The individual ratios of measured/predicted REE are presented in the Appendix (Figures A-1, A-2, A-3).

Table 2: Body composition and energy expenditure of a sample of weight loss maintainers, weight regainers and controls (n= 18) (mean ±SD)

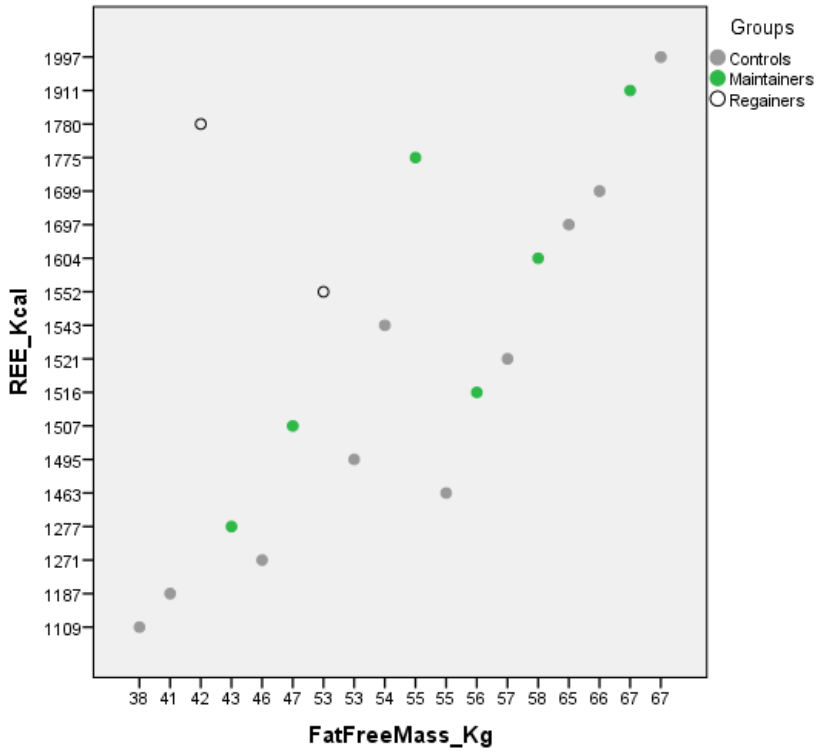
	Maintainers (n=6)	Regainers (n=2)	Controls (n=10)	P[†]
Weight	78.6 (±15.5)	91.6 (±6)	69.3 (±15.2)	0.135
BMI	25.8 (±3.2)	36.4 (±6.2)	21.9 (±2.4)	**0.012**
Body Composition				
Fat free mass (kg)	54.2 (±8.5)	47.4 (±7.2)	54.1 (±10.2)	0.435
Fat mass (kg)	27.8 (±12.7)	44.2 (±13.2)	14.9 (±6.3)	**0.017**
Ratio fat free/fat mass	2.30 (±1.01)	1.15 (±0.50)	4.19 (±2.00)	**0.012**
Fat free mass (%)	67.4 (±9.3)	52.2 (±11.2)	78.9 (±5.6)	**0.013**
Fat mass (%)	32.6 (±9.3)	47.9 (±11.2)	21.1 (±5.6)	**0.013**
Resting energy expenditure (REE)				
Measured (kcal)	1'598.3 (±222)	1'666 (±161)	1'498.2 (±265)	0.364
Per kg body weight (kcal/kg)	20.6 (±2.1)	18.2 (±0.6)	21.9 (±2)	**0.036**
Per kg fat free mass (kcal/kg)	29.6 (±2.4)	35.8 (±8.8)	27.8 (±1.5)	0.078
Respiratory Quotient	0.83 (±0.68)	0.81 (±0.42)	0.81 (±0.37)	0.978
Ratio REE Measured/Mifflin-St-Jeor (%)	104 (±5.5)	108 (±6.5)	99 (±6.5)	0.128
Ratio REE Measured/Harris-Benedict (%)	100 (±6.9)	102 (±4.4)	95 (±6.3)	0.169
Ratio REE Measured/Owen (%)	111 (±9.6)	133 (±27.6)	102 (±4.9)	**0.014**

[†] Kruskall-Wallis non parametric test

Figure 1: Resting energy expenditure as a function of (A) body weight and (B) fat free mass among 6 Weight loss maintainers, 10 Normal weight controls and 2 Weight regainers (N=18)



A) X axis is weight in kilograms, Y axis is resting energy expenditure assessed in kcal by calorimetry. Spearman Rho 0.88 (p <0.001)



B) X axis is fat free mass assessed in kilograms by BodPod, Y axis is resting energy expenditure assessed in kcal by calorimetry. Spearman Rho 0.69 (p= 0.02)

Physical activity and Nutritional intake

Mean PAL based on the reported activity was 1.43 (SD 0.182) for the whole group, and ranged from very low (PAL = 1.22) to high (PAL = 1.75). There was no difference in PAL between groups (Table 3), but its distribution within each group was wide (Figure 2). The analysis of the raw data of the ActiGraph devices showed that on average, the total time spent walking and the most usual cadence of daily walking episodes were similar in all groups (Table 3). However, the distribution of the results varied widely within each group (Table 3). At least half of each group's subjects, three Maintainers (50%), one Regainer (50%) and seven Controls (70%) did not reach 30 minutes in their longest single continuous walking episodes. Walking represented, on average, between 5 and 7% of monitored time, but plotting the detailed parameters of walking activity revealed individual or group differences (Figure 3).

Reported energy intake in kcal/kg of body weight was lower in Maintainers and Regainers than in Controls who reported a higher absolute fat consumption. The proportions of macronutrients in the diet were similar across groups (Table 3).

Table 3: Physical activity and nutritional intake of 18 participants in the HOMAWLO-Recontact study (mean ±SD)

	Maintainers (n=6)	Regainers (n=2)	Controls (n=10)	p†
Physical Activity				
PAL (including daily life 1.2)	1.43 (±0.181)	1.27 (±0.028)	1.46 (±0.194)	0.358
Total Walking (%monitored time)	7.6 (±2.4)	5.4 (±1.3)	7.1 (±2.4)	0.366
Usual walking cadence (steps/minutes)	106 (±13)	98 (±3)	103 (±18)	0.829
N of walking episodes of				
5 to <10 minutes	12 (±10)	13 (±6)	7 (±3)	0.587
10 to <15 minutes	4 (±3)	3 (±0)	3 (±2)	0.535
15 to <20 minutes	2 (±2)	1 (±2)	2 (±1)	0.743
20 to <30 minutes	1 (±2)	1 (±1)	1 (±2)	0.309
≥30 minutes	1 (±1)	0 (±0)	1 (±1)	0.589
Longest walking episode (minutes)	25 (±20)	24 (±5)	40 (±35)	0.692
Maximal cadence (steps/minutes)	128 (±10)	122 (±2)	125 (±3)	0.100
Number of brisk walking episodes[a]	39 (±50)	63 (±74)	40 (±50)	0.90
Nutritional Intake				
Total energy (kcal)	1613 (±575)	1762 (±26)	2026 (±376)	0.185
Energy (kcal/kg)	20.5 (±5.4)	19.3 (±1.5)	30.3 (±7.3)	**0.017**
Protein (g/kg)	0.9 (±0.18)	0.9 (±0.12)	1.0 (±0.2)	0.186
Protein (%)	17.4 (±5.15)	18.9 (±4.04)	13.9 (±2.02)	0.174
Carbohydrates (g/kg)	2.1 (±0.92)	2.1 (±0.12)	2.9 (±0.98)	0.204
Carbohydrates (%)	38.7 (±9.94)	42.7 (±0.96)	38.3 (±6.33)	0.366
Lipids (g/kg)	0.8 (±0.25)	0.7 (±0.15)	1.3 (±0.33)	**0.017**
Lipids (%)	37.0 (±6.6)	33.9 (±4.2)	38.7 (±3.3)	0.241
Alcohol (%)	3.9 (±2.67)	1.5 (±1.66)	6.8 (±5.8)	0.239

† Kruskal Wallis test

[a] Defined as episodes of ≥30 seconds and >100 steps/minutes

Figure 2: Distribution of average daily levels of physical activity (PAL_total) among 10 Normal weight controls, 6 Weight loss maintainers and 2 Weight regainers (N=18)

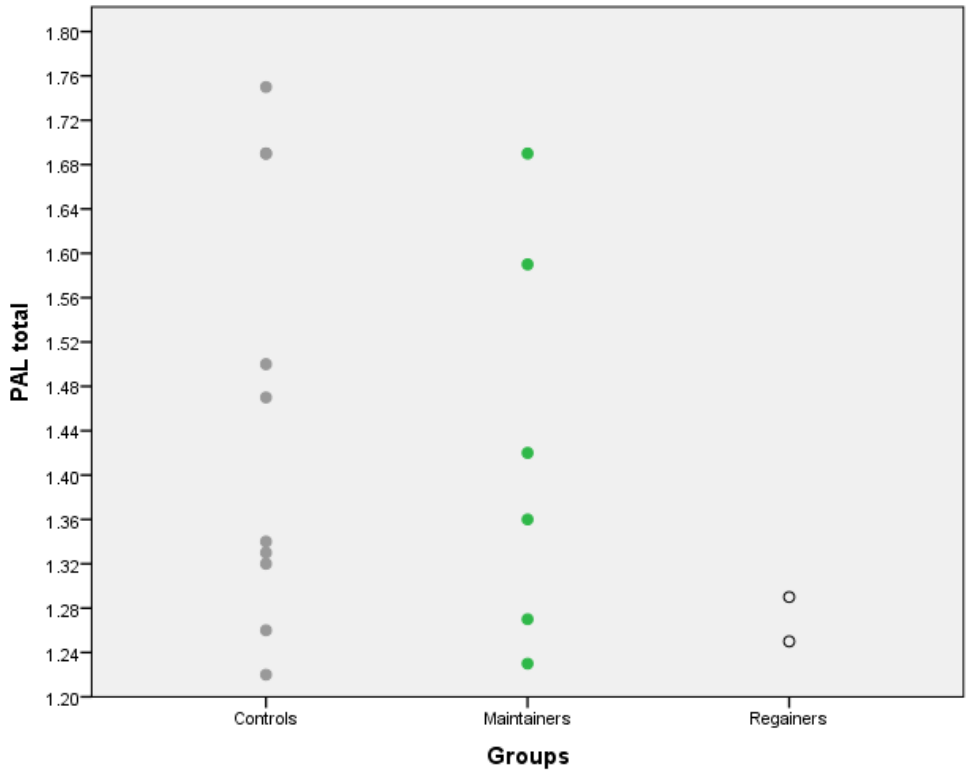
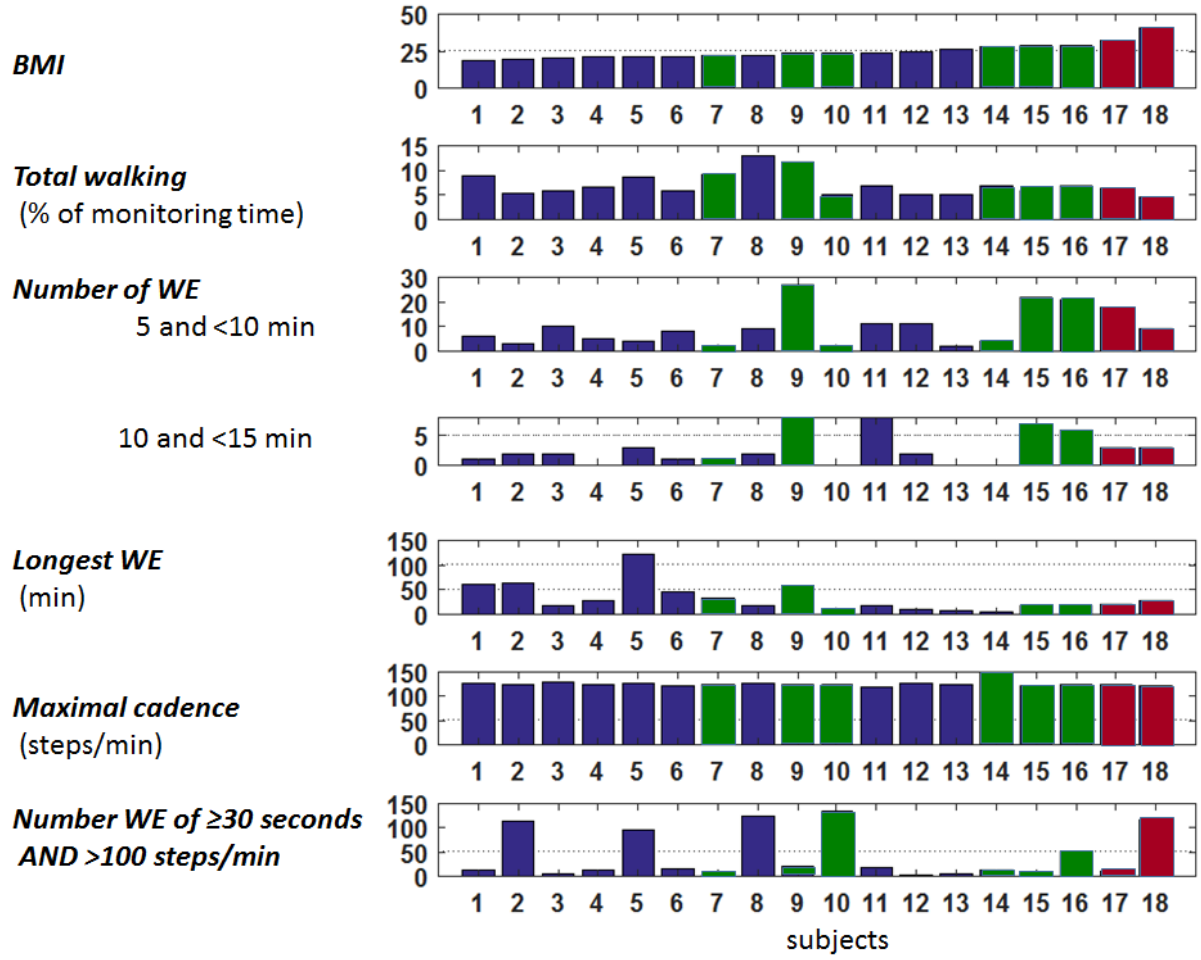


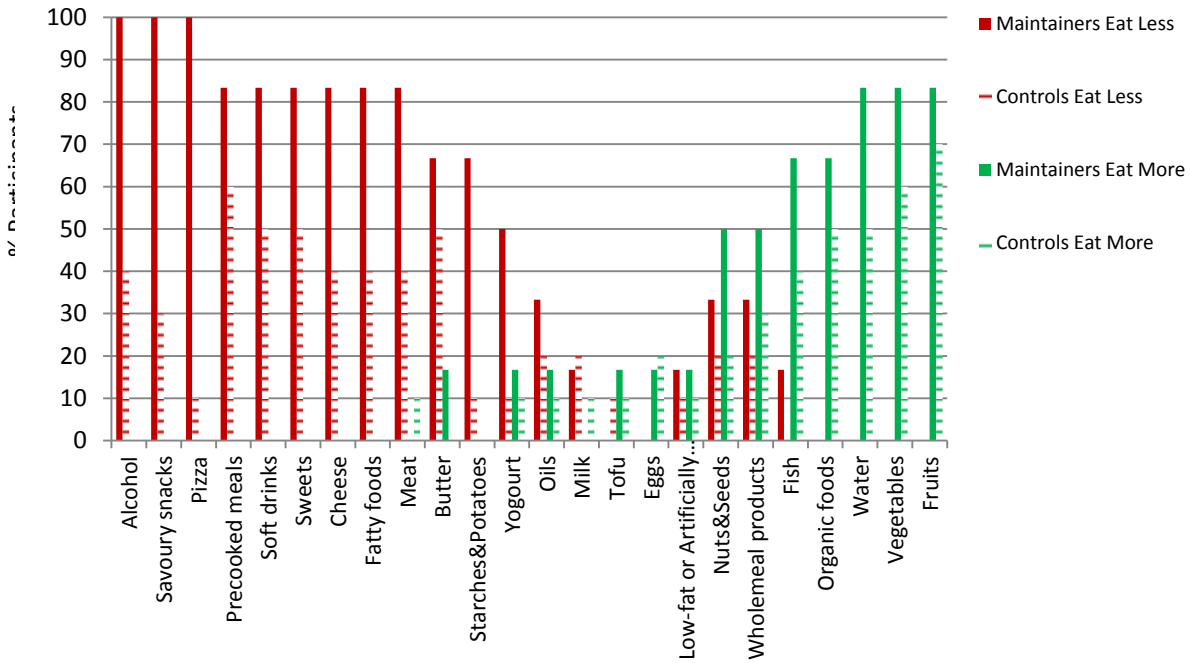
Figure 3: Objective walking behavior parameters in 10 Controls (blue), 6 Maintainers (green) and 2 Regainers (red) ranked by BMI



Weight Maintenance Strategies

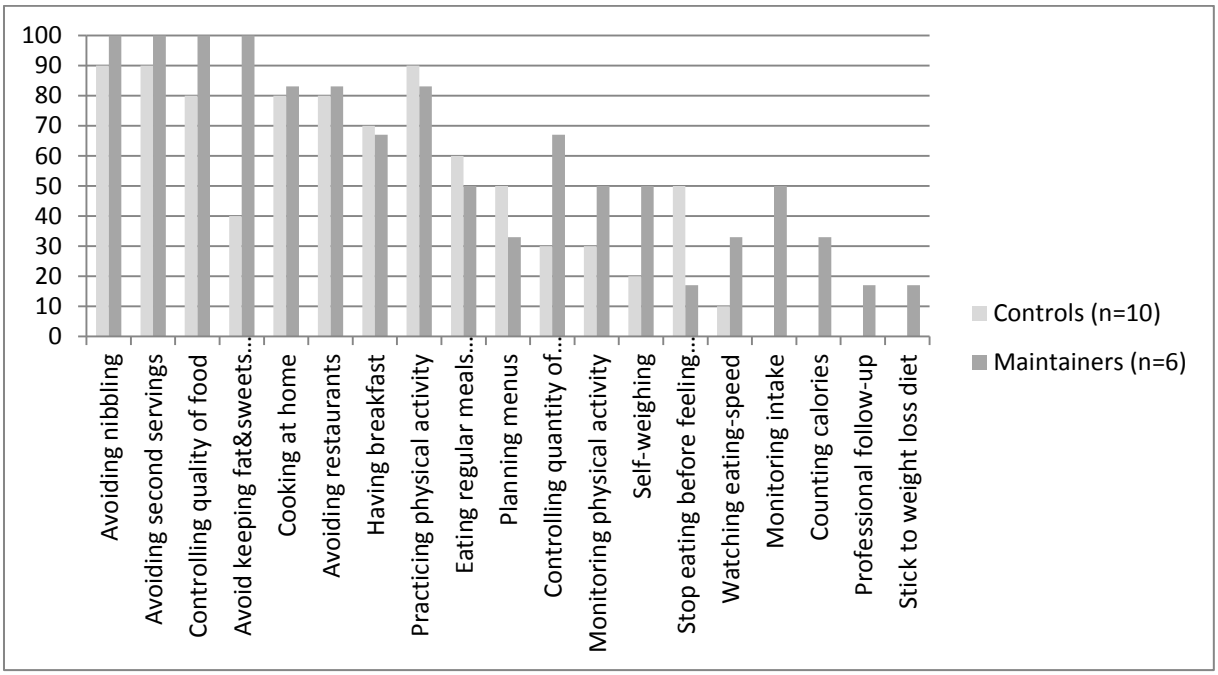
Assessing the weight maintenance strategies related to food choices as followed by the Maintainers and the Controls (excluding the two Regainers), we found that 15/29 strategies were adopted by more than 50% of the 16 Maintainers and Controls: consuming fewer precooked meals, drinking fewer alcoholic beverages and soft drinks, eating less cheese, meat, fatty foods, savory snacks and sweets, using less butter, eating more fruit, vegetables, fish and organic foods, and drinking more water (Figure 4). The consumption of yogurt, milk, oils and nuts was increased by some participants, and decreased by others. When comparing the two groups, Maintainers more often avoided starches (including potatoes), pizza, savory snacks and alcoholic beverages than Controls (all Chi^2 <0.05).

Figure 4: Percentage of Maintainers and Controls (total n= 16) eating less or more of a selection of food items.



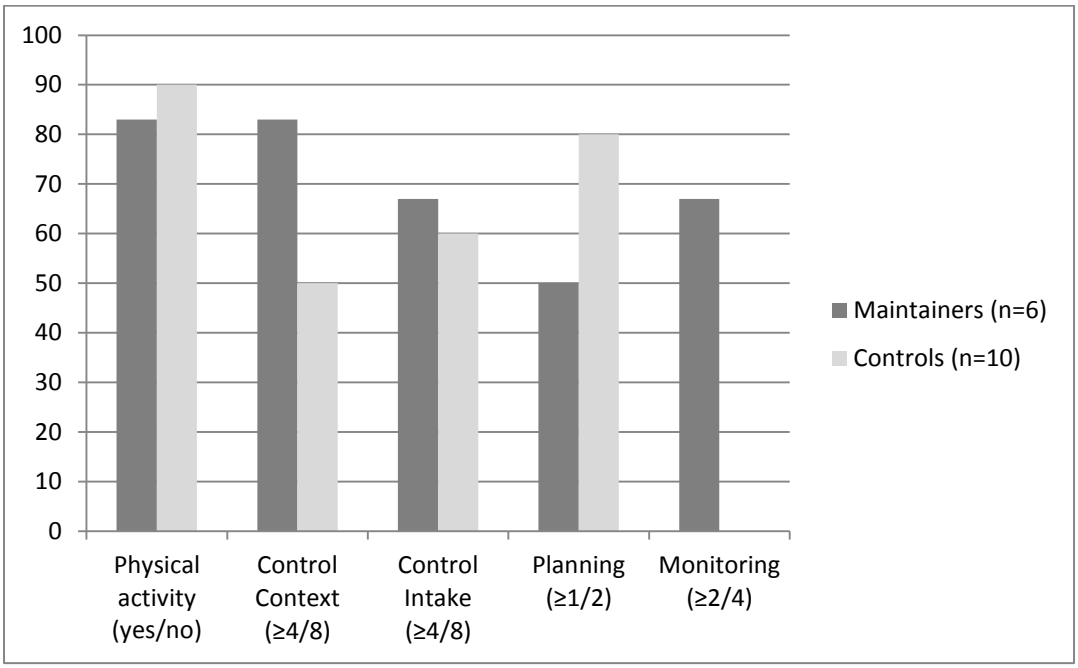
Assessing the weight maintenance strategies related to behaviors, we found that the most frequent (i.e. followed by at least 13 participants=81% of Maintainers and Controls) were “avoiding second servings”, “avoiding nibbling”, “controlling the quality of the food”, “practicing physical activity”, “cooking meals at home”, and “avoiding restaurants or eating out”. “Having breakfast” and “eating regular meals during the day” were used by 69% and 56% respectively. The median number of strategies followed by the Maintainers was 12 (minimum 2; maximum 16), and 9 (minimum 6, maximum 11) for Controls. Figure 5 displays the various strategies adopted by both groups.

Figure 5: Percentage of Maintainers and Controls (total n=16) following each strategy



In order to describe the types of strategies favored by the Maintainers and the Controls, we compared the numbers of participants of each group who followed at least half of the strategies of each category. Figure 6 shows that the Maintainers more often used strategies which involved controlling their eating context (e.g. avoiding restaurants) or their food choices (e.g. avoiding keeping sweets or fatty foods at home or work), whereas the Controls more often used planning strategies (e.g. planning their menus in advance). Monitoring strategies (e.g. self-weighing, monitoring intake) were used more often by Maintainers than by Controls. Strategies to control dietary intake (quantity or quality) and physical activity were used similarly by both groups (Figure 6).

Figure 6: Percentage of Maintainers and Controls (total n= 16) following at least half of the strategies of each category



Eating behaviors

The scores of Shape and Weight concerns, the total EDE-Q score and the TFEQ disinhibition score showed significant differences between the three groups (Table 5), with the Controls presenting the lowest, and the Regainers the highest scores.

Table 5: Eating behavior scores of 18 participants in the HOMAWLO-Recontact study (mean ±SD)

	Maintainers (n=6)	Regainers (n=2)	Controls (n=10)	p†
Eating Disorder Examination Questionnaire				
Restraint	2.1 (1.82)	0.9 (0.71)	0.4 (0.72)	**0.027**
Eating Concern	0.5 (0.77)	0.9 (0.42)	0.1 (0.14)	0.055
Weight Concern	2.5 (1.25)	4.2 (2.55)	0.6 (0.84)	**0.008**
Shape Concern	2.8 (1.23)	4.0 (1.14)	1.1 (0.95)	**0.009**
Total Score	2.0 (0.91)	2.5 (0.92)	0.6 (0.50)	**0.005**
Three-factor eating Questionnaire				
Restraint	13.3 (4.59)	8.0 (4.24)	6.8 (4.47)	0.075
Disinhibition	7.7 (3.98)	11.0 (4.24)	4.1 (2.28)	**0.036**
Hunger	3.5 (3.39)	4.0 (1.41)	2.8 (1.99)	0.733

† Kruskal Wallis test

Participants' experience

Work was most frequently cited as the reason for difficulties in maintaining a stable weight (three Maintainers 60%, one Regainer 50%, four Controls 40%). Only one person (a Control) mentioned work as a helping factor for weight maintenance, for the regularity it provided. The perceived impact of work on weight maintenance included both direct and indirect effects. The lack of healthy choices at the cafeteria, the necessity of eating in restaurants with clients or colleagues, the presence of large amounts of energy dense snacks in the office were reported as directly impeding weight maintenance. The indirect effects of work included stress, overworking and irregular schedules, which interfered with the ability to control intake and increased the desire for "comfort food". Another class of indirect effects of work was time-related, as when participants reported having no time to practice physical activity, or no time to eat a proper lunch, which they related to overeating later in the day. Finally, several participants described a state of fatigue related to the working schedules and lack of personnel, which left them without energy for cooking or physical activity. Apart from work, four participants (one Maintainer, one Regainer and two Controls) reported difficulties related to their family situation and the lack of support, either directly (e.g. conflicts surrounding the groceries and type of foods that are kept in the house) or indirectly (e.g. a conflictual divorce leading to emotional overeating).

The factors that participants quoted as helpful for weight loss maintenance were the sense of control and physical performance (two Maintainers, three Controls). One Maintainer explained that accepting her weight at 1.5 kg above what she considered her "ideal" weight had helped her with weight loss maintenance, because it allowed her to live with fewer dietary restrictions and less organization; and she found that her initial fear of total loss of control did not come true.

Discussion

The goal of this exploratory study was to test the measurements and evaluate the feasibility of a cohort study documenting a large range of determinants of weight loss maintenance.

The recruitment was more difficult than for the initial HOMAWLO study and only 50% of the first-time participants consented to take part. The traveling distance seems to have played a role: most of those living more than one hour away from Geneva did not renew their participation, which is not surprising since the measurements needed to be taken in a fasting state. In the first study, we had visited some participants in their homes to perform the interviews. These points suggest that, in order to avoid a selection bias, a larger study would necessitate several measurement sites distributed throughout the recruitment area. This would also reduce the variability of time between awakening and measurement of REE. In the laboratory, the measurement processes (calorimetry, body composition, impulsivity) went smoothly and the procedures were performed with a high quality control, providing reliable data.

The data on physical activity are more comprehensive and precise than in the initial HOMAWLO study (where it was assessed with the GPAC questionnaire (3)). In the present study, both a detailed interview and an ActiGraph measurement were used, in order to cover the whole range of physical activities, as the ActiGraph is a reliable device to assess walking time and cadence, but not other activities such as cycling, crossfit or swimming. The advantage of the interview is that it let the participant enumerate any activity without searching through a list (which might not include the ones they are practicing). Regarding the ActiGraph, we decided to analyze the raw data instead of the energy output calculated by the device's algorithm, in order to avoid the error related to the fixed cut points for light, moderate or vigorous activities. These cut points have been developed among healthy, lean and usually young people (42) and do not take into account the fact that the metabolic cost of walking increases with age and weight (43).

Assessing nutritional intake represents a well-known challenge (44, 45). We expected the 5 days food diary to provide more realistic results than the food frequency questionnaire used in the initial study, but the ratio Intake/REE was 1.01 among Maintainers, 1.05 among Regainers, and 1.4 among Controls, indicating an underestimation of total intake. The difference between the Controls and the others reflects the difficulty in estimating portion size experienced by persons who have been dieting

in the past (Johnson 2005). This problem could be addressed in the future with modern technology (digital pictures, automatic weighing of the plates). In any case, even with the best method, there will always be the issue that the assessment only captures a few days of intake, and that the (self) observation results in both a desirability bias and changes of habitual intake (46, 47). The advantage of the food diary compared to the FFQ is that it provides a complete list of consumed foods, whereas its disadvantage is that is time consuming (for both the participant and the researcher). The electronic food diary that we are currently developing in parallel to this project might alleviate this inconvenience (48). Ideally, this should be combined with doubly-labelled water to measure total energy expenditure.

We tested our questionnaire on weight maintenance strategies (based on the interviews from the initial study) during this study and identified several weaknesses (phrasing of the questions, answering options). However, a "Weight management strategies inventory" has recently been validated and published by the group of Siegrist at the ETH Zurich (49). Therefore, it could be worthwhile to develop a collaboration in order to translate and validate a French version of this instrument.

The assessments of decision making and inhibitory control by computerized tasks were easily performed by the participants. The data analyses are currently underway in collaboration with the Department of psychology of the University of Geneva. The sample size is too small for any significant difference to emerge, but the data collected with the computerized tasks are suitable for analysis, which is what we wanted to know.

Because of the small sample size, the data have to be considered with great caution. However, two observations can be made. First, although a longitudinal design would be necessary to evaluate any relationship between REE and weight regain, our data do not suggest that REE is abnormally low after weight loss. Instead, the results show variations between individuals. This has been shown in other studies (50, 51) and could reflect the dynamic relationship between weight change and REE

(52), which cannot be taken into account by cross-sectional studies. The ratio of measured/predicted REE suggested that heavier participants had a higher than expected REE, especially when the predicted value was based on the Owen formula, which takes the fat free mass into account. This could be related to measurement error (especially because of the small sample), but it also might illustrate the higher metabolic cost of fat free mass among persons with obesity, because of their higher proportion of organ mass (53, 54). The lower REE/kg of body weight among the heavier participants does not indicate hypometabolism, but rather an artifact related to the body composition (as shown by the higher REE/kg of fat free mass). The use of population-validated formula to predict individual REE of heavier individuals can be inaccurate (55) and the subsequent underestimation of energy needs could contribute to the difficulty of losing weight/maintaining weight loss, by increasing hunger and therefore rendering compliance more difficult.

Second, several of the weight control strategies were used only by a minority of the former Weight loss maintainers (whereas the Control group kept using more strategies), which shows the difficulty of sticking to changes in the long run. Together with the high scores on the EDE-Q and the TFEQ Restraint scales, this seems to confirm the burden of weight loss maintenance (1). Work environment seemed related to the withering of strategies. A recent Danish study showed that work strain, especially busyness, might contribute to weight gain (56). This suggests topics for interventions, either at individual or at public health level.

In summary, our initial hypothesis should be redefined in the light of these results, which, together with recently published data (51), weaken the supposed role of AT in weight loss resistance. The historical studies assessed AT on the basis of the available measurements of body composition, and could not take into account the various components of fat free mass and their relative impact on REE (organs contributing to higher energy expenditure than skeletal muscle mass) (11). The individual variability in REE leads to two hypotheses. The first is that AT might be a determinant in weight loss maintenance in some but not all individuals, who would have to be identified and offered a personalized set of strategies and innovative support for weight maintenance. The second possibility

is related to the fact that the individuals could be losing or gaining weight at the time of the measurement. In this case, AT would affect everyone but would eventually fade away and its variability would reflect the time-lag between the initiation of change in intake and its alignment with the new body weight. In this case, the reduction in REE will be proportional to weight loss, and the changes in eating and exercising habits do not have to be extremely severe.

In conclusion, a longitudinal study assessing the relationship between REE and weight change, taking into account dietary intake, physical activity, impulsivity and strategies seems feasible and appropriate. It could lead to a screening process identifying the persons more vulnerable to weight regain, and to the development of a predictive model supporting the tailoring of strategies adjusted for various typologies of patients. Such a study would however necessitate a very large number of subjects (the power of the study depending on the number of variables and the expected differences between groups), as well as several measurement centers scattered throughout the recruitment territory.

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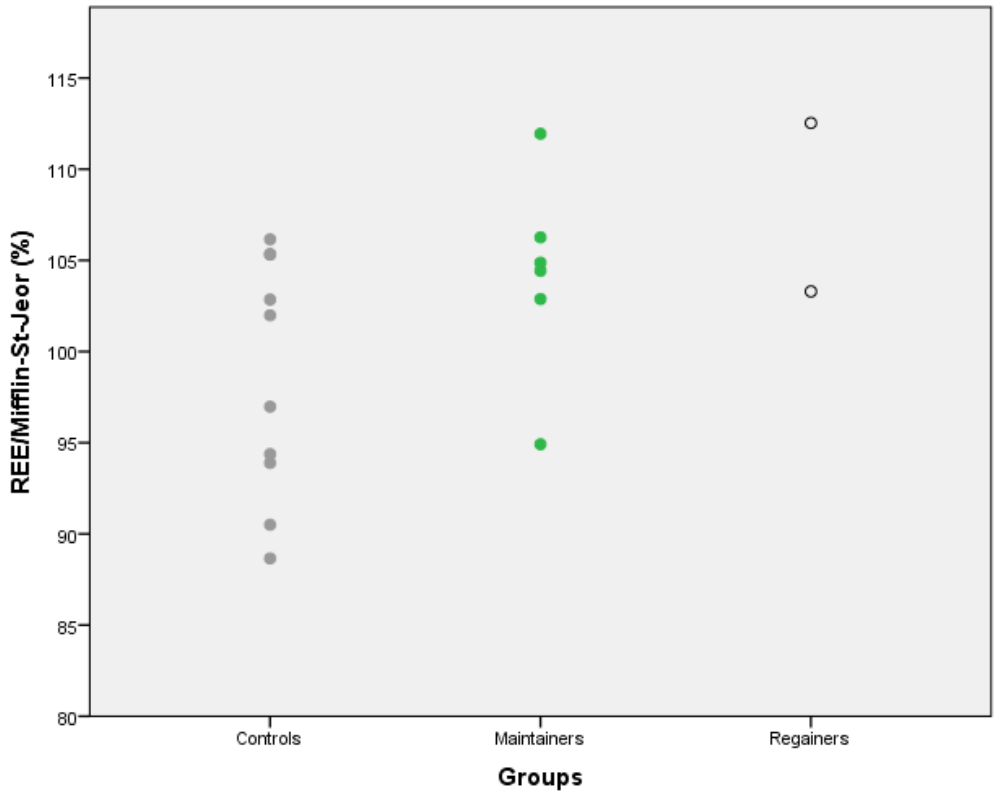
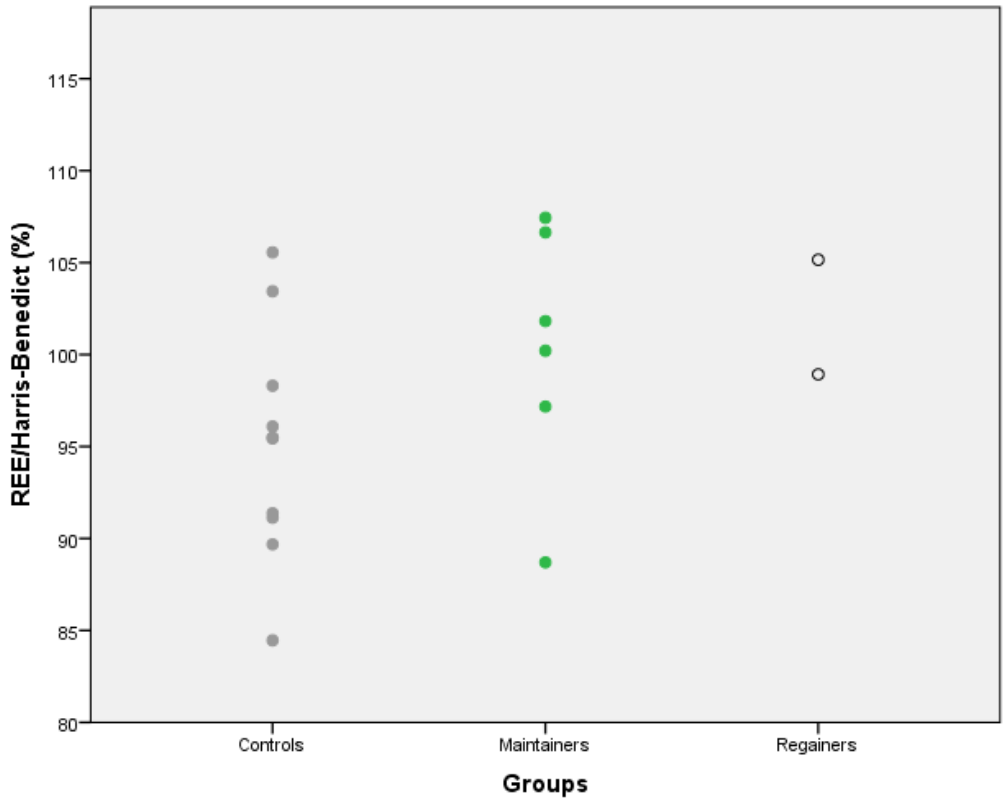
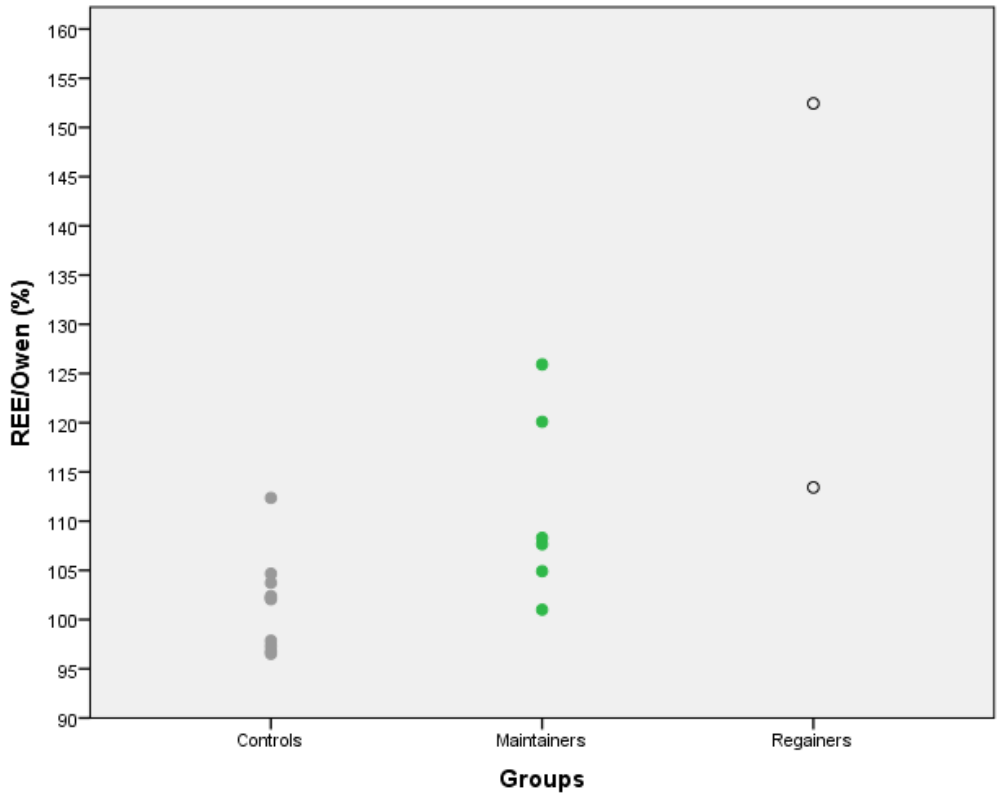
Appendix

Figure A: Ratio between REE as measured with calorimetry and predicted with three formulas: Mifflin-St-Jeor, Harris-Benedict and Owen among 10 Normal weight controls, 6 Weight loss maintainers and 2 Weight regainers (N=18)




REE/Harris-Benedict (%)
115
110
105
100
95
90
85
80
Controls
Maintainers
Regainers
Groups


REE/Owen (%)
160
155
150
145
140
135
130
125
120
115
110
105
100
95
90
Controls
Maintainers
Regainers
Groups