# Energy Compensation Following Exercise-Induced Energy Expenditure

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Thesis Submitted to the
Faculty of Graduate and Postdoctoral Studies
in partial fulfillment of the requirements
for the Doctorate in Philosophy degree in Human Kinetics

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# Abstract

This thesis aims to determine energy compensation following exercise induced energy expenditure (ExEE). The specific objectives were: I) to determine the impact of the time spent performing physical activity (PA) of varying intensities on body weight and composition (Study 1); II) to determine the overall energy compensation and the major predictors of energy compensation through the systematic review approach (Study 2); III) to develop new methods to measure energy intake (EI) (Study 3) and time spent performing different activities (Study 4); IV) to determine the effects of a lower (LI) and higher intensity (HI) ExEE intervention on energy compensation (Study 5); and V) to investigate the inter-individual variability regarding exercise induced energy compensation (Study 6). In Study 1, women spending more time performing light-intensity PA were shown to have lower adiposity compared to women spending more time performing moderate- and high-intensity PA. Results from Study 2 (systematic review) show an overall energy compensation of 25% following exercise interventions and that fat mass (FM), exercise intensity and duration of the intervention are the main predictors of energy compensation. To better capture energy compensation (*i.e.*, EI and EE), new methods to measure EI and time spent performing activities were developed (Studies 3 and 4) and used in the following studies. In Study 5, overweight/obese women training at HI displayed higher energy compensation when compared to women training at LI, which was accompanied by a reduction of NSPA (non-structured physical activity) and a greater amount of time spent lying down. Results from Study 6 showed that complete compensators (CC) had higher EI, fat and carbohydrate intake at the onset of the ExEE intervention when compared to incomplete compensators (IC). However, the results also showed that dietary disinhibition was increased, whereas NSPA

was decreased at the end of the intervention in IC. Taken together, these studies emphasize that weight loss following exercise is impeded by energy compensation. In addition to the impact of FM, exercise intensity and duration of the intervention on energy compensation, NSPA and cognitive factors also seem to modify energy compensation that occurs as a result of exercise.

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# Acknowledgments

I would like to acknowledge Dr. Éric Doucet, my thesis supervisor, for his guidance across my doctoral studies. It has not only been all of the scientific knowledge and discipline he helped me to attain during these years, but also the support he gave me and my limits he help me to surpass. I think it is obvious that my PhD is one of the best experiences I have had and I feel very confident to say that Éric has been a key player. It has been a pleasure working with you. Thanks for your patience and understanding.

I also would like to thank Dr. Ollie Jay for his implication in my graduate studies. Thank you for the brainstorming we had together and for having made me question what was obvious. Ollie, it not has only been a pleasure working with you but it has been a privilege. You have been the best classroom teacher I have ever had. You have been a model for me because of your passion and your intellectual curiosity. For all of this, I thank you.

I would also like to thank Dr Graham Finlayson and Dr John Blundell. During the internship I had at Leeds University, you have helped me to surpass my goals, to increase my understanding and to reinforce my critical thinking on many aspects. Thank you for having accepted me as part of your team, it has been a terrific experience.

I sincerely thank Dr Gilles Lamothe for all the discussions we had and for the patience he showed explaining to me different statistics. Thanks for the knowledge you gave me.

I also would like to thank Ms Martine Dumont for her supervision throughout my position as teaching assistant at the University of Ottawa. Your understanding and your joy of living are characteristics that make working with you pleasant. I also would like to thank Dr Pascal Imbeault for having made our lunchtime so interesting by raising surprising questions. The time I spent in the lab would have never been as wonderful as it was without Isabelle and Ann. It has been a pleasure working with you. Thanks for your precious collaboration.

I would like to thank my colleagues for having made a difference in my PhD. Thank you to Dr Nelson and Luzia for having brought an exotic aspect to the lab, to Karine who introduced me to the different testing performed in the lab, to Jessica (McNeil) for having been my hilarious travel buddy, to Joseph (Jo) for always having teased me, to Sébastien (Grand fouette) for his happiness and motivation, to Daniel for his thermoregulation advices, to Jameson, Angela and Zack for the funny memories, to Matt for our running training, discussion and for your English revisions, to Nathan for his cheerfulness and good humour as well as to Bimit, Jacinthe, Sahar, Tina, Alex, Alexandrine, Bernard, Natalie, Maxine, Antony, Thomasz, Nick and Travis for all of our discussions. A special thanks has to be given to Simon for his implication in 2 studies. Thanks for your perseverance. I will also always be grateful for the work done by Léa, Jean-Christian, Catherine and Isabelle.

I also want to thank Marie-Andrée and Jeff for having always been there and for listening to my "stories" without any judgment. Thank you also to Renée, Marie-Ève, Geneviève, Manon, Mélissa, Karine as well as my in laws and the members of my family for having encouraged me and having shown interest in this thesis. Thanks for being part of my life.

Thank you to my parents, Sylvain and Guylaine, for having always been there for me. Thank you for your support and for listening to me in good times and bad. Thanks for showing me that everything is always possible when you work hard and for your encouragement.

There is a special thanks to François, my boyfriend, for his help on a day-to-day basis. Thanks for having always encouraged me and to have never doubted my potential accomplishments. Thank for your critical questions, your revision, your understanding and your continued support. I love you.

# Chapter I

# Introduction

## 1.1 Introduction

Exercise has been widely investigated and recommended to prevent weight gain or to promote weight loss because of its contribution to energy balance (EB). Even if regular exercise may have a favourable impact on physiological and psychological well being[1], exercise-induced weight loss tends to be less than 3% of initial body weight[2-4]. One factor that may contribute to limit weight loss during an exercise intervention is "energy compensation". Briefly, energy compensation represents the change in energy storage, calculated using the caloric equivalents of changes in fat mass (FM) and fat-free mass (FFM), and total exercise induced energy expenditure (ExEE) over a given period of time. A compensation of 0% (incomplete compensation) is thus indicative of the fact that body composition varies perfectly as a function of the calculated ExEE. In contrast, a compensation of 100% (complete compensation) indicates that body composition remained the same in spite of the ExEE.

Complete energy compensation of ExEE (*i.e.,* absence of weight loss) must be a result of an increase in energy intake (EI), a decrease in energy expenditure (EE) or a combination of both. It has been demonstrated that individuals do not necessarily increase their EI during subsequent meals[5-12] following an acute exercise bout. However, this absence of an increase in EI often does not persist over time, as many individuals will ultimately increase their EI[13-15]. Although no consensus currently exists regarding the modification of EE during an ExEE[16,17], it has been proposed that non-structured physical activity (NSPA), defined as movements unrelated to an exercise session (*e.g.,* transportation, work-related movement and/or activity of daily living)[18-20], may slightly decrease due to, for example, an increase in perceived fatigue following ExEE[18,21-23]. Conversely, others have found no change[17,24,25], and even an increase in NSPA[16,26,27] in response to an ExEE intervention.

Some confounders likely come into play insofar as ExEE impacts EI and EE. For example, sex is known to impact EI following ExEE[14,28]. Specifically, it has been shown that EI was increased by 30% in women following ExEE of 7 days while no change in EI was observed for men[14,28]. Conversely, other studies have suggested that ExEE leads to the same amount of absolute weight loss in both men and women[29,30]. To make matters even more complex, it has been observed that ExEE can modify the relationship between EI and eating behaviour traits. For example, it is possible that cognitive dietary restriction may be eased following exercise, leading some individuals to assume that the EE associated with exercise allows them to eat as much as they want[31]. Additionally, large weight loss variability has been demonstrated between individuals[32] but the contribution of EI, NSPA and cognitive factors to this inter-individual variability has not been thoroughly investigated. Outside of participant characteristics, the impact on energy compensation by other factors such as the intensity of the exercise intervention remains contradictory[33-37]. For example, some studies have shown that body weight decreased significantly following a lower intensity (LI) exercise intervention compared to a higher intensity (HI) exercise intervention[34,37], while others have found no difference between high and low intensities[33,35,36].

The difficulty in properly and accurately measuring EI complicates the thorough investigation of energy compensation[38-43]. Low participant compliance due to the complexity and difficulty of accurately completing a food diary[38], and the under-reporting of EI frequently observed[39-42] are challenges that must be addressed. Lastly, even if EE can be objectively measured[44], the measurement of NSPA following ExEE in an unrestricted environment deserves more attention. The characterization of the time spent performing different activities throughout the duration of exercise interventions is another aspect of NSPA that needs to be further characterized.

## 1.2 Rationale and Statement of the Problem

Weight loss from exercise is less than expected[2,3]. When FFM and FM were measured, few studies have accounted for body composition changes varying as a function of specific amounts of EE[45]. As a result, energy compensation following ExEE is difficult to obtain from existing literature and needs additional characterization.

Since energy compensation is caused by either an increase in EI, a decrease EE or a combination of both, these factors should be measured accurately during exercise interventions aimed at producing weight loss. To date, the distinct contribution of EI and EE to energy compensation is not clear, and the literature covering the effects of exercise interventions on both sides of the EB (*i.e.,* EI and EE) is limited[13-15]. Additionally, few studies have been designed to directly address the impact of ExEE on EI and EE over a long period of time[15]. The difficulty of measuring EI and EE in an unrestricted environment makes the interpretation of the results challenging[39-42]. Moreover, several confounding factors (*e.g.,* sex, intensity, FM) that likely influence energy compensation are often not considered. As an example, the factors underlying the variability in energy compensation following an exercise at different intensities are not clear and warrant further investigation[33-35,37].

The prevalence of overweight and obese individuals in Canada is 60.1% in men and 44.2% in women. More specifically, obesity is present in 19.8% of men and 16.8% of women[46]. Of the individuals with a BMI higher that 27 kg/m², two-thirds of women and less than half of men are attempting weight loss at any given time[47], most of whom will be using exercise as an intervention strategy[48]. Therefore, a better understanding of the impact of ExEE on energy compensation is needed. Accordingly, changes in EI and EE during an exercise intervention, as well as the confounding factors related to the poor efficacy of ExEE to induce weight loss, should be further characterized.

## 1.3 Objectives

The overall objective of this thesis was to investigate the degree of energy compensation following ExEE as well as the potential underlying factors responsible for energy compensation in response to exercise. **Objective I** of this thesis was to determine the impact of the time spent in PA of varying intensities (sedentary, light, moderate and vigorous) on body weight and composition over a 5-year follow-up. For **Objective II (**systematic review), changes in body composition and total ExEE were considered to determine the overall energy compensation following exercise interventions. This systematic review was also used to determine the major independent predictors of energy compensation. For **Objectives III and IV**, a food menu and a classification model were developed and validated respectively to measure EI and macronutrients intake over 5 hours and to discriminate NSPA (with emphasis on the time spent performing different activities such as lying down, dynamic standing, sitting, walking and running). Using these new developed methods, energy compensation was investigated following a 3-month exercise intervention program performed at LI or HI in overweight/obese women (**Objective V**). Eating behaviour traits, food reward and other potential factors associated with energy compensation were also investigated. For **Objective VI**, the greatest contributors to inter-individual variability in energy compensation were investigated.

## 1.4 Hypotheses

It was hypothesized that energy compensation following ExEE, caused by either an increase in EI and/or a decrease in NSPA, would be largely influenced by the intensity of the exercise as well as by the sex and adiposity level of individuals. More specifically, it was hypothesized that:

> Objective I) In women, more time spent performing light PA would be associated with a significantly lower body weight and adiposity level (*e.g.,* FM, central FM, %FM) when compared to those spending more time performing moderate or high PA in women. Moreover, it was hypothesized that spending more time performing light physical activities would be associated with lower gain in body weight and adiposity during the 5-year follow-up;

> Objective II) Exercise interventions lead to positive energy compensation. Sex, intensity and the duration of the exercise would be the strongest predictors of energy compensation. More specifically, it was proposed that women would show a significantly greater energy compensation compared to men and that a longer

duration of intervention and higher exercise intensity would lead to a significantly higher energy compensation;

Objective III) The results obtained from the food menu developed to measure energy and macronutrient intakes over several meals (2 meals and snacks over 5 hours) would be reproducible in men and women under laboratory conditions and under free-living conditions;

Objective IV) The results obtained from the classification model developed to discriminate between the time spent performing different activities such as lying down, dynamic standing, sitting, walking and running would be accurate and reproducible in both confined and unrestricted environment;

Objective V) Overweight and obese women exercising at HI (60% $V\dot{O}_{2peak}$) would experience higher energy compensation (%) compared to women exercising at a LI (40% $V\dot{O}_{2peak}$), due to a significant increased EI and decreased NSPA across the exercise intervention;

Objective VI) Inter-individual variability regarding energy compensation (%) in overweight and obese women would be significant and mostly explained by a decreased NSPA as well as by changes in cognitive factors, which would lead to an increased EI during an exercise intervention.

## 1.5 Relevance

The literature suggests that weight loss following ExEE is impeded by energy compensation. Nevertheless, the potential underlying factors responsible for energy compensation in response to exercise intervention have not been comprehensively addressed. In order to understand energy compensation, the characteristics of the subjects (*e.g.*, sex, adiposity level) and the characteristics of the exercise (*e.g.*, intensity, duration of the intervention) were investigated. Especially, the impact of EI and NSPA on energy compensation was addressed in a study performed at LI and HI. Similarly, the inter-individual variability regarding the impact of EI and NSPA on energy compensation was also investigated. The findings included in this thesis help to determine and to understand the factors responsible for energy compensation.

## 1.6 Delimitations and Limitations

It is important to clarify that each study included in this thesis was based on a relatively healthy homogenous population, and the conclusions cannot be extended to the general population (*e.g.,* elderly and children). The results need to be confirmed in a larger population of subjects with a greater age range. It is also important to keep in mind that even if a large quantity of high quality measurements were obtained from the individuals tested, the EI and EE in Study V and Study VI were derived from non-continuous/snapshot measurements. Additionally, even if precise recommendations were given to the participants before each testing session, it is possible that these criteria have not been fully respected. For example, it is difficult to determine if a diet was followed during the intervention studies. Regarding the delimitations, women included in most studies, except for the systematic review, were only tested during the follicular phase of the menstrual cycle. Also, with the exception of some studies included in the systematic review, body composition has always been determined using DXA, which represents the gold standard for body composition measurement. Additionally, the studies performed in the laboratory were all supervised. Therefore, the exercise sessions in Study V and Study VI were precisely monitored.

# Chapter II

# Literature Review

This literature review is published as a book chapter.

Reprinted from: Riou, ME and Doucet, E. (2012). "Effects of Structured Exercise on Non-Structured Physical Activity and Food Intake: Can Compensation Limit Weight Loss?" (chap. 2), in *Weight Change: Patterns, Risks and Psychosocial Effects*. New-York: Gouveia, C and Melo, D, p. 0-181.

Modifications from the published book chapter have been included in this thesis in order to update the literature review.

MER wrote this literature review while ED critically appraised and approved the final version.

## 2.1 Acute and Short-Term EI Compensatory Responses following ExEE

Based on the early observations of Edholm (1955), it was determined that exercise leads to an increase in EI[49]. This theory is in line with the fact that food deprivation, which creates an energy deficit, is followed by an increase in hunger and EI at test meals, and increases food cravings during the day[31,50,51]. However, this notion was subsequently contradicted by Hubert *et al*.[31] who showed that the energy deficit induced by ExEE does not modify hunger and EI to the same extent when compared to food restriction[31].

In general, following acute ExEE, appetite and/or EI has been shown to be suppressed[5-10]. However, when carefully considering the characteristics of subjects (*e.g.,* sex, adiposity level) and the characteristics of the exercise (*e.g.,* intensity), specific conclusions are difficult to reach. For the purpose of this discussion, acute effects on EI will be considered as the food intake that follows exercise, while short-term effects on EI will be considered as the food intake taken during the same day as the exercise session. In addition, this literature review will specifically focus on aerobic-type exercise since EE following resistance training is typically lower[52].

### *2.1.1 Characteristics of the Subjects - Lean, Overweight and Obese Men and Women*

While EI and hunger have been shown to decrease or remain the same after exercise in sedentary lean men[8,53-55], sedentary women have shown to either increase or decrease EI after exercise[6,56]. The lack of consensus regarding sedentary women may reflect the role of adiposity level on EI compensation. For example, it was demonstrated that obese women tended not to compensate following ExEE compared to non-obese women[6,57]. Nevertheless, others have found an increase in EI for obese women after treadmill walking (60% $HR_{max}$ for 60 min)[56]. As for men, after moderate exercise (2 hours of cycling at 60%), it has been shown that obese and lean men reacted in the same way by decreasing their desire to eat and their EI[8]. Finally, the results from a study designed to investigate the difference between overweight men and lean women, who exercised on a cycle ergometer (70% $VO_{2max}$) until they burned 30% of their total energy expenditure, showed no significant difference in terms of relative EI and EI compensation, which suggests that more research is needed to better understand the differences between sexes and the potential role of the adiposity as far as EI following ExEE is concerned[58].

*2.1.2 Characteristics of the Subjects - Cognitive Factors*

We have recently demonstrated that exercise may influence the relationship between cognitive dietary factors and body mass index[59]. Cognitive dietary restraint and disinhibition, measured with the Three-Factors Eating Questionnaire (TFEQ), have been largely investigated due to their role on appetite and EI[60]. Restrained eaters seemed to finish their meal, "not in response to satiety but rather because they had reached a cognitively-set limit"[61], which is determined by the amount of food eaten[61,62]. Based on Hill's model (1995), it could be hypothesized that while dieting, restrained individuals would reduce or maintain EI following ExEE[63]. Conversely, without dieting, ExEE could lead restrained individuals to ease their EI control[63]. In the study conducted by Lluch (2000), it was shown that restrained and unrestrained women ate similarly after performing ExEE, while after a control condition unrestrained women ate less than restrained individuals[62]. As for dietary disinhibition, it can exert a positive or a negative influence on EI[64,65]. For example, dietary disinhibition is associated with unhealthy food consumption and lower physical activity level, and could predict a lower weight loss[65]. Nevertheless, exercise could help to better control appetite in individuals with high dietary disinhibition scores[64]. As such, ambiguity remains regarding the effects of cognitive factors, which deserves further investigation.

*2.1.3 Characteristics of the Subjects - Inter-Individual Variability*

Following acute ExEE, EI compensation may be explained by the pleasure associated with food (*i.e.,* food reward)[66]. Food reward can be divided into the "strength of motivational response to obtain available food (implicit wanting) and the subjective pleasure it induces (explicit liking and wanting)"[66]. In their study conducted on 24 non-dietary restrained women (18-40 years, BMI=22.3±2.9 kg/m²), Finlayson *et al.* reported that when compared to resting for 50 minutes, exercise (50 min at 70% of their $VO_{2max}$) induced a large inter-individual variability in regards to EI following a structured acute intervention. As such, the authors divided the participants into compensators and non-compensators. Non-compensators were individuals "who ate approximately the same or less after exercise", while compensators were those who "ate more after exercise"[66]. Based on this dichotomisation, significant differences regarding implicit wanting for food after exercise were observed between compensators and non-compensators. Lower implicit wanting could therefore explain why non-compensators may be less predisposed to overcompensate and more prone to lose weight in response to exercise[66].

*2.1.4 Characteristics of the Exercise - Intensity*

The impact of the different characteristics of the intervention (*e.g*., length, intensity, dose) on appetite and EI is controversial. This literature review will specifically focus on the intensity since it has been postulated to be an important mediator of the effects of exercise on appetite and acute EI[33-37]. Studies[6,7,9,51] have indicated "that exercise induced anorexia is characterized by a brief suppression of hunger, which is followed by a delay in the onset of eating"[67]. In this regard, it has been proposed that the "increased sympathetic nervous system activity during exercise may also reduce motility of the intestinal tract"[8]. Additionally, while postprandial levels of ghrelin did not change with exercise[68], the reduction of hunger may be related to changes in blood glucose, free fatty acids, and insulin[8]. The redistribution of the blood flow to muscles and away from the splanchnic circulation may also explain this brief suppression of hunger[69]. However, in women, it has been shown that the feelings of hunger are not decreased to the same extent as that seen in men[53,70,71]. Because the anorexia induced by exercise is very short in men and does not impact food intake to a great extent, it may not lead to sex-related differences in EI over longer periods.

Along the same lines, Pomerleau *et al*.[71] have shown in young lean women that an acute bout of exercise at LI and HI was compensated at 25% and 41% respectively. In fact, this translated into an increase in EI at both exercise intensities of a given caloric cost when compared to the control session. It also suggested that EI increased to a greater extent following an exercise at HI. After one day, the LI exercise bout was compensated at 41%, while the HI exercise bout was compensated at 91%. These findings suggest that energy compensation is dependent on exercise intensity as indicated by greater post-exercise EI. In contrast, the work done by Tremblay *et al*.[72] showed that in men, high-intensity intermittent training induced greater reductions in subcutaneous adiposity (*i.e.,* lower energy compensation) compared to endurance training. The outcome of increasing exercise intensity on EI and ultimately adiposity may potentially differ between men and women.

The relative EI (REI) is a different way to express compensation and is calculated by subtracting the ExEE from EI during the test meal[9]. In the study of Pomerleau *et al.*[71], the REI was lower in lower (LIE) and higher (HIE) intensity groups compared to the control group (C) (**Figure 1**).

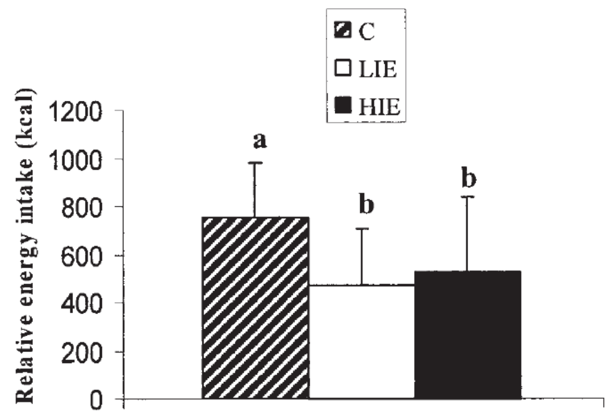


**Figure 1 -** Relative EI after lunch time and either the control session as well as the low and high intensity EE session[71] Values that share the same letter are not statistically different.

Conversely, even if REI were decreased after the exercise at lunch time, no significant differences were observed for the daily REI between the three conditions (control, low, and high intensity) (**Figure 2**).

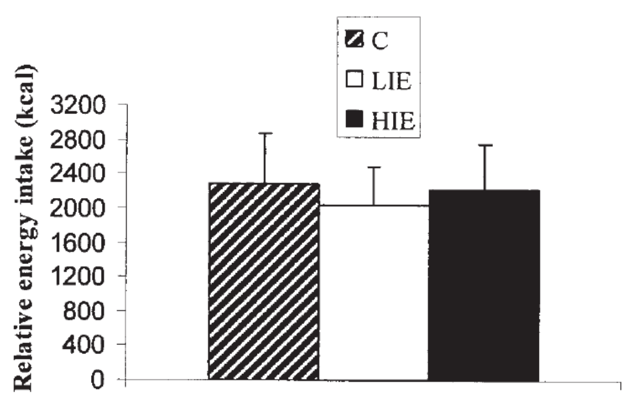


**Figure 2 -** Daily relative EE after the control session and the low and high intensity EE session[71]

In summary, these findings suggest that energy compensation shows an exercise intensity-dependent response. However, due to the paucity of data concerning the influence of adiposity levels and sex differences, firm conclusions cannot be made on this matter.

*2.1.5 Limitation of Food Intake Measurement*

To explain the discrepancies between studies regarding the impact of exercise on appetite and EI, it is important to consider that EI is one of the most difficult components to measure in the field[39-42]. In fact, currently available methods are hampered by limitations that often hinder extrapolation of results to real-life settings. Another aspect that deserves consideration is the time interval between the exercise and the consumption of the foods as well as the macronutrient composition of the foods[71]. For example, some studies have measured EI 15 minutes after the exercise[6,67], while others as much as one hour post-exercise[71]. Given the relatively short-lived anorectic effects of exercise, the timing for the measurement of EI should be taken into consideration and should also be standardized and interpreted accordingly. The macronutrient composition of the test meal after an exercise session is also important to consider when comparing different studies. In fact, it has been shown that the consumption of a high-fat diet could completely overcome the negative EB induced by exercise[53,73]. An insufficient amount of calories expend per session of exercise could also further complicate the interpretation of the data since the impact on energy balance is insufficient when compared to daily variations[74]. Nevertheless, it has been demonstrated in a larger EE study (1200 kcal) that, when two periods of intense exercise were performed on the same day, there was no impact on EI and hunger on the day of, and immediately after, exercise[75]. Prolonging the study period to days following exercise enables the investigation of a possible "delayed compensatory response" to ExEE as proposed by Edholm in 1955.

However, this finding has never been replicated[51,76] and suggests that there is no subsequent response following a large ExEE[75]. Factors such as timing, macronutrient composition, standardization of energy cost and intensity should be considered when comparing studies. As such, future research should aim to develop new methods that could better capture EI in real-life setting.

In summary, although current evidence suggests no EI compensation in acute and short-term interventions[5-12], it is suggested that this may be related to challenges in EI assessment[39-42] and thus more studies are needed to overcome the limitations associated with the measurement of EI and should carefully take into account the intensity of ExEE.

## 2.2 Acute and Short-Term NSPA Compensatory Responses following ExEE

NSPA is defined as all movements (transportation, work-related movement and/or activity of daily living) that are not related to training or to an exercise session[18,19]. To our knowledge, few studies have specifically investigated the impact of acute or short-term ExEE under free-living conditions. When measured using a whole-body indirect calorimeter, NSPA has been shown to explain a variability of 100-800 calories between subjects[77]. It has also been demonstrated that NSPA was inversely related to body weight in cross-sectional studies[78,79] and that trained and untrained men present the same level of NSPA following a bout of ExEE[80].

The reliability and accuracy challenges related to the measurement of NSPA under free-living conditions could partially explain why this component has not been thoroughly investigated in the past. With newly available technologies, it is now possible to better document how NSPA can be impacted by exercise interventions aimed at decreasing body weight. For example, it has been recently demonstrated with accelerometry that NSPA remains unchanged two days after an ExEE session (60 min) at moderate and high intensity but increases in both conditions on the third day[81]. This finding has been similarly observed in obese boys training at a moderate intensity[82].

In addition to the measurement of NSPA following ExEE, measurements of the time spent in sedentary (*i.e.*, sitting or lying down[83]) and active behaviours may provide a more comprehensive picture of the effects of ExEE on EB. In order to better measure the time spent performing different activities (*e.g.*, lying down, dynamic standing, sitting and walking), some studies have utilized raw accelerometry data as input for classification models in both confined and unrestricted environments[84-86]. Nevertheless, none of these studies has been performed in a context of ExEE and/or energy compensation and thus this topic requires more investigation.

## 2.3 Summary of Acute and Short-Term Effects of ExEE on EI and NSPA

It has been shown that EI is not systematically decreased when subjects are obliged to become sedentary (*i.e.* calorimetric chamber)[13]. It is therefore possible that perturbations in EE do not always contribute to a commensurate modification of appetite and EI. Hence, even if more data related to sex, exercise intensity, adiposity and cognitive factors are needed, no

EI compensation has been observed following ExEE[5-12]. When considering EE or more specifically NSPA following ExEE, there is simply not enough data to draw solid conclusions. New methods should therefore be further developed and investigated.

## 2.4 Medium and Long-Term EI Compensatory Responses following ExEE

Evidence suggests no compensation following acute and short-term ExEE[5-10]. Nevertheless, this negative EB does not seem to continue and EI seems to increase proportionally to EE. For example, a positive relationship between ExEE and EI in physically active individuals has been shown[87]. Additionally, consistent results are available when it comes to the effects of vigorous prolonged exercise induced EE. In this context, large energy deficits are tolerated for a considerable amount of time since the individuals engaged in these vigorous prolonged exercises are not capable to eat the same amount of calories required by their ExEE (*e.g.,* trans-Atlantic swimming[88], Greenland trekking[89], or high-altitude climbing[90]). Even with the high-energy deficits induced by exercise under such conditions[91], it should be noted that there generally is overcompensation upon completion of these events. Indeed, study by Tremblay *et al.* reported that expeditions in the North Pole was associated with weight regain[89]. The latter was explained by the fact that following the expedition total EE was decreased while *ad libitum* EI increased, which suggests that delayed compensation mechanisms are involved during these large exercise-induced energy deficits.

When considering the impact of an ExEE intervention on EI, the relation is not clear; some authors have found no association[93] while others have found a positive relationship[94,95]. Overall, when considering long-term exercise intervention, the review done by Blundell and King[92] showed that "19% of the intervention studies reported an increase in EI, 65% showed no change and 16% showed a decrease in appetite".

Therefore, there is a need to examine the impact of an exercise intervention on EI and EE as far as the potential of exercise to induce weight loss is concerned. It is often assumed that exercise should lead to weight loss based on the observation that individuals who perform relatively large volumes of exercise are generally leaner. One aspect that is often overlooked is the fact that lean individuals who are regular exercisers typically maintain a stable body weight, which suggests a compensation of the exercise induced energy deficit of 100%. An overview of the medium/long-term EI compensatory responses following ExEE is presented and discussed in the next sections. Factors that may explain compensation such as the characteristics of subjects (*e.g.,* sex, adiposity level) and the characteristics of the exercise (*e.g.,* intensity) and contradictory results about their effect is also discussed. For the purpose of this discussion, medium and long-term effects on EI will be considered as a period longer than two days.

### *2.4.1 Characteristics of the Subjects - Men vs Women*

Previous research has reported greater weight loss in men compared to women following exercise interventions[27,96,97]. However, when accounting for differences in ExEE (*i.e.,* ExEE was equivalent and carefully monitored in men and women), no sex related differences in weight loss were observed[29]. Similar results have been reported by McTiernan[98] and Donnelly[30].

In the absence of any sex-related difference in weight loss, men and women may still differ in EI following an exercise intervention as noted by Hagobian[99]. In sedentary subjects, five days of ExEE (60 min/day at 68-70% of the $VO_{2max}$) resulted in greater EI in men, but not in women[100]. Similar results have been found in physically active subjects (8 days of training over a 2-week period performed at 59% and 48% of the $VO_{2max}$ in women and men, respectively)[25]. Closer inspection of results from a series of studies revealed that after 7 days of moderate (2 x 40min/day; 21.4 kJ/kg/day) or high (3 x 40min/day; 42.8 kJ/kg/day) intensity ExEE, the compensatory response was not noticeable in lean men, while in lean women an EI compensation of ~30% occurred[14,28]. When training was extended from 7 to 14 days, an overall compensatory response of 30% was found when men and women were combined[15], which highlights the discrepancy in the literature regarding post-exercise EI between men and women. Nevertheless, some studies were limited by the fact that women were not tested during their follicular phase[101] and the fact that both men and women were living at the research institute for the duration of testing. Such factors warrant that results be interpreted in light of these factors, especially as far as EB is concerned. One factor that remains unresolved is whether weight loss is affected differently in men vs. women, and not simply by ExEE, irrespectively of intensity.

*2.4.2 Characteristics of the Subjects - Lean and Obese Women and Men*

There are results suggesting that differences in energy compensation may be influenced by adiposity after an acute/short-term period of ExEE. Indeed for a longer intervention, it has been demonstrated that when lean and obese women and men are compared, three days of exercise (mean EE in the lean group was 118 kcal/day and 100 kcal/day in obese individuals) increases EI in lean by 155 kcal per day but not in obese individuals[95]. In addition, a comparison between studies done with lean individuals and obese/overweight women showed that lean subjects increased their EI (measured by a food diary journal) to match the EE (measured with an activities diary), while overweight individuals did not increase their EI[94]. One hypothesis suggests that FM is a possible predictor of an increase in EI, while another hypothesis suggests that FM might serve "as an energy buffer"[69], so that the energy deficit induced by exercise might not increase EI as much[69,74]. It was also suggested that the compensatory mechanism in obese individuals will only occur when fat reserves are at a minimal level[94].

*2.4.3 Characteristics of the Subjects - Inter-Individual Variability*

Inter-Individual variability is an important concept that has been previously addressed by Bouchard *et al*. in 2001[102]. In a study of 35 overweight and obese sedentary individuals by King *et al*. (2008), mean group weight loss was 3.7 kg after 12 weeks of training designed to expend 2500 kcal/wk (five sessions per week and 500 kcal per session), with weight loss ranging between -14.7 kg and + 1.7 kg[32]. The authors then divided participants into compensators (non-responders) and non-compensators (responders). Non-compensators (37% body fat) were those in whom the actual weight loss was similar or superior to the predicted weight loss while compensators (33% body fat) were those in whom the actual weight loss was lower than the predicted weight loss. Findings revealed that compensators presented an increase in EI, greater hunger, and a small but non-significant decrease in resting EE compared to non-compensators[32]. Boutcher *et al*., (2009) proposed numerous factors that may explain the individual compensation[103]. In this paper, behavioural (*e.g*., sleep deficiency, sedentarity), inherited (*e.g*., body fat depot, sex) and physiological (*e.g*., fiber type, mitochondria) factors are discussed[103]. The authors suggested that these factors should be further investigated to address the inter-individual variability in terms of weight loss[103].

*2.4.4 Characteristics of the Subjects - Cognitive Factors*

Cognitive factors are also important to consider when investigating the relationship between exercise, appetite, and EB. Following a training intervention, it is possible that individuals ease their cognitive dietary restriction, leading to the belief that EE associated with ExEE allows them to eat as much as they want[62]. Nevertheless, it has been shown that ExEE can positively impact women with high disinhibition, suggesting a "decreased motivation to eat and an increased preference for a low fat diet"[65]. In addition, ExEE may improve the satiety signalling systems, suggesting that individuals would be able to better discriminate an "energy rich and a non-energy rich beverage" after an acute bout of ExEE[69,104]. It is also possible that exercise could modify macronutrient preferences, food choices, and the hedonic value of foods and could consequently favour a better control of feeding during a long-term physical activity intervention[74]. For example, Lluch *et al.* demonstrated that ExEE increased "the tastiness and pleasantness of food"[61,62]. Finally, it has been suggested that emotions are largely involved in the regulation of EI[105], and it has been proposed by Lluch and colleagues that, "if dietary compensation does occur, this may be due to cognitive factors rather than to a direct physiological linkage between EE and intake"[61,106].

*2.4.5 Characteristics of the Exercise Intervention - Intensity*

Regarding the intensity of an exercise intervention, available data suggest that a 12-week intervention designed for participants to expend 300kcal per exercise session at LI (50% of $VO_{2max}$) significantly decreased body weight in overweight women, while the HI intervention (80% $VO_{2max}$) did not change body weight in lean women[34]. Consistent with this study, body weight was found to decrease more in lean women training at LI (45% of $VO_{2max}$) than in women training at a HI (72% $VO_{2max}$)[37]. Nevertheless, in obese men, no change in body weight and composition have been shown following a training of 12 weeks performed at 40 and 70% of $VO_{2max}$[36], a finding similarly found in obese women training at 40% of $VO_{2max}$[35] and ~60% of the $VO_{2max}$[33]. Bearing in mind these inconsistencies, it is difficult to formulate a conclusion regarding to body composition changes.

In summary, it is generally suggested that EI is increased to match the EE. Sex[29,58] and adiposity level[94,95] are factors that modulate the effect of exercise intervention on EI and make results pertaining to energy compensation difficult to interpret. Cognitive factors could impact EI[62], more so than physiological determinants, making the interpretation of the data even more challenging. Additionally, the effectiveness of exercise to induce weight loss is highly variable[32] and energy compensation might also vary as a function of the characteristics of the exercise intervention (*e.g.,* intensity).

## 2.5 Medium and Long-Term NSPA Compensatory Responses Following ExEE

As previously defined, NSPA is defined as all movement (*e.g*., transportation, work-related movement and/or activity of daily living) that is not related to an exercise intervention[18,19]. While little evidence is available following an acute and/or short-term intervention, it has been suggested that failure to induce weight loss following ExEE may be related to a reduction in total EE, secondary to the adoption of a more sedentary lifestyle between exercise sessions[18,21-23]. In opposition to this view, others suggest that ExEE increases NSPA due to an increased ability to perform daily activities[16]. As such, the effect of ExEE on NSPA deserves more attention.

*2.5.1 Decrease in NSPA following ExEE*

Results from a study performed in elderly individuals revealed, with measures of doubly labelled water, that NSPA was decreased by 231 kcal/day in response to exercise training. More specifically, the percentage of reduction of NSPA accounts for ~60%[23]. Similarly, a moderate-intensity walking program designed to expend 1500 kcal/week during two months resulted in a significant decrease in NSPA (22% or 175 kcal/day) among obese individuals[18]. This decrease was explained by a significant increase in sleeping and by a decrease (not statistically significant) in the time spent performing light physical activity without any change in time spent in sedentary and moderate activity.

In addition to doubly labelled water, activity monitoring systems provide the advantage of being able to capture information related to patterns of physical activity over a short period of time. A study performed with tri-axial accelerometers showed that 12 weeks of training decreased NSPA in elderly subjects on training days[22]. The role of NSPA has also been investigated by Levine *et al*., in an attempt to objectively determine differences in posture allocation between lean and obese individuals[107]. Results showed that obese individuals were seated 164 min/day more than were lean individuals and that lean individuals were upright 152 min/day more than obese individuals[107]. As such, this method could help to identify areas of intervention that should be targeted in order to increase the resolution of ExEE in weight management.

*2.5.2 Increase in NSPA following ExEE*

In contrast to results presented in the previous section, some studies have reported that NSPA was not reduced following ExEE. Black *et al*., demonstrated that obese boys increased their

NSPA following a cycling program of 4 weeks (5 sessions/week) at 50-60% of the $VO_{2max}$[24]. Eight days of training in young lean women and men showed similar results when training at 48 and 59% of the $VO_{2max}$, respectively[25]. Measures obtained with triaxial accelerometry showed that men and women (aged between 28-41 years old) who were preparing to run a half marathon increased and maintained respectively their NSPA after 20 weeks of training[26] and also maintained this NSPA after 20 additional weeks of training[27]. Additionally, after 8 months of ExEE designed to expend 59-96 kJ/kg of body mass, middle aged sedentary obese and overweight men and women, did not modify their NSPA measured with triaxial accelerometry[16]. Finally, similar results were obtained after eight months of aerobic training in overweight and obese individuals[17] and after six months of exercise in eldery men and women[108].

In summary, these studies suggest that NSPA was not affected by ExEE. In order to explain the discrepancies with the previous section, it should be noted that the selection of the population is an important factor since healthy and obese young individuals have been shown to present no decrease or even an increase in NSPA in response to ExEE[109]. On the other hand, with the exception of the study performed by Fujita in 2003[108], elderly subjects have been shown to present a decrease in NSPA in response to ExEE. It is important to note that none of these studies has been specifically designed to determine the difference between young and elderly individuals and that the method used to measure NSPA, the intensity and the sex of the participants might influence the conclusions[109].

## 2.6 Summary for the Medium and Long-Term Effects of ExEE on EI and NSPA

Data suggest that EI compensation exists in men and women following medium and long-term ExEE (~30%)[15]. However, consensus has not been reached regarding changes in NSPA following ExEE. As such, this highlights the need for further studies to clearly delineate the impact of changes in NSPA on energy compensation. Additionally, the simultaneous impact of ExEE on both sides of the EB is not fully understood and requires further investigation.

# Chapter III

# Experimental Methods and Results

## 3.1 Thesis Article # 1

The article entitled "Light Physical Activity is a better Determinant of Lower Adiposity during the Menopausal Transition" presented in this section of the thesis is published in the journal *Climacteric* (Appendix A).

# Light Physical Activity is a better Determinant of Lower Adiposity during the Menopausal Transition

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**Running title:** Light Physical Activity and Adiposity

**Key words:** Physical activity, accelerometry, body weight, body composition, menopause and compensation

**Disclosure of funding**: This study was supported by CIHR (Canadian Institute for Health Research) grants: 63279 MONET study (Montreal Ottawa New Emerging Team : DP, MB, RRL and ED)

**Conflict of interest**: The authors declare no conflict of interest

## Abstract

**Objective**: To investigate the relationship between time spent performing physical activity (PA) and adiposity across the menopausal transition.

**Methods**: Body weight and body composition were analyzed in 65 women (48-54yrs; 23.2±2.4kg/m²) in a 5-year prospective study. Time spent in PA of varying intensities (sedentary, light, moderate and vigorous) was determined from 7-day accelerometer measurement and energy intake with a 7-day food diary.

**Results**: Significant negative correlations were observed between the time spent in light-intensity PA and fat mass (FM) ($r=-0.38$, $p<0.005$), central FM ($r=-0.36$, $p<0.005$), peripheral FM ($r=-0.33$, $p<0.01$), and percent body fat ($r=-0.42$, $p<0.001$) at year 1, respectively. No significant correlations were noted between measures of adiposity and time spent performing either moderate or vigorous PA. Analyses using tertiles of time spent in light PA at year 1, showed that FM (20.7±4.0 vs. 20.3±6.6 vs. 16.6±4.6 kg, $p<0.05$), central FM (10.1±2.6 vs. 10.0±3.8 vs. 7.8±2.4 kg; $p<0.05$) and percent body fat (34.5±5.1 vs. 32.2±7.7 vs. 28.1±6.2 %, $p<0.01$) were all significantly lower in women in the highest tertile. These differences remained significant after covariate analyses using time spent in moderate and high-intensity PA and total energy intake. Finally, lower levels of FM, percent body fat, central and peripheral FM persisted in women who spent more time in light PA (highest tertiles) over the 5-year follow-up.

**Conclusion**: Our results suggest that the time spent performing light PA has a greater impact on adiposity than moderate and/or vigorous PA, an observation independent of the menopausal status.

## Introduction

Exercise interventions have been widely investigated and recommended to prevent obesity or to promote weight loss. However, even if it has been associated with a favourable impact on physiological and psychological well being[1], the fact remains that the effects of exercise on the reduction of body weight are often much less than anticipated[2,3]. Several reasons have been proposed to explain this observation. These include, but are not limited to the small doses of prescribed exercise, a reduction of resting energy expenditure, an increased energy intake and/or a decrease in non-exercise activity following exercise[3-5].

In an attempt to provide a clearer picture of the effect of exercise on body weight, studies have manipulated the duration, the amount of exercise per week as well as the intensity of the exercise. In this sense, it has been demonstrated in overweight and premenopausal women with restricted energy intake that a 3-month walking intervention lasting either 30 or 60 minutes, lead to a similar weight reduction when performed 5 times per week[6]. In contrast, it was reported that obese postmenopausal women who performed exercise for longer duration lost a higher amount of weight, independent of the exercise intensity[7]. On the other hand, when taking into consideration intensity of physical activity, it has been suggested by Slentz and colleagues in 2004 that, when physical activity is performed at higher intensity, it has a small and non significant effect on fat mass when compared to a lower intensity physical activity, and this is even after controlling for energy expenditure during exercise (14 kcal/kg or 12 miles in both groups)[8]. It has also been proposed that intensity might be more related to a gain in lean body mass rather than to fat mass losses[8], suggesting that duration has a greater impact than intensity as far as weight and fat loss are concerned[7-9]. Similarly, after controlling for energy expenditure during exercise, in an intervention that lasted 3 months, it has been shown that weight loss was greater at lower intensity when compared to weight loss in women who exercised at higher intensity[9,10]. To explain, the authors' assumptions supports the idea of a lower energy intake and non-structured physical activity compensation across the intervention for women training at a lower intensity[10].

Considering the above evidence suggesting that the better cocktail to favour weight loss is to perform physical activity for a longer duration at lower intensity, we, for the first time, investigated whether this cocktail will have a greater impact on body composition across the menopause, which is a critical period that has been shown to be associated with changes in body composition and fat distribution[11,12]. As such, the main objective of this study was to investigate the impact of the time spent (duration) in sedentary physical activity (PA) and PA of varying intensities (light, moderate and vigorous) on body weight and composition during a 5-year follow-up of women going through menopause. It is hypothesized that light PA will be associated with a favourable change in body composition when compared to moderate or high PA. It is also hypothesized that spending more time performing light physical activities would be associated with a lower adiposity at baseline and with a lesser gain in adiposity during the 5-year follow-up.

## Methods

### Participants

This study was part of one of the MONET (Montréal Ottawa New Emerging Team) studies and details are provided elsewhere[13]. The inclusion criteria were as follows: *1*) premenopausal women between 48 and 55 years of age; *2)* regular menstrual cycle; *3*) non-smoker; *4*) body mass index (BMI) between 20 and 29 kg/m²; *5*) reported weight stability (± 2 kg) for ≥ 6 months before enrolment in the study; *6*) no known disease or disability; and *7*) no current medications that could influence energy intake or metabolism. Women were also allowed to be on oral contraceptives. Hormone replacement therapy was an exclusion criterion at inclusion. However, women who began this treatment during the study were kept in all analyses (*n=4*)[13]. A total of 314 women responded to the invitation in the local newspapers of the Ottawa City metropolitan area. As described by Abdulnour and colleagues[13], 102 women were found to be eligible. Among them, 11 dropped out of the study for personal reasons. A total of 91 Caucasian women completed the 5-year longitudinal study with body composition measurements performed each year. However, women without complete accelerometry data (n=26) were not included. Body weight (60.5±6.4 (n=65) vs. 61.2±6.1 (n=26); p=NS) and composition (%BF 31.6±6.9 (n=65) vs. 29.7±5.5 (n=26); p=NS, FFM 40.9±4.2 (n=65) vs. 41.8±4.9 (n=26), p=NS) were not significantly different at baseline and over the course of the study, between those who completed all accelerometery measurements and women who did not. Sixty-five premenopausal women were thus included in this prospective observational study. This study was conducted according to the guidelines laid down in the Declaration of Helsinki and all the procedures involving human subjects were approved by the University of Ottawa ethics committees. Written informed consent was obtained from all subjects.

**Menopausal status**

Women were classified, according to the STRAW classification[14], into three groups based on their menopause status at year 5: 1) women who remained premenopausal throughout the study (stable length of cycles) (n= 2); 2) women who were classified as perimenopausal (variable cycle length > 7 days different from normal and/or ≥ 2 skipped cycles and an interval of ≥ 60 days of amenorrhea) (n= 20); and 3) women who were classified as postmenopausal women during the course of the study (12 months without any menstrual cycles and follicle-stimulating hormone (FSH) >30mIU/ml[15]) (n=43). We combined women who remained premenopausal over the entire course of the study with those who were classified in menopause transition because their initial weight and body composition revealed no significant differences at baseline (not shown). FSH levels were also measured annually during the early follicular phase to verify the menopausal status. Women who had a hysterectomy were classified using their FSH value (n= 3).

**Measurements**

All measurements (except for the graded exercise test to exhaustion) were performed on a yearly basis at approximately the same time of the year (within 2 to 3 months) during the follicular phase (days 1-8), for as long as the women enrolled in this study were still premenopausal. Women who were perimenopausal and postmenopausal were tested during a specific time of the year.

**Body composition measurements**

Body weight was measured to the nearest 0.1 kg using a BWB-800AS digital scale, and standing height was measured to the nearest millimeter using a wall stadiometer (Tanita Corporation of America, Inc, Arlington Heights, IL). Waist circumference was assessed in duplicate at the mid-distance between the iliac crest and the last rib margin with a flexible steel metric tape. Body composition and central fat mass (FM) were measured by using dual-energy X-ray absorptiometry (DXA; GE-LUNAR Prodigy module; GE Medical Systems, Madison, WI.). In addition, peripheral fat, *i.e.* FM contained in both arms and legs, was obtained by subtracting central FM (FM contained in the trunk) from total fat measured with DXA. Coefficient of variation and correlation for body fat percentage (% BF) measured in 12 healthy subjects tested in our laboratory were 1.8 % and $r = 0.99$, respectively.

**Time spent in physical activity of varying intensities**

A 7-day accelerometer (Actical; Mini Mitter Co, Inc, Bend, OR) measure was used to estimate mean time spent in PA of varying intensities. Sedentary intensity was described as an intensity between 1.0–1.5 METs, light intensity was higher than 1.5 METs and lower than 3.0 METs, moderate intensity was higher or equal to 3 METs and lower than 6 METs and vigorous intensity was higher or equal to 6 METs[16]. As described in the actical software instruction manual, examples of a sedentary activity are sleeping and resting. Examples for light, moderate and high physical activity include walking at a pace lower than 4.8 km/h, lower than 7.2 km/h and higher than 7.2 km/h, respectively[16]. Participants wore the accelerometer upon waking up and took it off just before going to bed. Twenty-four hours of continuous recording was performed by the accelerometers and time spent performing sedentary was also considered when participants were not wearing the device (sleep time).

The accelerometer was worn on the right hip (anterior to the iliac crest)[17]. When compared to doubly labelled water, this tool has been shown to be a good predictor of energy expenditure[18]. However, we elected to use the time spent in PA of varying intensities instead of energy expenditure, because time does not have to be controlled for body weight.

**Cardiorespiratory fitness**

A progressive exercise stress test to exhaustion was performed to measure participants' peak maximal oxygen consumption ($VO_{2peak}$) on a treadmill at years 1, 3 and 5 of the study. The progressive test consisted of 3-min stages on a treadmill with an increasing workload to the point of exhaustion. For the first 15 minutes the speed was at 3.4 mph and the incline increased by 4% at every 3 minutes until 16%. The speed then increased to 4.0, 5.2 and 6.0 mph every 2 stages, while the incline changed at every stage (14, 16, 12, 15, 14 and 16%). Heart rate, blood pressure and the Borg scale[19] were taken at rest and at the end of each stage during the test. Breath-by-breath samples of expired air were collected through a mouthpiece throughout the test, and measurements of $VO_2$ and respiratory exchange ratio were made automatically using a Vmax 229 series metabolic cart (SensorMedics Corporation, Yorba Linda, CA, USA). Peak oxygen consumption was considered as the highest $VO_2$ reached during the test.

**Food records**

Energy intake and macronutrients were assessed with a 7-day dietary record during the same day where the accelerometer was worn. Subjects were asked to record the type and amount of foods and beverages consumed. The time and place of eating of food were recorded as well. Participants received oral and written instructions on how to record their energy intake.

They were asked to be as specific as possible in their description by indicating all main ingredients and the quantity, the brand of products, and the cooking method. Participants were also asked to bring food labels. Recorded data were carefully verified on the return of the food diary to obtain forgotten items or to correct misreported foods. Food Processor SQL software (version 9.6.2; ESHA Research, Salem, OR) was used for analyses.

**Statistical analyses**

Statistical analyses were performed using SPSS software (version 11.5; SPSS Inc, Chicago, IL). Data is presented as means ± standard deviations. A one-way repeated-measure analysis of variance (PROC MIXED) was used to determine the main effects of time spent in sedentary PA and PA of varying intensities (light, moderate and vigorous) across the 5 years' follow-up. When significant differences were found, Bonferroni *post hoc* test were used to determine the differences. Pearson correlations were then used to examine relationships between time spent in PA of varying intensities (year 1) and body weight and composition at year 1 and 5. Participants were then grouped into tertiles based of time spent in light PA at year 1. An ANOVA that compared these groups was then followed by an ANCOVA, controlling for the time spent in other intensities (moderate and vigorous) and total energy intake was used to determine differences in body weight and composition between tertiles at year 1. When significant differences were found, the Tukey *post hoc* test were used to determine group differences. Finally, a three-way repeated-measures ANOVA was used to determine the main effects of time, tertile of light PA (year 1) and menopausal satus*time on body composition variables during the follow-up. When significant differences were found, the Tukey *post hoc* test were used to determine group differences. Differences with *p*-values $< 0.05$ were considered statistically significant.

# Results

## Baseline characteristics of participants

The characteristics of the participants at year 1 are shown in **Table 1**. Although all women had a BMI lower than 30 kg/m² at baseline, participants in this cohort presented a large range of % BF (18.2 - 41.7 %), FM (9.6 - 30.0 kg), central FM (3.3-18.3 kg) and peripheral FM (5.0-15.5 kg). As described by Abdulnour and colleagues[13], increases in FM and % BF as well as a decrease in fat free mass were noted during the 5-year follow-up (data not shown). Time spent in sedentary PA and PA of varying intensities (light, moderate and vigorous) during the 7-day accelerometry measurement were not different over the course of the 5-year follow-up (**Figure 1**). The only significant difference was observed between years 3 and 4 in PA performed at moderate intensity.

## Correlations with time spent at different intensities

Our data revealed significant and positive relations between the time spent in sedentary and central FM (r=0.27 p<0.05) and % BF (r=0.26 p<0.05) at year 1 (**Table 2**). In contrast, at year 1, the time spent performing light PA was found to correlate negatively with BMI (r=-0.30 p<0.05), FM (r=-0.38 p<0.005), % BF (r=-0.42 p<0.001), central FM (r=-0.36 p<0.005) and peripheral FM (r=-0.33 p<0.01). Similar correlations were also found at year 5 with FM (r=-0.29 p<0.05), % BF (r=-0.31 p<0.05), central FM (r=-0.26 p<0.05) and peripheral FM (r=-0.27 p<0.05). No significant correlations were noted between adiposity and time spent performing either moderate or vigorous PA at years 1 and 5. Energy intake measured at year 1 was correlated with the time spent performing light PA (r=0.22 p<0.05) (data not shown).

**Comparison of body weight and composition between tertiles of time spent performing light PA**

Since negative correlations were only found between time spent in light PA and body weight and body composition, we decided to further investigate this issue by grouping women into tertiles of time spent performing light PA at year 1. As presented in **Table 3**, women in the highest tertile of time performing light PA displayed lower FM ($p<0.05$), % BF ($p<0.01$) and higher fat-free mass ($p<0.05$) when compared to women in the lowest tertile. Similarly, women in this tertile displayed lower central FM ($p<0.05$) when compared to women in the lower and moderate tertiles. No significant differences were observed for body weight, BMI and waist circumference, while a trend ($p=0.06$) was observed for peripheral FM. Also, no significant difference was noted for cardiorespiratory fitness.

Because spending more time performing light PA impacts the time spent performing moderate and/or high intensity PA, the same analyses were performed after controlling for the sum of time spent performing moderate and high intensity PA. Differences remained significant for FM ($p<0.05$), % BF ($p<0.01$) and fat-free mass ($p<0.05$), while a trend was noted for peripheral FM ($p=0.06$) between the highest and lowest tertiles. Finally, even if no significant group differences for time performing light PA were noted for total energy intake at year 1 (total energy intake at lowest tertile of time performing light PA: 1850±377 kcal (n=22); at middle tertile of time performing light PA: 2074±344 kcal (n=21); at highest tertile of time performing light PA: 2053±434 kcal (n=22); p not significant), total energy intake was used as a covariate in all analyses. Results show that most differences remained when corrected for both time spent performing moderate- and high-intensity PA and total energy intake (**Table 3**).

**Time spent performing light PA and changes in body weight and composition**

Repeated-measures ANOVA analyses were performed in order to determine the main effect of time (year 1 to 5), of tertiles (lowest, moderate and high) on time performing light PA and menopause status. Analyses revealed a main (increase) effect of time (year 1 to year 5) for waist circumference ($p<0.005$), FM ($p<0.0001$), % BF ($p<0.0001$), central FM ($p<0.0001$), peripheral FM ($p<0.0001$) as well as a main (decrease) effect for fat-free mass ($p<0.0001$), while no significant effects were found for weight and BMI (data not shown). Similarly, significant effects were observed between tertiles for FM ($p<0.01$), % BF ($p<0.01$), peripheral FM ($p<0.05$) and central FM ($p<0.01$) (data not shown). Women in the highest tertile of time performing light PA displayed lower FM, % BF, and central FM when compared to women in the lowest or moderate tertile of time performing light PA. An overview of these findings for % BF, for women who had worn an accelerometer every 5 years (*n=41*), is presented in **Figure 2**. No significant difference was noted as far as menopausal status was concerned. Finally, no significant interaction of time by group, time by menopausal status or time by group by menopausal status was noted (data not shown), indicating that adiposity differences between tertiles were not different across the 5-year follow-up and regarding the menopausal status. However, it is important to note that even if women in the highest tertile of time performing light PA displayed lower FM, % BF, and central FM when compared to women in the lowest or moderate tertile of time performing light PA, they present a similar increase in body weight and body composition across the 5-years follow-up. Last, after controlling for time spent performing moderate and high PA and total energy intake at year 1, adiposity differences between tertiles remained significant across the 5-year follow-up. However, no effect of time was observed after controlling for these variables (data not shown).

## Discussion

Due to reported compensatory effects on energy intake[20] and energy expenditure[4] following a physical activity practice at a higher intensity, we hypothesized that women spending more time performing light PA would have lower body weight and adiposity. In addition, we further hypothesized that spending more time in light PA would attenuate the adiposity gain during a 5-year follow-up. Our data suggest that spending more time doing light PA is associated with lower body weight as well as with some indices of adiposity at the onset of a 5-year follow-up. However, even if spending more time performing light PA was associated with lower adiposity throughout the 5-year follow-up, it was not associated with a reduction of the adiposity gain normally observed with menopause and aging[12,21,22].

Our results showed that the time spent in light PA is associated with lower adiposity, which was not the case for time spent performing moderate or vigorous PA. This would seem to suggest a possible implication for compensatory mechanisms as intensity increases. In fact, it has been shown that PA increases the palatability, pleasantness, as well as the tastiness of foods[23,24]. More recently, it has also been reported that the hedonic value of food is at least partly modulated by exercise[20]. As such, it could be postulated that increased compensation from energy intake might differ in response to the time spent performing light, moderate or vigorous intensity. For example, it has been demonstrated that women have a significantly lower energy intake over 24 h after a bout of low-intensity exercise than they did after a high-intensity exercise bout[25]. However, in this study, light physical activity was positively correlated to energy intake at year 1 while no significant correlation was noticed at year 5. Another explanation as to why women spending more time performing light PA display lower adiposity may relate to energy expenditure from non-structured PA. Results from a study done in elderly individuals who were performing high-intensity exercise revealed that energy expenditure from non-structured PA was decreased by 231 kcal/day[26]. More recently, it was also reported that a moderate intensity walking program designed to expend 1500 kcal/week during two months produced a significant decrease of non-structured PA (22% or 175 kcal/day) in a group of obese women[4]. These findings lend support to the notion that non-exercise activity thermogenesis may be reduced in response to exercise. Whether the magnitude of this decrease is greater when performing exercise at high intensity remains, however, to be determined.

Our analyses also demonstrated that larger amounts of PA performed at a light intensity (highest tertile of time spent in light PA) are associated with lower body weight and with lower indices of adiposity in women going through the menopausal transition. In accordance with results from Jakicic and colleagues (2003), this could be explained by the fact that women performing more minutes of exercise per week (200 min/week) were the ones displaying the largest weight losses when compared to those performing less than 150 min/week, independently of exercise intensity[7]. In summary, time performing light PA is associated with lower adiposity, at least in the sample we investigated. Furthermore, it is also associated with the maintenance of lower body fat over the course of the study period, an effect that is independent of the menopausal status.

BMI at inclusion was <30 kg/m$^2$. It is clear that conclusions cannot be extended to the general population. However, it is important to mention that 45% of the women aged between 40 to 59 in the Canadian population[27] present a BMI between 20 and 29 kg/m$^2$. In addition, our findings need to be confirmed in a larger cohort of subjects that should include obese women with a greater age range as well as women with high levels of vigorous physical activity. Nonetheless, it is relevant to note that our conclusions are based on results obtained from objective measures such as DXA and accelerometry. It should also be reiterated that women were investigated across the menopausal transition during a 5-year follow-up and were grouped accordingly (premenopausal and perimenopausal as well as postmenopausal) for all analyses.

As mentioned previously, our results suggest that women spending more time performing light PA have lower adiposity, an effect that is independent of the menopausal status. Additionally, the lower adiposity values observed in women performing light PA persist over a 5-year follow-up across the menopausal transition. These findings seem to suggest that women should increase the amount of time spent performing light PA as a potential strategy to maintain lower levels of adiposity.

## Acknowledgements

The authors would like to thank the participants for their devoted participation and to the staff of BMRU for their contribution to this study. We especially want to thank the study nurse, Ann Beninato for her significant role in the collection of the data and overall study coordination. This study was supported by CIHR (Canadian Institute for Health Research) grants: 63279 MONET study (Montreal Ottawa New Emerging Team: IS, DP, MB, RRL and ED). ME Riou is a recipient of the Frederick Banting and Charles Best Doctoral Award (CIHR). R Rabasa-Lhoret is a FRQ-S (Fonds de recherche du Quebec en santé) senior scholar and holds the J-A DeSève chair in clinical research. ME Riou and É Doucet analysed the data and wrote the manuscript while the co-authors: Abdulnour J, Brochu M, Prud'homme D, Rabasa-Lhoret R critically appraised and approved the final version of the manuscript. In addition, Prud'homme D, Brochu M, Rabasa-Lhoret R and Éric Doucet participated in the research design.

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**Table 1 -** Characteristic of the subjects at baseline (n=65)

| | Mean±SD |
|---|---|
| Age (yr) | 49.7±1.8 |
| $VO_{2peak}$ (min/kg/ml) (n=62) | 33.7±6.5 |
| Antropometric variables | |
| Body weight (kg) | 60.5±6.4 |
| BMI(kg/m²) | 23.2±2.4 |
| WC(cm) | 78.3±7.0 |
| FM (kg) | 19.2±5.4 |
| FFM (kg) | 40.9±4.2 |
| BF % | 31.6±6.9 |
| Central FM (kg) | 9.3±3.2 |
| Peripheral FM (kg) | 9.9±2.7 |

Values are means ± SD
FM, Fat mass; BF%, body fat percentage; FFM, fat-free mass

**Table 2 -** Correlation coefficients (r values) between time spent in physical activity of varying intensities at year 1 and body weight and composition at year 1 and 5

| | | Time spent in physical activity of varying intensities at year 1 | | | |
|---|---|---|---|---|---|
| | | Sedentary | Light | Moderate | Vigorous |
| *n=65* | | | | | |
| Body weight (kg) | Year 1 | $0.10^{NS}$ | $-0.20^{NS}$ | $-0.04^{NS}$ | $-0.06^{NS}$ |
| | Year 5 | $0.11^{NS}$ | $-0.18^{NS}$ | $-0.04^{NS}$ | $-0.04^{NS}$ |
| BMI (kg/m²) | Year 1 | $0.19^{NS}$ | -0.30* | $-0.12^{NS}$ | $-0.08^{NS}$ |
| | Year 5 | $0.17^{NS}$ | $-0.24^{NS}$ | $-0.11^{NS}$ | $-0.05^{NS}$ |
| WC (cm) | Year 1 | $-0.02^{NS}$ | $-0.12^{NS}$ | $0.07^{NS}$ | $-0.06^{NS}$ |
| | Year 5 [1] | $-0.01^{NS}$ | $-0.02^{NS}$ | $0.07^{NS}$ | $-0.09^{NS}$ |
| FM (kg) | Year 1 | $0.22^{NS}$ | $-0.38^{**}$ | $-0.08^{NS}$ | $-0.04^{NS}$ |
| | Year 5 | $0.19^{NS}$ | -0.29* | $-0.07^{NS}$ | $-0.03^{NS}$ |
| FFM (kg) | Year 1 | $-0.15^{NS}$ | $0.22^{NS}$ | $0.05^{NS}$ | $-0.03^{NS}$ |
| | Year 5 | $-0.13^{NS}$ | $0.17^{NS}$ | $0.04^{NS}$ | $-0.01^{NS}$ |
| BF % | Year 1 | 0.26* | $-0.42^{\ddagger}$ | $-0.10^{NS}$ | $-0.03^{NS}$ |
| | Year 5 | $0.23^{NS}$ | -0.31* | $-0.09^{NS}$ | $-0.01^{NS}$ |
| Central FM (kg) | Year 1 | 0.27* | $-0.36^{**}$ | $-0.15^{NS}$ | $-0.08^{NS}$ |
| | Year 5 | $0.24^{NS}$ | $-0.26^{*}$ | $-0.14^{NS}$ | $-0.05^{NS}$ |
| Peripheral FM (kg) | Year 1 | $0.13^{NS}$ | $-0.33^{\dagger}$ | $0.03^{NS}$ | $0.01^{NS}$ |
| | Year 5 | $0.11^{NS}$ | $-0.27^{*}$ | $0.03^{NS}$ | $-0.00^{NS}$ |
| *n=62* | | | | | |
| $VO_{2peak}$ (min/kg/ml) | Year 1 | $-0.08^{NS}$ | $0.20^{NS}$ | $-0.05^{NS}$ | $0.19^{NS}$ |
| | Year 5 [2] | $-0.13^{NS}$ | $0.21^{NS}$ | $-0.01^{NS}$ | $0.18^{NS}$ |

$^{*}$, $p<0.05$; $^{\dagger}$, $p<0.01$; $^{**}$, $p<0.005$; $^{\ddagger}$, $p<0.001$; $^{NS}$, not significant
$VO_{2peak}$, maximal aerobic power; FM, Fat mass; BF%, body fat percentage
[1] For WC at year 5, n=64
[2] For $VO_{2peak}$ at year 5, n=58

**Table 3 -** Comparison of tertiles of time spent in light physical activity with body weight and composition at year 1

| | Tertile of Light Physical Activity | | | | | |
|---|---|---|---|---|---|---|
| | Low Light (*n=22*) | Moderate Light (*n=21*) | High Light (*n=22*) | *p* value | *p* value corrected[1] | *p* value corrected[2] |
| Time spent (min) | 1451±170 | 1744±73 | 2081±179 | <0.0001 | <0.0001 | <0.0001 |
| Body Composition | | | | | | |
| Body weight (kg) | 60.3 ± 4.9 | 62.6 ± 7.8 | 58.8 ± 6.1 | 0.16 | 0.16 | 0.14 |
| BMI (kg/m²) | 23.5 ± 1.7 | 23.7 ± 3.0 | 22.4 ± 2.0 | 0.11 | 0.15 | 0.13 |
| WC(cm) | 78.2 ± 7.0 | 79.7 ± 7.4 | 77.1 ± 6.6 | 0.47 | 0.47 | 0.44 |
| FM (kg) | $20.7 \pm 4.0^{A}$ | $20.3 \pm 6.6^{AB}$ | $16.6 \pm 4.6^{B}$ | 0.02 | 0.02 | 0.03 |
| FFM (kg) | $39.0 \pm 2.9^{A}$ | $41.8 \pm 4.3^{AB}$ | $42.0 \pm 4.7^{B}$ | 0.03 | 0.03 | 0.07 |
| BF % | $34.5 \pm 5.1^{A}$ | $32.2 \pm 7.7^{AB}$ | $28.1 \pm 6.2^{B}$ | 0.006 | 0.009 | 0.02 |
| Peripheral FM (kg) | 10.6 ± 2.0 | 10.3 ± 3.2 | 8.8 ± 2.7 | 0.06 | 0.05 | 0.07 |
| Central FM (kg) | $10.1 \pm 2.6^{A}$ | $10.0 \pm 3.8^{A}$ | $7.8 \pm 2.4^{B}$ | 0.02 | 0.03 | 0.04 |
| | *(n=21)* | *(n=20)* | *(n=21)* | | | |
| Aerobic fitness | | | | | | |
| $VO_{2peak}$ (ml/kg/min) | 33.2 ± 5.8 | 32.6 ± 6.2 | 35.2 ± 7.4 | 0.40 | 0.39 | 0.32 |

Values are means ± SD
Values that share the same letter are not statistically different using the Tukey HSD post-hoc test performed without correction for time spent performing moderate and high intensity physical activity and energy intake
$VO_{2peak}$, maximal aerobic power; FM, Fat mass; BF%, body fat percentage; FFM, fat free mass
[1] *p* value corrected for time spent performing moderate and high intensity physical activity
[2] *p* value corrected for time spent performing moderate and high intensity physical activity and energy intake

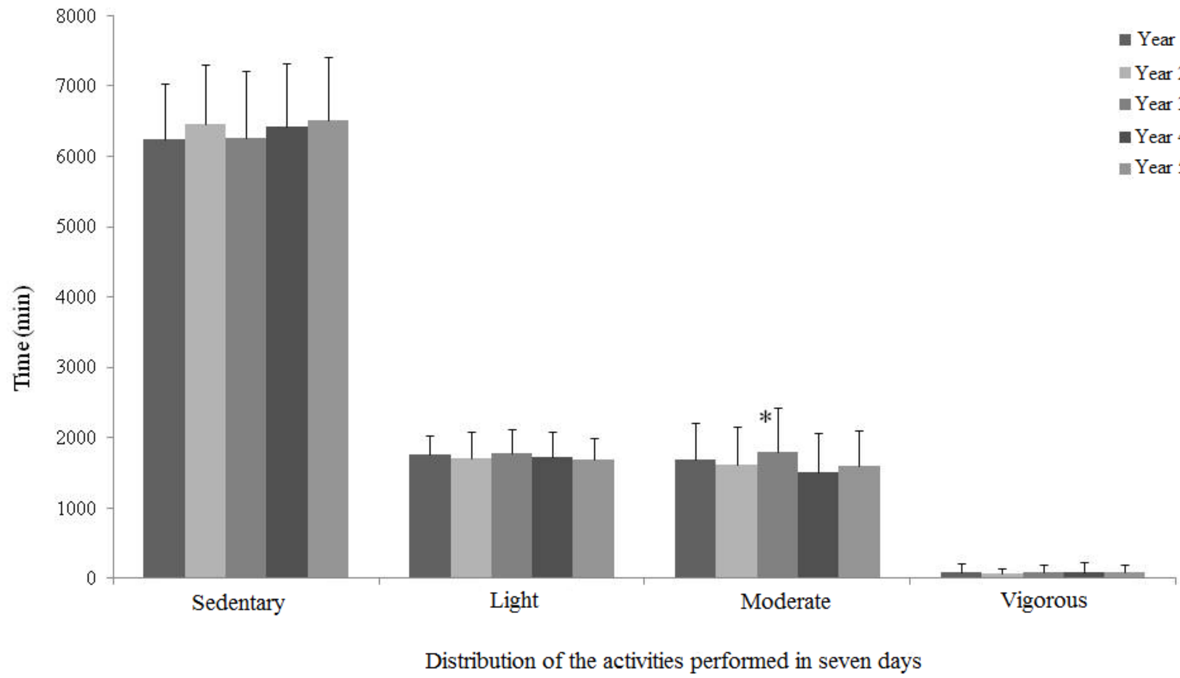


**Figure 1 -** Time (min) spent in sedentary and PA of varying intensities in seven days across the 5-years follow-up

*Represent significant difference between year 3 and 4 for moderate intensity
For sedentary, the mean (min) and SD are at year 1 (6245.4±785.1), year 2 (6464.7±848.4), year 3 (6265.2±946.8), year 4 (6417.8±906.2) and year 5 (6521.1±884.7), n=41
For light, the mean (min) and SD are at year 1 (1756.9±265.0), year 2 (1711.7±367.0), year 3 (1771.4±345.8), year 4 (1726.8±357.8) and year 5 (1681.3±310.3), n=41
For moderate, the mean (min) and SD are at year 1 (1689.0±528.2), year 2 (1608.1±540.4), year 3 (1795.2±621.3), year 4 (1514.3±556.0) and year 5 (1602.1±498.4), n=41
For vigorous, the mean (min) and SD are at year 1 (84.3±130.3), year 2 (68.1±66.0), year 3 (86.9±103.6), year 4 (76.2±147.4) and year 5 (81.0±105.1), n=41

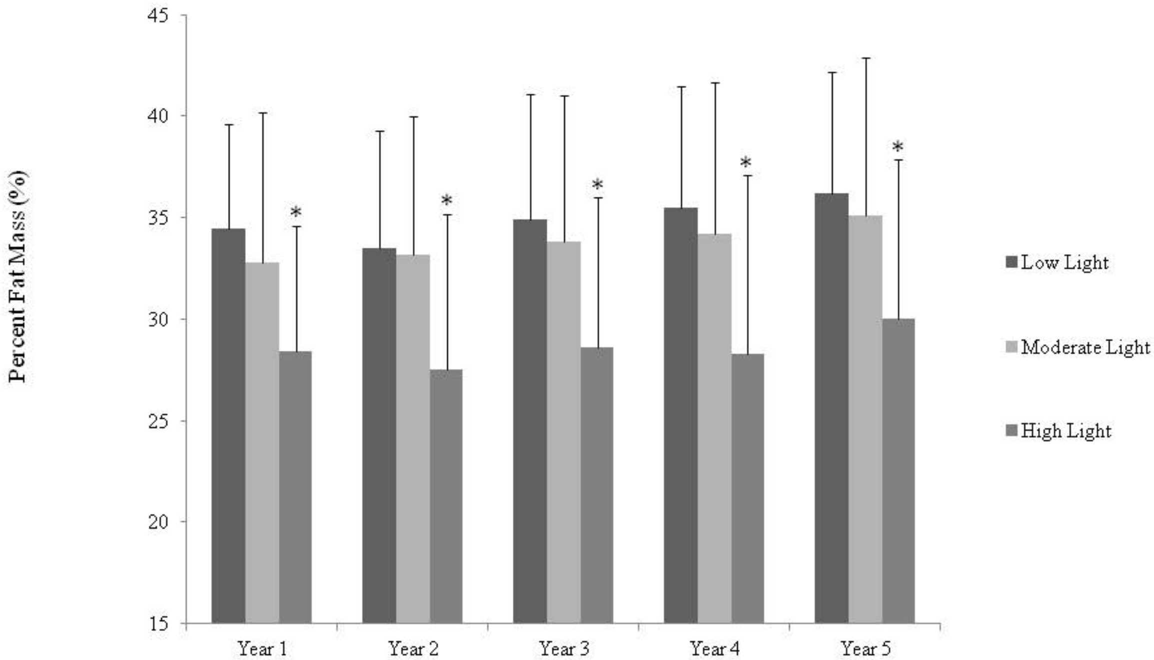


**Figure 2 -** Tertiles of time spent in light PA (low (n=22), moderate (n=20) and high (n=21)) and percent body fat over the 5-years follow-up

*Represent significant difference for percent fat mass in women spending more time performing high light PA and women spending more time performing low or moderate light PA

## 3.2 Thesis Article # 2

The article entitled "Predictors of Energy Compensation during Exercise Interventions - A Systematic Review Analysis" presented in this section of the thesis will be submitted in *Obesity Review*.

# Predictors of Energy Compensation during Exercise Interventions - A Systematic Review Analysis

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Author's contribution: MER, SJM, DS and ED designed the research, AS performed the literature search, MER and SJM performed the screening procedure, data extraction as well as the quality appraisal, MER and GL conceptualized the data analysis, GL performed the statistical analysis, MER wrote the manuscript while the co-authors: SJT, SJM, GL, DS, AS and ED critically appraised and approved the final version of the manuscript.

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**Running title:** Predictors of Energy Compensation

**Key words**: Energy compensation; body composition; exercise intervention

**Disclosure of funding**: None

**Conflict of interest:** The authors declare no conflict of interest

## Abstract

**Background/Objectives:** Weight loss following exercise induced energy deficits is usually less than expected. The objective of this systematic review was to investigate predictors of energy compensation, which is defined as body energy changes (fat mass and fat-free mass) over the total amount of exercise energy expenditure (ExEE).

**Design:** The following databases were searched (Medline, Embase, Cochrane Central Register of Controlled Trials, Cinahl, SportsDiscuss and Physical Education Index) with no date limits applied. From the 4745 studies found, 71 were included in this systematic review, for a total of 1565 subjects.

**Results:** The overall mean energy compensation was 25±36%. The analyses indicated that 59% of the variance of energy compensation is explained from the interaction between FM, intensity and duration of the exercise intervention. Sex, frequency, and dose of ExEE were not significant predictors of energy compensation. The fitted model suggested that for shorter study duration, lower energy compensation was observed in individuals with excess body weight who exercise at higher intensity. In contrast, lower energy compensation was noted for lean individuals training at lower intensity. Longer duration (> 20 weeks) is accompanied by energy compensation that closely approaches 100%, irrespective of FM or the intensity of the exercise.

**Conclusion:** These results show lower energy compensation with short-term exercise intervention. In contrast, a much higher level of energy compensation accompanies long-term exercise interventions.

## Introduction

Obesity results from a long-term mismatch between the readily available energy-dense and palatable food energy and the low level of daily energy expenditure (EE) that characterizes our modern way of life[1]. In order to promote weight loss, diets over a short period of time lead to successful results[2], although weight lost is regained in 97% of the cases after dietary induced weight losses[2]. As far as exercise induced weight loss is concerned, it would seem that weight loss is often much less. Indeed, in a meta-analysis done in the late nineties it was reported that the impact of exercise on body weight changes is usually less than 2 to 3 kg of the initial body weight[3,4], a weight loss similar to that noted in more recent reviews and/or meta-analyses[5]. Since the observed weight loss is often much less than what could be anticipated from the dose of exercise, it implies that some form of energy compensation, *i.e.* increased energy intake (EI), decreased EE, or simply a lack of compliance to the prescribed exercise[6], is at play.

To examine the impact of exercise on body energy stores, body weight has often been the main target[7]. However, this variable does not take into account the individual and independent variation of fat-free mass (FFM) and fat mass (FM)[8]. Therefore body composition rather than body weight changes have to be investigated as a function of the exercise energy expenditure (ExEE) in order to allow a fair comparison between studies[8]. Accordingly, a relative measure (energy compensation) of the response to exercise that accounts for body composition changes as a function of ExEE has been used in a very limited number of studies[8]. However, the contribution of sex[9-12] and adiposity to energy compensation[13-16] remains contradictory and deserves more attention. Similarly, the effects of dose (kcal/wk)[8,17,18] and intensity of exercise[19,20] have not been clearly established as far as energy compensation in response to exercise is concerned. Finally, the frequency and duration of exercise intervention also need to be investigated to allow a better understanding of ExEE on energy compensation.

The purpose of this systematic review was to determine the energy compensation following an exercise intervention. The contribution of sex, duration, dose, frequency and intensity of exercise to energy compensation remains largely unknown. Therefore the independent contributions of all of these predictors as well as their interactions were investigated. It was hypothesized that exercise interventions would lead to positive energy compensation and that sex, intensity and the duration of the exercise would be the strongest predictors of energy compensation. More specifically, we proposed that women would show greater energy compensation when compared to men and that a longer duration of intervention and higher intensity would lead to higher energy compensation.

## Methods

### Search protocol

A literature search was performed in August 2013. The search strategy included a combination of key words and controlled vocabulary related to body weight and body composition changes across the intervention (*e.g.,* FM, FFM, maximal aerobic capacity ($VO_{2peak}$), ExEE and aerobic exercise) (**Figure 1**). The librarian performed a literature search using the following databases: Medline (Ovid MEDLINE(R) In-Process & Other Non-Indexed Citations and Ovid MEDLINE(R) 1946 to 2013 (OVID)), Embase (Embase Classic and Embase 1947 to 2013 august (OVID)), Cochrane Central Register of Controlled Trials September 2013 (OVID), Cinahl (Ebsco), SportsDiscuss (Ebsco) and Physical Education Index (Proquest). Filters listed in the exclusion criteria table were added to limit and specify the search. A detailed list of all inclusion and exclusion criteria for the search is presented in **Table 1.**

### Article selection process

From the search strategies, the title-screening phase was performed on a web portal. The screening procedure was carried out by two authors (MER and SJT). They independently decided whether the titles were accepted, rejected or unsure due to the absence of determining factors. Rejected titles from both authors were taken out of the pool of articles while accepted titles were kept for full article screening. The corresponding abstracts from titles marked with unsure were screened using the same method on a web portal. Rejected abstracts were similarly taken out of the pool of articles. Finally, a database with the full articles was created using an Excel sheet. The full articles were printed and the two authors separately revised all of them. When both authors rejected articles, the main reason was written on the paper and it was classified by reason of exclusion in order to keep a record of all excluded papers. Ambiguities in the paper (*e.g.,* impossibility of obtain ExEE, possibility of the use of a dietary intervention during the intervention) were discussed and validated with a third party (ED). Additional articles found from reviews and/or articles in bibliography were also added and fully revised (n=13). Throughout the screening process article duplicates were removed (n=43). The data extraction as well as the quality appraisal were performed in an alternating fashion by MER and SJT in an Excel database. Both authors contributed equally and revised each other's work. Inconsistencies between the reviewers were resolved by consensus.

**Synthesis process – Body composition, EE related to exercise and energy compensation**

Data from every eligible study was imported into an Excel spreasheet. Body composition (FM and FFM) changes were calculated by subtracting the pre-exercise from the post intervention values. ExEE was obtained directly from the text of the articles (ExEE per session or for overall study) or by through the following calculations, when all data were available:

$$Estimated\ EE\ (kcal) = \%VO_{2\,peak}\left(\frac{mL}{kg \cdot \min}\right) \cdot weight\ (kg) \cdot time\ (\min) \cdot \frac{1L}{1000mL} \cdot \frac{5\ kcal}{1LO_2}$$

Articles lacking ExEE, or the data needed to calculate ExEE as described above were excluded from this review (*e.g.,* no ExEE, no precise measure of EE or mention of % $FC_{max}$ only) (**Figure 2**).

Energy compensation was calculated from the ExEE (kcal) and body composition changes (kg transformed in kcal) over the course of the exercise intervention. As described by Rosenkilde *et al*., (2012)[8], the changes in body energy were calculated using the equivalents described by Forbes (1990), where a gain of 1 kg of FM corresponds to 12 000 kcal, while it corresponds to 1780 kcal for FFM[21]. On the other hand, a loss of 1 kg of FM corresponds to 9417 kcal while a loss of 1 kg of FFM corresponds to 884 kcal[22]. Energy compensation (%) was calculated using the following equation:

$$Compensation(\%) = \frac{100}{Energy\ Expenditure\ from\ Exercise(kcal)} \cdot \left[\left(Delta\ FM(kg) \cdot A(kcal)\right) + \left(Delta\ FFM(kg) \cdot B(kcal)\right)\right] + 100$$

$$\begin{aligned} &A: If\ \ Delta\ FM \geq 0 \Rightarrow 12000\ kcal \\ &\qquad\qquad\qquad\quad < 0 \Rightarrow 9417\ kcal \\ &B: If\ \ Delta\ FFM \geq 0 \Rightarrow 1780\ kcal \\ &\qquad\qquad\qquad\quad\ \ < 0 \Rightarrow 884\ kcal \end{aligned}$$

A compensation of 0% is indicative of the fact that body composition varied perfectly as a function of ExEE. In contrast, a compensation of 100% indicates that body composition remained the same despite ExEE.

**Statistical analysis**

Data are presented as a mean ± standard error. Statistical analyses were performed using SPSS software (version 21; SPSS Inc, Chicago, IL) and with R (version 3.0.1). Results were considered significant at $P < 0.05$. Studies included were weighted for number of participants in each study. One study was excluded because of the short period of the exercise intervention (2 weeks). Linear regressions were used to compare energy compensation between groups (sex and intensity) and to determine the association between energy compensation and the following predictors: FM, dose of exercise, duration of the intervention and frequency.

A general linear model with interactions was constructed to determine the significant predictors of energy compensation (%). Factors with fixed effects were sex, initial FM, initial BMI, intensity, frequency (sessions/wk), dose (kcal/wk) and duration of exercise intervention (wk). Initial FM, BMI, frequency, and dose of exercise as well as the duration of exercise intervention were entered into the model as continuous factors. Sex and intensity (two groups divided on the basis of exercise intensity lower/equal or higher than 60% of $VO_{2max}$ or heart rate[23]) were entered into the model as categorical factors. The variable intensity was divided into high and low because not all the studies provided accurate values of measured cardiorespiratory assessments. Random effects were attributable to the different studies.

Before the construction of the model, studies that included men and women but that did not provide independent results for each of the sexes were not included (n=17). Based on the energy compensation formula, we used the inverse of the frequency, dose and duration of exercise intervention to better fit the model. Because of variance inflation due to multicollinairity of the predictors, we used linear regressions to examine the association between the continuous predictors. Since initial FM and BMI were strongly associated (R-Squared=0.86; p<0.000), initial BMI was no further used in the model. Decision was mostly based on the fact that several missing data was noted for this variable and because FM is a more accurate measure of adiposity. Since the inclusion of second order terms such interaction terms and quadratic terms in the model can cause variance inflation due to multicollinearity, continuous predictors to include second order terms were standardized[24].

The model was initially fitted with a weighted least squares while considering the number of participants in each of the studies included in the analyses. The constancy of the weighted error variance was assessed with the Breush-Pagan test (Chi-Square(1)=6.82;p=0.009). Based on the significant study effect, an iterated weight least square was used to properly account for the variability in the error variance. The Breush-Pagan test was then non-significant (Chi-Square (1)=0.134; p=0.71), suggesting that proper accounting for the non-constancy of the error variance was achieved. The fit of the model was visually assessed with a Q-Q plot and a residual plot of the weighted residuals. The quadratic terms were dropped from the model since they were not significant (F(4,58)=0.84; p=0.50). The interaction terms were significant (F(15,62)=2.34; p=0.01). Neither sex (F(6,62)=1.65; p=0.1482) nor frequency (F(6,62)=1.25; p=0.30) nor dose (F(6,62)=1.29; p=0.28) were significant, thus they were not dropped from the model. Intervention duration (F(6,62)=3.39; p=0.006), intensity (F(6,62)=2.44; p=0.035) and FM (F(6,62)=3.54; p=0.005) were significant. The reduced interaction model was fitted with an iterated weighted least squares and was highly significant (F(8,76)=15.95; p<0.0001). The fit of the model was assessed with the Breush-Pagan test (Chi-Square(1)=0.002; p=0.88) and visually with a Q-Q plot and a residual plot of the weighted residuals.

## Results

The overall characteristics of the studies included in this review and the baseline characteristics of the participants are presented in **Table 1**. **Table 2** presents the characteristics of the intervention and **Table 3** presents the outcomes of the different studies. The risks of bias are also illustrated in **Figure 3**. This systematic review included a total of 89 studies. After close inspection, 18 studies from the 89 studies were excluded because they consisted of secondary data analysis. Therefore, 71 studies were included for the final analyses. The 71 studies were subdivided into 101 groups (*i.e.*, re-divided on the basis of sex, intensity), which included a total of 1565 subjects.

From the 71 studies, we were able to retrieve 84 groups that presented results for each sex (n=35 and 49 for male and female, respectively). Analyses revealed no significant difference in energy compensation between male and female (34±16% and 13±13%, respectively, ($p=0.30$)). When considering the intensity of the interventions, the analyses showed no significant difference for energy compensation between lower (15±11%) or higher intensity (29±18%) ($p=0.51$) (n=101 groups). To further investigate the relationship between continuous variables and the energy compensation, linear regressions were performed. A significant positive correlation between energy compensation and the duration of the exercise interventions was observed, suggesting that interventions performed over a longer period lead to higher energy compensation (R-Squared=0.11, $p<0.001$) (n=101 studies). FM was also significantly correlated to energy compensation (R-Squared=0.04, $p<0.05$) (n=101), suggesting that a higher FM is associated with lower energy compensation. Frequency

($p=0.21$) ($n=100$) and dose of exercise ($p=0.88$) ($n=101$) were not correlated with energy compensation.

We used a multiple linear regression model with interactions to describe energy compensation as a function of FM, intensity and duration of the exercise intervention. We fitted the model with iteratively reweighted least squares. The weighted coefficient of determination was 59% and the model was highly significant ($p<0.0001$). The third order interaction terms between the intensity of exercise, FM and duration of the exercise intervention were significant. To illustrate the validity of our model, **Figure 4** presents the fitted energy compensation obtained from our model in comparison to the energy compensation observed in studies considered in this review. As we focus in on a region of the graph with a few studies, it can be observed that the model does capture the general tendency of the observed energy compensation.

**Figure 5** illustrates energy compensation as the interaction between exercise intensity and the FM of individuals according to studies of different intervention duration. Overall, energy compensation is highly variable for interventions of shorter duration while it is near 100% for interventions of longer duration. For individuals with larger FM who perform exercise at a lower intensity, it is shown that energy compensation is maintained at about 85% independently of the intervention duration. The energy compensation is also similar for varying duration of the exercise intervention in individuals with smaller FM who engage in exercise participation at higher intensity (Energy compensation = 67%). There is a significant difference between these two groups in terms of energy compensation ($p<0.0001$). A hyperbolic relation was also observed for individuals training at higher intensity with higher FM and individuals training at lower intensity with smaller FM. The asymptote was higher for individuals with smaller FM and training at a lower intensity when compared to individuals with a higher FM and training at higher intensity ($p<0.0001$). The equations were respectively:

$$Energy compensation\ (\%) = 84.862 - 1164.944 / Duration$$

and

$$Energy compensation\ (\%) = 165.121 - 2431.212 / Duration$$

In order to describe energy compensation without dichotomizing FM (*i.e.,* low and high FM), the predicted energy compensation is illustrated in **Figure 6** as a function of exercise intensity, intervention duration and the FM of individuals. The values in the **Figure 6** are the predicted energy compensations. The model without the dichotomization of FM leads to similar observations as the model with the dichotomization of FM.

## Discussion

This systematic review aimed at determining the energy compensation following aerobic exercise interventions that did not include dietary modifications as part of the intervention. More specifically, the independent predictors of energy compensation and their interactions were investigated. Outcomes were obtained from 71 original publications published between 1980 and 2013. Energy compensation in all included studies was objectively determined based on ExEE and body composition changes. The resulting mean energy compensation for these studies was 25±36%. Fifty-nine percent of the variance in energy compensation was explained by interaction between FM, intensity and intervention duration. Our analyses also revealed that negative energy compensation induced through exercise seems to be present for short-term interventions, but tends to subside when exercise interventions are prolonged.

The results of the analyses suggested that for exercise intervention of shorter duration (approximately less than 20 weeks), a greater weight loss was achieved in individuals with higher adiposity who exercised at higher intensity. This review also highlighted that individuals with greater adiposity training at lower intensity and leaner individuals training at higher intensity presented an energy compensation of approximately 100% for exercise interventions of shorter duration. Although, the effects of adiposity[13-16] and the intensity of the intervention[19,20] on energy compensation have been separately investigated, the findings of the possible association between FM, intensity and duration of the exercise intervention on energy compensation is a novel contribution of this paper and warrants further investigation.

The explanation as to why a longer period of exercise intervention would lead to higher energy compensation is intriguing. It could be speculated that the energy compensation is explained by an increase in fatigue or a decrease in non-structured physical activity (NSPA) over time[25-28]. Conversely, as fitness increases, it could also be speculated that the same exercise would be less tiring. Moreover, it is also possible that a longer exercise intervention would increase hunger, which would ultimately lead to a higher EI[29-31]. Nevertheless, since we did not have access to EI or EE for the majority of these studies (*i.e.,* EI and EE available in only two over 101 groups), it is impossible to determine to what extent these factors contributed to these observations. Therefore, the specific role of the modifications of EI and EE in response to long-term exercise interventions, likely needs to be more closely inspected to ascertain their respective contribution to energy compensation.

Our analyses suggested that neither sex, frequency, or the dose of the exercise contributed to the variance in energy compensation. It has been suggested that following exercise, energy compensation would be greater in women[10]. However, the results from this systematic review are rather in line with the results proposed by Caudwell *et al.,*[11] and McTiernan *et al.,*[12], as their results suggested that exercise-induced weight loss is similar between men and women as long as ExEE is equivalent between groups. Additionally, the results of this systematic review show that energy compensation does not vary as a function of the frequency and/or the dose of ExEE. Nevertheless, it is not impossible that the small amount of weight loss following exercise intervention shown by Thomas *et al*. in 2012[32] in their systematic review could be caused by the small dose of ExEE.

This systematic review is limited to an adult population and cannot be extended to youth or elderly individuals. Individuals included in the different studies were not all sedentary and not all papers mentioned a stable body weight as an inclusion criterion. Moreover, only 58 studies over 71 were randomised controlled trials. ExEE was either provided in the articles or was calculated from available data. When calculated, it was assumed that for each exercise session the energy cost was 5kcal/$LO_2$. As well, the compendium of physical activities (2011) was used to estimate the ExEE when needed, which could have under/overestimated the ExEE in some cases. As for the training, not all sessions were performed under supervision and the compliance was for most of the studies not reported. For example, it is possible to speculate that not all exercise sessions lasted for the same amount of time throughout the intervention, reducing the total amount of ExEE, and thus inflating the energy compensation. The different methods used to measure body composition could have also influenced the results due to their varying degree of accuracy. In addition, the possibility that some participants included in the different studies might have followed a diet throughout the intervention cannot be excluded. Finally, the dichotomisation of the variable intensity could have introduced a bias. However, only considering the studies that reported the intensity of the exercise based on $VO_{2peak}$ would have reduced the number of groups included (N=54/101).

In conclusion, results from this systematic review show that FM, exercise intensity and the duration of the intervention are the most significant predictors of energy compensation. The current findings demonstrate that when negative energy compensation is achieved with ExEE, it can only be maintained over a relatively short time-span. In contrast, longer-term exercise interventions are accompanied by levels of energy compensation that hover around

100%, which could be related to more potent compensatory mechanisms that oppose the decrease of body energy stores. In order to fully comprehend exercise-induced energy compensation, future studies should include accurate determinations of EI and EE throughout the studies design.

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**Table 1 -** Criteria of included and excluded items for study selection

| Criteria | Included | Excluded |
| --- | --- | --- |
| Population | Men and Women<br>Aged from 18-55 years old<br>Any BMI<br>Women with period on a regular basis<br>Healthy individual | Under 18 or over 55 years old<br>Menopausal women<br>Illness (Type 2 diabetes, hypertension, cancer, hyperinsuliminemia)<br>Athletes or military<br>Smoker, drinker (>2 drinks/day) or individual with drug abuse<br>Under medication |
| Focus/Intervention | Aerobic training<br>Interval training<br>Any intervention time<br>Any intervention duration | Yoga<br>Stretching program<br>Resistance training/callisthenic exercise<br>Animal intervention<br>Diet, caloric restriction and dietary or vitamin supplement<br>Nutrition or cognitive counselling<br>Intervention that aim to maintain or increasing NSPA |
| Outcomes | Body weight<br>FFM<br>FM<br>EE<br>$VO_{2max}$ reserve<br>Maximal heart rate reserve | Maximal heart rate |
| Study design | RCTs<br>Pre & Post test design<br>Interrupted time series | |
| Language | English<br>French | Other languages |
| Publication status | Published articles (included all years) | Unpublished articles<br>Undergoing publication process<br>Abstract only available |

## **Table 2 -** Baseline participants characteristics of included studies (N=71)

| Studies | Studies characteristics | | | *n* | Participants characteristics at baseline | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| First authors | Years | Country | Group design | Inclusion | Sex | Seden-tary | Stable body weight | $VO_{2peak}$ (ml/kg/min) | Age (yr) | BMI (kg/m²) | Weight (kg) | FM (%) |
| Abderrahman[33] | 2013 | France | RCT | 9 | male | No | N/A | 59.0 ± 9.0 | 21.1 ± 1.0 | 23.9 ± N/A | 76.8 ± 10.9 (9) | 10.6 ± 3.4 (9) |
| Abe[34] | 1997 | Japan | RCT | 9 | female | Yes | N/A | N/A | 19-23 | N/A | 54.5 ± 4.9 (9) | 28.0 ± 3.2 (9) |
| Blaney[35] | 1991 | USA | Before-after | 7 | male | Yes | N/A | 32.4 ± N/A | 42.0 ± 6.0 | N/A | 91.0 ± 15.0 (7) | 28.0 ± 4 (7) |
| Bourque[36] | 1997 | USA | RCT + ITS | 6 | female | Yes | N/A | 32.5 ± 6.3 | 32.0 ± 7.0 | 21.7 ± 3.5 | 58.0 ± 10.0 (6) | 24.0 ± 8.0 (6) |
| Bourque[36] | 1997 | USA | RCT + ITS | 8 | female | Yes | N/A | 36.2 ± 4.8 | 33.0 ± 4.0 | 23.1 ± 3.1 | 62.0 ± 9.0 (8) | 28.0 ± 7.0 (8) |
| Brandon[37] | 2006 | USA | RCT | 28 | female | Yes | Yes | 32.0 ± N/A | 37.3 ± N/A | 32.0 ± N/A | 85.6 ± N/A (28) | 45.0 ± N/A (28) |
| Broeder[38] | 1992 | USA | RCT | 22 | male | N/A | Yes | 49.6 ± 2.2 | 18-35 | 25.1 ± 1.1 | 79.0 ± 3.8(15) | 18.5 ± 1.9 (15) |
| Carter[39] | 2001 | Canada | Before-after | 8 | male | N/A | N/A | 41.5 ± 6.7 | 22.0 ± 1.0 | 25.0 ± N/A | 78.1 ± 7.2 (8) | 16.1 ± 3.9 (8) |
| Carter[39] | 2001 | Canada | Before-after | 8 | female | N/A | N/A | 31.9 ± 3.9 | 22.0 ± 2.0 | 25.0 ± N/A | 68.2 ± 7.0 (8) | 26.1 ± 2.6 (8) |
| Caudwell[11, 1] | 2013 | UK | ITS | 35 | male | Yes | Yes | 34.9 ± 6.9 | 41.3 ± 8.6 | 30.5 ± 8.6 | 96.9 ± 13.2 (35) | 33.8 ± 6.6 (35) |
| Caudwell[11, 1] | 2013 | UK | ITS | 72 | female | Yes | Yes | 29.1 ± 6.5 | 40.6 ± 9.5 | 31.8 ± 4.3 | 85.9 ± 11.5 (72) | 44.1 ± 6.0 (72) |
| Cowan[40] | 1985 | USA | RCT | 16 | female | Yes | N/A | N/A | 41.3 ± 4.4 | 25.2 ± N/A | 67.5 ± 11.2 (16) | 31.6 ± N/A (16) |
| Cramer[41] | 1991 | USA | RCT | 25 | female | N/A | N/A | 25.7 ± 0.9 | 36.0 ± 1.6 | 28.3 ± 0.7 | 76.5 ± 1.9 (18) | 36.5 ± 1.1 (18) |
| Dalleck[42] | 2008 | USA | Before-after | 23 | female | Yes | N/A | 34.8 ± 5.8 | 37.4 ± 6.3 | 26.1 ± 3.9 | 72.1 ± 11.2 (15) | 32.5 ± 5.8 (15) |
| Després[43] | 1991 | Canada | Before-after | 13 | female | N/A | N/A | 24.3 ± N/A | 38.8 ± 5.3 | 34.5 ± 4.3 | 90.0 ± 11.8 (13) | 47.0 ± 5.5 (13) |
| Dickson-Parnell[44] | 1985 | USA | I ITS | 12 | female | Yes | N/A | N/A | 23.6 ± N/A | N/A | 59.3 ± 10.2 (11) | 25.2 ± 0.7 (11) |
| Dickson-Parnell[44] | 1985 | USA | ITS | 12 | female | Yes | N/A | N/A | 23.6 ± N/A | N/A | 65.1 ± 15.5 (11) | 25.6 ± 0.6 (11) |
| Donnelly[45] | 2000 | USA | ITS | 11 | female | Yes | N/A | 23.6 ± 2.8 | 54.0 ± 9.0 | 30.1 ± 2.5 | 81.4 ± 5.7 (11) | 41.8 ± 3.4 (11) |
| Donnelly[45] | 2000 | USA | ITS | 11 | female | Yes | N/A | 22.9 ± 4.1 | 49.0 ± 8.0 | 32.3 ± 5.1 | 85.9 ± 13.1 (11) | 42.6 ± 4.1 (11) |
| Donnelly[46] | 2013 | USA | RCT | 32 | female | N/A | N/A | 31.6 ± 3.8 | 22.6 ± 3.2 | 29.1 ± 3.8 | 81.3 ± 13 (18) | 43.5 ± 5.7 (18) |
| Donnelly[46] | 2013 | USA | RCT | 31 | female | N/A | N/A | 29.8 ± 4.1 | 22.6 ± 2.9 | 30.4 ± 5.6 | 83.3 ± 18.9 (19) | 43.6 ± 5.8 (19) |
| Donnelly[46] | 2013 | USA | RCT | 30 | male | N/A | N/A | 36.4 ± 6.4 | 23.3 ± 3.7 | 32.1 ± 3.5 | 102. 0 ± 11.7 (19) | 37.0 ± 5.0 (19) |
| Donnelly[46] | 2013 | USA | RCT | 22 | male | N/A | N/A | 37.1 ± 6.5 | 23.5 ± 3.2 | 32.0 ± 5.5 | 99.9 ± 19.4 (18) | 35.4 ± 6.8 (18) |
| Dowdy[47] | 1985 | USA | Before-after | 18 | female | Yes | N/A | 33.8 ± 3.9 | 31.5 ± 5.6 | 22.8 ± N/A | 63.4 ± 7.2 (18) | 30.1 ± 7.0 (18) |
| Duncan[48] | 1991 | USA | RCT | 29 | female | Yes | N/A | 30.6 ± 3.9 | 20-40 | 22.6 ± N/A | 60.3 ± 9.5 (16) | 27.5 ± 7.6 (16) |
| Duncan[48] | 1991 | USA | RCT | 26 | female | Yes | N/A | 32.4 ± 6.1 | 20-40 | 23.6 ± N/A | 64.2 ± 3.8 (12) | 26.2 ± 6.6 (12) |
| Duncan[48] | 1991 | USA | RCT | 26 | female | Yes | N/A | 31.8 ± 6.9 | 20-40 | 22.8 ± N/A | 62.0 ± 9.8 (18) | 27.9 ± 6.0 (18) |
| Durstine[49] | 1990 | USA | RCT | 10 | male | N/A | N/A | 50.3 ± 2.1 | 21.9 ± 1.2 | 22.9 ± N/A | 70.4 ± 1.8 (10) | 9.3 ± 1.1 (10) |
| Earnest[50, 2] | 2013 | USA | Before-after | 21 | male | Yes | N/A | 29.5 ± 2.9 | 48.0 ± 9.0 | 30.4 ± 2.3 | 93.9 ± 9.6 (21) | 29.2 ± N/A (21) |
| Earnest[50] | 2013 | USA | Before-after | 21 | male | Yes | N/A | 28.3 ± 4.5 | 49.0 ± 9.0 | 31.4 ± 3.4 | 98.9 ± 12.7 (16) | 28.8 ± N/A (16) |
| Glisezinski[51] | 2003 | France | Before-after | 11 | male | N/A | Yes | 34.3 ± 1.3 | 25.6 ± 1.4 | 27.7 ± 0.2 | 89.5 ± 1.6 (11) | 22.8 ± 0.9 (11) |
| Glowacki[52] | 2004 | USA | RCT + ITS | N/A | male | Yes | N/A | 40.8 ± 9.0 | 25.0 ± 5.0 | 27.7 ± N/A | 87.9 ± 16.6 (12) | 20.5 ± 9.7 (12) |
| Grandjean[53] | 1996 | USA | RCT | 20 | female | Yes | N/A | 28.4 ± 5.9[8] | N/A | N/A | 66.2 ± 13.5 (20) | 27.6 ± 6.5 (20) |
| Grediagin[19] | 1995 | USA | Before-after | 9 | female | Yes | Yes | 31.5 ± 3.8 | 30.0 ± 5.0 | 23.8 ± 2.3 | 68.2 ± 5.9 (6) | 31.1 ± 3.8 (6) |
| Grediagin[19] | 1995 | USA | Before-after | 9 | female | Yes | Yes | 31.3 ± 3.3 | 31.0 ± 6.0 | 26.2 ± 1.4 | 68.6 ± 4.6 (6) | 31.0 ± 4.8 (6) |
| Greene[54] | 2009 | USA | Before-after | N/A | Both | Yes | N/A | 27.3 ± 1.2 | 43.0 ± 2.0 | 30.7 ± 1.0 | 89.6 ± 3.4 (29) | 37.8 ± N/A (29) |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Greene[54] | 2009 | USA) | Before-after | N/A | Both | Yes | N/A | 26.9 ± 1.2 | 45.0 ± 2.0 | 30.4 ± 0.9 | 90.3 ± 3.4 (28) | 37.3 ± N/A (28) |
| Gormley[55] | 2008 | USA | RCT | 61 | Both | N/A | N/A | 35.3 ± 7.9 | 23.0 ± 4.0 | 24.0 ± 3.3 | 67.4 ± 11.7 (14) | 21.5 ± 5.5 (14) |
| Gormley[55] | 2008 | USA | RCT | 61 | Both | N/A | N/A | 33.6 ± 9.0 | 22.0 ± 4.0 | 25.4 ± 5.1 | 71.9 ± 14.7 (15) | 20.9 ± 10.5 (15) |
| Gormley[55] | 2008 | USA | RCT | 61 | Both | N/A | N/A | 35.7 ± 6.2 | 21.0 ± 1.0 | 23.8 ± 3.4 | 67.6 ± 13.9 (13) | 16.7 ± 5.7 (13) |
| Hardman[56] | 1992 | England | ITS | 34 | female | Yes | N/A | N/A | 44.9 ± 1.5 | 23.9 ± 0.6 | 64.0 ± 1.7 (28) | 36.1 ± 1.4 (28) |
| Hass[57] | 2001 | USA | RCT + ITS | 23 | Both | Yes | N/A | 25.7 ± 3.2 | 49.0 ± 5.8 | 28.1 ± N/A | 81.3 ± 14.0 (17) | 31.5 ± 6.0 (17) |
| Hinkleman[58] | 1993 | USA | RCT | 25 | female | N/A | N/A | 25.7 ± 0.9 | 36.0 ± 1.6 | 28.3 ± 0.7 | 76.5 ± N/A (18) | 36.5 ± 1.1 (18) |
| Hottenrott[59] | 2012 | Germany | Before-after | 17 | Both | No | N/A | 38.8 ± 5.0 | 44.7 ± N/A | 23.7 ± N/A | 70.5 ± 9.8 (16) | 22.4 ± 6.3 (16) |
| Joubert[60] | 2011 | USA | Before-after | 20 | Both | N/A | N/A | 39.9 ± 10.7 | 23.7 ± 6.3 | 24.9 ± 5.9 | 74.8 ± 20.3 (20) | 21.4 ± 11.0 (20) |
| Juneau[61] | 1987 | USA | RCT | 30 | male | Yes | N/A | 31.9 ± 4.4 | 49.0 ± 6.0 | N/A | 79.4 ± 11.0 (28) | 22.0 ± 4.0 (28) |
| Juneau[61] | 1987 | USA | RCT | 30 | female | Yes | N/A | 25.8 ± 3.9 | 47.0 ± 5.0 | N/A | 63.8 ± 8.0 (24) | 27.0 ± 7.0 (24) |
| Kirk[62] | 2003 | USA | RCT | N/A | female | Yes | N/A | 32.8 ± 4.2 | 24.0 ± 5.0 | 28.7 ± 3.2 | 77.0 ± 11.4 (25) | 35.3 ± 4.6 (25) |
| Kirk[62] | 2003 | USA | RCT | N/A | male | Yes | N/A | 39.2 ± 5.2 | 22.0 ± 4.0 | 29.7 ± 2.9 | 94.0 ± 12.6 (16) | 28.3 ± 4.6 (16) |
| Krustrup[63] | 2010 | Denmark | RCT | 25 | female | Yes | N/A | 32.7 ± 1.1 | 37.0 ± 2.0 | 25.0 ± 0.9 | 71.6 ± 2.3 (21) | 35.8 ± 1.2 (21) |
| Krustrup[63] | 2010 | Denmark | RCT | 25 | female | Yes | N/A | 35.5 ± 1.4 | 37.0 ± 1.0 | 23.7 ± 0.7 | 67.1 ± 1.8 (17) | 32.6 ± 1.7 (17) |
| Krustrup[64] | 2009 | Denmark | RCT | 13 | male | Yes | N/A | 39.6 ± 1.5 | 30.0 ± 2.0 | 24.9 ± 0.8 | 82.2 ± 2.9 (12) | 24.9 ± 2.3 (12) |
| Krustrup[64] | 2009 | Denmark | RCT | 12 | male | Yes | N/A | 39.3 ± 2.5 | 31.0 ± 2.0 | 26.2 ± 1.5 | 85.8 ± 5.5 (10) | 24.3 ± 1.6 (10) |
| Lee[65] | 2009 | USA | RCT | 10 | male | N/A | Yes | 46.2 ± 1.2 | 26.2 ± 1.4 | 24.2 ± N/A | 73.8 ± 2.1 (9) | 16.4 ± 1.7 (9) |
| Lee[66] | 2013 | Korea | Before-after | 98 | female | Yes | N/A | 25.5 ± 0.9 | 47.0 ± 5.1 | 26.8 ± 0.4 | 65.7 ± 1.0 (90) | 34.2 ± 0.6 (90) |
| Lee[67] | 2012 | Korea | RCT | N/A | female | N/A | N/A | 26.3 ± 2.8 | 41.6 ± 4.5 | 27.4 ± 2.7 | 67.3 ± 5.3 (8) | 35.8 ± 4.1 (8) |
| Lee[67] | 2012 | Korea | RCT | N/A | female | N/A | N/A | 28.3 ± 3.1 | 41.7 ± 4.3 | 25.4 ± 2.7 | 65.2 ± 6.7 (7) | 33.4 ± 1.9 (7) |
| Macpherson[68] | 2011 | Canada | Before-after | 10 | Both | No | N/A | 44.0 ± 5.1 | 22.8 ± 3.1 | 24.2 ± N/A | 68.8 ± 9.5 (10) | 20.8 ± 9.7 (10) |
| McCarthy[69] | 1995 | USA | Before-after | 10 | male | Yes | N/A | 41.4 ± 2.6 | 26.5 ± 1.6 | N/A | 84.5 ± 5.5 (10) | 20.4 ± 2.3 (10) |
| Mogensen[70] | 2009 | Denmark | Before-after | 14 | male | N/A | N/A | 29.0 ± 1.7 | 53.6 ± 1.8 | 33.2 ± 0.8 | 111.0 ± 4.0 (11) | 32.4 ± N/A (10) |
| Moghadasi[71] | 2012 | Iran | RCT | 8 | male | Yes | N/A | 32.1 ± 3.6 | N/A | 31.0 ± 2.1 | 87.9 ± 8.5 (8) | 29.6 ± 3.1 (8) |
| Moro[72] | 2005 | France | Before-after | 10 | male | N/A | Yes | 34.7 ± 1.2 | 26.0 ± 1.4 | 27.6 ± 0.2 | 90.3 ± 1.6 (10) | 22.4 ± 0.8 (10) |
| Mougios[20] | 2006 | Greece | Before-after | 7 | female | Yes | Yes | 36.6 ± 3.8 | 30.0 ± 9.0 | 24.6 ± 1.7 | 64.1 ± 6.3 (7) | 33.0 ± 3.3 (7) |
| Mougios[20] | 2006 | Greece | Before-after | 7 | female | Yes | Yes | 34.0 ± 5.6 | 31.0 ± 9.0 | 24.8 ± 2.3 | 68.7 ± 8.7 (7) | 33.2 ± 4.6 (7) |
| Murtagh[73] | 2005 | UK | RCT | 19 | Both | Yes | N/A | N/A | N/A | N/A | 74.2 ± 14.3 (15) | 26.9 ± 7.6 (15) |
| Murtagh[73] | 2005 | UK | RCT | 18 | Both | Yes | N/A | N/A | N/A | N/A | 74.6 ± 12.0 (9) | 28 ± 5.9 (9) |
| Nielsen[74] | 1993 | Denmark | Before-after | 6 | Both | N/A | N/A | 30.6 ± N/A | 25.1 ± 1.3 | 32.6 ± N/A | 96.4 ± 14.3[7] (6) | 37.4 ± 5.5[7] (6) |
| Nielsen[74] | 1993 | Denmark | Before-after | 6 | Both | N/A | N/A | 45.2 ± N/A | 28.1 ± 1.3 | 22.7 ± N/A | 67 ± 8[7] (6) | 16.6 ± 3.3[7] (6) |
| Nishida[75] | 2010 | Japan | Before-after | 6 | male | Yes | N/A | 41.3 ± 2.0 | 24.5 ± 1.9 | 22.0 ± 1.3 | 66.4 ± 3.5 (6) | 13.7 ± 2.1 (6) |
| Nordby[76 3] | 2012 | Denmark | RCT | 17 | male | Yes | Yes | 38.2 ± 1.7 | 28.0 ± 1.0 | 28.3 ± 0.3 | 94.5 ± 2.3 (12) | 31.3 ± 1.3 (12) |
| Nybo[77] | 2010 | Danemark | Before-after | 9 | male | Yes | N/A | 39.3 ± 2.5 | 31.0 ± 2.0 | N/A | 85.8 ± 5.5 (9) | 24.3 ± 1.6 (9) |
| Pagels[78] | 2012 | Sweden | RCT | 19 | Both | Not all | N/A | N/A | 40.0 ± 4.4 | 26.2 ± 4.4 | 79.1 ± 13.8 (16) | 29.6 ± 7.1 (16) |
| Polak[79] | 2006 | Czech republic | Before-after | 25 | female | Yes | Yes | 24.6 ± 3.9 | 40.4 ± 6.7 | 32.2 ± 2.2 | 88.5 ± 8.2 (25) | 38.8 ± 4.2 (25) |
| Prud'homme[80] | 1984 | Canada | Before-after | 20 | Both | N/A | N/A | 44.2 ± 6.0 | 20.0 ± 2.9 | N/A | 56.8 ± 10.5 (20) | 12.2 ± N/A (20) |
| Rajaram[81] | 1995 | US | RCT | N/A | female | Yes | N/A | 33.1 ± 3.1 | 19.2 ± 1.1 | 23.0 ± N/A | 58.3 ± 9.5 (13) | 25.4 ± 4.9 (13) |
| Revan[82] | 2011 | Turkey | RCT | 12 | male | Yes | N/A | 51.8 ± 1.3 | N/A | 23.4 ± 0.6 | 73.1 ± 2.1 (12) | 12.7 ± 0.7 (12) |
| Ring-Dimitriou[83] | 2007 | Austria | RCT | 26 | Both | Yes | N/A | 35.9 ± 4.3 | 39.7 ± 3.4 | 24.5 ± 4.2 | 72.5 ± 13.7 (20) | 24.2 ± 6.6 (20) |
| Rosenkilde[8 4] | 2012 | Copenhagen | RCT | 21 | male | Yes | Yes | 34.6 ± 4.1 | 30.0 ± 7.0 | 28.6 ± 1.8 | 93.2 ± 8.1 (18) | 32.2 ± N/A (18) |
| Rosenkilde[8 4] | 2012 | Copenhagen | RCT | 22 | male | Yes | Yes | 36.2 ± 5.3 | 28.0 ± 5.0 | 27.6 ± 1.4 | 91.3 ± 7.2 (18) | 30.0 ± N/A (18) |
| Ruby[84] | 1996 | USA | Before-after | 6 | female | Yes | N/A | 39.9 ± 1.2[8] | 20.3 ± 0.9 | 22.7 ± N/A | 58.2 ± 3.3 (6) | 20.6 ± 2.2 (6) |
| Ruby[84] | 1996 | USA | Before-after | 6 | female | Yes | N/A | 33.6 ± 0.2[8] | 20.5 ± 1.0 | 22.5 ± N/A | 61.6 ± 3.6 (6) | 23.5 ± 1.8 (6) |
| Ruby[84] | 1996 | USA | Before-after | 6 | female | Yes | N/A | 36.8 ± 1.4[8] | 21.3 ± 0.6 | 22.6 ± N/A | 62.4 ± 3.0 (6) | 28.0 ± 3.1 (6) |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Santiago[85] | 1995 | USA | RCT | 21 | female | Yes | N/A | 31.5 ± 4.2 | 30.1 ± 5.3 | 24.6 ± 3.8 | 64.4 ± 10.2 (16) | 28.6 ± 6.3 (16) |
| Scharhag-Rosenberger[86] | 2010 | Germany | Before-after | 25 | Both | Yes | N/A | 37.5 ± 4.7 | 42.0 ± 5.0 | 24.6 ± 2.2 | 72.9 ± 13.4 (17) | 30.4 ± 5.2 (17) |
| Sedlock[87] | 2010 | USA | RCT | 10 | male | N/A | Yes | 46.2 ± 1.2 | 26.2 ± 1.4 | 24.2 ± N/A | 73.8 ± 2.1 (9) | 16.4 ± 1.7 (9) |
| Sijie[88] | 2012 | China | RCT | 20 | female | N/A | N/A | 33.3 ± 3.9 | 19.8 ± 1.0 | 27.7 ± 1.9 | 73.7 ± 7.5 (17) | 40.6 ± 4.0 (17) |
| Sijie[88] | 2012 | China | RCT | 20 | female | N/A | N/A | 32.9 ± 4.7 | 19.3 ± 0.7 | 28.3 ± 2.0 | 74.2 ± 9.0 (16) | 41.1 ± 4.2 (16) |
| Snyder[89] | 1997 | USA | Before-after | 15 | female | Yes | Yes | 24.0 ± 4.6 | 43.0 ± 11.0 | 32.5 ± 8.0 | 87.2 ± 21.5 (13) | 40.6 ± 8.8 (13) |
| Stensel[90] | 1994 | UK | RCT + ITS | 48 | male | Yes | N/A | N/A | 50.3 ± 0.8 | 25.4 ± 0.4 | 79.3 ± 1.5 (42) | 28.7 ± 0.8 (42) |
| Suter[91] | 1995 | Switzerland | Before-after | 20 | male | Yes | N/A | 39.3 ± 5.5 | 39.1 ± 8.3 | 24.3 ± N/A | 75.6 ± 9.8 (12) | N/A |
| Szmedra[92] | 1998 | USA | Before-after | 10 | female | Yes | N/A | 28.3 ± 1.4 | 21.0 ± 0.8 | 29.7 ± 9.1 | 76.8 ± 12.5 (7) | 33.0 ± 4.0 (7) |
| Tan[93] | 2012 | China | RCT | 30 | female | Yes | N/A | 34.1 ± 2.6 | 20-23 | 27.5 ± 1.9 | 70.4 ± 5.3 (29) | 43.9 ± 5.7 (29) |
| Trapp[94] | 2008 | Australia | RCT | 15 | female | Yes | N/A | 28.8 ± 2.1 | 22.4 ± 0.7 | 24.4 ± 1.5 | 63.3 ± 3.8 (11) | 35.1 ± 2.7 (11) |
| Trapp[94] | 2008 | Australia | RCT | 15 | female | Yes | N/A | 30.9 ± 2.1 | 21.0 ± 0.8 | 22.4 ± 1.0 | 59.8 ± 2.4 (8) | 31.7 ± 3.0 (8) |
| Van Aggel-Leijssen[95] | 2002 | Netherlands | RCT | 8 | male | Yes | Yes | 31.1 ± N/A | 43.4 ± 6.3 | 31.6 ± 3.1 | 102.7 ± 10.8 (8) | 31.9 ± 2.4 (8) |
| Van Aggel-Leijssen[95] | 2002 | Netherlands | RCT | 8 | male | Yes | Yes | 31.4 ± N/A | 40.0 ± 6.3 | 32.2 ± 1.6 | 105.5 ± 6.6 (8) | 31.3 ± 4.3 (8) |
| Van Aggel-Leijssen[96] | 2001 | Netherlands | Before-after | 8 | female | Yes | Yes | 24.7 ± N/A | 32.8 ± 9.6 | 32.8[5] ± 3.9 | 91.2 ± 9.7 (8) | 45.0 ± 4.4 (8) |
| Van Aggel-Leijssen[96] | 2001 | Netherlands | RCT | 7 | female | Yes | Yes | 24.6 ± N/A | 37.7 ± 6.4 | 32.1[6] ± 2.9 | 86.5 ± 10.2 (7) | 42.6 ± 3.1 (7) |
| Weltman[97] | 1980 | USA | Before-after | 11 | male | Yes | N/A | N/A | N/A | N/A | 75.9 ± 11.4 (11) | 22.6 ± 4.7 (11) |
| Wilmore[98] | 1980 | USA | RCT | 9 | male | Yes | N/A | 38.6 ± N/A | 37.0 ± 8.9 | 26.7 ± N/A | 85.7 ± 18.9 (9) | 21.2 ± N/A (9) |
| Wilmore[98] | 1980 | USA | RCT | 9 | male | Yes | N/A | 42.2 ± N/A | 35.6 ± 8.3 | 25.6 ± N/A | 79.8 ± 8.9 (9) | 19.8 ± N/A (9) |

The value are mean ± SD or presented as a range
The number in parentheses represents the number of participants tested
RCT, randomised controlled trial; ITS, Interrupted time series
[1] Trial registration: ISRCTN47291569
[2] Trial registration: PBRC29018
[3] Trial registration: NCT01090869
[4] Trial registration: NCT01430143
[5] Lower body obesity
[6] Upper body obesity
[7] SD was estimated from the difference of the range divided by 4
[8] SD was calculated from the SD obtained in L/min and multiplying by 1000 and dividing by the weight at baseline

**Table 3 -** Characteristics of the interventions and outcomes (N=71)

| Studies | Interventions characteristics | | | | Outcomes of the interventions | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| First author, year | Super-vised | Com-pliance (%) | Exercise intervention | Measure of BC | FM (initial) (Kg) | FM (Final) (Kg) | FFM (initial) (Kg) | FFM (Final) (Kg) | ExEE Total (kcal) | Compen-sation (%) |
| Abderrahman 2013 | Yes | N/A | 3x/wk during 7 wks of running interval at 110, 100 and 50% of maximal aerobic velocity | SK | 8.1 ± N/A (9) | 8.3 ± N/A (9) | 68.4 ± 7.8 (9) | 68.7 ± 7.2 (9) | 6483 | 147 |
| Abe 1997 | Yes | N/A | 2.8x/wk for 30 min during 13 wks of continuous bike at 50-60% $HRR_{max}$ | HW | 15.3 ± 2.7 (9) | 12.7 ± 2.1 (9) | 39.2 ± 3.3 (9) | 38.5 ± 3.4 (9) | 7280 | -245 |
| Blaney 1991 | No | N/A | 3x/wk for 28 min during 16 wks of continuous run/walk at 70-80% $VO_{2max}$ | HW | 25.5 ± N/A (7) | 23.7 ± N/A (7) | 65.0 ± 10.0 (7) | 67.0 ± 10.0 (7) | 16131 | 14 |
| Bourque 1997 | Not always | 81%[2] | 3.5x/wk for 40 minutes during 12 wks of continuous bike at 80% $VO_{2max}$ | SK | 13.9 ± N/A (6) | 13.9 ± N/A (6) | 44.1 ± N/A (6) | 44.1 ± N/A (6) | 11931 | 100 |
| Bourque 1997 | Not always | 81%[2] | 3.5x/wk for 33 minutes during 12 wks of continuous run/walk at 80% $VO_{2max}$ | SK | 17.4 ± N/A (8) | 17.0 ± N/A (8) | 44.6 ± N/A (8) | 46.0 ± N/A (8) | 12432 | 93 |
| Brandon 2006 | No | 87.6 | 3x/wk for 50 min during 18 wks of continuous brisk walk at a self pace with an objective of 3.5 mph | DEXA | 38.5 ± N/A (28) | 36.1 ± N/A (28) | 47.1 ± N/A (28) | 47.6 ± N/A (28) | 17521 | -24 |
| Broeder 1992 | Yes | ≥ 90% | 4x/wk for 40 min (first 4 wks) and 50 min (last 8 wks) of continuous run/walk at 70% (first 4 wks) and 78% (last 8 wks) $VO_{2peak}$ | HW | 14.6 ± 2.0 (15) | 13.2 ± 1.7 (15) | 64.4 ± 2.3 (15) | 64.7 ± 2.2 (15) | 35141 | 64 |
| Carter 2001 | No | N/A | 5x/wk for 60 min during 7 wks of continuous bike at 60% $VO_{2peak}$ | DEXA | 12.2 ± N/A (8) | 11.8 ± N/A (8) | 65.9 ± 7.1 (8) | 66.0 ± 6.6 (8) | 22191 | 84 |
| Carter 2001 | No | N/A | 5x/wk for 60 min during 7 wks of continuous bike at 60% $VO_{2peak}$ | DEXA | 17.9 ± N/A (8) | 17.2 ± N/A (8) | 50.3± 4.2 (8) | 50.3 ± 4.1 (8) | 15769 | 58 |
| Caudwell 2013 | Yes | N/A | 5x/wk during 12 wks of continuous walk/bike/run/oar /stepping machine at 70% $HR_{max}$ | BI | 33.2 ± 10.4 (35) | 30.1 ± N/A (35) | 63.4 ± 6.5 (35) | 63.5 ± N/A (35) | 29339 | 0 |
| Caudwell 2013 | Yes | N/A | 5x/wk during 12 wks of continuous walk/bike/run/oar/stepping machine at 70% $HR_{max}$ | BI | 38.3 ± 9.0 (72) | 35.3 ± N/A (72) | 47.7 ± 5.8 (72) | 48.3 ± N/A (72) | 27547 | 1 |
| Cowan 1985 | No | 93.75 | 4x/wk for 17-44 min during 9 wks of continuous walk at 80% aged predicted $HR_{max}$ | HW | 21.9 ± N/A (16) | 21.2 ± N/A (16) | 45.6 ± N/A (16) | 46.3 ± N/A (16) | 6001 | 11 |
| Cramer 1991 | Yes | 100 | 5x/wk for 45 min during 15 wks of continuous walk/bike at 62% $VO_{2max}$ | HW | 27.9 ± N/A (18) | 27.8 ± N/A (18) | 48.6 ± N/A (18) | 48.7 ± N/A (18) | 20810 | 94 |
| Dalleck 2008 | Not always | 100 | 3.4x/wk for 181 min during 10 wks of continuous walk at 50% $VO_{2reserve}$ | SK | 23.4 ± N/A (15) | 22.1 ± N/A (15) | 48.7 ± N/A (15) | 49.4 ± N/A (15) | 8469 | -33 |
| Després 1991 | No | N/A | 4.5x/wk for 90 min during 61 wks of continuous walk/bike/aerobic danse/swim at 55% $VO_{2max}$ | HW | 42.6 ± 9.4 (13) | 38.0 ± 7.3 (13) | 47.4 ± 5.1 (13) | 48.3 ± 4.1 (13) | 163327 | 74 |
| Dickson-Parnell 1985 | No | ≥ 86% | 3x/wk during 7 wks of continuous bike at 80% $HR_{max}$ | SK | 15.0 ± N/A (11) | 14.0 ± N/A (11) | 44.4 ± N/A (11) | 45.3 ± N/A (11) | 4200 | -73 |
| Dickson-Parnell 1985 | No | ≥ 86% | 3x/wk during 7 wks of continuous bike at 55% $HR_{max}$ | SK | 16.7 ± N/A (11) | 15.1 ± N/A (11) | 48.4 ± N/A (11) | 49.5 ± N/A (11) | 4200 | -199 |
| Donnelly 2000 | Yes | 91.9 | 3x/wk for 29 min during 78 wks of continuous exercise (N/A) at 60-75% $VO_{2max}$ | HW | 34.0 ± 3.7 (11) | 31.9 ± 3.3 (11) | 47.4 ± 3.7 (11) | 47.8 ± 3.8 (11) | 41793 | 54 |
| Donnelly 2000 | Not always | 90.3 | 5x/wk for 14.5 min twice daily during 78 wks of continuous walk at 50-65% $HR_{reserve}$ | HW | 36.7 ± 7.0 (11) | 36.0 ± 7.7 (11) | 49.1 ± 7.7 (11) | 49.1 ± 7.5 (11) | 60492 | 89 |
| Donnelly 2013 | Yes | >90 | 5x/wk for the time necessary to expend 600 kcal/session during 43.5 wks of continous bike/run/walk/exercise on elliptic at 70-80% $HR_{max}$ | DEXA | 34.1 ± 9.4 (18) | 29.7 ± 9.6 (18) | 46.1 ± 5.3 (18) | 46.9 ± 4.8 (18) | 111703 | 64 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Donnelly 2013 | Yes | >90 | 5x/wk for the time necessary to expend 400 kcal/session during 43.5 wks of continous bike/run/walk/exercise on elliptic at 70-80% $HR_{max}$ | DEXA | 34.8 ± 11.1 (19) | 31.7 ±12.2 (19) | 46.9 ± 8.0 (19) | 47.0 ± 7.7 (19) | 74744 | 61 |
| Donnelly 2013 | Yes | >90 | 5x/wk for the time necessary to expend 600 kcal/session during 43.5 wks of continous bike/run/walk/exercise on elliptic at 70-80% $HR_{max}$ | DEXA | 36.4 ± 7.5 (19) | 30.5 ± 10.1 (19) | 65.0 ± 7.3 (19) | 65.4 ± 7.4 (19) | 111703 | 51 |
| Donnelly 2013 | Yes | >90 | 5x/wk for the time necessary to expend 400 kcal/session during 43.5 wks of continous bike/run/walk/exercise on elliptic at 70-80% $HR_{max}$ | DEXA | 34.5 ± 11.6 (18) | 31.0 ± 11.4 (18) | 64.4 ± 9.9 (18) | 64.4 ± 9.2 (18) | 74744 | 56 |
| Dowdy 1985 | No | ≥ 90 | 3x/wk for 45 min during 10 wks of continuous aerobic danse at 77% $HR_{reserve}$ | HW | 19.3 ± 6.4 (18) | 19.7 ± 5.8 (18) | 43.8 ± 3.1 (18) | 44.1 ± 2.3 (18) | 11525 | 146 |
| Duncan 1991 | Yes | ≥ 85 | 5x/wk for 26-36 min during 24 wks of continuous walk that increased from 70-100% of 8.0 km/hr | HW | 16.6 ± N/A (16) | 16.2 ± N/A (16) | 43.7 ± N/A (16) | 45.2 ± N/A (16) | 31002 | 97 |
| Duncan 1991 | Yes | ≥ 85 | 5x/wk for 32-45 min during 24 wks of continuous walk that increased from 70-100% of 6.4 km/hr | HW | 16.8 ± N/A (12) | 15.9 ± N/A (12) | 47.4 ± N/A (12) | 48.4 ± N/A (12) | 26763 | 76 |
| Duncan 1991 | Yes | ≥ 85 | 5x/wk for 43-60 min during 24 wks of continuous walk that increased from 70-100% of 4.8 km/hr | HW | 17.3 ± N/A (18) | 16.5 ± N/A (18) | 44.7 ± N/A (18) | 46.3 ± N/A (18) | 25161 | 80 |
| Durstine 1990 | Yes | N/A | 3x/wk during 10 wks of continuous run at 70-85% $HR_{max}$ | SK | 6.5 ± N/A (10) | 7.4 ± N/A (10) | 63.9 ± N/A (10) | 64.2 ± N/A (10) | 8933 | 227 |
| Earnest 2013 | No | N/A | 3-4x/wk during 12 wks of continuous run/walk at 50-70% $VO_{2max}$ and running/walking interval between 90-95% $VO_{2max}$ with recuperation at 50% $VO_{2max}$ | DEXA | 27.5 ± N/A (21) | 26.1 ± N/A (21) | 66.4 ± N/A (21) | 65.5 ± N/A (21) | 12096 | -15 |
| Earnest 2013 | No | N/A | 3-4x/wk during 12 wks of continuous run/walk at 50-70% $VO_{2max}$ | DEXA | 28.3 ± N/A (16) | 27.8 ± N/A (16) | 70.6 ± N/A (16) | 69.9 ± N/A (16) | 12096 | 50 |
| Glisezinski 2003 | Yes | N/A | 5x/wk for 60 min during 17 wks of continuous run/bike at a $VO_{2max}$ that increased from 50-85% | DEXA | 20.4 ± N/A (11) | 19.0 ± N/A (11) | 69.1 ± N/A (11) | 68.6 ± N/A (11) | 58785 | 77 |
| Glowacki 2004 | Yes | N/A | 2-3x/wk for 20- 40 min during 12 wks of continuous run at 65-80% $HR_{reserve}$ | HW | 19.2 ± N/A (12) | 17.3 ± N/A (12) | 68.7 ± 9.5 (12) | 69.5 ± 9.3 (12) | 13210 | -25 |
| Grandjean 1996 | N/A | N/A | 3x/wk for 40 min during 24 wks of continuous bike/run/walk from 60-70% to 70-80% of $VO_{2max}$ | SK | 18.3 ± N/A (20) | 15.1 ± N/A (20) | 47.9 ± N/A (20) | 49.1 ± N/A (20) | 28800 | 3 |
| Grediagin 1995 | No | 100 | 4x/wk during 12 wks of continuous exercise on a treadmill at 80% $VO_{2max}$ | HW | 21.2 ± N/A (6) | 18.9 ± N/A (6) | 47.0 ± N/A (6) | 48.9 ± N/A (6) | 14400 | -24 |
| Grediagin 1995 | No | 100 | 4x/wk during 12 wks of continuous exercise on a treadmill at 50% $VO_{2max}$ | HW | 21.3 ± N/A (6) | 19.0 ± N/A (6) | 47.4 ± N/A (6) | 48.2 ± N/A (6) | 14400 | -39 |
| Greene 2009 | No | 90% | 3x/wk during 12 wks of continuous run/walk (land treadmill) with an increase from 60-85% $VO_{2max}$ | DEXA | 33.9 ± 2.3 (29) | 32.8 ± 2.2 (29) | 51.2 ± 2.2 (29) | 51.1 ± 2.1 (29) | 15750 | 34 |
| Greene 2009 | No | 90% | 3x/wk during 12 wks of continuous run/walk (underwater treadmill) with an increase from 60-85%$VO_{2max}$ | DEXA | 33.7 ± 2.0 (28) | 32.8 ± 2.1 (28) | 51.9 ± 2.4 (28) | 52.5 ± 2.4 (28) | 15750 | 53 |
| Gormley 2008 | Yes | 93.8 | 3-4x/wk for 30-45-60 min during 6 wks of continuous bike at 50% $VO_{2reserve}$ | SK | 14.5 ± N/A (14) | 14.0 ± N/A (14) | 52.9 ± N/A (14) | 53.8 ± N/A (14) | 6943 | 53 |
| Gormley 2008 | Yes | 93.3 | 3-4x/wk for 30-40 min during 6 wks of continuous bike at 50%-75% of $VO_{2reserve}$ | SK | 15.0 ± N/A (15) | 13.7 ± N/A (15) | 56.9 ± N/A (15) | 58.0 ± N/A (15) | 7186 | -47 |
| Gormley 2008 | Yes | 94.4 | 3x/wk for 30-40-55 min of continuous bike at 50% $VO_{2reserve}$ (first 2 wks) and biking interval at 90-100% $VO_{2reserve}$ (4 last wks) | SK | 11.3 ± N/A (13) | 10.6 ± N/A (13) | 56.3 ± N/A (13) | 55.8 ± N/A (13) | 7442 | 9 |
| Hardman 1992 | No | N/A | ≥3x/wk for > 20 min during 52 wks of continuous brisk walking | HW | 23.7 ± 1.5 (28) | 24.7 ± 1.6 (28) | 40.3 ± N/A (28) | 39.6 ± N/A (28) | 44726 | 125 |
| Hass 2001 | Yes | ≥ 85% | 3x/wk from 20-40 min during 12 wks of continuous body recumbent step with an increase from 50-75% $HR_{reserve}$ | SK | 25.4 ± 5.9 (17) | 23.8 ± 5.1 (17) | 55.9 ± 13.7 (17) | 57.2 ± 14.1 (17) | 9795 | -30 |

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|---|---|---|---|---|---|---|---|---|---|---|
| Hinkleman 1993 | Yes | N/A | 5x/wk for 45 min during 15 wks of continuous walk at 60% $HR_{reserve}$ | HW | 28.1 ± 1.4 (18) | 28.0 ± 1.3 (18) | 48.4 ± 0.9 (18) | 48.5 ± 0.9 (18) | 20139 | 96 |
| Hottenrott 2012 | No | 93 | 2x/wk for 30-60 and 60-120 min during 12 wks of continuous run at 75-85% velocity lactate threshold | BI | 15.8 ± N/A (16) | 14.7 ± N/A (16) | 52.1 ± 9.3 (16) | 51.4 ± 8.7 (16) | 17055 | 36 |
| Joubert 2011 | No | 86.25 | 4x/wk for 30 min during 4 wks of continuous run at 80% $HR_{max}$ | BP | 16.0 ± N/A (20) | 15.4 ± N/A (20) | 58.8 ± N/A (20) | 59.1 ± N/A (20) | 4863 | -1 |
| Juneau 1987 | No | N/A | 5x/wk for 47 min during 24 wks of continuous exercise (N/A) at 50-66% $VO_{2max}$ | HW | 17.9 ± N/A (28) | 14.0 ± N/A (28) | 61.5 ± 8.0 (28) | 63.9 ± 13.0 (28) | 38160 | 15 |
| Juneau 1987 | No | N/A | 5x/wk for 54 min during 24 wks of continuous exercise (N/A) at 50-66% $VO_{2max}$ | HW | 17.8 ± N/A (24) | 16.6 ± N/A (24) | 46.0 ± 5.0 (24) | 46.8 ± 4.0 (24) | 30960 | 68 |
| Kirk 2003 | Yes | 89.6 | 3-5x/wk for 20-45 min during 70 wks of continuous bike/walk/aerobic exercise in water at a $VO_{2max}$ that increased from 55-70% | HW | 27.4 ± 7.1 (25) | 27.2 ± 7.9 (25) | 49.5 ± 5.8 (25) | 50.4 ± 5.8 (25) | 118837 | 100 |
| Kirk 2003 | Yes | 90.3 | 3-5x/wk for 20-45 min during 70 wks of continuous bike/walk/aerobic exercise in water at a $VO_{2max}$ that increased from 55-70% | HW | 26.8 ± 6.8 (16) | 21.9 ± 5.5 (16) | 67.1 ± 8.3 (16) | 66.9 ± 7.8 (16) | 177717 | 74 |
| Krustrup 2010 | No | 90 | 2x/wk for 60 min during 16 wks of soccer at 83% $HR_{max}$ | DEXA | 25.6 ± 1.4 (21) | 24.2 ± 1.5 (21) | 42.5 ± 1.2 (21) | 43.9 ± 1.3 (21) | 16055 | 33 |
| Krustrup 2010 | No | 92.5 | 2x/wk for 60 min during 16 wks of continuous run at 82% $HR_{max}$ | DEXA | 22.0 ± 1.7 (17) | 20.9 ± 1.6 (17) | 41.6 ± 0.8 (17) | 42.9 ± 0.8 (17) | 16055 | 50 |
| Krustrup 2009 | No | 92 | 2.3x/wk for 60 min during 12 wks of soccer at 82% $HR_{max}$ | DEXA | 19.9 ± 2.4 (12) | 17.2 ± 2.1 (12) | 57.7 ± 2.2 (12) | 59.4 ±1.9 (12) | 19783 | -13 |
| Krustrup 2009 | No | 100 | 2.5x/wk for 60 min during 12 wks of continuous run at 82% $HR_{max}$ | DEXA | 20.7 ± 2.7 (10) | 19.0 ± 2.6 (10) | 61.3 ± 2.8 (10) | 61.9 ± 2.7 (10) | 21503 | 31 |
| Lee 2009 | Yes | 100 | 3x/wk for 25 min during 6 wks of continuous run at 60% $VO_{2max}$ and then 4x/wk for 40 min during the following 6 wks of continuous run at 80% $VO_{2max}$ | HW | 12.1 ± 1.4 (9) | 11.2 ± 1.4 (9) | 61.7 ± 2.0 (9) | 62.1 ± 2.0 (9) | 18615 | 58 |
| Lee 2013 | Yes | N/A | 4x/wk for 45 min during 13 wks of continuous run/walk at 60% $VO_{2max}$ | BI | 22.5 ± N/A (90) | 21.3 ± N/A (90) | 43.3 ± N/A (90) | 42.8 ± N/A (90) | 12228 | 5 |
| Lee 2012 | Yes | ≥ 96 | 3-4-5x/wk during 14 wks of continuous run at 50% $VO_{2max}$ | BI | 24.1 ± N/A (8) | 23.4 ± N/A (8) | 43.2 ± 3.0 (8) | 42.2 ± 2.7 (8) | 18124 | 57 |
| Lee 2012 | Yes | ≥ 96 | 3-4-5x/wk during 14 wks of continuous run at 70% $VO_{2max}$ | BI | 21.8 ± N/A (7) | 19.8 ± N/A (7) | 43.3 ± 3.9 (7) | 42.6 ± 4.0 (7) | 17558 | -11 |
| Macpherson 2011 | No | 100 | 3x/wk for 30-45-60 min during 6 wks of continuous run at 65% $VO_{2max}$ | BP | 13.9 ± 5.5 (10) | 13.1 ± 5.0 (10) | 54.9 ± 12.2 (10) | 55.4 ± 12.0 (10) | 8467 | 22 |
| McCarthy 1995 | Yes | 97 | 3x/wk for 45 min during 10 wks of continuous bike at 70% $HR_{reserve}$ | SK | 18.3 ± 3.1 (10) | 16.7 ± 3.4 (10) | 66.2 ± 2.6 (10) | 66.5 ± 2.5 (10) | 17387 | 16 |
| Mogensen 2009 | Not always | 97 | 4.5x/wk for 18-30 min of continuous bike (home) and biking interval (laboratory) at a $VO_{2peak}$ that increased from 60 (wk1-6) to 70% (wk7-10) | N/A | 36.0 ± N/A (10) | 33.2 ± N/A (10) | 75.0 ± 2.3 (10) | 76.8 ± 2.2 (10) | 14944 | -55 |
| Moghadasi 2012 | No | N/A | 4x/wk for 45 min during 12 wks of continuous run at 75-80% $VO_{2max}$ | BI | 26.0 ± 3.7 (8) | 23.2 ± 3.2 (8) | 58.7 ± 6.1 (8) | 59.3 ± 7.5 (8) | 24523 | -1 |
| Moro 2005 | Yes | ≥ 90 | 5x/wk for 45 min (mos1-2) and 60 min (mos 3-4) during 17.4 wks of continuous run/bike at 50-85% $VO_{2max}$ | DEXA | 20.2 ± N/A (10) | 18.6 ± N/A (10) | 70.1 ± N/A (10) | 68.7 ± N/A (10) | 52038 | 68 |
| Mougios 2006 | Yes | N/A | 4x/wk during 13 wks of continuous run at 72% $VO_{2max}$ | HW | 21.1 ± 2.9 (7) | 18.8 ± 2.3 (7) | 42.9 ± 4.7 (7) | 43.4 ± 4.7 (7) | 18500 | -12 |
| Mougios 2006 | Yes | N/A | 4x/wk during 13 wks of continuous run/walk at 45% $VO_{2max}$ | HW | 23.0 ± 5.7 (7) | 20.0 ± 5.9 (7) | 45.7 ± 4.2 (7) | 45.4 ± 4.6 (7) | 18500 | -54 |
| Murtagh 2005 | Not always | 90.4 | 3x/wk for 20 min during 12 wks of continuous single bout of walk at 73.1% $HR_{max}$ | BI | 20.0 ± N/A (15) | 19.8 ± N/A (15) | 54.2 ± N/A (15) | 54.6 ± N/A (15) | 4440 | 79 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Murtagh 2005 | Not always | 82.1 | 3x/wk for 20 min during 12 wks of continuous accumulated bout of walk at 72.1% $HR_{max}$ | BI | 20.9 ± N/A (9) | 22.1 ± N/A (9) | 53.7 ± N/A (9) | 53.1 ± N/A (9) | 4440 | 418 |
| Nielsen 1993 | Yes | 100 | 5x/wk for 60 min during 5 wks of continuous bike at 60-80% $VO_{2max}$ | HW | 36.2 ± N/A (6) | 33.0 ± N/A (6) | 60.2 ± 10.8[1] (6) | 59.7 ± 10.8[1] (6) | 16834 | -82 |
| Nielsen 1993 | Yes | 100 | 5x/wk for 60 min during 5 wks of continuous bike at 60-80% $VO_{2max}$ | HW | 11.1 ± N/A (6) | 9.9 ± N/A (6) | 55.9 ± 7.0[1] (6) | 56.2 ± 7.8[1] (6) | 17612 | 39 |
| Nishida 2010 | Yes | 100 | 5x/wk for 60 min during 12 wks of continuous bike at a $VO_{2max}$ that increased from 36.8-54.8% | HW | 9.1 ± N/A (6) | 8.9 ± N/A (6) | 57.3 ± N/A (6) | 57.6 ± N/A (6) | 25304 | 95 |
| Nordby 2012 | Not always | 85.6 | 3.5x/wk for 51.4 min during 12 wks of continuous bike at 65% $HR_{reserve}$ and bike/run/oar/elliptic interval at 85% $HR_{reserve}$ | DEXA | 28.5 ± 1.4 (12) | 20.8 ± 1.7 (12) | 66.0 ± 2.0 (12) | 67.8 ± N/A (12) | 24205 | -186 |
| Nybo 2010 | No | N/A | 2.5x/wk for 60 min during 12 wks of continuous run at 65% $VO_{2max}$ | DEXA | 21.1 ± N/A (9) | 19.5 ± N/A (9) | 61.3 ± 2.8 (9) | 61.9 ± 2.7 (9) | 20454 | 32 |
| Pagels 2012 | Yes | 100 | 7x/wk for 30 min during 3 wks of continuous brisk walking | BI | 23.4 ± N/A (16) | 22.9 ± N/A (16) | 55.7 ± N/A (16) | 55.6 ± N/A (16) | 4011 | -18 |
| Polak 2006 | Not always | N/A | 5x/wk for 45 min during 12 wks of continuous bike/gymnasium exercise with an increase from 50-60-65% $VO_{2peak}$ every 3 weeks | DEXA | 34.3 ± N/A (25) | 30.2 ± N/A (25) | 54.2 ± N/A (25) | 53.1 ± N/A (25) | 17965 | -120 |
| Prud'homme 1984 | No | N/A | 4-5x/wk for 43 min during 20 wks of continuous bike and bike interval at a mean (continuous and interval) of 80% $HR_{reserve}$ | HW | 6.9 ± N/A (20) | 8.0 ± N/A (20) | 49.9 ± N/A (20) | 51.2 ± N/A (20) | 40801 | 137 |
| Rajaram 1995 | No | 80 | 3x/wk for 30 min during 24 wks of continuous aerobic dance at 60-75% $HR_{reserve}$ | BI | 14.8 ± N/A (13) | 15.3 ± N/A (13) | 43.5 ± N/A (13) | 44.9 ± N/A (13) | 14493 | 157 |
| Revan 2011 | No | N/A | 3x/wk for 43 min during 8 wks of continuous run at 50-70% $HR_{reserve}$ | N/A | 9.3 ± N/A (12) | 8.4 ± N/A (12) | 63.8 ± N/A (12) | 63.7 ± N/A (12) | 12113 | 33 |
| Ring-Dimitriou 2007 | Not always | 90/70[3] | 120 min (mos 1-3), 150 min (mos 4-6) and 180 min (mos 7-9) during 39 wks of continuous run at 64-73% $VO_{2peak}$ | BI | 17.6 ± N/A (20) | 16.1 ± N/A (20) | 55.0 ± N/A (20) | 54.4 ± N/A (20) | 58595 | 75 |
| Rosenkilde 2012 | No | 99 | 6.2x/wk for 30 min during 10 wks of continuous bike/run at 66% $VO_{2peak}$ | DEXA | 30.0 ± 4.6 (18) | 26.0 ± N/A (18) | 63.3 ± 6.9 (18) | 63.6 ± N/A (18) | 21105 | -76 |
| Rosenkilde 2012 | No | 96 | 6.2x/wk for 55min during 10 wks of continuous bike/run at 67% $VO_{2peak}$ | DEXA | 27.4 ± 4.2 (18) | 23.6 ± N/A (18) | 64.0 ± 5.7 (18) | 65.0 ± N/A (18) | 41139 | 17 |
| Ruby 1996 | Yes | ≥ 95 | 4x/wk for 45 min during 10 wks of continuous run at 70-80% $HR_{reserve}$ | HW | 12.0 ± N/A (6) | 10.5 ± N/A (6) | 46.2 ± N/A (6) | 46.5 ± N/A (6) | 16686 | 21 |
| Ruby 1996 | Yes | ≥ 95 | 4x/wk for 45 min during 10 wks of continuous bike at 70-80% $HR_{reserve}$ | HW | 14.5 ± N/A (6) | 13.5 ± N/A (6) | 47.1 ± N/A (6) | 47.7 ± N/A (6) | 14936 | 47 |
| Ruby 1996 | Yes | ≥ 95 | 4x/wk for 45 min during 10 wks of continuous bike/run at 70-80% $HR_{reserve}$ | HW | 17.5 ± N/A (6) | 17.4 ± N/A (6) | 44.9 ± N/A (6) | 45.4 ± N/A (6) | 16330 | 101 |
| Santiago 1995 | Yes | 91 | 4x/wk during 38 wks of continuous walk at 72% $HR_{max}$ | HW | 18.4 ± N/A (16) | 17.0 ± N/A (16) | 46.0 ± N/A (16) | 46.4 ± N/A (16) | 52440 | 76 |
| Scharhag-Rosenberger 2010 | Not always | 93.3 | 3x/wk for 48 min during 52 wks of continuous run/walk at 62% $HR_{reserve}$ | SK | 21.8 ± N/A (17) | 19.2 ± N/A (17) | 51.1 ± 11.9 (17) | 52.6 ± 11.0 (17) | 68514 | 68 |
| Sedlock 2010 | Yes | 100 | 3-4x/wk for 25-40 min during 12 wks of continuous run at a $VO_{2max}$ that increased from 60-80% | HW | 12.1 ± 1.4 (9) | 11.2 ± 1.4 (9) | 61.7 ± 2.0 (9) | 62.1 ± 2.0 (9) | 16905 | 54 |
| Sijie 2012 | Yes | N/A | 5x/wk for 27 min during 12 wks of walking (12 min) /running (15 min) interval at 50% and 85% $VO_{2peak}$ | DEXA | 29.9 ± N/A (17) | 24.7 ± N/A (17) | 43.8 ± N/A (17) | 42.8 ± N/A (17) | 14385 | -248 |
| Sijie 2012 | Yes | N/A | 5x/wk for 40 min during 12 wks of continuous run/walk at 50% $VO_{2peak}$ | DEXA | 30.5 ± N/A (16) | 27.2 ± N/A (16) | 43.7 ± N/A (16) | 42.6 ± N/A (16) | 15003 | -114 |
| Snyder 1997 | Not always | 82.6 | 5x/wk for 3 X 10 min during 32 wks of continuous walk at 52% $HR_{reserve}$ | HW | 36.7 ± 14.5 (13) | 37.2 ± 14.7 (13) | 50.6 ± 9.8 (13) | 49.9 ± 10.1 (13) | 19554 | 128 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Stensel 1994 | No | N/A | ≥3x/wk for 28 min during 52 wks of continuous walk at 68% $HR_{max}$ | HW | 22.8 ± N/A (42) | 21.8 ± N/A (42) | 56.5 ± N/A (42) | 57.3 ± N/A (42) | 56528 | 87 |
| Suter 1995 | No | N/A[4] | 4x/wk for 30 min during 26 wks of continuous run at 75% $VO_{2max}$ | DEXA | 16.6 ± 6.1 (12) | 15.7 ± 6.4 (12) | 52.9 ± 6.6 (12) | 53.5 ± 6.3 (12) | 36433 | 80 |
| Szmedra 1998 | No | N/A | 3x/wk from 30 min during 6 wks of continuous bike/run/oar at 70% $VO_{2max}$ | SK | 25.3 ± N/A (7) | 23.8 ± N/A (7) | 51.5 ± N/A (7) | 51.2 ± N/A (7) | 4667 | -221 |
| Tan 2012 | Yes | ≥ 88 | 5x/wk for 40 min during 8 wks of continuous run at 54% $VO_{2max}$ | DEXA | 31.0 ± 4.6 (29) | 27.0 ± 4.0 (29) | 39.5 ± 4.9 (29) | 39.4 ± 4.4 (29) | 10797 | -250 |
| Trapp 2008 | No | 100 | 3x/wk for 20 min during 15 wks of bike interval at 53.2 % $VO_{2peak\ power\ outpout}$ | DEXA | 22.2 ± 30.0 (11) | 19.7 ± 2.6 (11) | 41.1 ± N/A (11) | 42.1 ± N/A (11) | 9915 | -119 |
| Trapp 2008 | No | 100 | 3x/wk for 30 min during 15 wks of continuous bike at 60% $VO_{2peak}$ | DEXA | 18.4 ± 2.2 (8) | 18.8 ± 2.1 (8) | 41.4 ± N/A (8) | 40.9 ± N/A (8) | 8673 | 150 |
| Van Aggel-Leijssen 2002 | Yes | 89.4 | 3x/wk for 57 min during 12 wks of continuous bike at 40% $VO_{2max}$ | HW | 32.7 ± N/A (8) | 32.4 ± N/A (8) | 70.0 ± 9.6 (8) | 70.7 ± 8.7 (8) | 12600 | 87 |
| Van Aggel-Leijssen 2002 | Yes | 92.6 | 3x/wk for 33 min during 12 wks of continuous bike at 70% $VO_{2max}$ | HW | 32.7 ± N/A (8) | 33.3 ± N/A (8) | 72.8 ± 5.4 (8) | 71.8 ± 6.7 (8) | 13104 | 148 |
| Van Aggel-Leijssen 2001 | Yes | 81 | 3x/wk for 57 min during 12 wks of continuous bike at 40% $VO_{2max}$ | HW | 41.2 ± N/A (8) | 41.7 ± N/A (8) | 50.0 ± 2.4 (8) | 49.5 ± 2.7 (8) | 9000 | 162 |
| Van Aggel-Leijssen 2001 | Yes | 88 | 3x/wk for 57 min during 12 wks of continuous bike at 40% $VO_{2max}$ | HW | 37.1 ± N/A (7) | 37.5 ± N/A (7) | 49.4 ± 3.7 (7) | 49.6 ± 3.8 (7) | 8892 | 158 |
| Weltman 1980 | No | N/A | 4x/wk for 35 min during 10 wks of continuous brisk walk at 3.5mph | HW | 17.6 ± 6.2 (11) | 16.6 ± 5.8 (11) | 58.2 ± 5.9 (11) | 58.3 ± 6.4 (11) | 7881 | -17 |
| Wilmore 1980 | No | 99.1 | 3x/wk for 30 min during 20 wks of continuous bike at 75% $HR_{reserve}$ | HW | 19.3 ± N/A (9) | 18. 0 ± N/A (9) | 66.4 ± N/A (9) | 67.4 ± N/A (9) | 23978 | 56 |
| Wilmore 1980 | No | 93.3 | 3x/wk for 30 min during 20 wks of continuous run at 75% $HR_{reserve}$ | HW | 16.2 ± N/A (9) | 14.5 ± N/A (9) | 63.6 ± N/A (9) | 63.5 ± N/A (9) | 24239 | 34 |

The value are mean ± SD

The number in parentheses represents the number of participants tested

HRRmax, heart rate reserve maximal; HRmax, heart rate maximal; HW, Hydrostatic weighing; SK, Skinfold; DEXA, Dual x-ray absorptiometry; BI, Bio-impedance; BP, Bod pod

[1] SD was estimated from the difference of the range divided by 4

[2] For the supervised training only

[3] 90% for the first 6 months and 70% for the last 3 months

[4] Compliance minimal of 60 min/wk

**Figure 1 -** Flow chart of excluded/included articles

| | | | |
|---|---|---|---|
| 1 | exercise/ or running/ or jogging/ or swimming/ or walking/ | 30 | (oxygen adj2 intake).tw. |
| 2 | Motor activity/ | 31 | (aerobic capacity adj3 max*).tw. |
| 3 | Physical Fitness/ | 32 | or/17-31 |
| 4 | Exercise Therapy/ | 33 | body composition.mp. |
| 5 | exp Sports/ | 34 | Body Fat Distribution/ |
| 6 | Dancing/ | 35 | (fat adj3 mass).tw. |
| 7 | exercis*.tw. | 36 | body fat.tw. |
| 8 | physical activit*.tw. | 37 | (fat adj3 percentage).tw. |
| 9 | vigorous activit*.tw. | 38 | body weight/ |
| 10 | physical training.tw. | 39 | body weight changes/ |
| 11 | exertion.tw. | 40 | weight gain/ or weight loss/ |
| 12 | (aerobic* or walking or jogging or swimming or cycling or bicycling or running).tw. | 41 | obesity/ or overweight/ |
| 13 | (fitness adj3 (class* or regime* or program*)).tw. | 42 | normal weight.tw. |
| 14 | danc*.tw. | 43 | lean body.tw. |
| 15 | endurance training.tw. | 44 | or/33-43 |
| 16 | or/1-15 | 45 | randomized controlled trial.pt. |
| 17 | Energy Metabolism/ | 46 | controlled clinical trial.pt. |
| 18 | (energy adj3 spent).tw. | 47 | (randomized or randomly).tw. |
| 19 | (energy adj3 output).tw. | 48 | trial.ti. |
| 20 | (energy adj2 expend*).tw. | 49 | (control* adj3 (study or studies or trial)).tw,hw. |
| 21 | (calori* adj3 burn*).tw. | 50 | time series.tw. |
| 22 | (calori* adj3 expend*).tw. | 51 | (pre test or pretest or posttest or post test).tw. |
| 23 | Oxygen Consumption/ | 52 | quantitative.tw. |
| 24 | (oxygen adj3 consum*).tw. | 53 | cohort studies/ |
| 25 | (O2 adj3 consum*).tw. | 54 | or/45-53 |
| 26 | "(VO(2 max))".tw. | 55 | exp animals/ not humans.sh. |
| 27 | VO2max.tw. | 56 | 54 not 55 |
| 28 | (VO2 adj2 peak).tw. | 57 | 16 and 32 and 44 |
| 29 | (oxygen adj2 uptake).tw. | 58 | 56 and 57 |
| | | 59 | limit 58 to (english or french) |

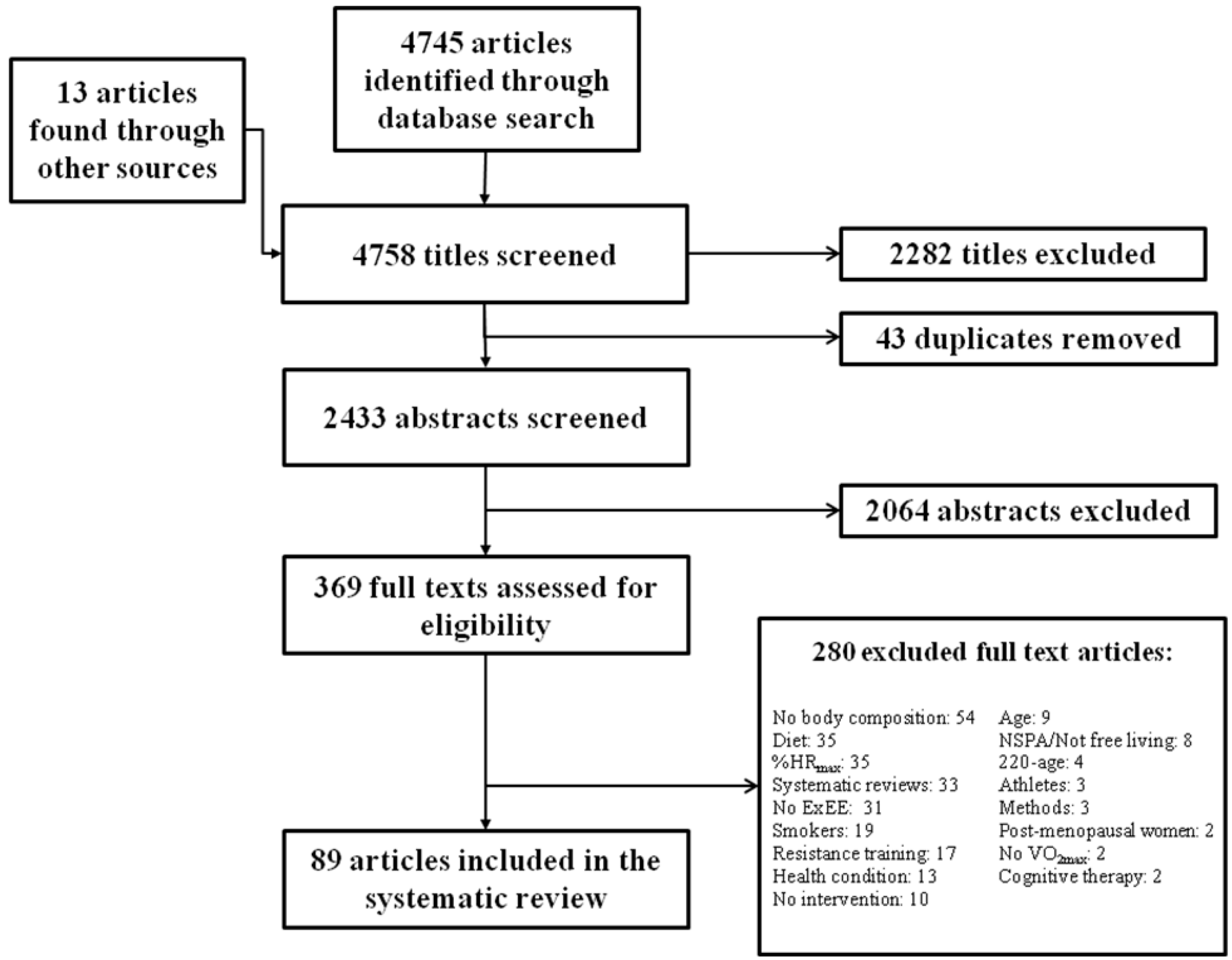


**Figure 2 -** Flow chart summarizing the search strategy

From the 89 articles included in the systematic review, 71 were from original studies and 18 were from secondary data analysis

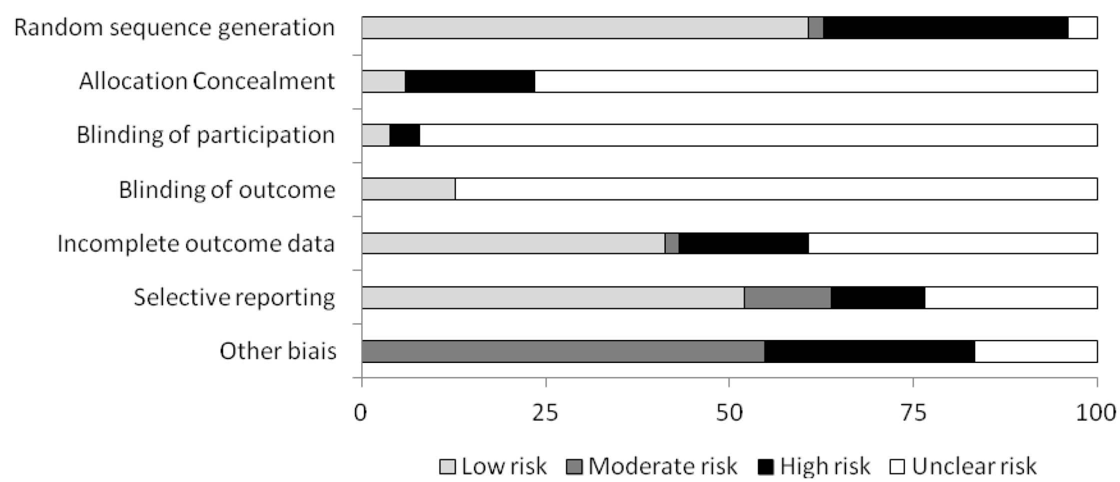


**Figure 3 -** Risk of bias

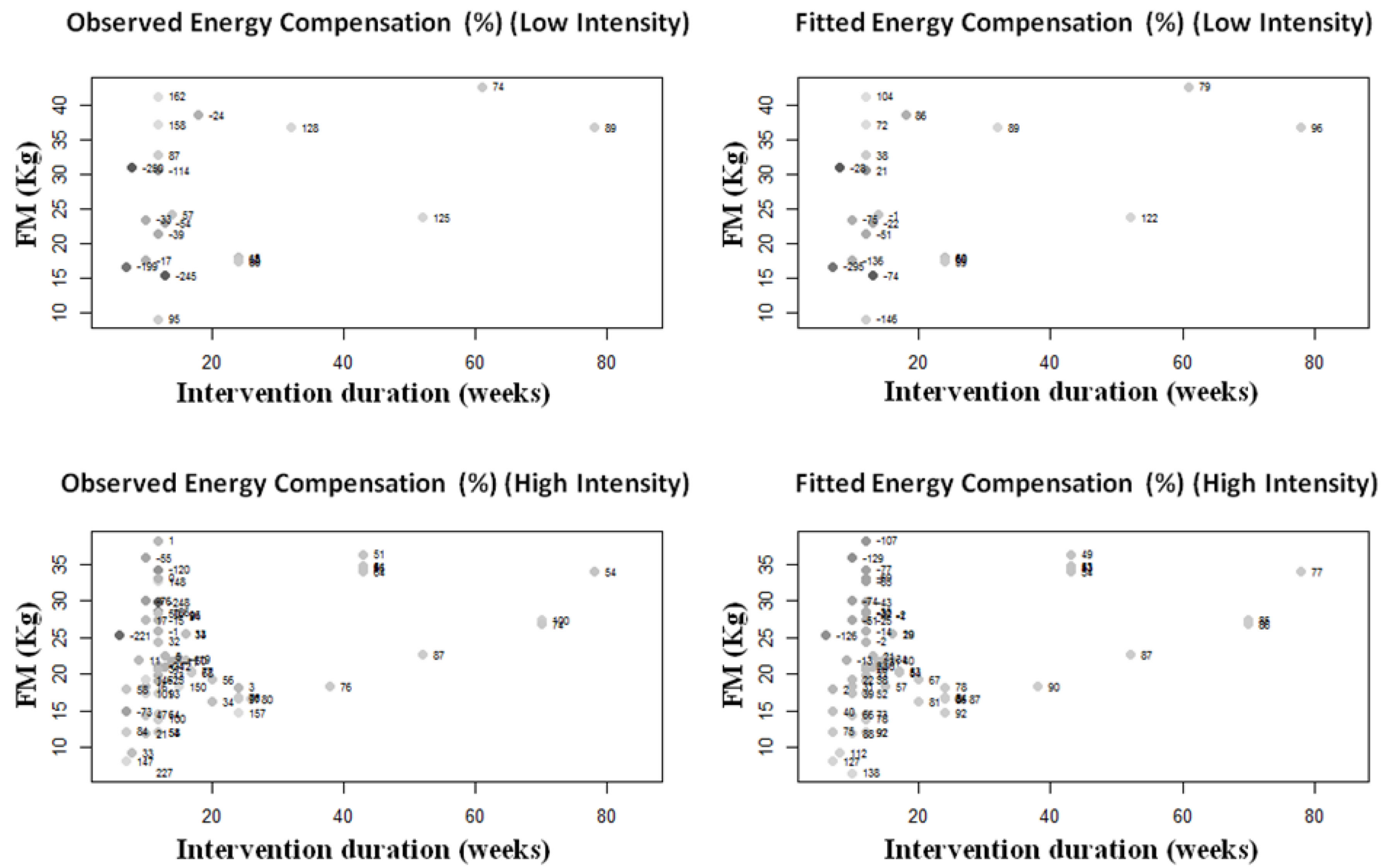


**Figure 4 -** Fitted energy compensation (%) in comparison to the observed energy compensation (%)

For each study (represented by a dot), the energy compensation is either calculated from the real data (observed energy compensation) or estimated with the model (fitted energy compensation)

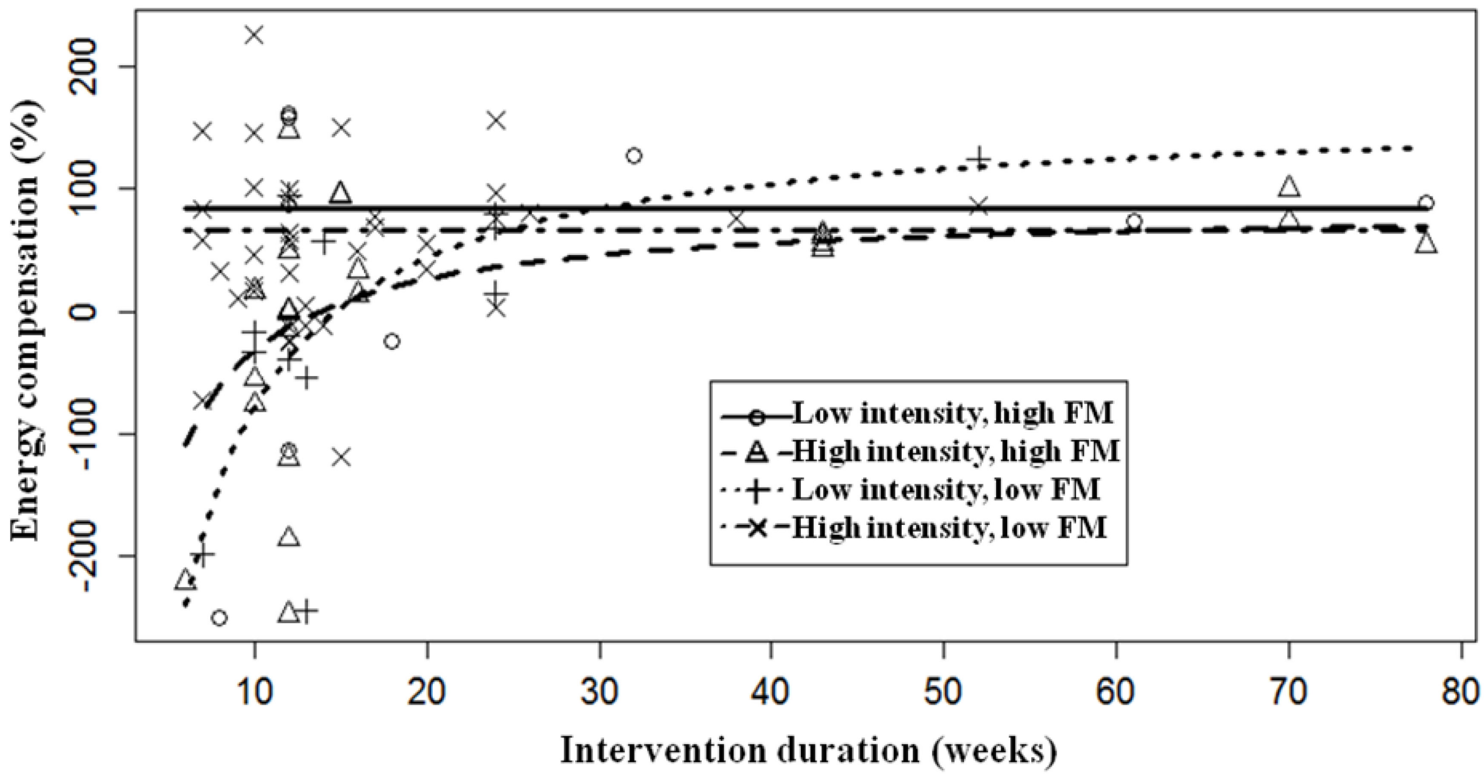


**Figure 5 -** Energy compensation illustrated as the interaction between exercise intensity and the FM of individuals according to studies of different intervention duration

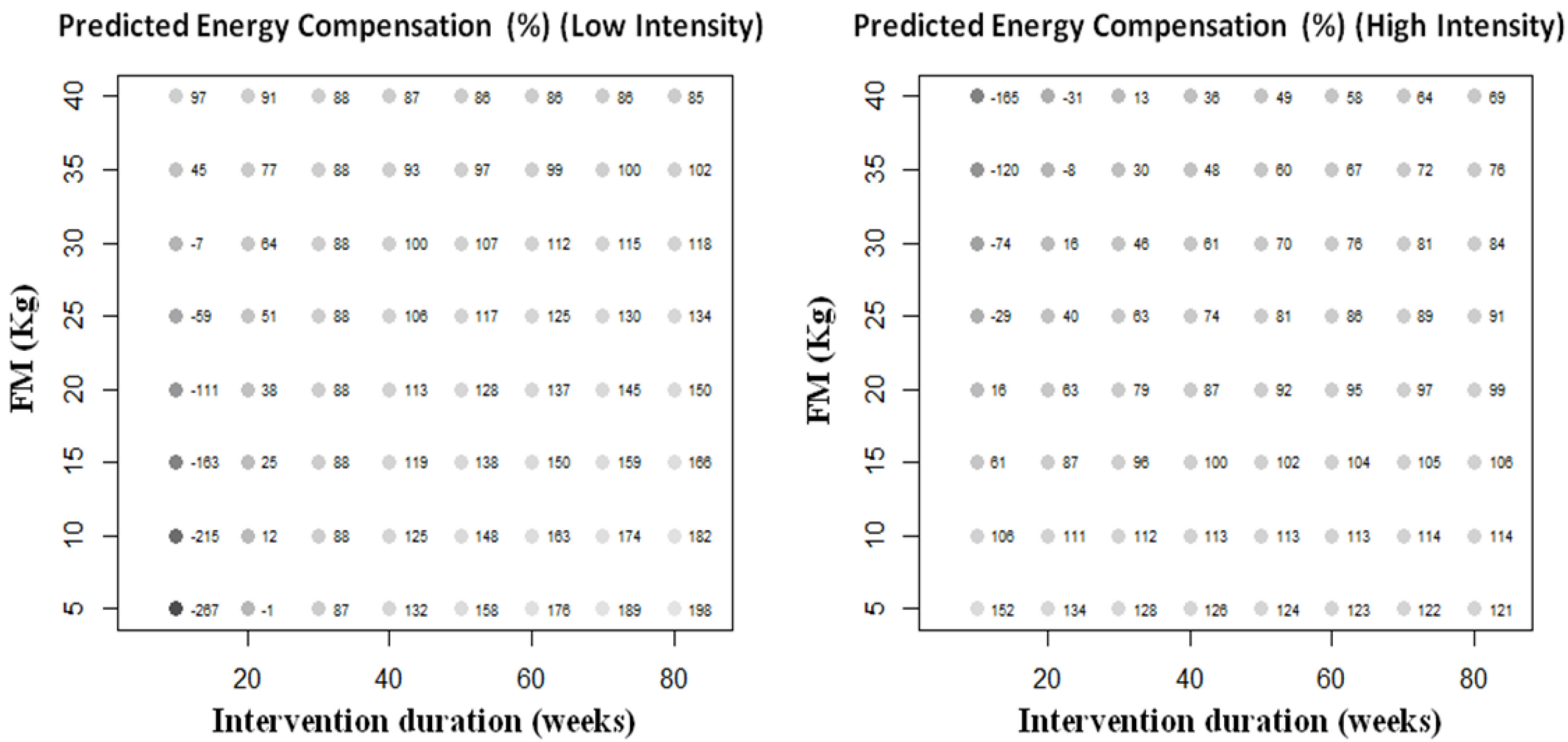


**Figure 6 -** Energy compensation illustrated as the interaction between exercise intensity and intervention duration according to the FM of individuals

## 3.3 Thesis Article # 3

The article entitled "Reproducibility of a Food Menu to Measure Energy and Macronutrient Intakes in a Laboratory and Under Real-Life Conditions" presented in this section of the thesis is published in the *British Journal of Nutrition* (Appendix B).

# Reproducibility of a Food Menu to Measure Energy and Macronutrient Intakes in a Laboratory and Under Real-Life Conditions

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Author's contribution: MER, JM and ED designed the research, MER, JM, SR and SC conducted the research, MER and JM conceptualized the data analysis, MER and JM performed statistical analysis and MER and JM wrote the manuscript while the co-authors: SR, SC and ED critically appraised and approved the final version of the manuscript.

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**Running title:** Measuring Energy Intake with a Food Menu

**Key words:** Food intake, food menu, reproducibility and free-living

**Disclosure of funding**: None

**Conflict of interest:** The authors declare no conflict of interest

## Abstract

Given the limitations associated with the measurement of food intake, we aimed to determine the reliability of a food menu to measure energy intake (EI) and macronutrient intake within the laboratory and under free-living conditions. A total of eight men and eight women (age: 25.7±5.9 years, BMI: 23.7±2.7 kg/m²) completed three identical in-laboratory sessions (ILS) and three out-of-laboratory sessions (OLS). During the ILS, participants had *ad libitum* access to a variety of foods, which they chose from a menu every hour, for 5 hours. For the OLS, the foods were chosen from the menu at the start of the day and packed into containers to bring home. There were no significant differences in total EI (6118.6±2691.2, 6678.8±2371.3, 6489.5±2742.9 kJ; p=NS) between the three ILS and three OLS (6816.0±2713.2, 6553.5±2364.5, 6456.4±3066.8 kJ; p=NS). Significant intraclass correlations (ICC) for total energy (r=0.77, p<0.0001), carbohydrate (r=0.81, p<0.0001), dietary fat (r=0.54, p<0.0001) and protein (r=0.81, p<0.0001) intakes for ILS and significant ICC for total energy (r=0.85, p<0.0001), carbohydrate (0.85, p<0.0001), dietary fat (0.72 p<0.0001) and protein (0.80, p<0.0001) intakes for OLS were noted. The average within-subject coefficient of variation for total EI was 18.3±10.0% and 16.1±10.3% for ILS and OLS respectively, with a pleasantness rating for foods consumed of 124±14 mm out of 150 mm (83%). Overall, the food menu produces a relatively reliable measure of EI inside and outside the laboratory. The results also underscore the difficulties in capturing a representative image of food intake given the relatively high day-to-day variation in the amount and composition of foods consumed.

## Introduction

Few studies have attempted to establish the validity of tools that directly measure food intake. The use of an *ad libitum* buffet-style meal has previously been validated to measure energy intake (EI) inside a laboratory setting[1]. This method has been shown to have a very high reliability with an intraclass correlation (ICC) of 0.97 and a within-subject coefficient of variation (CVws) of 10% for total EI between two identical experimental sessions in 14 men[1]. Another study later tested the reproducibility of a slightly different method in 55 men who were given *ad libitum* access to one meal item (a mixed hot pot meal containing pasta, vegetables, minced meat and cream) at lunch time on two separate occasions in a controlled laboratory setting[2]. A slightly lower ICC (r=0.86) with similar CVws (8.9%) to those reported by Arvaniti *et al.*[1] was noted. In a study using refrigerated vending machines to measure *ad libitum* EI inside a laboratory setting[3], CVws for EI over 1.5 h at lunch time on four separate occasions was found to be 6.3% in five women[3]. While each one of these methods has shown a good repeatability, they have only investigated the measurement of energy and macronutrient intakes over a short period of time (one meal) and they do not offer a very large variety of hot meal-type foods, which may be encountered by the participants under free-living conditions.

Although these methods employed to directly measure EI have been shown to be reproducible under controlled laboratory conditions, they have not been evaluated outside of the laboratory setting. Food records have previously been validated in order to measure EI outside of the laboratory setting[4]. However, the complexity and inconvenience related to the description and measurement of each food and beverage consumed is often associated with poor compliance and thus may lead to a certain degree of under-reporting and/or under-eating[5]. To make matters more complex, underreporting has also been found to be associated with many factors, such as adiposity level, body size, dietary restraint and socio-economic status[6-9]. As such, the limitations associated with self-reporting of energy and macronutrient intakes[5,10] warrant the investigation of tools that are able to capture the volatility of food intake more accurately outside of the laboratory setting. One study has previously attempted to validate and measure *ad libitum* protein intake under free living conditions in 65 obese men and women who were given access to a food store that offered 900 food and beverage items[11]. This study did demonstrate a high level of agreement in protein intake between the first and second half of the intervention. However, even if it was assumed that carbohydrate and dietary fat intakes did not vary much between both parts of the intervention, this study only objectively captured protein intake.

The objectives of the present study were thus twofold. The first objective was to evaluate the reproducibility of a food menu to measure food intake over several meals (two meals and snacks over 5 h). The second objective was to compare the reproducibility of this food menu between in-laboratory sessions (ILS) and out-of-laboratory sessions (OLS). A third objective was to evaluate sex differences in energy and macronutrient intakes because not many studies have investigated the reproducibility of tools that may be used for the measurement of total EI in men and women together. We hypothesized that energy and macronutrient intakes over several meals (two meals and snacks over 5 h) would be reliable and reproducible in men and women.

## Methods

### Participants

A total of eight women and eight men completed three ILS and three OLS testing sessions. Participants were individually interviewed to evaluate whether they met the study's inclusion criteria: *1*) over the age of 18 years; *2*) stable weight (± 2 kg) within the past 6 months; 3) non-smokers; *4*) no drug and alcohol abuse. Women were tested during the follicular phase of the menstrual cycle and at least 7 d separated each testing session. This study was conducted according to the guidelines laid down in the Declaration of Helsinki and all the procedures involving human participants were approved by the University of Ottawa ethics committee. Written informed consent was also obtained from all participants.

### Body Composition

Body weight was measured to the nearest 0.1 kg using a BWB-800AS digital scale and standing height was measured to the nearest centimeter using a wall stadiometer, Tanita HR-100 height rod, without shoes (Tanita Corporation of America, Inc, Arlington Heights, IL) before the start of each testing session, when participants were fasting. Body composition was measured using dual-energy X-ray absorptiometry (GE-LUNAR Prodigy module; GE Medical Systems, Madison, WI.) on one occasion, once all testing sessions were completed. The coefficient of variation and correlation for the percentage of body fat measured in 12 healthy participants tested in our laboratory were 1.8% and $r$ = 0.99, respectively.

**Design and procedure**

Participants were asked to come to the laboratory for six sessions divided into three ILS and three OLS. The order of the sessions was not randomized. In fact, when we started this study, we had initially decided to test our food menu for two consecutive sessions in the laboratory only. Soon after we had begun testing, we slightly modified the study design to include a third ILS and also decided to add the three OLS as well. This is the reason why the sessions were not randomized. It should be noted that no differences in EI were noted across all sessions based on the session at which participants started the study (results not shown). During the ILS, participants were in a room with a desk and a chair, a television and most participants brought and used their own laptop computer. They were allowed to perform any type of sedentary activities while in that room. As for the OLS, no restrictions were given with regard to the amount and types of activities that the participant could perform. However, they were instructed to only eat items that were found in the lunch boxes throughout the 5 h session. The participants arrived at the laboratory following a 12 h overnight fast. They had been instructed not to consume any alcohol or to engage in any type of structured physical activity (*e.g.* playing sports or training) for at least 24 h before the start of testing.

**Energy intake assessment - in-laboratory and out-of-laboratory sessions**

Total energy and macronutrient intakes were measured by the use of an *ad libitum* food menu (**Appendix 1**). A total of sixty-two items were provided on the menu in order to ensure that a sufficient amount of hot meals, breakfast items, snacks, fruits, vegetables and beverages were made available to the participant. This menu was mainly based on the items provided in the Arvaniti *et al*. (2000) buffet, while some breakfast and hot-meal items were added in order to study the reproducibility of this tool over 5 h. During the ILS, this food menu was presented to the participants every hour, for 5 h (8am-1pm). Every hour, the participants could choose the types of foods and beverages from the menu that they wanted to consume at that time. During the OLS, the participants were given the same food menu at 8am and were asked to choose the types of foods and beverages that they wanted to consume over the next 5 h (until 1pm). The food items were then packed into plastic containers, while the beverages were packed into plastic bottles. These containers and bottles were then placed into a portable cooler for the participants to bring with them. They were also asked to bring back all leftovers, wrappings and peels and to put them into their original containers when applicable. In both cases, two portions of each of the food and beverage items selected were prepared and served or packed into the portable cooler for the participants. The specific quantity (portions) of each food and beverage item provided/served to the participants is presented in **Appendix 1**. The participants were then given the instructions to "eat as little or as much as you want". The chosen and prepared food items were weighed to the nearest gram before serving (ILS) or before being put into coolers (OLS) using an electronic scale (Scout Pro SP2001, Ohaus Corporation, Pine Brook, N.J.), and after the allocated 30 minute time period (ILS) or after the coolers were brought back to the laboratory (OLS). The macronutrient composition of foods and beverages consumed was determined and analyzed with Food Processor SQL software (version 9.6.2; ESHA Research, Salem, OR).

**Pleasantness of the foods**

During the three OLS, all participants were asked to draw a vertical line on a 150 mm visual analogue scale, reflecting their appreciation for all foods and beverages that they consumed during these experimental sessions. The question asked on each visual analogue scale was:

"How pleasant is the taste of this food?" The pleasantness rating of each item on the food menu was performed in order to determine whether the participants enjoyed/liked the foods and beverages consumed. Lastly, these ratings also served in determining whether items on the food menu should be removed and/or replaced due to low pleasantness ratings for future studies.

**Statistical analyses**

Statistical analyses were performed using SPSS software (version 17.0; SPSS Inc, Chicago, IL). An independent *t* test was done in order to determine whether any significant differences in participant characteristics existed between men and women. A two-way repeated measures ANOVA was used (PROC MIXED) to determine the main effects of the sessions (ILS and OLS) and sex on the components of dietary intake (total amount of energy (kJ), protein (kJ), carbohydrate (kJ) and dietary fat (kJ) during the ILS, the OLS as well as for the combination of the six sessions). In addition, a repeated-measure ANOVA was used (PROC MIXED) to determine the main effects of the session on the distribution of total EI (main meal, snack and beverage intakes) over the course of the ILS, OLS and the combination of the six sessions. ANOVA and Bonferroni tests were also used to evaluate where significant differences existed when looking at the distribution of total EI. Intraclass correlations (ICC) and within-subject coefficients of variations (CVws) were calculated for energy and macronutrient intakes for the ILS, OLS, as well as the combination of all six experimental sessions. The pleasantness ratings of the foods consumed are presented as the mean obtained for all foods and beverages chosen and consumed during the OLS sessions for all 16 participants. Values are presented as means and standard deviations. Differences with $p$ values $< 0.05$ were considered statistically significant.

## Results

### Characteristics of participants

The characteristics of the participants are shown in **Table 1**. As expected, there was a significant difference in body weight, height, percent of fat mass and fat-free mass between women and men. No significant differences were, however, found between men and women with regard to their age, BMI and fat mass (kg). Body weight was also stable across the six experimental sessions in men (77.0±7.9, 77.4±8.4, 76.8±8.9, 77.5±8.6, 77.4±8.5, 77.0±8.8kg; p=NS) and women (60.0±6.7, 60.1±6.4, 60.0±6.7, 60.1±6.5, 59.4±6.3, 59.4±6.1 kg; p=NS). Although it is understood that energy balance can be substantially altered before any changes in energy reserves and body weight can actually be detected, body weight measured at the beginning of each session was used as a gross proxy of weight stability and energy balance.

### Energy and macronutrient intakes

**Table 2** presents the results for energy and macronutrient intakes across the three ILS and three OLS. No significant differences were noted for total EI, carbohydrate, dietary fat and protein intakes between the three ILS and three OLS. When all six sessions were analyzed (three ILS and three OLS), no significant differences were observed for energy and macronutrient intakes. The power for the analyses of energy, carbohydrate, dietary fat and protein intakes over two meals and snacks over 5 h was 0.24, 0.16, 0.33 and 0.11, respectively. Additionally, the estimate of effect size was extremely low for the same analyses (estimate of effect size = 0.05, 0.03, 0.06 and 0.02 for energy, carbohydrate, dietary fat and protein intakes, respectively).

No significant interactions were noted between sessions and sex for EI, carbohydrate and dietary fat intakes (data not shown). However, a significant interaction was noted between sessions and sex for protein intake ($p<0.05$) only. The present results also revealed that total energy, carbohydrate and protein intakes were significantly higher in men when compared to women (**Table 2**). However, no significant difference was noted for dietary fat intake between sexes.

**Distribution of energy intake over the course of the six sessions**

The distribution of EI across the experiment was also investigated. We subdivided the foods and beverages found on the menu into main meals, snacks, energy beverages and water. The categorization of each item is presented in **Appendix 1** and is based on the type of food or beverage, and does not take into account the time at which the foods were consumed since participants were able to choose any item on the food menu, at any time. As shown in **Figure 1**, no significant differences were noted for EI (kJ) of main meals and snacks during the three ILS, three OLS and all six sessions. However, a significant difference in energy intake from beverage was noted across the six sessions ($p<0.01$), even though no significant differences were noted in the latter between the three ILS and three OLS. Indeed, significant differences were found between session 3 of the ILS and sessions 2 ($p<0.05$) and 3 ($p<0.05$) of the OLS. A significant difference was seen for water consumption (g) across sessions (565.1±270.0, 517.1±289.7, 626.7±356.6, 524.1±300.0, 528.2±317.2, 370.8±271.2 g; $p<0.01$, data not shown). More specifically, this difference was observed between the last sessions of the ILS and OLS ($p<0.05$). Additionally, a significant difference in water consumption was noted during the OLS ($p<0.05$).

**Intraclass correlations and coefficient of variation**

The ICC observed for total EI during the ILS, OLS and over the course of the six sessions are r= 0.77 (p<0.0001), r=0.85 (p<0.0001) and r=0.82 (p<0.0001), respectively (**Table 3**). However, when excluding two participants (one man and one woman) who were outliers based on their high CVws (+ 2 SDs from the mean), the calculated ICC (n=14) for total EI increased to r=0.82 (p<0.0001) for ILS, r=0.89 (p<0.0001) for OLS and r=0.86 (p<0.0001) for the six sessions. As for macronutrient intake (n=14), the ICC for carbohydrates, dietary fat and protein intakes were r=0.85 (p<0.0001), r=0.56 (p<0.0001), r=0.86 (p<0.0001) for the ILS; r=0.88 (p<0.0001), r=0.77 (p<0.0001), r=0.81 (p<0.0001) for the OLS; and r=0.86 (p<0.0001), r=0.70 (p<0.0001), r=0.81 (p<0.0001) for the six sessions.

Additionally, when the CVws were investigated, analyses revealed a CVws of 18.3±10.0% for the ILS, a CVws of 16.1±10.3% for the OLS as well as a CVws of 17.2±8.0% for the combination of the six sessions for total EI. As for macronutrient intake, CVws for carbohydrate, dietary fat and protein intakes were respectively 17.3±8.3%, 34.8±15.8% and 17.5±10.7% for the ILS; 14.7±9.4%, 34.8±22.3% and 14.7±11.4% for the OLS; 16.3±6.8%, 35.1±14.1% and 17.4±7.5% for the six sessions. When excluding the two outlier participants, the CVws decreased to 16.5±9.3% for the ILS, 14.9±10.0% for the OLS and 15.8±7.6% for the combination of the six sessions for total EI. The CVws for all components of macronutrient intake also slightly decreased after controlling for outliers, where CVws for carbohydrate, dietary fat and protein intakes were, respectively, 16.1±7.5%, 32.0±14.0% and 16.2±10.9% for the ILS; 13.7±8.0%, 30.9±19.7% and 15.8±11.7% for the OLS; 15.2±6.5%, 32.0±12.1% and 17.3±8.0% for the six sessions. Furthermore, the average pleasantness of the foods that were actually eaten and rated by all participants during the three OLS sessions was calculated to be 124±14 mm on a scale of 150 mm, which represented an average rating of 83% (**Appendix 1**).

## Discussion

Given the limitations associated with the measurement of food intake, we aimed to determine the reproducibility of a food menu that includes a large variety of meal-type foods, beverages and snacks (62 items in total) in order to measure total energy and macronutrient intakes during breakfast, mid-morning and lunch for three ILS and three OLS. We hypothesized that the energy and macronutrient intakes over several meals (two meals and snacks over 5 h) would be reproducible in men and women. The present results show no significant differences in our three ILS and three OLS as well as for the combination of these six sessions, as far as EI and macronutrient intakes are concerned. No significant interactions were noted between sex and experimental sessions for EI, carbohydrate and dietary fat intakes, while a significant interaction was found for protein intake between sexes over time. We also reported a good ICC and a relatively good CVws for total EI, while the reproducibility for macronutrient intake, especially dietary fat, was lower. Food items on the menu were overall well appreciated as participants rated them highly on a visual analogue scale (83%).

The present data show that there are no significant differences for energy and macronutrient intakes over the course of the ILS, OLS and all six sessions. In fact, this suggests that there is no more variation within each environment than there is between them. In addition, when investigating our data with regard to sex, while significant differences were noted between men and women, where men consumed a larger quantity of food, no interactions, except for protein intake, were noted between sex and each experimental session. Even though a significant interaction was noted between sex and sessions for protein intake only, no significant differences were observed in protein intake over time when analyzing men and women separately. This suggests that within the variations shown for this measurement, this tool can be used in men or women as well as within and outside the laboratory setting. When looking at the distribution of EI, even though no significant differences were noted in main meal and snack intakes, significant differences were indeed noted in energy intake from beverage and water intakes across the sessions. Water intake was higher during the last session of the ILS in comparison to the last session of OLS, while energy intake from beverage was higher during the second and third OLS in comparison with the last session of the ILS. Based on these results, it may be assumed that when participants consumed more water, energy beverage intake was decreased and vice versa. Certain studies[12,13] have noted an increase in total EI when participants consumed more energy from energy beverages. However, the increases in energy beverage intakes during sessions 2 and 3 of the OLS, in comparison with session 3 of the ILS, in the present study did not significantly influence total EI values. Finally, it can be hypothesized that a decrease in water intake may be related to an increase in the intake of water contained in foods. This was, however, not analysed because the quantity of water contained in each food was not available from the software that we used.

The present results also demonstrated positive and significant ICC for total EI during the ILS, the OLS and for the six sessions. The ICC values obtained in the present study are lower than the ICC of 0.97 obtained by Arvaniti *et al*[1] but are similar to the ICC of 0.86 presented by Gregersen *et al.*[2]. It could be argued that the buffet-style meal used by Arvaniti *et al*. [1] was only presented to the participants on one single occasion and this buffet, even if it does provide a wide variety of foods, does not offer any hot food items. Along these lines, Gregersen *et al.*[2] provided a mixed hot pot meal but, in this case, the EI was only considered for one meal on two separate occasions. A novel aspect of the present study is that nine hot meal-type options were made available from the food menu (**Appendix 1**) along with most of the items provided in the Arvaniti *et al.*[1] buffet. In addition, our food menu was investigated over several episodes (breakfast, mid-morning and lunch) of feeding as opposed to a single-sitting measure of EI. While we believe that the food menu that was investigated in the present study provides distinctive benefits, we must concede that it is not as reproducible and sensitive as single-sitting measures of EI.

With regard to the CVws values noted in the present study, these are slightly lower than the CVws of 23% noted by Bingham *et al.*[14], obtained with weighed food records over 4 d on four different occasions (total of 16 d). Studies using direct measurements with single-meal designs have reported CVws between ~6-10%[1-3]. These differences are probably explained by the use of single-meal designs, a lower number of food items offered, and possibly because food intake was measured in the laboratory. Although many studies have measured appetitive and food intake responses to manipulations such as knowledge-based work[15,16], exercise[17] and functional foods[18,19] with single meal designs, it should be noted that compensation to dietary[20,21] and exercise[22-24] manipulations is often delayed[21]. As such, the validation of a tool that measures food and beverage intake over multiple meals including snacks may provide a more accurate image of the true effect of such manipulations on EI. It is nevertheless important to note that the measurement of energy and macronutrient intakes over the course of multiple meals and multiple days instead of two meals, as in the present study, would have likely been even more revealing. It would thus be ideal to test this food menu for a more prolonged period to determine whether its reliability would increase under such conditions. In considering such a study, it would be important to weigh the logistical aspects of administration and the cost against the added precision of this tool.

Although some studies have provided foods to participants for consumption outside of the laboratory setting[25-28], to our knowledge, none has tried to study the reproducibility of these tools for measurements of total EI and all macronutrient intakes under free-living conditions. Moreover, the investigation of the same tool both inside and outside of a laboratory setting has never been done before, and the results in the present study indicate that the environment in which the participants consumed the foods and beverages provided to them did not greatly affect their total energy and macronutrient intakes. As such, the reproducibility of our food menu outside and inside of the laboratory setting provides convenience and ecological validity to our tool. However, this tool is accompanied by limitations when used outside of the laboratory, including the fact that it does not offer the certainty that only the foods that were provided were eaten, as is the case when it is used in the laboratory. Although not performed in this study, adding a follow-up questionnaire to verify whether only foods from the lunch boxes were consumed could help control for this possibility. Additionally, the activities performed by the participants during the OLS were not assessed or restricted. As such, adding an objective measure of participants' physical activity participation outside of the laboratory during the measure of food intake could also help to better understand some of the observed differences.

Furthermore, although the reproducibility of carbohydrate and protein intakes from our food menu was relatively good, it was much less the case for dietary fat. As such, certain studies have found higher variation ratios for fat intake, in comparison to carbohydrate and protein intakes[29-32] when measured over time. Cai *et al*.[33] even noted a CVws of 65.3% in fat intake (g/d) when evaluating data measured over 24 d evenly distributed over one year, using 24 h diet recall interviews. This CVws was also higher than the CVws for carbohydrate (29.5%) and protein (37.5%) intakes measured over this same time period. When comparing the mean difference in macronutrient intakes using food diaries vs. food questionnaires, higher differences were also noted in fat intake (25%), when compared with protein (5%) and carbohydrate (4%) intakes[34]. Based on these findings, it may be safe to say that dietary fat intake seems to be more variable than other macronutrients, supporting the idea that dietary fat intake may not be as reproducible over time.

Finally, the present findings are limited to a small normal-weight population, in which case only eight men and eight women were tested. It is thus not surprising to see that the power was low for energy, carbohydrate, dietary fat and protein intakes over several meals. However, as mentioned in the results, the estimate of effect size was also very low for these analyses indicating that increasing the number of participants would have very likely led to the same results for our primary outcomes. In addition, these results should be interpreted in light of the characteristics of the participants who took part in the present study. Future studies should look into the reproducibility of this tool in populations with different characteristics, such as age and BMI.

Overall, the present results suggest that the food menu investigated in the present study is a reproducible tool that can be used to measure energy and macronutrient intakes under the conditions described in the present study. However, these results also emphasize the difficulties in capturing a stable measure of EI, which is most likely due to the fact that this variable, although relatively stable over long periods of time, presents relatively high day-to-day variations. It is also suggested that both men and women respond similarly with regard to energy and macronutrient intakes, meaning that the reproducibility of this tool is not seemingly affected by the sex of the individual. Future studies should try to find the ideal timeframe for the measurement of total EI to obtain stability of the measurement while not making the tool too cumbersome and costly for experimental use.

## Acknowledgements

The authors would like to thank the participants for their devoted participation. Dr. É. Doucet is a recipient of a CIHR/Merck-Frosst New Investigator Award, CFI/OIT New Opportunities Award and of an Early Research Award. Marie-Ève Riou is a recipient of the Frederick Banting and Charles Best Doctoral Award (CIHR). Jessica McNeil is a recipient of an Ontario Graduate Scholarship. The authors declare no conflict of interest. É Doucet, MÈ Riou and J McNeil designed the research, ME Riou, J McNeil, S Cadieux, S Razmjou collected the data. MÈ Riou and J McNeil analysed the data. MÈ Riou, J McNeil and É Doucet wrote the manuscript. All authors critically appraised and approved the final version of the manuscript.

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**Table 1 -** Characteristics of women (n=8), men (n=8) and all participants (n=16)

| | Women | | Men | | Overall | | *P* value between women and men |
|---|---|---|---|---|---|---|---|
| | Mean | SD | Mean | SD | Mean | SD | |
| Age (y) | 28.1 | 9.7 | 24.9 | 2.5 | 26.5 | 7.0 | NS |
| Body weight (kg) | 60.2 | 6.8 | 77.0 | 7.9 | 68.6 | 11.2 | < 0.0001 |
| Height (cm) | 162.4 | 5.3 | 178.4 | 4.5 | 170.4 | 9.5 | < 0.0001 |
| BMI ($kg \cdot m^{-2}$) | 22.8 | 1.7 | 24.2 | 3.1 | 23.5 | 2.6 | NS |
| Fat mass (kg) | 17.1 | 3.5 | 13.2 | 8.2 | 15.2 | 6.4 | NS |
| Fat mass (%) | 28.8 | 4.1 | 16.8 | 9.0 | 22.8 | 9.2 | < 0.005 |
| Fat free mass (kg) | 42.0 | 3.7 | 64.1 | 7.8 | 53.1 | 12.8 | < 0.0001 |

NS, not significant

**Table 2 -** Energy and macronutrient intakes for each session in all participants (n=16)

| | In-lab session | | | | | | Out-lab session | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Session 1 | | Session 2 | | Session 3 | | Session 4 | | Session 5 | | Session 6 | | Overall | In-Lab | Out-Lab | Between Sex |
| | Mean | SD | Mean | SD | Mean | SD | Mean | SD | Mean | SD | Mean | SD | | | | |
| Total EI (kj) | | | | | | | | | | | | | | | | |
| Women | 5106.5 | 1440.0 | 5436.7 | 1466.8 | 4629.2 | 1301.6 | 5675.7 | 1769.5 | 5148.5 | 1023.4 | 4716.3 | 1658.8 | NS | NS | NS | 0.02 |
| Men | 7130.8 | 3332.3 | 7920.9 | 2524.2 | 8349.8 | 2552.8 | 7956.3 | 3110.0 | 7958.6 | 2534.0 | 8196.5 | 3237.6 | | | | |
| Overall | 6118.6 | 2691.2 | 6678.8 | 2371.3 | 6489.5 | 2742.9 | 6816.0 | 2713.2 | 6553.5 | 2364.5 | 6456.4 | 3066.8 | | | | |
| Carb (kj) | | | | | | | | | | | | | | | | |
| Women | 3358.2 | 1193.4 | 3259.9 | 981.4 | 2892.3 | 554.6 | 3573.7 | 1361.0 | 3357.0 | 1012.6 | 2953.8 | 835.9 | NS | NS | NS | 0.02 |
| Men | 4557.3 | 1812.0 | 5026.8 | 1895.2 | 5289.9 | 1894.5 | 5028.5 | 1670.9 | 5076.7 | 1569.4 | 5439.7 | 2123.6 | | | | |
| Overall | 3957.7 | 1606.3 | 4143.4 | 1719.9 | 4091.1 | 1830.7 | 4301.1 | 1652.8 | 4216.9 | 1554.5 | 4196.8 | 2019.5 | | | | |
| Fat (kj) | | | | | | | | | | | | | | | | |
| Women | 1063.8 | 386.5 | 1564.0 | 684.2 | 1170.7 | 762.5 | 1475.0 | 809.2 | 1164.8 | 512.1 | 1126.2 | 865.6 | NS | NS | NS | NS |
| Men | 1788.4 | 1327.0 | 1954.5 | 823.1 | 2052.3 | 799.2 | 2070.7 | 1351.0 | 2025.5 | 929.0 | 1855.9 | 1064.7 | | | | |
| Overall | 1426.1 | 1015.6 | 1759.2 | 758.5 | 1611.5 | 881.3 | 1772.8 | 1118.9 | 1595.1 | 850.1 | 1491.1 | 1010.3 | | | | |
| Protein (kj) | | | | | | | | | | | | | | | | |
| Women | 777.0 | 307.8 | 751.3 | 304.7 | 672.8 | 262.5 | 781.4 | 289.1 | 796.2 | 241.7 | 756.5 | 307.4 | NS | NS | NS | 0.04 |
| Men | 1037.9 | 450.9 | 1105.1 | 279.6 | 1188.3 | 334.9 | 1005.9 | 265.4 | 984.0 | 211.4 | 1112.9 | 341.3 | | | | |
| Overall | 907.5 | 396.6 | 928.2 | 336.4 | 930.6 | 394.2 | 893.6 | 292.1 | 890.1 | 239.8 | 934.7 | 363.8 | | | | |

EI, Energy intake; Carb, carbohydrate; Fat, Dietary Fat; NS, not significant

**Table 3 -** Intraclass correlations in all participants (n=16)

| | Intraclass Correlations | | |
|---|---|---|---|
| | In-lab | Out-lab | Overall |
| Total Energy Intake (kJ) | 0.77[†] | 0.85[†] | 0.82[†] |
| Carbohydrate (kJ) | 0.81[†] | 0.85[†] | 0.83[†] |
| Dietary fat (kJ) | 0.54[†] | 0.72[†] | 0.65[†] |
| Protein (kJ) | 0.81[†] | 0.80[†] | 0.78[†] |

[*], *p*<0.05; [**], *p*<0.01; [£], *p*<0.001; [†], *p*<0.0001; NS, not significant

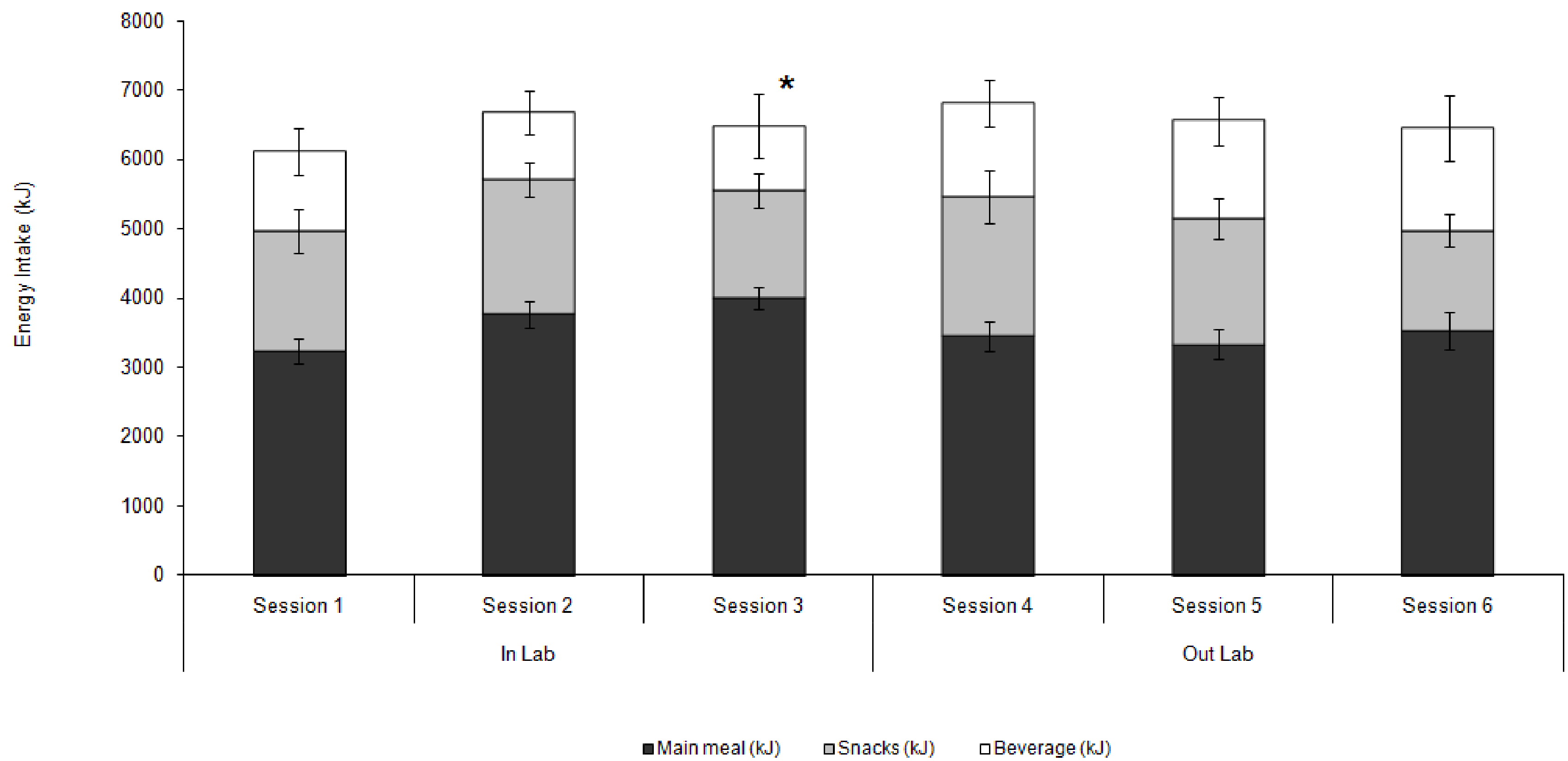


**Figure 1 -** Distribution of energy intake (kJ) as main meals, snacks and caloric beverages over the course of each session

Values are presented as means for 8 women and 8 men with standard errors of the mean represented by vertical bars
*represents a significant difference in caloric beverage intake between session 3 and sessions 5 ($p<0.05$) and 6 ($p<0.05$)

**Appendix 1 -** Energy content and macronutrient composition of the items found on the food menu[A]

| Food Item | Energy (kJ/kg) | Protein (g/kg) | % | Dietary fat (g/kg) | % | Carbohydrate (g/kg) | % | Palatability of food (150 mm) |
|---|---|---|---|---|---|---|---|---|
| Main meal: | | | | | | | | |
| Croissant (142g) | 14732.4 | 70.42 | 8.0 | 183.10 | 47.0 | 394.37 | 45.0 | 115.75 |
| White bagel (180 g) | 11157.3 | 88.89 | 13.4 | 27.78 | 9.4 | 511.11 | 77.1 | 141.5 |
| Whole wheat bagel with sesame seed (180 g) | 10692.5 | 88.89 | 13.8 | 38.89 | 13.6 | 466.67 | 72.6 | 121.81 |
| White bread (288 g) | 10460.0 | 83.33 | 13.2 | 27.78 | 9.9 | 486.11 | 76.9 | NA |
| Whole wheat bread (312 g) | 10728.2 | 115.38 | 18.5 | 32.05 | 11.6 | 435.90 | 69.9 | 131.25 |
| Packaged oats* (56 g + 375 ml of water) | 2769.2 | 24.07 | 14.5 | 12.03 | 16.4 | 114.32 | 69.1 | NA |
| Honey nut All bran cereal (150 g) | 13473.9 | 101.69 | 10.6 | 25.42 | 6 | 796.61 | 83.4 | 115.5 |
| Corn Flakes (100 g) | 15341.3 | 66.67 | 7.1 | 0.00 | 0 | 866.67 | 92.9 | 104.17 |
| Harvest crunch cereal (300 g) | 20455.1 | 88.89 | 7.2 | 200.00 | 36.7 | 688.89 | 56.1 | 100.3 |
| Honey nut cheerios (100 g) | 15870.3 | 68.97 | 7.3 | 34.48 | 8.3 | 793.10 | 84.4 | 114.03 |
| Butter (1/8 cup) | 29288.0 | ---- | 0 | 800.00 | 100 | ---- | 0 | NA |
| 3 cheese pizza (284 g) | 11491.3 | 98.59 | 14.5 | 133.80 | 44.2 | 281.69 | 41.3 | 131.73 |
| Meat lasagna (572 g) | 4681.4 | 83.92 | 29.6 | 27.97 | 22.2 | 136.36 | 48.1 | 129.79 |
| Marinara grilled chicken (566 g) | 3683.1 | 73.94 | 32.8 | 14.08 | 14.1 | 119.72 | 53.1 | 130 |
| Sweet sesame chicken (584 g) | 4728.5 | 58.22 | 20.9 | 17.12 | 13.8 | 181.51 | 65.2 | 126.25 |
| Chicken pot pie (566 g) | 9757.8 | 67.14 | 11.6 | 130.74 | 50.7 | 219.08 | 37.7 | 121.1 |
| Beef pot roast (464 g) | 3787.2 | 47.41 | 21.5 | 21.55 | 22 | 125.00 | 56.6 | 70 |
| Vegetable soup (540 ml) | 1673.6 | 16.00 | 16.7 | ---- | 0 | 80.00 | 83.3 | NA |
| Chicken noodle soup (540 ml) | 1673.6 | 28.00 | 28.6 | 8.00 | 18.4 | 52.00 | 53.1 | NA |
| Beef and vegetable soup (540 ml) | 2175.7 | 32.00 | 24 | 6.00 | 10.1 | 88.00 | 65.9 | 128.75 |
| Creamy peanut butter (60 g) | 25104.0 | 200.00 | 12 | 533.33 | 72 | 266.67 | 16 | 125.22 |
| Cream cheese (60 g) | 12552.0 | 66.67 | 9.1 | 266.67 | 81.8 | 66.67 | 9.1 | 137.66 |
| Strawberry jam (60 g) | 16736.0 | ---- | 0 | ---- | 0 | 933.33 | 100 | 97.17 |
| Salt (28 g) | ---- | ---- | 0 | ---- | 0 | ---- | 0 | NA |
| Pepper (28 g) | 10669.2 | 109.48 | 13.2 | 32.60 | 8.8 | 648.09 | 78 | NA |
| Mustard (60 g) | 2761.4 | 39.50 | 21.1 | 31.10 | 37.4 | 77.80 | 41.5 | NA |
| Mayonnaise (60 g) | 29885.7 | ---- | 0 | 785.71 | 100 | ---- | 0 | NA |
| Ketchup (60 g) | 4184 | 17.40 | 6.1 | 4.90 | 3.9 | 257.80 | 90.1 | NA |
| Snack: | | | | | | | | |
| Orange (2 medium size) | 1924.6 | 10.30 | 8 | 0.90 | 1.6 | 116.30 | 90.4 | 142.88 |
| Banana (2 medium size) | 3849.3 | 10.30 | 4 | 4.80 | 4.2 | 234.30 | 91.7 | 126.93 |
| Apple (2 medium size) | 2468.6 | 1.90 | 1.2 | 3.60 | 5 | 152.50 | 93.8 | 128.58 |
| Green grapes (350 g) | 2887.0 | 7.20 | 3.8 | 1.60 | 1.9 | 181.00 | 94.4 | 115.19 |
| Valley nature sweet and salty granola bar (70 g) | 20322.3 | 85.71 | 7.1 | 228.57 | 42.9 | 600.00 | 50 | 124.33 |
| " Chewy Quaker" chocolate granola bar (62 g) | 18895.5 | 64.52 | 5.5 | 161.29 | 31 | 741.94 | 63.4 | 128.33 |
| Nutri-grain blueberry bar (74 g) | 14700.5 | ---- | 0 | 81.08 | 22 | 648.65 | 78 | 107.35 |
| Vanilla ice cream* (500 ml) | 9372.2 | 40.00 | 7.2 | 152.00 | 61.3 | 176.00 | 31.5 | NA |
| Chocolate ice cream* (500 ml) | 9037.4 | 40.00 | 7.3 | 144.00 | 59.1 | 184.00 | 33.6 | NA |
| Skittles (160 g) | 16736 | 2.50 | 0.3 | 37.50 | 8.5 | 900.00 | 91.2 | 140 |
| Kit Kat (90 g) | 21384.9 | 66.67 | 5.1 | 266.67 | 45.8 | 644.44 | 49.2 | 133.9 |
| Caramilk (104 g) | 19310.7 | 57.69 | 4.9 | 211.54 | 40.1 | 653.85 | 55.1 | 144 |
| Hershey chocolate with almonds (86 g) | 23352.6 | 116.28 | 8.2 | 348.84 | 55.6 | 511.63 | 36.2 | 141 |
| 70% dark chocolate (100 g) | 25104 | 60.00 | 3.8 | 480.00 | 69.2 | 420.00 | 26.9 | 138.75 |
| Chocolate chip cookies (140 g) | 20322.3 | 57.14 | 4.7 | 228.57 | 41.9 | 657.14 | 53.5 | NA |
| Lays regular chips (200 g) | 23430.4 | 60.00 | 4.3 | 360.00 | 58.3 | 520.00 | 37.4 | 130.17 |
| Lays BBQ chips (200 g) | 21756.8 | 60.00 | 4.6 | 300.00 | 51.3 | 580.00 | 44.1 | 120 |
| Silhouette 0% yogurt (400 g) | 1464.4 | 30.00 | 33.3 | ---- | 0 | 60.00 | 66.7 | 133.4 |
| Danone 1.5% yogurt (400 g) | 3765.6 | 40.00 | 17.1 | 15.00 | 14.4 | 160.00 | 68.4 | 126.56 |
| Red pepper (1 medium size) | 1129.7 | 8.90 | 11.5 | 1.90 | 5.5 | 64.30 | 83 | 117.47 |
| Cucumber (1/2 of a whole) | 502.1 | 5.70 | 16.6 | 1.60 | 10.5 | 25.00 | 72.9 | 115.75 |
| Baby carrots (250 g) | 1476.7 | 11.76 | 12.5 | ---- | 0 | 82.35 | 87.5 | 111.38 |
| Ranch vegetable dip (60 ml) | 19525.3 | 33.33 | 2.9 | 466.67 | 91.3 | 66.67 | 5.8 | NA |
| Cheddar cheese (147 g) | 16736.0 | 233.33 | 23.7 | 333.33 | 76.3 | ---- | 0 | 134.45 |
| Brie cheese (90 g) | 12552.0 | 200.00 | 27.6 | 233.33 | 72.4 | ---- | 0 | 122.38 |
| Breton original crackers (66 g) | 20920.0 | 90.91 | 7.3 | 227.27 | 41.3 | 636.36 | 51.4 | 133 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Caloric beverage: | | | | | | | | |
| Tropicana apple juice† (500 ml) | 2008.3 | 4.00 | 3.3 | ---- | 0 | 116.00 | 96.7 | 124.59 |
| Tropicana orange juice† (500 ml) | 1841.0 | 8.00 | 6.9 | ---- | 0 | 108.00 | 93.1 | 131.75 |
| Pepsi† (500 ml) | 1841.0 | ---- | 0 | ---- | 0 | 116.00 | 100 | 125.17 |
| 7 up† (500 ml) | 1885.7 | ---- | 0 | ---- | 0 | 121.13 | 100 | 100 |
| 1% milk† (500 ml) | 1673.6 | 36.00 | 33.8 | 10.00 | 21.1 | 48.00 | 45.1 | 127.74 |
| 3.25% milk† (500 ml) | 2677.8 | 36.00 | 23.1 | 32.00 | 46.2 | 48.00 | 30.8 | NA |
| 1% chocolate milk† (500 ml) | 2677.8 | 28.00 | 17.7 | 10.00 | 14.2 | 108.00 | 68.1 | 131.47 |
| Water† (500 ml) | ---- | ---- | 0 | ---- | 0 | ---- | 0 | 132.13 |

[A] Energy, protein, dietary fat and carbohydrate contents are based on information found on the food labels while fruits and vegetable are based on information found in the Food processor SQL program
*These items were only offered during the in-lab sessions
NA, no data on pleasantness rating was obtained during the out-of-lab sessions for these food items
† 1000 ml were given in the OLS over five hours.

## 3.4 Thesis Article # 4

The article entitled "Validation and Reliability of a Method to Measure the Time Spent Performing Different Activities" presented in this section of the thesis is currently under review in *Research Quarterly for Exercise and Sports*.

# Validation and Reliability of a Method to Measure the Time Spent Performing Different Activities

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**Running title:** Measurement of Time Spent Performing Activities

**Key words**: Activity monitoring systems, classification model, support vector machine, confusion matrix

**Disclosure of funding**: None

**Conflict of interest:** The authors declare no conflict of interest

## Abstract

**Purpose**: To validate the performance and reliability of results obtained from a classification model that measures time spent performing activities in confined (CE) and unrestricted (UE) environments.

**Methods**: In CE, participants wore a pair of biaxial and/or triaxial accelerometers while performing pre-determined training activities classified as variants of lying down, dynamic standing, sitting, walking and running on two separate days. A classification model trained with activities performed in a specific order during the first day was developed to validate the activities performed in a random order on the second day (CE) and over 24 hours on a separate day (UE). The performance of the classification model was validated against triaxial accelerometers using six (x, y and step counts for arm and thigh) or eight (same as six features plus z axis) features. The reproductibility of the classification model was tested in both environments using six features.

**Results:** Results revealed an overall accuracy of 94% in CE and 90% in UE. The sensitivity in CE and UE was 94% and 95% for lying down, 88% and 80% for dynamic standing, 97% and 89% for sitting, 96% and 78% for walking and 90% and 64% for running, respectively. No significant differences were noted between performances obtained with six or eight features. Results were highly reproducible in both environments.

**Conclusions**: The results obtained from the classification model were accurate and reproducible, and highlight the potential use of this approach in research to quantify the time spent performing different activities.

## Introduction

Activity monitoring systems are used to estimate energy expenditure using data captured by accelerometers and other sensors. They have been widely used due to their small size, low cost, and low power consumption[1,2]. Nevertheless, the measurement of energy expenditure does not allow the characterization of the different activities performed during a determined time frame. As reviewed by Preece *et al* (2009) and Yang & Hsu (2010), activities performed can be computed from raw accelerometry data using classification models that are obtained from machine learning classifiers (*e.g.,* decision trees, neural networks, Bayesian classifiers, support vector machines and others)[1,2].

The validation of classification models aimed at recognizing activities has been conducted in a confined environment (CE), showing a high accuracy[3-6]. Some studies have also been performed in a semi-unsupervised environment showing similar results[7-13]. Under a free, unsupervised period of 4 hours, Ermes[14] showed a sensitivity (chances of classifying an activity as positive when it is indeed positive) of 98% for lying down, 80% for sitting/standing and 30% for walking when four annotated activities were considered over a total of nine recognized activities. Long *et al.* also demonstrated a sensitivity of 80% for walking and 93% for running when participants annotated five activities over a 10-hour period when using one accelerometer[15]. However, to our knowledge, no study has validated the results obtained from a classification model over 24 hours in an unrestricted environment (UE). One of the reasons is that the internal memory of devices is limited in size and quickly fills up when data are sampled at a high frequency. Nevertheless, recognizing only major categories of activities (*i.e.*, lying down, dynamic standing, sitting and walking) does not require a high data-sampling frequency due to the nature of these activities and thus makes the recording over a longer period of time possible.

The first objective of this study was to build a classification model for biaxial and triaxial accelerometers and to validate the performance of this model in discriminating five different activities. Specifically, the performance was validated using data gathered under 2 hours in CE and under 24 hours in UE. The second objective was to compare the performance of the classification model using a set of six (x, y and step counts for arm and thigh) or eight (x, y, z and step counts for arm and thigh) features recorded from the triaxial accelerometers. The third objective was to assess the reliability of the results acquired from the classification model obtained with biaxial and triaxial using six features under CE and UE. We hypothesized that (a) the results would be highly accurate in both environments using biaxial or triaxial accelerometers (b) the performance of the classification model obtained with six or eight features would be similar and (c) the results obtained from the classification model would be highly reproducible in both the CE and UE.

## Methods

### Participants

A total of seventeen males and nineteen females students were recruited to complete this set of experiments. The inclusion criteria were as follows (a) over the age of 18 years; (b) stable weight (±2 kg) within the past six months; (c) nonsmokers; (d) no drug or alcohol abuse; and (e) without any orthopedic limitation. All experiments were conducted according to the guidelines laid down in the Declaration of Helsinki and the ethics committee approved all the procedures involving human participants. Written informed consent was obtained from all participants.

### Accelerometers

A pair of biaxial and/or triaxial activity-monitoring systems (accelerometers) (SenseWear Pro 3 Armbands©, HealthWear Bodymedia, Pittsburgh, PA) were used. SenseWear Pro 3 Armbands were chosen because they provide access to raw data (acceleration axes and step counts) and provide accurate estimates of energy expenditure[16]. One accelerometer was placed around the upper arm (midway between the acromion and the olecranon) while the other was placed around the thigh (midway between the patella and the inguinal fold). The internal clocks of both accelerometers were synchronized before the beginning of each session with the researcher's watch or with the participants' watch. The data recorded over time were the following features: x and y acceleration axes and the step counts (for the arm and thigh) while using a biaxial accelerometer and the x, y and z acceleration axes and the step counts (for the arm and thigh) while using a triaxial accelerometers. Therefore, the biaxial accelerometers provided six features while the triaxial accelerometers provided eight features. In terms of anatomic axes, the x, y and z axes represent the horizontal, vertical and sagittal axes, respectively. The acceleration axes were sampled every five seconds and the step count every minute. The combination of the accelerations and step counts recorded every five seconds refer to one data sample.

**General Procedures of the Study**

This study consisted of four experiments (**Figure 1**) (a) Building the classification model with biaxial and triaxial accelerometers (Experiment I); (b) Validating the performance of the classification model in CE and in UE with biaxial and triaxial accelerometers (Experiment II); (c) Validating the performance of the classification model with triaxial accelerometer when using six or eight features (Experiment III); (d) Investigating the reproducibility of results obtained from the classification model when using six features recorded by a biaxial and a triaxial accelerometers under CE and UE (Experiment IV). The four experiments are further described in the following sections.

**Experiment I - Building the Classification Model.** The data (acceleration axes and step counts) were obtained from accelerometers worn by participants performing 22 predetermined training activities classified as variants of lying down, dynamic standing, sitting, walking, running, biking, and climbing stairs in a specific order. The procedures were performed under the supervision of the researcher who recorded the beginning and end of each activity.

The INNERVIEW software (version 4.02; Bodymedia, Pittsburgh, PA) was used to extract the data obtained from the 22 predetermined training activities (training data) from the accelerometers (**Figure 2 A**). Training data were exported in two Comma-Separated Values (CSV) files: one file for the accelerometer worn on the arm and one for the accelerometer worn on the thigh. *Activity Recognition* software was used to combine and to synchronize these two training data files, which produced a single file containing a sequence of training data samples. The associated activity for each sample was then identified based on the recording time. Transitions from one activity to another were manually removed from the training data set. Two classification models (support vector machines, kernel type: radial basis function; cost: 10; gamma parameter: 0.01) were then built using those training samples (recorded features and known activity): one model with the biaxial accelerometers (*Experiment 1: Biaxial*) and one with the triaxial accelerometers (*Experiment 1: Triaxial*). To facilitate the discrimination between variants of dynamic standing and walking, a threshold of 30 steps per minute or less was used. The rationale for using a 30 step counts per minute threshold is based on the reasoning that dynamic standing could be associated with minor lower body movement at low speeds for short distances (which is equivalent to one step every two second or less).

**Experiment II - Validating the Performance of the Classification Model.** To validate the performance of the classification model under CE (*Experiment 2: Biaxial_CE and Experiment 2: Triaxial_CE*), participants were asked to perform the same 22 predetermined training activities in a different order, which was different for each participant. After initial analyses, low accuracy of biking and climbing stairs (*i.e.,* 37% for climbing the stairs and 74% for biking in *Experiment 2: Biaxial_CE*) were obtained. Therefore, these activities were removed from the models and were not further classified as part of this study. The classification model therefore classified climbing stairs or biking as either walking or running. During the validation of the UE (*Experiment 2: Biaxial_UE and experiment 2: Triaxial_UE*), participants were asked to mark down on a sheet of paper five categories of activities (lying down, dynamic standing, sitting, walking or running) with the start and finish times (precision within one second) over a 24-hour period. Dynamic standing was described to the participants as a static standing position that could include dynamic movement of the upper body. Since it could be associated with minor lower body movement, walking for short distances (less than 30 steps per minute) was also considered as dynamic standing. Examples include meal preparation, washing dishes, talking to someone while standing, etc. Walking was categorized as a displacement of more than 30 consecutive steps per minute. Examples include walking to work, walking to the bus stop, walking the dog, etc. Each data sample from *Experiment II* was obtained as previously described (*i.e.,* INNERVIEW software, CSV, *Activities Recognition Software*) and classified as an activity either by the biaxial or triaxial classification model (**Figure 2 B**). The *Activity Recognition Software* was used to coordinate this sequence. The total time spent performing each activity was determined as the product of the sampling rate (5 s) and the number of occurrences of the different activities. The classification was then compiled in a confusion matrix to determine the validity of the results obtained from the classification model. Under UE, participants were instructed to remove the accelerometer during all water activity, including bathing, but to wear it overnight.

**Experiment III - Validating the Performance of the Classification Model with Triaxial Accelerometer when Using six or eight Features.** For this experiment, data samples obtained from six (*i.e.,* x, y axes and step counts times two accelerometers) and eight features (*i.e.,* x, y and z axes and step counts times two accelerometers) were compared in a CE and in a UE. The results in terms of activity classification were obtained from the same triaxial accelerometers while either including (eight features) or removing the z axis (six features) (**Figure 1**).

**Experiment IV - Investigating the Reliability of the Results Obtained from the Classification Model using six Features**. The reliability of the results obtained from the classification model using six features was investigated. Results of *Experiment 2: Biaxial* were compared with results of *Experiment 2:* Triaxial in both CE and UE (**Figure 1**). The z axis (arm and thigh) from each data sample obtained with the triaxial accelerometers was removed for this analysis.

**Statistical Analysis**

Statistical analyses were performed in Excel (version 2007). Performance of the classification model was determined with the overall accuracy (*i.e.,* mean proportion of all activities that are correctly classified per person) and using five indicators: sensitivity (chances of classifying an activity as positive when it is indeed positive), the positive predictive value (chances that an activity is indeed positive, when it is classified as positive), the F-Score (the "harmonic mean between sensitivity and positive predictive values"[17] $\left(2\frac{(sensitivity \cdot precision)}{(sensitivity + precision)}\right)$) and the specificity (chances of classifying an activity as negative when they are truly negative) in a confusion matrix. Cohen's kappa coefficient (measure of the agreement between the real activity and the classifications) was also determined[18]. In order to investigate the difference between the performance of the classification model using six or eight features, a Wilcoxon matched-pairs signed rank test was performed using statistical software (Prism v5, GraphPad Software Inc., San Diego, CA). To investigate the reliability of the results obtained from the classification model when using six features (overall accuracies) in CE and UE, an independent samples t-test was performed. The underlying assumption of normality of the two samples t-test was verified with a normal probability plot performed with Minitab 16. A linear tendency was observed in both plots suggesting that it is reasonable to assume that the accuracy is normally distributed (**Figure 3 A** and **B**). However, since the slopes were very different in CE, the equality of the variance was not assumed. As a result, a t-test with a Welch correction was performed with the GraphPad Prism. Values are presented as percentage ± standard deviation.

## Results

The participants' characteristics are described in **Table 1**.

### Phase II - Validating the Performance of the Classification Model in CE

The confusion matrix presented in **Table 2** shows the real and classified time (s) spent performing activities in CE. The classification model had an overall accuracy of 94±4%, including lying down, dynamic standing, sitting, walking and running. The sensitivity was higher than 90% for all the time spent in activities except for dynamic standing, which had the lowest classification results (88±18%). The positive predictive value was 95±8% for lying down, 95±8% for dynamic standing, 98±3% for sitting, 66±8% for walking, and 88±18% for running. The F-score demonstrated a high overall performance for lying down, dynamic standing, sitting, running, and with the lowest value for walking (76±16%). The high specificity (higher than 99% for most of the activities) suggested that the classification model can accurately detect a specific activity with limited false-positive values. Finally, the association between the real activities and the classification, measured with Cohen's Kappa Coefficient, indicated that the classification model developed in CE highly agrees with the reality (0.93±0.004).

### Phase II - Validating the Performance of the Classification Model in UE

The confusion matrix presented in **Table 3** presents the real and classified time (s) spent performing activities in UE. The classification model had an overall accuracy of 90±4% and a sensitivity that varies between 64 and 95%. Of all activities, lying down and sitting had the highest sensitivity. The positive predictive values were 85±9% for lying down, 76±12% for dynamic standing, 85±6% for sitting, 56±21% for walking and 88±18% for running. Since walking had the lowest sensitivity and positive predictive value, it had an F-Score of 62±18%. The high specificity (between 87 and 100%) and a Cohen's Kappa Coefficient of 0.85±0.001 suggested respectively that the classification model had a low false-positive rate and that there was a high degree of agreement between the reality and the classification.

**Phase III - Validating the Performance of the Classification Model with Triaxial Accelerometer when using six or eight Features**

**Table 4** presents results of the performance of the triaxial accelerometer when using six or eight features in CE and UE. The difference between both overall accuracies revealed no significant difference in CE (p=0.81) and UE (p=1.0).

**Phase IV - Investigating the Reliability of the Results Obtained from the Classification Model using six Features**

The analyses of the reliability of the results obtained from the classification model showed no significant differences for the overall accuracy in CE (p=0.056) or UE (p=0.447). The results confirmed with 95% confidence that the difference in the overall accuracies was 6.0% with a maximum error of 6.3% in CE. Similarly, the analyses revealed with 95% confidence that the difference in the overall accuracies was 1.6% with a maximum error of 4.3% in the UE.

## Discussion

To our knowledge, this is the first study to validate a model to determine the time spent performing activities in UE for a period of 24 hours. Collectively, these results indicate the relatively high performance of the classification model in CE and UE. Furthermore, the present findings demonstrate that including eight features *vs*. six features does not increase the performance of the classification model, at least when investigating the five categories of activities presented in this paper. Finally, the results obtained from the classification model showed a high level of reliability when using six features in both CE and UE.

**Phase II - Validating the Performance of the Classification Model in CE**

The results obtained in CE suggest an overall accuracy of 94%. This accuracy is similar to that previously reported[4]. When further investigating the time spent in activities, our results showed a higher sensitivity than the one observed by Van Laerhoven in a case study measuring seven activities[5]. The only exception was for dynamic standing, which is 6% lower in our study[5]. The lower recognition accuracy for dynamic standing in our study could be related to the confusion involving the transition between the static and dynamic activities[19]. The model could not accurately recognize the transitions between each task, which highlights a need for machine-learning classifiers that can detect temporal sequences such as Hidden Markov Models. However, it could be speculated that in a normal environment, the number of transitions between different activities is relatively low compared to the transition that was done every 2 min in the CE protocol. Nevertheless, when dynamic standing was combined with walking, the sensitivity increased to 98±4%. The number of accelerometers used could also explain slight differences between studies. The classification model shows better accuracy for sitting and dynamic standing as did other studies that used multiple sensors[7,9,20] compared to studies that only used one accelerometer[4,19,21]. Our results as well as those from other studies[19,22] emphasize the importance of using at least two sensors to improve the classification accuracy of sitting and dynamic standing. This is particularly important because these activities constitute a large proportion of daily activity in a modern environment[23].

**Phase II - Validating the Performance of the Classification Model in UE**

Based on Foester's research, a reduction in the overall accuracy of the classification model would have been expected in CE (95.8%) compared to UE (66.7%) (nine activities)[9]. The overall accuracy obtained from the 24 hours of participants' annotations was only 4% lower, which is less than what has been observed by others[8,14]. A closer inspection of our data revealed that the sensitivity for dynamic standing, walking, and running were the lowest. Nevertheless, after combining dynamic standing and walking, the sensitivity improved to 93±5%. These values are slightly better than those reported by Ermes *et al.* (2008) for 4 hours of testing when four out of nine activities were annotated by the participants. It is also important to note that the proportion of time was 37% or 8.9 hours for lying down, 12% or 2.9 hours for dynamic standing, 45% or 10.8 hours for sitting, 5% or 1.2 hours for walking and 0.05% or 0.01 hours for running[14]. In this case, even if the proportion of time spent lying down and sitting (82% or 19.7 hours) is high, it represents the percentage of time spent in sedentary behaviors (*i.e.,* lying down and sitting) generally observed in the population[23].

**Phase III - Validating the Performance of the Classification Model with Triaxial Accelerometer when using six or eight Features**

It would seem logical that adding the z acceleration axes should lead to a better activity classification. However, this is not the case since no significant differences were noted between the overall accuracy when including or excluding the z axis of both accelerometers. It should be noted that the step count was part of both features sets. In addition, the activities analyzed were mostly performed in the x and y acceleration axes, which does make the inclusion of a third axis (z axis) rather unnecessary. We can thus conclude from our data that using a model that was trained using either six or eight features does not improve classification accuracy under the conditions described in this study.

**Phase IV - Investigating the Reliability of the Results Obtained from the Classification Model using six Features**

Our results suggest that the classification model obtained in CE and in UE is reproducible. Indeed, the maximum error was 6.3% in CE and 4.3% in UE. A small difference between the internal clocks of both accelerometers and the researcher's watch could have increased the variability across sessions in the CE. Similarly, the maximal error can be explained by the small difference between internal clocks of both accelerometers and the participant's watch in UE. The complexity and inconvenience related to the exact description of the movement second-by-second by the participant may have been associated with lower annotation compliance and thus may have lead to a certain degree of under-reporting that could have also reduced the reliability of the classification model.

## Limitations

Even if the classification model presented and discussed could be considered to have good classification accuracy in both CE and UE, several confounding factors should be considered and identified. Only 2 min in each activity were used to construct the classification model and the transition between the static and dynamic movements was not taken into account. In addition, even with pre-determined training activities classified as variants of lying down, dynamic standing, sitting, walking, and running, more variations of these activities exist and are likely adopted in a real life setting. In this regard, it is important to note that this study initially included stair ascending and descending as well as biking. Because the preliminary validation of the performance of the classification model obtained with biaxial accelerometers in CE gave us a low sensitivity for these activities (*i.e.,* 37% for climbing stairs and 74% for biking), they were not included in the classification model nor were they further investigated. Firstly, the protocol used to measure stairs climbing included 2 min of ascending and descending stairs. Since both patterns are different, the method used was not specific enough for a good classification. Secondly, the sampling rate of 5 s for the accelerations and 1 min for the step count was not high enough to measure biking. It could be hypothesized that a longer time spent doing the activity and a higher sampling frequency would have been helpful in this case. The decision to maintain the sampling frequency was mostly informed by the fact that a higher sampling frequency would have overwhelmed the storage capacities of the devices over longer sampling periods under real life conditions. Finally, the use of an another accelerometer and/or a GPS could have help to measure biking[24].

The classification model developed in this study was shown to be accurate and reliable over 24 hours in UE. Our results show no significant benefit of using eight compared to six features to determine the time spent performing five activities as far as the present classification model is concerned. The study highlights the potential use of this classification model in applied research aimed at investigating the time spent performing activities.

**What Does This Article Add?**

The results highlight the high accuracy and reliability of both classification models in CE and UE. To the best of our knowledge, no study has investigated and validated several activities under unrestrictive conditions for longer periods (*i.e.,* 24 hours), which is explained mainly by a limited internal memory capacity of sensors is that is quickly filled up at high sampling frequencies. In this study, we show that our model, which was developed while using a lower sampling frequency, is equally valid for activity recognition, with a major advantage being the simultaneous measurement of several activities that comprise a substantial proportion of daily modern activities for a much longer duration (up to seven days). Finally, this study also shows that activity recognition models including either six or eight features (*i.e.,* biaxial vs. triaxial accelerometers, respectively) are not different in terms of their performance, at least when investigating the five categories of activities presented in this paper. Future research in this area is needed to develop classification models that are more sensitive to capture activities such as biking, stair climbing as well as transitions between activities.

## Acknowledgements

The authors would like to thank the participants for their devoted participation.

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**Table 1 -** Participants characteristics

| Experiment | | Weight (kg) | BMI (kg/m²) | Age (yr) |
|---|---|---|---|---|
| | All (N=12) | 67.9 ± 11.2 | 23.5 ± 2.4 | 24.6 ± 4.6 |
| Experiment I | Females (n=7) | 60.2 ± 6.8 | 22.7 ± 1.8 | 24.7 ± 5.9 |
| | Males (n=5) | 78.7 ± 4.8 | 24.5 ± 3.0 | 24.4 ± 2.4 |
| | All (N=12) | 68.0±12.4 | 23.6±3.0 | 26.7±2.9 |
| Experiment II | Females (n=6) | 58.9±6.3 | 22.4±1.1 | 26.0±2.8 |
| | Males (n=6) | 77.2±10.1 | 24.9±3.9 | 27.3±3.1 |
| | All (N=6) | 68.5±13.2 | 23.2±2.8 | 21.3±2.7 |
| Experiment III (CE) | Females (n=3) | 58.1±7.5 | 21.6±1.5 | 22.7±3.5 |
| | Males (n=3) | 79.0±7.0 | 24.8±3.2 | 20.0±1.0 |
| | All (N=6) | 65.2±11.5 | 22.5±2.2 | 21.5±1.5 |
| Experiment III (UE) | Females (n=3) | 55.2±4.8 | 21.1±0.9 | 21.0±2.0 |
| | Males (n=3) | 75.1±3.4 | 24.0±2.3 | 22.0±1.0 |

Values are mean ± SD
BMI, body mass index
[a] A total of 13 participants, were recruited. However, one participant had to be excluded because of incomplete accelerometry data

**Table 2 -** Confusion matrix of the time spent performing activities obtain from the results of the classification model in CE sessions

| | | Class | | | | | |
|---|---|---|---|---|---|---|---|
| | | Walking | Sitting | Running | Lying down | Dynamic Standing | Overall |
| Real | Walking | 1334 | 0 | 36 | 0 | 24 | |
| | Sitting | 0 | 2552 | 0 | 55 | 10 | |
| | Running | 60 | 0 | 478 | 0 | 0 | |
| | Lying down | 9 | 43 | 0 | 1057 | 15 | |
| | Dynamic Standing | 96 | 9 | 0 | 0 | 734 | |
| Overall Accuracy (%)[a] | | | | | | | 94±4 |
| Sensitivity (%)[b] | | 96±12 | 97±4 | 90±20 | 94±7 | 88±18 | |
| F-Score (%)[c] | | 76±16 | 98±2 | 88±18 | 94±6 | 90±11 | |
| Specificity (%)[d] | | 88±4 | 99±2 | 99±2 | 99±2 | 99±1 | |
| Kappa[e] | | | | | | | 0.93±0.00 |
| Linear Weight Kappa | | | | | | | 0.90±0.01 |
| Quadratic Weighted Kappa | | | | | | | 0.87±0.01 |

[a] Overall accuracy is the mean proportion of all activities that are correctly classified per person
[b] Sensitivity corresponds to the chances of classifying an activity as positive when it is indeed positive
[c] F-Score is defined as the "harmonic mean between sensitivity and positive predictive values"[17]
[d] Specificity is a measure of chances of classifying an activity as negative when they are truly negative
[e] Cohen's Kappa is the measure of the agreement between the real activity and the classifications

**Table 3 -** Confusion matrix of the time spent performing activities obtained from the results of the classification model in UE sessions

| | | Class | | | | | |
|---|---|---|---|---|---|---|---|
| | | Walking | Sitting | Running | Lying down | Dynamic Standing | Overall |
| Real | Walking | 7663 | 318 | 60 | 17 | 1471 | |
| | Sitting | 515 | 80640 | 0 | 6495 | 2307 | |
| | Running | 260 | 0 | 780 | 0 | 0 | |
| | Lying down | 22 | 3855 | 0 | 69878 | 89 | |
| | Dynamic Standing | 2418 | 1454 | 0 | 266 | 19937 | |
| Overall Accuracy (%)[a] | | | | | | | 90±4 |
| Sensitivity (%)[b] | | 78±16 | 89±11 | 64±27[c] | 95±4 | 80±7 | |
| F-Score (%)[d] | | 62±18 | 83±7 | 73±24[c] | 86±4 | 75±8 | |
| Specificity (%)[e] | | 90±2 | 88±4 | 100±0[c] | 87±6 | 90±2 | |
| Kappa[f] | | | | | | | 0.85±0.00 |
| Linear Weight Kappa | | | | | | | 0.81±0.00 |
| Quadratic Weighted Kappa | | | | | | | 0.77±0.00 |

[a] Overall accuracy is the mean proportion of all activities that are correctly classified per person
[b] Sensitivity corresponds to the chances of classifying an activity as positive when it is indeed positive
[c] F-Score is defined as the "harmonic mean between sensitivity and positive predictive values"[17]
[d] Specificity is a measure of chances of classifying an activity as negative when they are truly negative
[e] Cohen's Kappa is the measure of the agreement between the real activity and the classifications

**Table 4 -** Confusion matrix of the time spent performing activities with triaxial accelerometers when using six and eight features

| | | CE | | UE | |
|---|---|---|---|---|---|
| | | 6 features | 8 features | 6 features | 8 features |
| Sensitivity (%)[a] | Walking | 91±7 | 91±7 | 83±6 | 83±6 |
| | Sitting | 92±8 | 94±7 | 93±3 | 94±5 |
| | Running | 64±25 | 64±25 | - | - |
| | Lying Down | 92±4 | 90±11 | 88±11 | 87±10[A] |
| | Dynamic Standing | 85±11 | 87±9 | 79±8 | 79±8 |
| F-Score (%)[b] | Walking | 85±6 | 85±6 | 77±4 | 77±4 |
| | Sitting | 94±5 | 95±3 | 90±5 | 90±5 |
| | Running | 69±21 | 69±21 | - | - |
| | Lying Down | 86±13 | 88±9 | 91±6 | 91±5[A] |
| | Dynamic Standing | 88±6 | 89±5 | 83±5 | 84±5 |
| Specificity (%)[c] | Walking | 94±3 | 94±3 | 98±1 | 98±1 |
| | Sitting | 98±1 | 97±2 | 90±5 | 89±7 |
| | Running | 99±2 | 99±2 | 100±0 | 100±0 |
| | Lying Down | 96±5 | 97±3 | 97±2 | 97±4 |
| | Dynamic Standing | 99±1 | 99±1 | 99±1 | 99±1 |
| Overall Accuracy (%)[d] | | 88±6 | 89±4 | 89±4 | 89±4 |
| Kappa[e] | | 0.84±0.01 | 0.85±0.00 | 0.82±0.00 | 0.83±0.00 |
| Kappa linear weight | | 0.81±0.01 | 0.81±0.00 | 0.79±0.00 | 0.80±0.00 |
| Kappa quadratic weight | | 0.79±0.02 | 0.79±0.02 | 0.76±0.01 | 0.76±0.01 |

Running was not included in UE due to the fact that no participants practiced this activity
For lying down in UE n = 5 due to the fact that one participant did not practiced this activity

[a] Sensitivity corresponds to the chances of classifying an activity as positive when it is indeed positive
[b] F-Score is defined as the "harmonic mean between sensitivity and positive predictive values"[17]
[c] Specificity is a measure of chances of classifying an activity as negative when they are truly negative
[d] Overall accuracy is the mean proportion of all activities that are correctly classified per person
[e] Cohen's Kappa is the measure of the agreement between the real activity and the classifications.

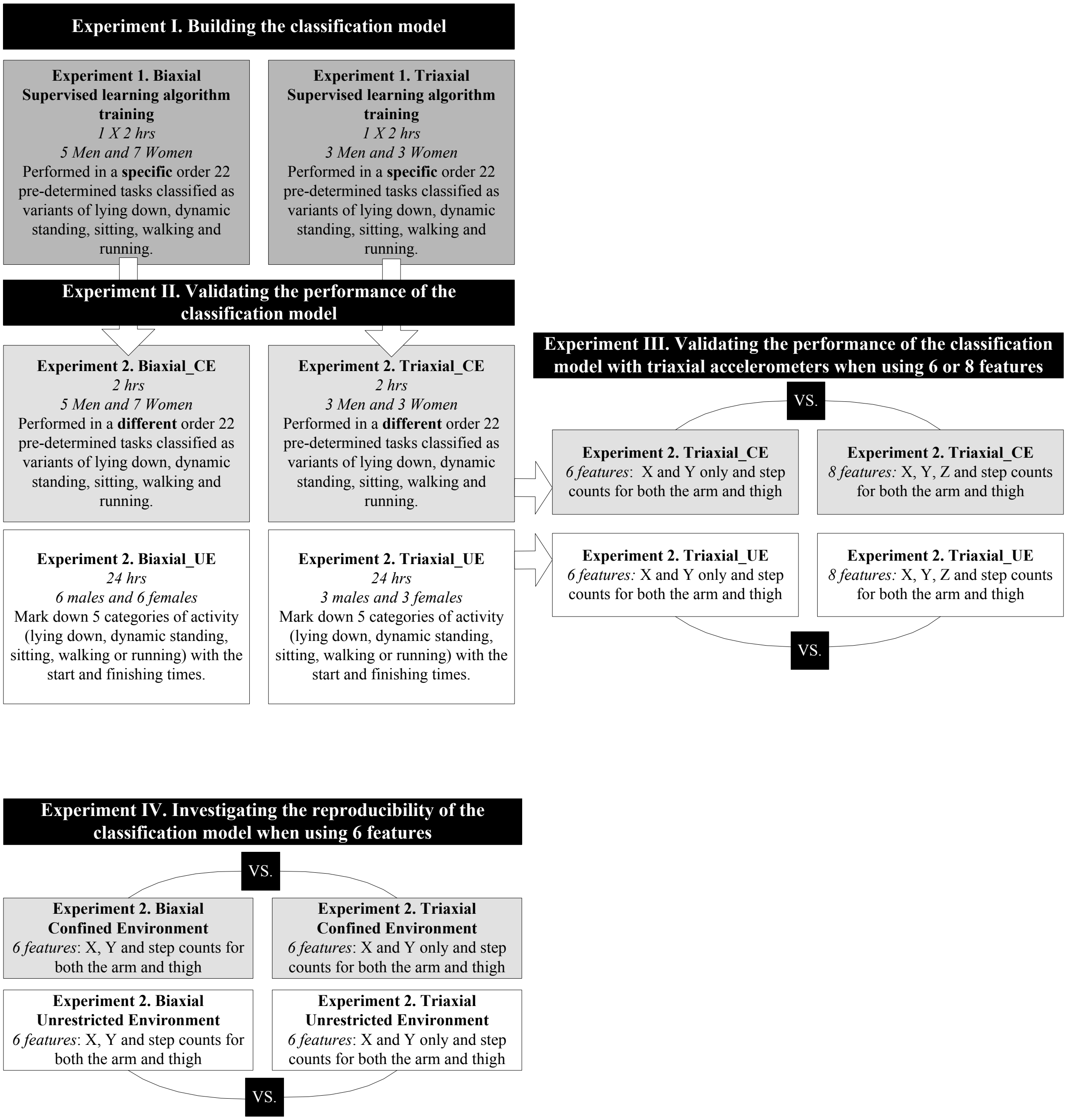



**Figure 1 -** General procedures of the study

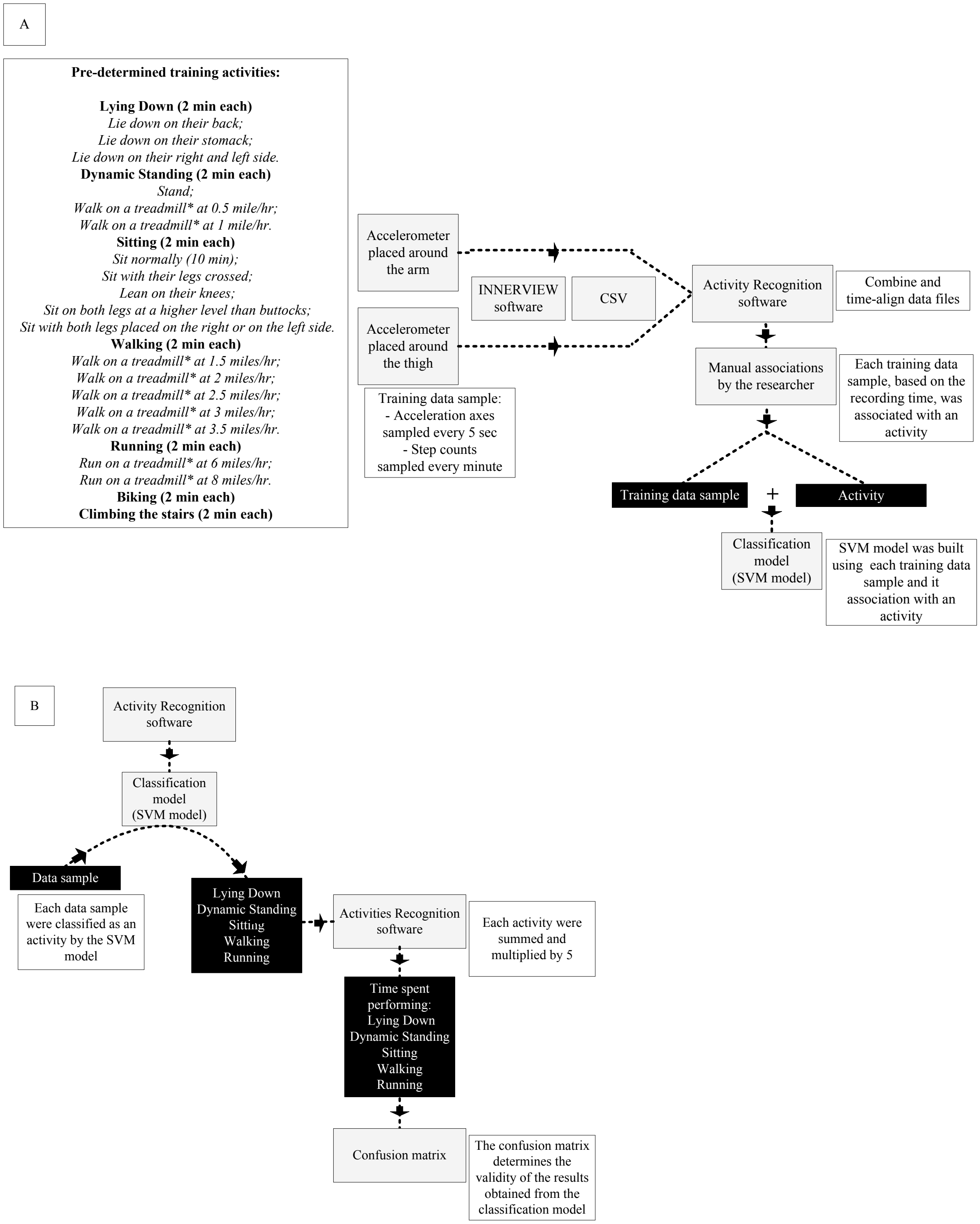
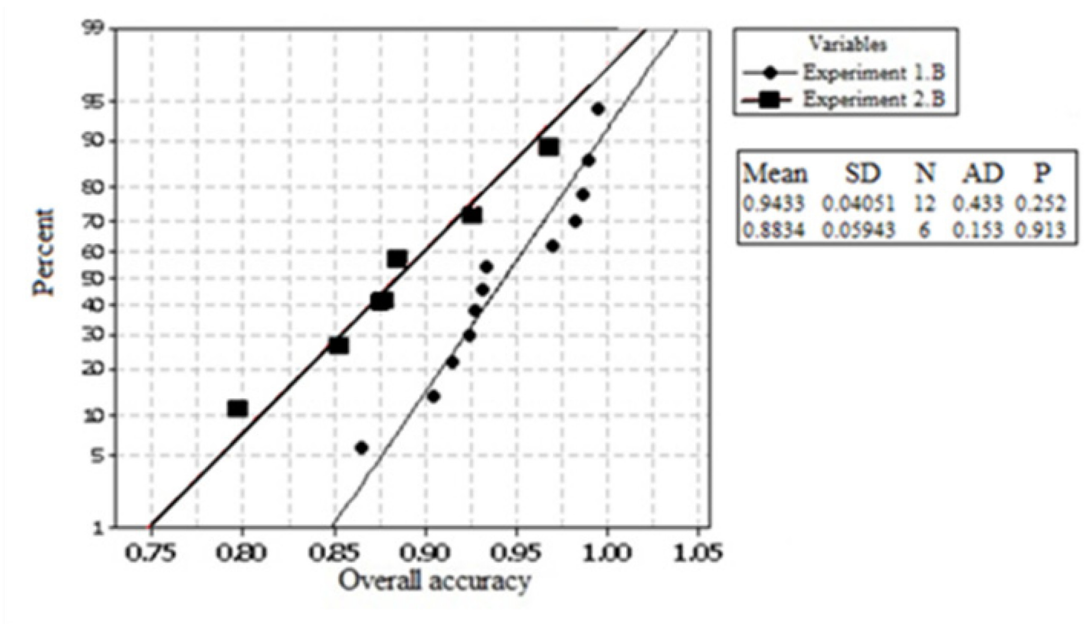



**Figure 2 -** Building the classification model (A) and obtainment of the time spent performing activities (B)

The treadmill used is True 850 SOFT system, TRUE Fitness Technology 865 Hoff Road St. Louis, MO

A




B

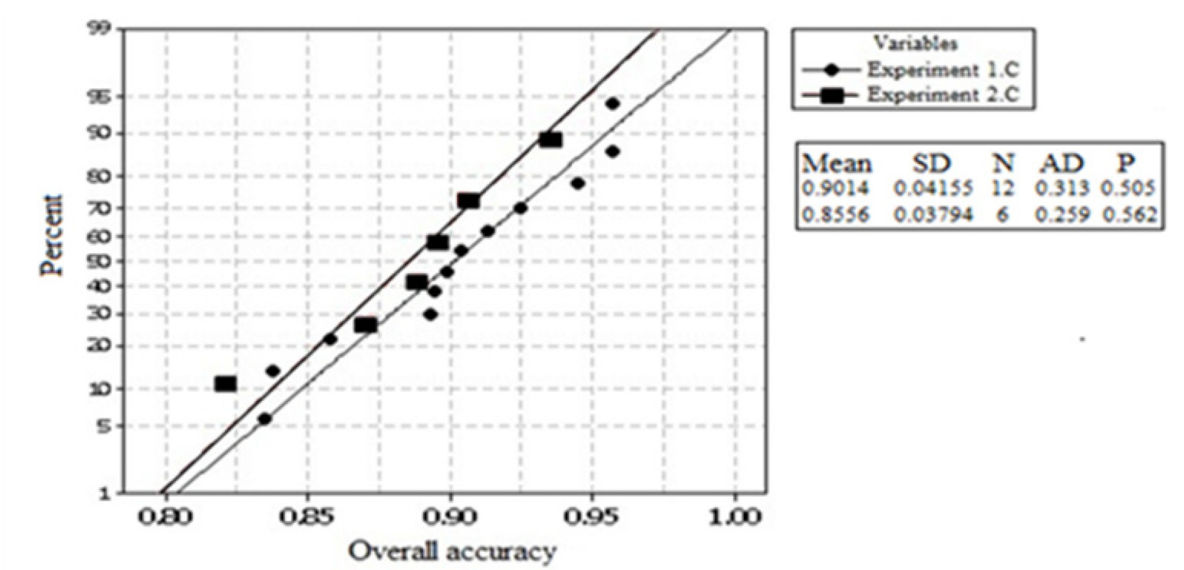



**Figure 3 -** Normal probability plots under CE (A) and UE (B)

## 3.5 Thesis Article # 5

The article entitled "Effects of a Lower and Higher Intensity Exercise Intervention on Energy Compensation in Overweight and Obese Women" presented in this section of the thesis will be submitted in the *American Journal of Clinical Nutrition.*

# Effects of a Lower and Higher Intensity Exercise Intervention on Energy Compensation in Overweight and Obese Women

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**Running title:** Exercise Intensity on Energy Compensation

**Key words**: Intensity, women, energy compensation, body composition, exercise intervention

**Disclosure of funding**: None

**Conflict of interest:** The authors declare no conflict of interest

## Abstract

**Background/Objective:** Body composition does not always vary as a function of exercise induced energy expenditure (ExEE). Energy balance components were investigated to understand energy compensation in response to an ExEE intervention performed at lower or higher intensity.

**Methods:** Twenty-one overweight/obese women (33.7±5.2kg/m²; 29±10yr; 31.0±4.4ml/kg/min) were randomised to 3-month exercise intervention (lower (LI) or higher intensity exercise intervention (HI) (40 or 60% of $V\dot{O}_{2reserve}$)) matched to expend 1500 kcal/week (compliance=97±5%). Body energy reserves (DXA), energy intake (EI) (lunch boxes and food diaries), energy expenditure (EE) (indirect calorimetry and accelerometers), time spent in different activities (accelerometers), appetite (visual analogue scale), eating behaviour traits (TFEQ) and food reward (liking and wanting) were assessed at baseline (wk -1), at the onset (wk 1 and wk 2) and at the end of the ExEE intervention (wk 12-14).

**Results:** Energy compensation based on body composition changes (fat mass and fat-free mass) after the ExEE intervention was 58±88% and 188±104% in LI and HI groups, respectively ($p<0.01$). EI, appetite and eating behaviour traits did not differ across the intervention, but food reward was modulated by the ExEE intervention. Total EE ($p<0.05$) and non-structured physical activity (NSPA) ($p=0.06$) tended to decrease across the intervention. NSPA also tended to be lower for women training at HI ($p=0.08$). HI also spent more time lying down when compared to LI ($p<0.005$). Additionally, compared to LI, HI tended to spend less time standing and walking ($p=0.09$).

**Conclusion:** Overweight/obese women training at LI presented lower energy compensation when compared to women training at a HI and this for a given energy cost of exercise. NSPA

and the time spent in different activities may play a role in mediating the effects of exercise intensity on energy balance and ultimately on body composition.

## Introduction

Food restriction has been reported to increase hunger and energy intake (EI) over a short period of time[1], while it has been associated with a weight regain over a long period of time[2,3]. On the other side of the energy balance, the impact of exercise induced energy expenditure (ExEE) on weight loss is often less than expected[4]. We recently reported from a systematic review that overall energy compensation from ExEE interventions is ~ 25 %; a phenomenon explained mostly through the interaction between adiposity, the intensity of exercise and the duration of the intervention[5].

EI has been investigated through numerous studies to understand the energy compensation that occurs in response to ExEE. Following an acute bout of ExEE, evidence suggests that no EI compensation takes place ([6-8]; for reviews see[9-11]). However, following 14 days, EI compensation hovers around 30%[12-14]. Additionally, data show that the sex of subjects[15-18], eating behaviour traits and hedonic processes[19-21], as well as adiposity levels[22-26] have the potential to influence EI in response to ExEE (for reviews see[10,27]).

As for energy expenditure (EE), many have suggested that if ExEE fails to induce weight loss, it may be because of an increase in sedentary lifestyle outside of exercise sessions, which results in no change in total energy expenditure (TEE)[28-32]. However, non-structured physical activity (NSPA), defined as movements (transportation, work-related movement and/or activity of daily living) that are not related to an exercise session[28,33,34], has been found to be unchanged[35-37], and to even increase[17,38,39] in response to an ExEE intervention.

Exercise intensity might also influence ExEE. Available data in lean and overweight individuals suggest that body weight decreased significantly following lower intensity (LI) ExEE intervention when compared to higher intensity (HI)[40,41]. In contrast, no changes in body weight and composition were noted following exercise training performed at either LI or HI in obese individuals[42-44]. These observations suggest a certain degree of incongruence with the longer-term weight loss results and emphasize the need to more clearly establish the impact of an ExEE intervention on long-term EI and NSPA.

The objective of this study was to investigate the impact of an equicaloric (1500 kcal/week) 3-month ExEE intervention performed at 2 different intensities (40% $V\dot{O}_{2reserve}$ or 60% $V\dot{O}_{2reserve}$) on energy compensation by closely investigating body composition, EI, EE, eating behaviour traits and food reward. It was hypothesized that women training at a HI would have higher energy compensation across the intervention due to greater EI and lower NSPA, when compared to women training at a LI.

## Methods

### Participants

Twenty-five premenopausal overweight and obese women aged between 19 to 51 years old were recruited from advertisement placed around the University of Ottawa to complete a 3-month ExEE intervention. The inclusion criteria were as follows: 1) regular menstrual cycle; 2) non-smoker; 3) body mass index (BMI) higher than 27kg/m²; 4) reported weight stability (± 2 kg) for ≥ 2 months before the study; and 5) being sedentary (<150 min of exercise/week). All participants were healthy with no orthopedic limitation, were not taking any medications and had no history of alcohol (<2 drinks/day) or drug abuse. As presented in **Figure 1**, 4 women withdrew from the study due to personal reasons (n=2), dieting (n=1) and irregular menstrual cycle (n=1). Two participants were also excluded from the analyses because of: 1) Technical problems with measurements obtained from the DXA (n=1); and 2*)* Energy compensation lower than the predicted value (outlier) (n=1). Participants were not aware of the true purpose of this study. It was mentioned that the objective was to determine if a training program performed at a lower (LI) or higher intensity (HI) was associated with an increase in physical fitness in sedentary overweight and obese women. This study was conducted according to the guidelines laid down in the Declaration of Helsinki and the University of Ottawa ethics committees approved all procedures involving human subjects. Written informed consent was obtained from all subjects.

### Procedures of the experimentation

This study consisted of three different phases: a baseline phase of 7 days, 1 month before the beginning of the ExEE intervention (wk-1); a 14-day phase at the onset of the ExEE intervention (wk 1, wk 2); and finally a 7-day phase at the end of the 3-month ExEE intervention (wk 12-14) (**Figure 2**). Data collection was performed at these four time points during the study.

**Morning testing**

On the first day of each phase, body weight (BW) and composition (7:50am) and REE (8:00-9:00am) were measured. Anthropometric measurements are described elsewhere[45]. Body composition was measured with a dual-energy X-ray absorptiometry system (DXA; GE-LUNAR Prodigy module; GE Medical Systems, Madison, WI.). REE was measured using indirect calorimetry and the details of the coefficient of correlation are described elsewhere[46]. Indicators of appetite (*i.e.*, desire to eat, hunger, fullness and prospective consumption) were measured with a visual analogue scale (9:10am and 9:30am) before and after breakfast[47,48]. The breakfast (9:15am) included *ad libitum* whole wheat bread, strawberry jam, peanut butter, cheddar cheese and orange juice. The amount (kcal) and macronutrient selection at wk-1 was used for the following two sampling points (wk 1 and week 12-14). Eating behaviour traits (9:35am) were measured with the Three-Factor Eating Questionnaire[49]. The Leeds Food Preference Questionnaire (LFPQ), a forced choice computer task (9:45am) was used to evaluate the implicit hedonic wanting (speed and frequency of choice) and the explicit hedonic liking (subjective VAS rating) for different visual food cues, which varied in both fat and sugar content[50]. More specifically for food reward measures, mean scores for high fat/low fat and savoury/sweet categories were computed for implicit wanting and explicit liking outcomes. For implicit wanting scores (indicating which foods they most want to eat), mean response times for choices outside of each food category, adjusted for choice frequency were subtracted from response times for choices towards each category, adjusted for frequency. Therefore positive scores for a specific category indicated a more rapid preference (*i.e.*, 'implicit wanting'). For explicit liking (indicating how pleasant the taste of each food would be), mean scores for each food category were calculated from 100-mm visual analogue scale responses. Instructions (*e.g.,* explaining how to correctly fill out the food diary) were then given to the participants (10:00am). At wk -1, the hour that followed (10:45-11:45am) comprised of a sedentary session (*e.g.* writing, reading, studying, etc.), while exercise training was done on the first day of wk 1 and wk 12-14.

**Afternoon testing**

Before and after lunch, indicators of appetite (11:45am and 1:00pm) were measured and the LFPQ was performed before lunch (11:50am). For the lunch, a food menu was presented to participants (12:00pm) in order for them to determine the types of food and beverages that they wanted to consume (see the following article for more information[45]). Afterwards, participants were asked to choose (1:15pm), based on the same food menu, the foods and beverages that they wanted to consume for the rest of the day as well as for the following day (1.5 days).

**Free-living environment wk 1**

Participants received the foods they had selected (2:00pm) and were instructed to bring back all leftovers and wrappers. Participants were also instructed to fill out the food diary diaries for seven days. No under-reporters and/or over-reporters were detected at wk -1 based on the calculations proposed by Black *et al.*[51]. They were fitted with two triaxial accelerometers around the arm and thigh (SenseWear Pro 3 Armbands©, HealthWear Bodymedia, Pittsburgh, PA) that were used to measure the time spent in different activities (*i.e.*, time spent walking, standing, sitting and lying down) (Please refer here for more information [52]). The INNERVIEW software (version 4.02; Bodymedia, Pittsburgh, PA) was used to retrieve data for both accelerometers and the time spent in different activities was determined using the *Activities Recognition Software*[52]. The accelerometer placed around the upper arm was also used to measure TEE[53]. By subtracting the REE and 10% of the TEE (thermic effect of food) from TEE (measured with the armband), it was possible to obtain NSPA on days when exercise was not performed. On days when exercise was performed, ExEE was also subtracted from TEE to obtain NSPA. Days during which participants did not wear accelerometers for more than 80 % of the day or had technical problems (*e.g.*, data were impossible to download, loss of the device) were excluded from the analyses (n=5) as well as days when participants were sick (n=5) were not included in the analyses.

**Free-living environment wk 2**

On the first two days of wk 2, participants received two lunch boxes containing foods chosen from the menu filled out on the previous day or in the morning. They were instructed to wear the armbands and fill out the food diary diaries for a second week.

**Cardiorespiratory Fitness ($V\dot{O}_{2peak}$)**

A progressive exercise stress test was performed to measure participants' peak maximal oxygen consumption ($V\dot{O}_{2peak}$) at wk -1 as well as one and a half months after the onset of exercise and at wk 12-14. The ramp medium protocol test on a treadmill was used. It consists of an increasing workload every 30 seconds interlaced by stage of 1 minute every three minutes for the first 9 minutes and is then followed by an increase in workload every 40 seconds until exhaustion. The test was terminated when at least 2 of the following criteria were achieved[54]: 1) predicted maximal heart rate reached, 2) respiratory quotient > 1.1, 3) oxygen consumption remained stable or decreased with an increase in workload, or 4) rate of Borg-type scale reached ≥ 19/20. The $\dot{V}O_{2reserve}$ [(($\dot{V}O_{2peak}$ –3.5ml*kg$^{-1}$min$^{-1}$)*Intensity) +3.5ml*kg$^{-1}$min$^{-1}$] was used to prescribe the corresponding target heart rate (HR) for the ExEE intervention.

**ExEE Intervention**

Participants were randomly assigned to one of the two intensity ExEE interventions (n=21). When not considering the exclusions (n=19), eleven participants trained at a LI (40% of the $\dot{V}O_{2reserve}$) while eight participants trained at a HI (60% of the $\dot{V}O_{2reserve}$). The duration of each training session was precisely monitored with a watch in order to obtain 300 kcal of ExEE per session, which is consistent with the recommendations given by the ACSM for weight loss and health benefits[55]. Participants were invited to train 3 times per week at the laboratory under supervision and twice per week by themselves. Most women trained using a treadmill and some used a cycle-ergometer (n=2 in HI). HR was recorded for each training session (Polar RS300). The target HR was set to ±10 beats of the HR prescribed. When HR deviated outside of this range, treadmill speed or incline was adjusted accordingly. Data were downloaded every week to track compliance and to determine the mean HR for each session in order to calculate ExEE over REE. During the study, women had a compliance of 97±5%. During the study, women trained for an average of 14±2 weeks and were tested between days 1-9 of the follicular phase of the menstrual cycle at all sampling points.

**Energy compensation**

Energy compensation was calculated from the real ExEE above REE over the training intervention and body composition changes (kcal) obtained from the difference between the first day of wk 12-14 and the first day of wk 1. The changes in body energy were calculated using the equivalents described by Forbes (1990), where a gain of 1 kg of FM corresponds to 12 000 kcal, while it corresponds to 1780 kcal for fat free mass (FFM)[56]. Similarly, a loss of 1 kg of FM corresponds to 9417 kcal while a loss of 1 kg of FFM corresponds to 884 kcal[57]. Compensation (%) was calculated using this equation:

$$Compensation(\%) = \frac{100}{Energy\ Expenditure\ from\ Exercise(kcal)} \cdot \left[ \left( Delta\ FM(kg) \cdot A(kcal) \right) + \left( Delta\ FFM(kg) \cdot B(kcal) \right) \right] + 100$$

$$\begin{aligned} A &: If\ \ Delta\ FM \geq 0 \Rightarrow 12000\ kcal \\ & \qquad\qquad\quad < 0 \Rightarrow 9417\ kcal \\ B &: If\ \ Delta\ FFM \geq 0 \Rightarrow 1780\ kcal \\ & \qquad\qquad\qquad < 0 \Rightarrow 884\ kcal \end{aligned}$$

A compensation of 0% is indicative of the fact that body composition varies perfectly as a function of estimated ExEE. In contrast, a compensation of 100% indicates that body composition remained the same in spite of the ExEE.

**Statistical analysis**

Data are presented as mean ± SD. The normality of all variables was assessed with a Shapiro-Wilk test over variables. Residuals were visually inspected with Q-Q plots. Differences between LI and HI for the baseline characteristics (**Table 1**) and as a result of the ExEE intervention (**Table 2**) were assessed using an independent sample t-test. In the case of violations of normality, a wilcoxon rank-sum test was performed. In the case of non normal distribution of residuals, a logarithmic transformation was performed on the variables. A two-way mixed model ANOVA with the repeated factor of "phase" (wk -1, wk

1, wk 2 and wk 12-14) and the non-repeated factor of "intensity" (2 levels: LI (40% of $\dot{V}O_{2reserve}$ and HI: 60% of $\dot{V}O_{2reserve}$) was used to analyze the dependent variables of body composition, EI, appetite variables, cognitive factors and food reward and EE. When significant differences were found, *post hoc* test analyses were performed using independent t-tests and paired t-tests and Bonferroni correction was applied. Statistical significance was set at $P < 0.05$. Statistical analyses were performed using SPSS (version 21; SPSS Inc, Chicago, IL).

## Results

### Baseline participants' characteristics and body composition changes

The participants' baseline characteristics are shown in **Table 1**. Data relative to the training sessions are presented in **Table 2**. The analyses revealed no main effect of time, no group effect and no interaction for maximal oxygen consumption (data not shown). Significant interactions of phase by group were noted for BW ($p<0.05$) and FM ($p<0.05$) across the ExEE intervention (wk 1 and wk 12-14). Significant differences for delta FM and BW were also noted between groups (**Figure 3**). When further investigating the body composition changes in relation to ExEE, the analyses revealed an overall energy compensation from body composition of 113±113%; more specifically, 58±88% for LI and 188±104% for HI ($p<0.01$).

### Energy Intake, Macronutrient and Appetite Variables

Our analyses revealed no significant difference between women training at LI and HI for EI at breakfast. No main effect of phase, no group effect and no interaction were noted for EI and macronutrient intake during lunch on day 1 and 2 or for the mean value over 7 days, with the exception of an increase in dietary fat between wk -1 and wk 2 ($p=0.02$). No significant differences were noted for appetite variables measured before breakfast. Similarly, no effect was noted for desire to eat and hunger measured after ExEE (data not shown). However, an effect of intensity was obtained for fullness and mean prospective of consumption. Further analyses showed that women training at HI had a higher degree of fullness and had a lower mean prospective food consumption when compared to women training at LI (data not shown). Appreciation of the food consumed after breakfast and after lunch was similar across the intervention with no significant effect of group, or group by phases (data not shown).

**Cognitive Factors and Food Reward**

No significant differences were noted for TFEQ variables (data not shown). Our analyses demonstrated an effect of time ($p<0.001$), an effect of phase ($p<0.05$), and an effect of group ($p<0.05$) for implicit hedonic wanting of fat for food reward. Implicit hedonic wanting for fat decreased after the ExEE sessions and decreased over the study. Women in the LI group demonstrated a higher implicit wanting for fat when compared to women training in the HI group. An effect of time was also observed for explicit hedonic liking for fat ($p<0.05$) and for implicit hedonic wanting for sweet ($p<0.005$), suggesting a decrease after the ExEE session when compared to before the ExEE session. Additionally, explicit hedonic wanting for sweet increased between wk -1and wk 1 ($p<0.01$) and tended to increase between wk -1 and wk 12-14 ($p=0.06$). The results also showed an interaction between phase and time ($p<0.01$) for explicit hedonic liking for sweet. Before ExEE, explicit liking for sweet tended to decrease during wk 1 and wk 12-14 ($p=0.06$), while it tended to increase after ExEE for the same time period ($p=0.07$).

**Energy Expenditure and Time Spent Performing Activities**

A main effect for TEE ($p<0.001$) suggested an increase from wk -1 to wk 1 ($p<0.001$) and wk -1 to wk 2 ($p<0.001$) (**Figure 4**). TEE decreased across the intervention when baseline value was subtracted at every sampling time during the intervention ($p<0.05$) (delta wk 1 to delta wk 2, $p<0.05$; delta wk1 to delta wk 12-14, $p=0.08$). More specifically, a significant difference for TEE was noted when only considering days when women were training (p<0.05) (**Figure 5**). An increase was observed from wk -1 to wk1 (p<0.001), wk -1 to wk 2 (p<0.001) and wk -1 to wk 12-14 (p<0.005). No significant differences were shown on days when no ExEE was performed. As for mean NSPA, significantly lower values (p<0.05) were found for women training at HI (668 kcal/day) when compared to women training at LI (857 kcal/day) (**Figure 6**). When subtracting NSPA obtained at every sampling time from the baseline value, our data suggested a trend for NSPA over the study (p=0.07). The trend was noted between delta wk 1and delta wk 2 (p=0.07) (**Figure 7**). No difference was noted for REE. HI spent more time lying down when compared to LI (635±44 min vs. 532±44 min, respectively; p<0.005). When subtracting the time spent exercising from the sum of the time spent standing and walking, a trend was noted (p=0.09) between LI and HI (319±93 min vs. 224±93 min, respectively).

## Discussion

This study measured energy compensation in overweight/obese women training at LI and HI over a 3-month period. We investigated how both sides of the energy balance equation contribute to compensation at the onset and after a 3-month ExEE intervention. Outcomes were obtained from objective measurements and a high level of compliance to exercise (>94%) was maintained throughout the intervention. Our data suggested that overall ExEE was fully compensated over the intervention (113%), an effect that was much greater in women training at HI (188%) when compared to women training at LI (58%).

Our results are in agreement with available literature showing that EI following acute ExEE or over a two-day period does not increase when compared to baseline values ([6-8]; for reviews see[9-11]). Our results also show that this effect still persists after a 3-month period as no significant difference for EI was noted between groups (HI and LI). For a longer period, it would have been expected to note an increase in EI due to the documented high level of EI compensation under similar conditions[12,58]. It could also be speculated that the greater physical strain for women training at HI could have translated into a higher desire for food consumption[59]. However, no group differences were noted although results from the food diaries and lunch boxes suggested an increase for dietary fat (g) consumed between wk -1 and wk 2. This suggests that women may have consumed more palatable and energy dense food across the intervention, which could have contributed to at least partially compensate for the ExEE[60]. The explanation as to why this ExEE intervention did not significantly lead to a significant increase in EI will have to be further investigated. It is possible that the techniques (*i.e.*, food diaries and food menu) are not sensitive enough to accurately capture

EI variations over this period. In addition, participants could have eaten foods other than that provided to them (food menu), and the results might not be representative of reality[61]. However, it is important to note that the data suggest no under-reporting across the intervention. As demonstrated by Bingham *et al.*[62]*,* day-to-day variations in EI may be in the realm of around 23%. As such, it is possible that EI would need to be extended to much longer periods to fully capture these day-to-day variations. Although we assessed dietary intake over 7 days at 4 different time points during the entire study, it is likely that additional measures should have been taken in order to provide a more comprehensive overview of EI variation that occurred during the ExEE intervention. Further investigation in a free-living environment should be performed in this sense.

Eating behaviour traits and food reward are likely to be important contributors EI variability[9,11]. Following an ExEE intervention, it is possible that individuals decrease their cognitive dietary restraint due to the perceived amount of ExEE[1,9,63]. Nevertheless, no significant differences were noted suggesting that eating behaviours traits remained stable over the course of this ExEE study. ExEE could also modify macronutrient preferences, food choices, and modulate hedonic response to food[14] and could thus favour a better control of EI[9,19,21,63-65]. In this sense, our data suggested a decrease in implicit hedonic wanting for fat across the intervention and after the ExEE session as well as a decrease in explicit hedonic liking for fat after the ExEE session. Similarly, implicit wanting for sweet decreased after the ExEE session. The decrease for explicit liking for sweet before the ExEE session when compared to the increase after the ExEE session between wk 1 and wk 12-14 is in accordance with an increased preference for carbohydrate following an acute ExEE[26]. The reason why women training at a LI presented a higher implicit wanting for fat, a lower degree of fullness and a higher mean prospective for food consumption when compared to women training in the HI group will however have to be further investigated.

Our study suggested that TEE decreased across the intervention. Since ExEE was closely monitored throughout the study, and that REE remained stable, it is thus reasonable to assume that the decrease in TEE is explained by a decrease of NSPA over the course of the ExEE intervention. Results from previous studies have shown a decrease in NSPA in elderly subjects in response to an ExEE intervention, whereas healthy and obese young individuals display no decrease or even an increase of this component under similar conditions[66]. When NSPA was compared to baseline value, a trend was only noted at the onset of the intervention (wk 1 and 2). Our results also suggest that NSPA was lower for women training at a HI. In addition, the sum of time spent walking and standing was lower for women training at a HI when compared to women training at a LI. Our results also showed that women training at a HI spent significantly more time lying down when compared to women training at a LI. Consequently, this study suggests that the decrease of NSPA across the intervention contributes to the energy compensation, especially for women training at a HI. Collectively, it is suggested that the decrease in NSPA is explained by the fact that women training at HI engage in more sedentary activities.

BMI at inclusion was >27 kg/m². Therefore, conclusions cannot be extended to the general population. Our findings need to be confirmed in a larger cohort that should include obese men and active individuals[67-69]. The high quantity and quality of the variables measured lead to the inclusion of a relatively small number of participants. Consequently, the results present a lower statistical power. Nevertheless, the low effect size noted for important primary outcomes such as EI over 7 days suggests that a higher number of participants would have very likely led to similar results. A greater weight loss could have been obtained with increased ExEE[70]. However, the ExEE of 300 kcal per session is consistent with recommendations provided by the ACSM for weight loss and health benefits. Additionally, two participants mostly trained on an ergometer, which could have reduced their EE across the intervention. The absence of change for the fitness level ($VO_{2peak}$) across the intervention might suggest that the intensity was not high enough to cause an increase. Nevertheless, exercise intensities between 40 and 59% is normally recommended for sedentary individuals[71]. Even if data were collected with objective measures that included variables from both sides of the energy balance, the limits associated with the non-continuous measures of EI and NSPA should not be underestimated.

These data suggest a total energy compensation of 113 % and a higher compensation in women training at a HI when compared to women training at a LI. This study adds new perspectives by suggesting that NSPA and the time spent in different activities should be taken in consideration when investigating changes in body energy stores in response to ExEE interventions. Our study also points to the limitations of using snapshot measures to predict long-term outcomes.

## Acknowledgement

The authors would like to thank the participants for their devoted participation. We especially want to thank Dr Gilles Lamothe and Dr François Rioux for their contribution to the statistical analysis and the analysis of the time spent in different activities, respectively. MER and ED designed the research, MER conducted the research, MER, GF, JB and ED conceptualized the analysis of the data, MER, SJT, JC and LDS analysed the data, MER performed the statistical analysis, MER wrote the manuscript while the co-authors: SJT, GF, JB, LDS, JC and ED critically appraised and approved the final version of the manuscript. Finally, ED had primary responsibility for final content. The authors declare no conflict of interest.

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**Table 1 -** Anthropometric variables, EI, EE and eating behaviour traits in women training at a LI and HI at wk -1

| | LI | HI | P values |
|---|---|---|---|
| *n* | 11 | 8 | |
| Age (y) | 27±9 | 29±11 | 0.56[1] |
| Body Composition | | | |
| Body weight (kg) | 88.1±12.0 | 88.7±17.2 | 0.92 |
| BMI (kg·m-2) | 32.3±3.8 | 33.5±5.3 | 0.58 |
| Fat mass (kg) | 41.9±8.2 | 40.8±11.5 | 0.81 |
| Percent fat mass (%) | 47.9±3.4 | 45.9±5.0 | 0.31 |
| Fat free mass (kg) | 45.0±4.3 | 46.8±5.9 | 0.19[1] |
| EI | | | |
| Energy (Breakfast) (kcal) | 648±166 | 746±256 | 0.33 |
| Energy (Lunch) (kcal) | 772±322 | 676±330 | 0.54 |
| Energy (Day 1) (kcal) | 2620±780 | 2842±959 | 0.59 |
| Energy (Day 2) (kcal) | 2418±659 | 2443±1050 | 0.95 |
| Energy (Day 3-7) (kcal) | 2048±378 | 2290±718 | 0.40 |
| Energy (Day 1-7) (kcal) | 2182±410 | 2391±714 | 0.48 |
| EE | | | |
| REE (kcal)[2] | 1469±185 | 1559±233 | 0.36 |
| NSPA (kcal) | 671±306 | 566±197 | 0.16 |
| TEE (kcal) | 2640±430 | 2550±387 | 0.65 |
| Eating behaviours traits | | | |
| Dietary restraint | 8.6±3.2 | 9.4±2.7 | 0.61 |
| Flexible dietary restraint | 2.0±0.8 | 1.8±1.0 | 0.63[2] |
| Rigid dietary restraint | 1.6±1.4 | 2.5±0.5 | 0.17[2] |
| Disinhibition | 8.5±2.9 | 8.5±1.5 | 0.97 |
| Hunger | 7.0±2.6 | 7.5±2.9 | 0.70 |

Values are mean ± SD
NS=not significant
[1] A wilcoxon sum rank test was performed due to the non-normal distribution of the variables
[2] REE was not performed at wk 12-14 for one participant. The value used was the one obtain at wk 1

**Table 2 -** Characteristics of the ExEE intervention

| | LI | HI | P values |
|---|---|---|---|
| *n* | 11 | 8 | |
| Characteristics of the ExEE intervention | | | |
| Weeks of training | 14±1 | 15±3 | NS |
| Estimated days of training | 68±6 | 73±13 | NS |
| Days of training completed | 68±6 | 69±13 | NS |
| Compliance (%) | 100±2 | 94±6 | 0.005[1] |
| ExEE (kcal) | 352±20 | 337±25 | NS |
| ExEE above REE (kcal) | 290±18 | 286±24 | NS |
| Total ExEE for the intervention (kcal) | 23902±2584 | 23286±4396 | NS |
| Time spent exercising (min) | 62 ± 6 | 47 ± 6 | <0.000 |
| $VO_{2peak}$ (ml/kg/min) | 31.2±3.4 | 30.6±4.7 | NS |
| Actual mean HR during ExEE (bpm) | 117±10 | 137±16 | 0.004 |

Values are mean ± SD
NS=not significant
[1] A wilcoxon sum rank test was performed when the normal distribution was not respected

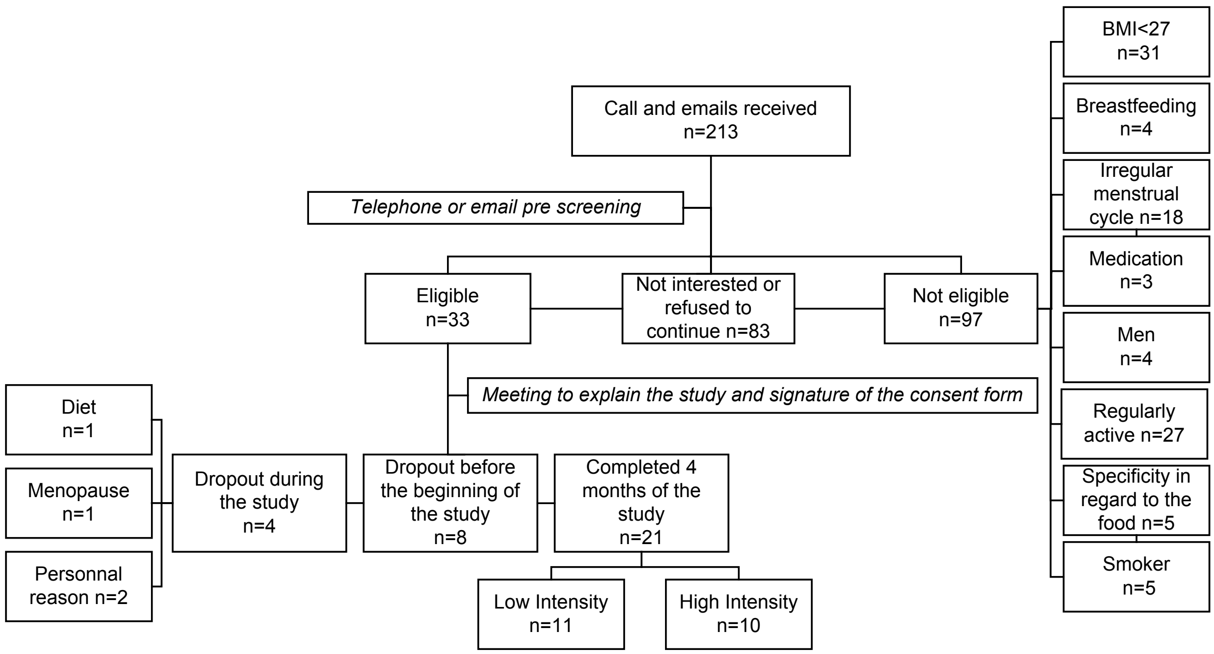


**Figure 1 -** Recruitment and sample size of the study

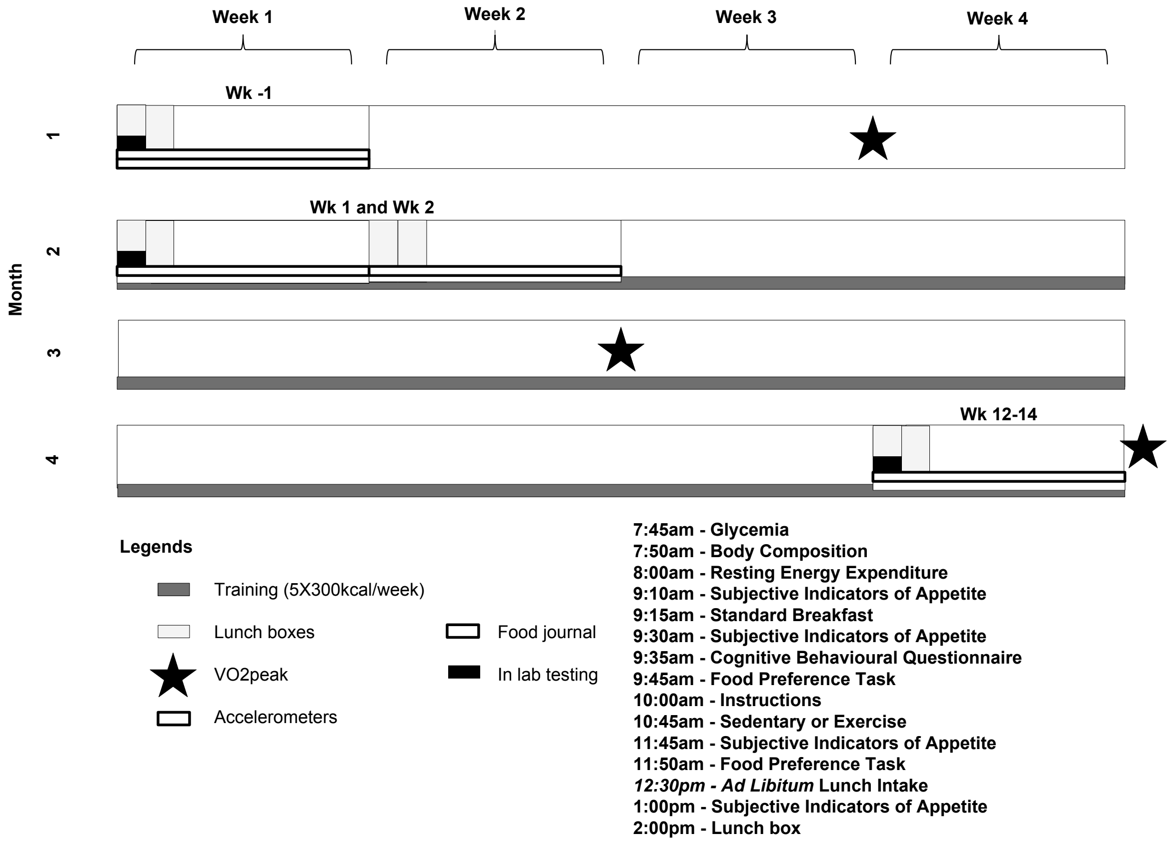


**Figure 2 -** Experimental design

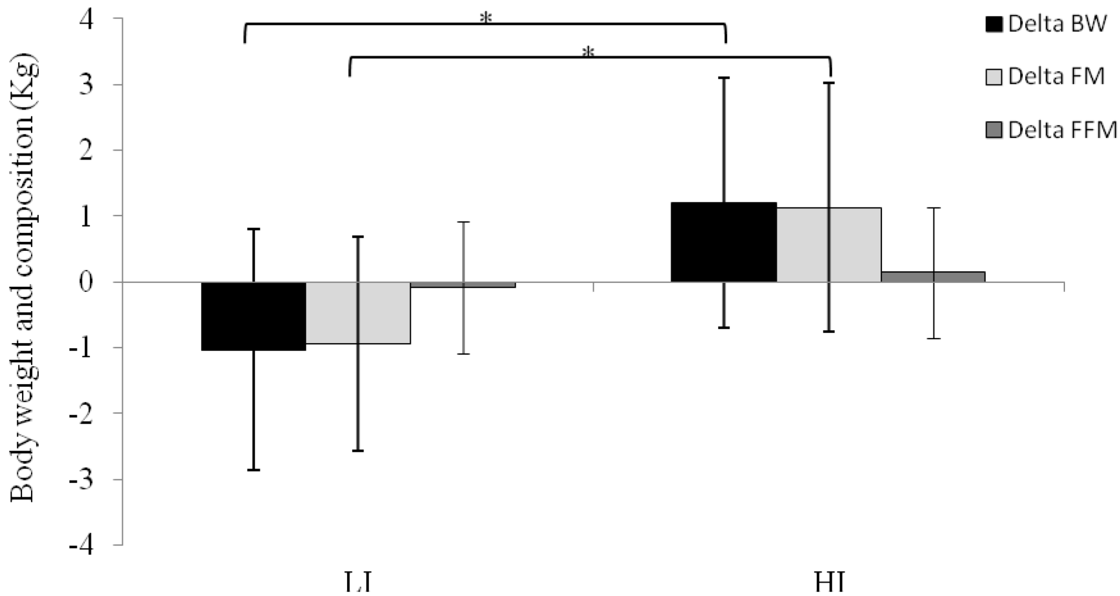


**Figure 3 -** Change in body weight and composition during the ExEE intervention performed at a LI (n=11) and HI (n=8)

For LI, values are -1.04±1.83, -0.94±1.63 and -0.09±1.68 for BW, FM and FFM respectively
Values for HI are 1.20±1.90, 1.13±1.89 and 0.14±2.69 for BW, FM and FFM, respectively
* Represents difference between intensity

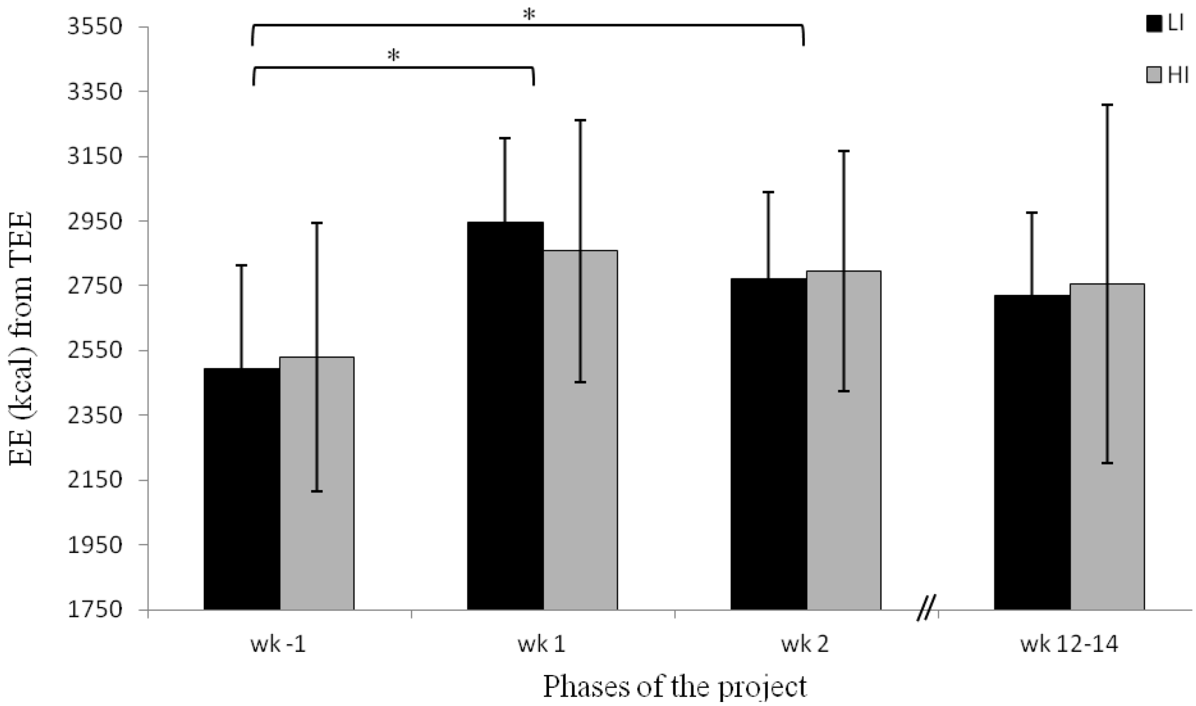


**Figure 4 -** TEE across the intervention in LI (n=9) and in HI (n=7)

* Represents a significant difference across the intervention (p<0.000)

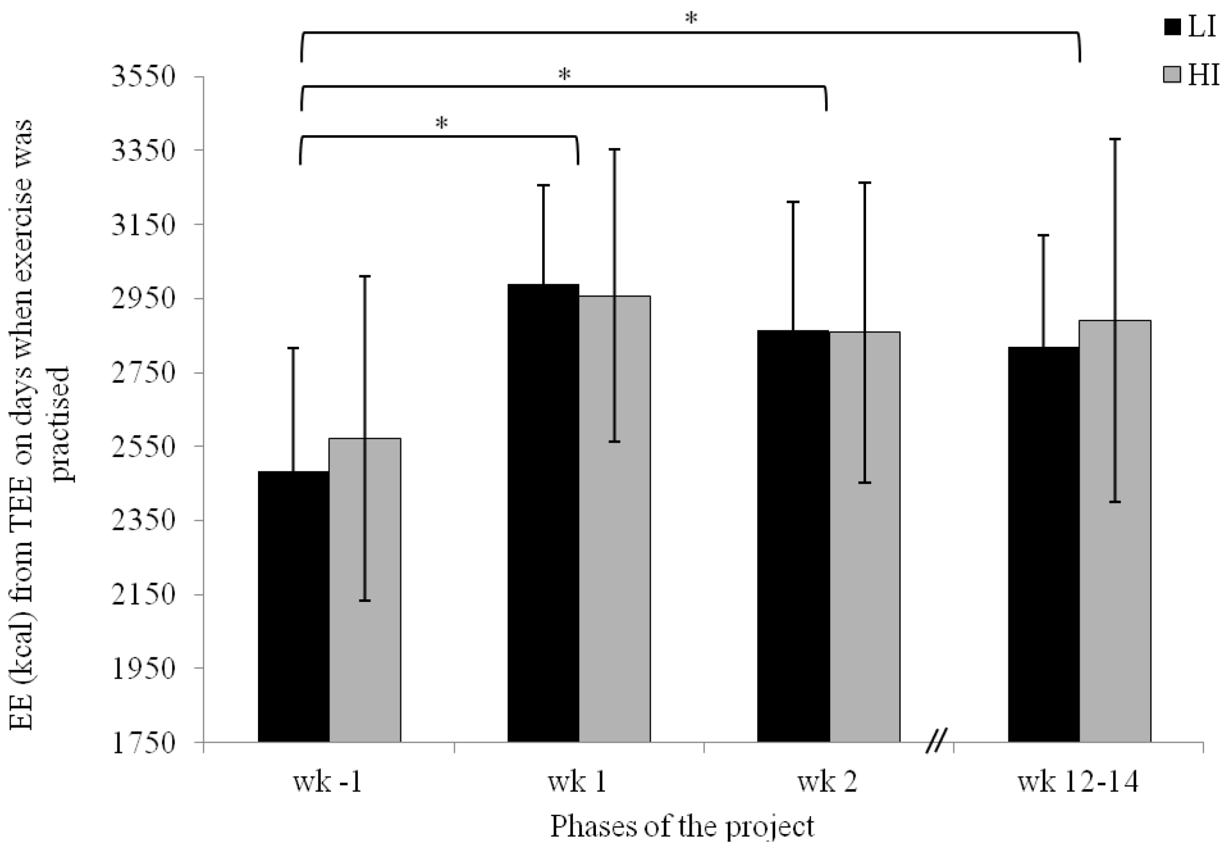


**Figure 5 -** TEE across the intervention on days when ExEE was performed in LI (n=8) and HI (n=6)

* Represents a significant difference across the intervention (p<0.05)

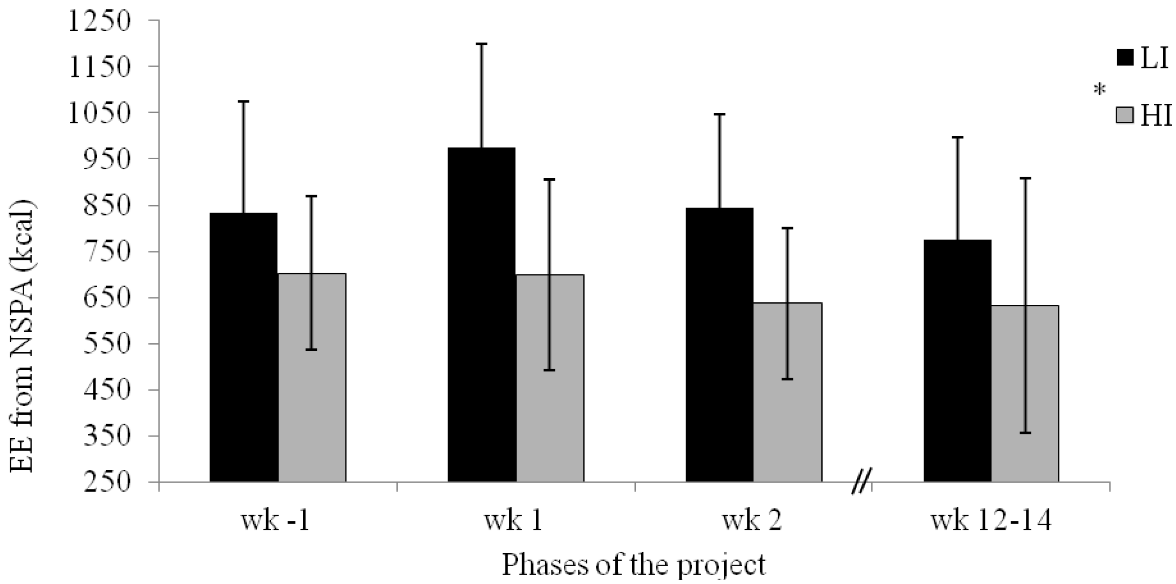


**Figure 6** - EE (kcal) from NSPA across the intervention in LI (n=8) and HI (n=7)

* Represents a significant difference between intensity ($p<0.05$)

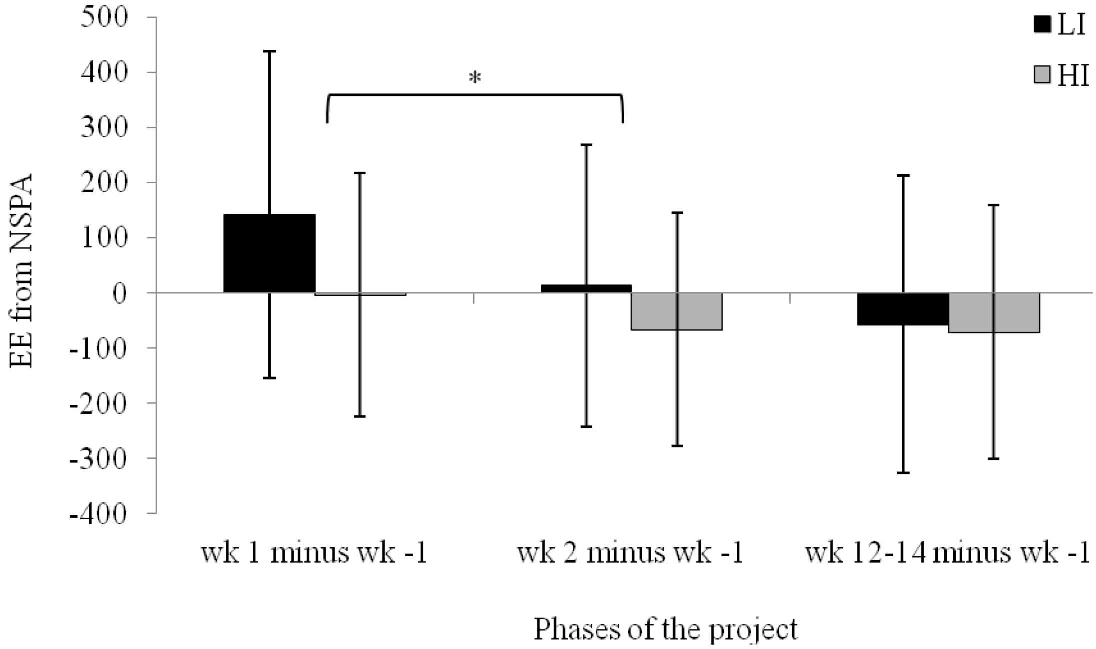


**Figure 7 -** EE (kcal) from NSPA when subtracting baseline value of NSPA in LI (n=8) and HI (n=7)

* Significant differences across time (p=0.06) were noticed between delta wk 1 and delta wk 2 (p=0.07)

## 3.6 Thesis Article # 6

The article entitled "Dietary Disinhibition, Susceptibility to Hunger and Energy Intake in Complete and Incomplete Energy Compensators During an Exercise Intervention" presented in this section of the thesis will be submitted in the *International Journal of Obesity.*

# Dietary Disinhibition, Susceptibility to Hunger and Energy Intake in Complete and Incomplete Energy Compensators During an Exercise Intervention

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Author's contribution: MER and ED designed the research, MER conducted the research, MER, GF, JB and ED conceptualized the data analysis, MER, SJT, FR and LDS analysed the data, MER performed the statistical analysis, MER wrote the manuscript while the co-authors: SJT, GF, JB, LDS, FR and ED critically appraised and approved the final version of the manuscript.

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**Running title:** Compensation following an Exercise Intervention

**Key words:** Energy compensation, energy intake, dietary disinhibition, susceptibility to hunger, women, exercise intervention

**Disclosure of funding**: None

**Conflict of interest**: The authors declare no conflict of interest

## Abstract

**Background/Objectives:** Changes in body composition in response to exercise are subject to large inter-individual variability and there is a lack of controlled laboratory research to identify the causes of this variance. The objective of this study was to examine accurate markers of energy intake (EI), eating behaviours traits, food reward and energy expenditure (EE), as predictors of body composition response to mandatory exercise training in overweight and obese women.

**Subjects/Methods:** Nineteen overweight/obese women (32.8±4.4kg/m²; 28±10 years; 31.4±4.4ml/kg/min) participated in a 3-month exercise intervention designed to expend 1500 kcal/week (compliance=97±5%). EI (lunch boxes and food diaries), appetite (visual analogue scale), eating behaviour traits (TFEQ) and food reward (liking and wanting) along with EE (indirect calorimetry and accelerometry), and the time spent in different activities (accelerometry), were measured at baseline (wk -1), at the onset (wk 1 and wk 2) and at the end of the exercise intervention (wk 12-14). Energy compensation was calculated using body composition change (DXA) and subjects were divided into incomplete (IC) and complete compensators (CC) energy compensation.

**Results:** By design, mean energy compensation was higher in CC (230%), compared to IC (27%). CC presented higher hunger, EI, fat and carbohydrate intakes when compared to IC (all $p<0.05$). CC also had a higher EI at wk1 and wk2 when compared to wk -1. At wk 12-14, dietary fat, carbohydrate intakes and dietary disinhibition were increased in IC while non-structured physical activity (NSPA) was decreased.

**Conclusion:** IC are characterised by lower EI and hunger at the onset of mandatory exercise training. However, the increase in dietary disinhibition and decrease in NSPA observed at the

end of the intervention in IC suggests that these variables should be carefully monitored to ensure improvements in body composition are maintained.

## Introduction

The impact of exercise induced energy expenditure (ExEE) on weight loss is often less than expected. From our systematic review, we showed that energy compensation was around 25% following ExEE interventions and mostly explained by the interaction between adiposity, the intensity of exercise and the duration of the intervention[1]. The limited dose of prescribed exercise, the lack of compliance, the reduction of resting energy expenditure (REE), the increase of energy intake (EI) and/or the decrease in non-structured physical activity (NSPA) following exercise are among the reasons that have been proposed to explain this observation[2,3]. The intensity of the exercise intervention may also influence the compensation. Results from a recent study from our group also demonstrated that overweight/obese women training at lower intensity presented lower energy compensation (*i.e.*, higher weight loss and fat mass) when compared to women training at a higher intensity[4]. Amongst other findings, our data suggested that NSPA was lower in women training at higher intensity when compared to women training at a lower intensity[4].

An interesting observation is that energy intake following ExEE is subject to large inter-individual variability[5]. Along those lines, Finlayson *et al*. showed that following an acute bout of ExEE, lean women who presented a higher EI following ExEE (compensators) displayed a higher preference for high-fat sweet food and generally found foods more palatable[6]. Exercise-induced weight loss is also highly variable between individuals (-14.7 kg to + 1.7 kg)[7]. Similar to acute studies, compensators (individuals with a weight loss smaller than predicted) have been shown to present an increase in EI, with a greater intake from fat over the course of a 3-month ExEE intervention[7]. Compensators also displayed an increase in hunger across the intervention[7]. It has also been demonstrated that individuals for whom liking, wanting and the preference for high fat sweet food increased following acute ExEE, were also more likely to present smaller decreases in fat mass (FM) as a result of an exercise intervention[8].

In light of the above-mentioned evidence, the main objective of this paper was to compare incomplete (IC) (*i.e*., energy compensation lower than 100%) and complete compensators (CC) (*i.e*., energy compensation of 100% or higher) for physiological factors and for eating behaviours traits and food reward. It was hypothesized that overweight/obese women training for 3 months would present a large inter-variability in terms of energy compensation. It was also hypothesized that CC would present higher EI, dietary disinhibition and food reward. Finally, we also hypothesized that a lower NSPA would be seen in CC.

## Methods

### Participants

This manuscript is a secondary data analysis of the results of a study designed to investigate the impact of a 3-month ExEE intervention (1500 kcal/week) performed at a lower (40% $VO_{2peak}$) or higher intensity (60% $VO_{2peak}$) on body composition, EI, EE, and eating behaviours traits and food reward. As described, a total of 25 participants were found to be eligible[4]. Four women withdrew the study and 2 participants were excluded[4]. As a result, a total of 19 overweight and obese women were included in this prospective study. This study was conducted according to the guidelines defined in the Declaration of Helsinki and the University of Ottawa ethics committees approved all procedures involving human subjects. Written informed consent was obtained from all subjects.

### Procedures of the experimentation

As previously described[4], this study consisted of three different phases: a baseline phase of 7 days, 1 month before the beginning of the ExEE intervention (wk-1); a phase at the onset of the ExEE intervention that lasted 14 days (wk 1, wk 2); and finally a 7-day phase at the end of the 3-month ExEE intervention (wk 12-14). Data collection was performed at these four time points during the study.

### Morning testing

On the first day of each phase, body weight (BW) and composition (7:50am) and REE (8:00-9:00am) were measured. Anthropometric measurements are described elsewhere[9]. Body composition was measured with a dual-energy X-ray absorptiometry system (DXA; GE-

LUNAR Prodigy module; GE Medical Systems, Madison, WI.). REE was measured using indirect calorimetry and the details of the coefficient of variation and correlation are described elsewhere[10]. Before and after breakfast, indicators of appetite (*i.e.*, desire to eat, hunger, fullness and prospective consumption) were measured with a visual analogue scale (9:10am and 9:30am)[11,12]. The breakfast (9:15am) included *ad libitum* whole wheat bread, strawberry jam, peanut butter, cheddar cheese and orange juice. The amount (kcal) and macronutrient selection at wk-1 was used for the following two sampling points (wk 1 and week 12-14). Eating behaviours traits (9:35am) were measured with the Three-Factor Eating Questionnaire[13]. The Leeds Food Preference Questionnaire (LFPQ), a forced choice computer task (9:45am) was used to evaluate the implicit hedonic wanting (speed and frequency of choice) and the explicit hedonic liking (subjective VAS rating) for different visual food cues, which varied in both fat and sugar content[14]. More specifically for food reward measures, mean scores for high fat/low fat and savoury/sweet categories were computed for implicit wanting and explicit liking outcomes. For implicit wanting scores (indicating which foods they most want to eat), mean response times for choices outside of each food category, adjusted for choice frequency were subtracted from response times for choices towards each category, adjusted for frequency. Therefore positive scores for a specific category indicated a more rapid preference (*i.e.*, 'implicit wanting'). For explicit liking (indicating how pleasant the taste of each food would be), mean scores for each food category were calculated from 100-mm visual analogue scale responses. Instructions (*e.g.,* explaining how to correctly fill out the food diary) were then given to the participants (10:00am). At wk -1, the hour that followed (10:45-11:45am) comprised of a sedentary session (*e.g*. writing, reading, studying, etc.), while exercise training was done on the first day of wk 1 and wk 12-14.

**Afternoon testing**

Before and after lunch, indicators of appetite (11:45am and 1:00pm) were measured and the LFPQ was performed before lunch (11:50am)[11,12,14]. As for the lunch, a food menu was presented to participants (12:00pm) in order for them to determine the types of food and beverages that they wanted to consume (See the following article for more information[9]). Afterward, participants were asked to choose (1:15pm), based on the same food menu, the foods and beverages that they wanted to consume for the rest of the day as well as for the following day (1.5 days).

**Free-living environment wk 1**

Participants received the foods they had selected (2:00pm) and were instructed to bring back all leftovers and wrappers. They received two triaxial accelerometers (SenseWear Pro 3 Armbands©, HealthWear Bodymedia, Pittsburgh, PA) that were used to measure the time spent in different activities (*i.e.*, time spent walking, standing, sitting and lying down) (Please refer here for more information[15]). They were installed around the arm and thigh. The INNERVIEW software (version 4.02; Bodymedia, Pittsburgh, PA) was used to retrieve data for both accelerometers and the time spent in different activities was determined using the *Activities Recognition Software*[15]. The accelerometer placed around the upper arm was also used to measure TEE[16]. By subtracting the REE and 10% of the TEE (thermic effect of food) from TEE (measured with the armband), it was possible to obtain NSPA on days when exercise was not performed. On days when exercise was performed, ExEE was subtracted to obtain NSPA. Days during which participants did not wear accelerometers for more than 80 % of the day or had technical problems (*e.g.*, data were impossible to download, loss of the device) were excluded from the analyses (n=5).

**Free-living environment wk 2**

On the first two days of wk 2, participants received two lunch boxes containing foods chosen from the menu filled out on the previous day or in the morning. They were instructed to wear the armbands and fill out the food diary diaries for a second week. There were no under-reporters and/or over-reporters at wk -1 based on the calculations proposed by Black *et al.*[17].

**Cardiorespiratory Fitness ($\dot{V}O_{2peak}$)**

As previously described[4], a progressive exercise stress test was performed to measure participants' peak maximal oxygen consumption ($\dot{V}O_{2peak}$) at wk -1 as well, 6 weeks after the onset of exercise and at wk 12-14. The ramp medium protocol test on a treadmill was used. It consists of an increasing workload every 30 seconds interlaced by stage of 1 minute every three minutes for the first 9 minutes and is then followed by an increase in workload every 40 seconds until exhaustion. The test was stopped when at least 2 of the following criteria were achieved[18]: 1) predicted maximal heart rate reached, 2) respiratory quotient > 1.1, 3) oxygen consumption remained stable or decreased with an increase in workload, or 4) Borg-type scale reached $\geq 19$. The $\dot{V}O_{2reserve}$ $[((\dot{V}O_{2peak} - 3.5\text{ml}*\text{kg}^{-1}\text{min}^{-1})*\text{Intensity}) + 3.5\text{ml}*\text{kg}^{-1}\text{min}^{-1}]$ was used to prescribe the corresponding target heart rate (HR) for the ExEE intervention.

**ExEE Intervention**

The main objective of this study was to investigate the impact of a lower and higher intensity on energy compensation (40 vs 60% of $VO_{2reserve}$). In the present study, participants from both groups were pooled together and then divided on the basis of their energy compensation. By design, both groups were set to expend 300 kcal per session and 1500 kcal per week. Participants were invited to train 3 times per week at the laboratory under supervision and twice per week by themselves. They trained mostly on a treadmill and some used a cycle-ergometer (n=2 in HI). HR was recorded for each training session (Polar RS300). The target HR was set to ±10 beats of the HR prescribed. When HR deviated outside of this range, treadmill speed or incline was adjusted accordingly. Data were downloaded every week to track compliance and to determine the mean HR for each session in order to calculate ExEE over REE. During the study, women had a compliance of 97±5%. They trained for an average of 14±2 weeks and were tested between days 1-9 of the follicular phase of the menstrual cycle at all sampling point.

**Energy compensation**

As previously reported[1,4], energy compensation was calculated from the real ExEE above REE over the training intervention and body composition changes (kcal) obtained from the difference between the first day of wk 12-14 and the first day of wk 1. The changes in body energy were calculated using the equivalents described by Forbes (1990), where a gain of 1 kg of FM corresponds to 12 000 kcal, while it corresponds to 1780 kcal for fat free mass (FFM)[19]. Similarly, a loss of 1 kg of FM corresponds to 9417 kcal while a loss of 1 kg of FFM corresponds to 884 kcal[20].

Compensation (%) was calculated using this equation:

$$Compensation(\%) = \frac{100}{Energy\ Expenditure\ from\ Exercise(kcal)} \cdot \left[ \left( Delta\ FM(kg) \cdot A(kcal) \right) + \left( Delta\ FFM(kg) \cdot B(kcal) \right) \right] + 100$$

$$\begin{aligned} A &: If\ \ Delta\ FM \geq 0 \Rightarrow 12000\ kcal / kg \\ & \qquad\qquad\quad < 0 \Rightarrow 9417\ kcal / kg \\ B &: If\ \ Delta\ FFM \geq 0 \Rightarrow 1780\ kcal / kg \\ & \qquad\qquad\quad\ < 0 \Rightarrow 884\ kcal / kg \end{aligned}$$

A compensation of 0% is indicative of the fact that body composition varies perfectly as a function of estimated ExEE. In contrast, a compensation of 100% indicates that body composition remained the same in spite of the ExEE.

**Statistical analysis**

Data are presented as mean and standard deviation (±). Normality of all variables was assessed with a Shapiro-Wilk test over variables. Additionally, the Q-Q plots were visually inspected. A cut off of 100%, or perfect energy compensation, was used to form two groups: women who compensated less than 100% (IC) and women who compensated at 100% or more (CC). Differences between IC and CC for the baseline characteristics and the ExEE intervention were assessed using an independent sample t-test. In the case of a non-respect of normality, a wilcoxon rank-sum test was performed. A two-way mixed model ANOVA with the repeated factor of "phase" (wk -1, wk 1, wk 2 and wk 12-14) and the non-repeated factor of "compensation" was used to analyze the dependent variables of body composition, EI, appetite variables, TFEQ factors and food reward and EE. When significant differences were found, *post-hoc* test analyses were performed using independent t-tests and paired t-tests and Bonferroni correction was applied. Statistical significance was set at $P < 0.05$. Statistical analyses were performed using SPSS (version 21; SPSS Inc, Chicago, IL).

## Results

### Inter-Individual Variability in Energy Compensation

**Figure 1** presents the inter-individual variability in energy compensation (%) (n=19). Baseline participants' characteristics from the two groups formed on the basis of energy compensation are shown in **Table 1**. The analyses revealed that IC had a lower FFM, REE and hunger when compared to CC. The significant lower REE for IC did not persist after correction for variation in FFM between groups was applied. The analysis of training characteristics (**Table 2**) showed significant differences for the compliance and time spent exercising between the two groups. Nevertheless, no significant differences were shown for the energy expended during each session and across the intervention. A significant interaction of Phase by Group was observed for BW ($p<0.05$), FM ($p<0.000$), %FM ($p<0.000$) and BMI ($p<0.05$). IC significantly decreased their FM ($p<0.000$) and %FM ($p<0.005$) across the intervention while the same variables increased for CC (FM: $p<0.000$; %FM: $p<0.05$). Significant differences for delta FM and BW were noted between groups (**Figure 2**).

### Energy Balance

As presented in **Figure 3**, a significant interaction of phase by group ($p<0.01$) was noted when subtracting EI from TEE. Further analyses revealed that significant differences were noted for IC between wk -1 to wk 1 ($p=0.005$), between wk 1 to wk 2 ($p<0.005$) and between wk 1 to wk 12-14 ($p<0.005$).

**Energy Expenditure and Time Spent Performing Activities**

The main effect for TEE ($p<0.000$) suggested an increase from wk -1 to wk 1 ($p<0.000$), wk -1 to wk 2 ($p<0.001$), wk -1 to wk 12-14 ($p=0.08$). On days when women were training ($p<0.05$), TEE increased from wk -1 to wk1 ($p<0.000$), wk -1 to wk 2 ($p<0.000$) and wk -1 to wk 12-14 ($p<0.005$). No significant differences were shown on days when no exercise was performed. TEE ($p<0.05$) decreased across the intervention when subtracting the baseline value from every sample taken during the intervention. A trend was noticed between delta wk 1 and delta wk 2 ($p=0.08$). When subtracting the baseline value from NSPA obtained for every sample taken during the intervention, data demonstrated an interaction Phase by Group ($p<0.05$). Further analyses suggest that IC decreased their NSPA between delta wk 1 and delta wk 12-14 ($p<0.005$), while CC maintained it (**Figure 4**). The group effect for REE disappeared when correction was applied for FFM. CC tended to spend more time lying down ($p=0.07$) when compared to IC (613±60 min vs. 545±59 min).

**Energy Intake, Macronutrient and Appetite Variables**

As presented in **Figure 5 (Panel A)**, the analyses revealed an interaction for Phase by Group ($p<0.01$) for EI. Specifically, EI significantly increased for CC between wk -1 and wk 1 ($p<0.05$) and tended to increase between wk -1 and wk 2 ($p=0.07$). Group differences for EI were also shown at wk 1 ($p<0.005$) and wk 2 ($p<0.05$). Similarly, the analyses revealed an interaction ($p<0.01$) for mean dietary fat (g) **Figure 5** (**Panel B**). The results suggested an increase for IC between wk -1 and wk 12-14 ($p=0.07$), while no change was noted for CC. Group differences were shown at wk 1 ($p<0.05$) and wk 2 ($p=0.06$). The interaction (Phase by Group) for mean carbohydrate (g) ($p<0.005$) suggested a significant increase for CC between wk -1 and wk 1 ($p<0.005$) and significant decrease between wk 1 and wk 12-14

($p=0.08$). Conversely, mean carbohydrate increased for IC between wk 1 and wk 2 ($p<0.005$) and wk 1 and wk 12-14 ($p=0.07$). A group difference was also noticed at wk 1 ($p<0.005$). No significant differences were noted for the mean protein (g) consumed and for appetite variables.

**TFEQ and Food Reward**

The analyses of TFEQ revealed no significant effect for dietary restraint and its subscales. The analyses suggested an interaction for dietary disinhibition ($p=0.07$) where IC presented an increase ($p=0.06$) between wk 1 and wk 12-14, while no changes were noted for CC. As for hunger, the analyses suggested a significant increase ($p<0.005$) between wk -1 and wk 1 ($p=0.06$) and between wk -1 and wk 12-14 ($p<0.01$). Analyses demonstrated that CC presented a higher level of hunger when compared to IC ($p<0.05$). Implicit hedonic wanting for fat decreased after the exercise session when compared to before the exercise session ($p<0.001$) and decreased over the study ($p<0.05$). An interaction (Time by Group; $p=0.06$) was noticed for explicit hedonic liking for fat suggesting a decrease for CC only after the exercise session ($p<0.05$). An effect of time for implicit hedonic wanting for sweet ($p<0.05$) suggested a decrease for sweet after the exercise session when compared to before the exercise session. The interaction Phase by Group ($p=0.06$) for explicit hedonic wanting for sweet revealed an increase between wk -1and wk 1 for IC ($p<0.05$) and CC ($p<0.05$) and an increase for CC only between wk -1 and wk 12-14 ($p<0.01$). The results also depicted an interaction between phase and time ($p<0.01$) for explicit hedonic liking for sweet. Explicit liking for sweet tended to decrease between wk 1 and wk 12-14 before exercise ($p=0.06$), while it tended to increase after exercise ($p=0.07$).

## Discussion

To our knowledge, this is the first study to investigate both sides of the energy balance as well as eating behaviour traits and food reward in IC and CC after a 3-month equicaloric ExEE intervention. Our data highlighted a large inter-individual variability in terms of energy compensation. In parallel to their higher energy compensation, a higher EI, fat and carbohydrate intake at the onset of the ExEE intervention (wk 1 and wk 2) was observed in the CC. The results also show that CC presented a higher EI at the wk1 and wk2 when compared to wk -1. Dietary disinhibition was increased for IC, an increase that was accompanied by an increase in dietary fat and carbohydrate intake at wk 12-14. NSPA was also decreased for IC when compared to the delta wk 1 value and delta wk12-14.

Energy compensation has been shown to be highly variable between subjects[7,21,22]. By design, the mean energy compensation in the CC (230%) was greater than that noted in the IC (27%). When EI and TEE were investigated together, our results revealed a negative energy balance for the IC at the onset of the intervention whereas a positive energy balance was seen at the end of the intervention. When considering EE variables, the only difference between groups was noted for the time spent lying down. In fact, CC spent 68 minutes more lying down than IC. Nevertheless, even if this change likely contributed to differences in energy compensation, it is unlikely to entirely explain group differences in energy compensation, which was on average 48 000 calories.

We report greater susceptibility to hunger (obtained from the TFEQ) in CC when compared to IC, and this effect was maintained across the intervention. A positive relationship has been observed between susceptibility to hunger measured with the TFEQ and BW changes in longitudinal study[23]. In addition, it has been shown that lower hunger is an important predictor of weight loss maintenance following a diet intervention[24]. It is therefore possible to speculate that the higher level of hunger could have contributed to the increase of energy, fat and carbohydrate intake in CC when compared to IC. This could possibly explain a portion of the weight gain observed across the intervention. Nevertheless, there is a need to explore more susceptibility to hunger since others have also shown no significant association between hunger (measured by the TFEQ) and weight loss and/or weight loss maintenance in obese women[25,26].

The overconsumption in CC at wk 1 and wk 2 when compared to wk -1 further supports the speculations that increased EI could be involved in the relatively large energy compensation (230%) noted in this group. Similarly, the implicit hedonic wanting for sweets suggested that CC increased their desire for sweet across the intervention, which thus could have also contributed to this higher energy compensation. Nevertheless, the measurements of EI performed during this study over 7 days, even if well representative of the reality[27], are limited by the time gap that exists between the measurements. Measurements should thus be probably taken more frequently during the course of studies to more accurately reflect actual day-to-day EI.

The inter-individual variability in energy compensation is explained by the difference in EI observed at the onset of the intervention, differences that likely persisted throughout the intervention in light of the observations that IC lost more weight. However, different results between groups were observed at wk 12-14. Indeed, by the end of the intervention our results show that IC increased their dietary fat and carbohydrate intake. It could be speculated that these dietary intake modifications are explained by an increase in dietary disinhibition observed for IC between the wk 1 to wk 12-14. In fact, positive correlations between dietary disinhibition and BMI[28], and between disinhibition and weight regain[26 29] have been demonstrated. Similarly, it has been shown that an acute bout of ExEE associated with a higher level of disinhibition was related with an increase in EI[30]. As suggested by Bryant *et al*. (2008), disinhibition is also correlated with a higher level of sedentary behaviours[31]. This finding could be related to the observation that a decrease of NSPA was observed for IC at the end of the intervention. Therefore, even with a body weight reduction for IC, the increase in dietary disinhibition and decrease in NSPA over time suggest that these variables should be carefully monitored in order to avoid weight regain.

Our findings are limited to a small population that included only women with a BMI higher than 27 kg/m². Thus, conclusions cannot be extended to the general population and other studies should include obese men and active individuals in order to investigate the similarities or differences between sex and between active and sedentary individuals[32-34]. It is also possible that a greater weight loss would have been obtained with increased ExEE. However, the ExEE of 300 kcal per session is consistent with the recommendations given by the American College of Sports Medicine for weight loss and health benefits. As part of a secondary analysis, the cut off of 100% (perfect energy compensation) that was used to dichotomize groups could be viewed as somewhat arbitrary. Nevertheless, a cut off of 100% was used primarily because it corresponds to a perfect energy compensation, but also in order to balance the number of women in each group. Also, since a significant difference for the amount of time spent exercising was noted between groups, women training at lower intensity predominantly constituted the IC group. Finally, even though data were collected with the most available objective measures (*e.g.,* DXA and accelerometry) and included both sides of the energy balance, the limits associated with the snapshot measures of EI and NSPA should not be underestimated.

These data highlight the presence of inter-individual energy compensation in overweight/obese women training for a 3-month intervention. This study highlights that CC and IC do present different response patterns to ExEE, as far as EI and EE variables are concerned. Our study also highlights the limitations associated with the use of snapshot measures to predict long-term outcomes.

## Acknowledgements

The authors would like to thank the participants for their devoted participation. We especially want to thank Dr Gilles Lamothe for his precious collaboration with the statistical analysis. MER and ED designed the research, MER, SJT conducted the research, MER, FG, JB and ED conceptualized the analysed of the data, MER, FR, SJT and LDS analyse data, MER performed statistical analysis and MER wrote the manuscript while the co-authors: SJT, FG, JB, LDS, FR and ED critically appraised and approved the final version of the manuscript. Finally, ED had primary responsibility for final content. The authors declare no conflict of interest.

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**Table 1 -** Anthropometric variables, EE and eating behaviour traits in IC and CC at wk -1

| | IC | CC | P values |
|---|---|---|---|
| *n* | 11 | 8 | |
| Age (y) | 29±10 | 26±11 | 0.48[1] |
| Body composition | | | |
| Body weight (kg) | 84.6±13.5 | 93.5±13.8 | 0.18 |
| BMI (kg·m-2) | 31.3±3.9 | 34.8±4.4 | 0.09 |
| Fat mass (kg) | 39.4±9.4 | 44.2±9.4 | 0.28 |
| Percent fat mass (%) | 46.7±4.6 | 47.5±3.7 | 0.68 |
| Fat free mass (kg) | 44.1±4.8 | 48.1±4.5 | 0.06[1] |
| EE | | | |
| REE (kcal)[2] | 1414±183 | 1635±168 | 0.015 |
| NSPA (kcal) | 612±309 | 647±208 | 0.77 |
| TEE (kcal) | 2514±439 | 2724±339 | 0.28 |
| Eating behaviour traits | | | |
| Dietary restraint | 9.2±3.6 | 8.6±1.9 | 0.70 |
| Flexible dietary restraint | 2.1±0.8 | 1.6±0.9 | 0.29[1] |
| Rigid dietary restraint | 1.6±1.4 | 2.5±0.5 | 0.17[1] |
| Dietary disinhibition | 8.6±2.8 | 8.4±1.6 | 0.88 |
| Susceptibility to hunger | 6.0±2.2 | 8.9±2.4 | 0.015 |

Values are mean ± SD

NS, not significant; IC, incomplete compensators; CC, complete compensators; BMI, body mass index; EE, energy expenditure; REE, resting energy expenditure; NSPA, non-structured physical activity; TEE, total energy expenditure

[1] A wilcoxon matched-pairs signed rank test was performed due to the non-normal distribution of the variables

[2] The REE for one participant was not performed at the end phase. The value used was the one obtain at the onset phase

**Table 2 -** Characteristics of the exercise intervention

| | IC | CC | P values |
|---|---|---|---|
| *n* | 11 | 8 | |
| Characteristics of the ExEE intervention | | | |
| Weeks of training | 13±1 | 15±2 | NS[1] |
| Estimated days of training | 67±6 | 75±12 | NS |
| Days of training completed | 66±7 | 72±11 | NS |
| Compliance (%) | 98±5 | 96±4 | 0.04[1] |
| ExEE (kcal) | 349±25 | 341±20 | NS |
| ExEE above REE (kcal) | 291±23 | 285±17 | NS |
| Total EE across the intervention (kcal) | 23001±3559 | 24525±3079 | NS |
| Time spent exercising (min) | 60 ± 8 | 50 ± 9 | 0.01 |
| VO2max (ml/kg/min) | 31.9±4.6 | 30.9±4.2 | NS |
| Real mean Heart Rate (bpm) | 121±16 | 132±15 | NS |

Values are mean ± SD
NS, not significant; IC, incomplete compensators; CC, complete compensators; ExEE, exercise induced energy expenditure; REE, resting energy expenditure; EE, energy expenditure
[1] A wilcoxon matched-pairs signed rank test was performed when the normal distribution was not respected

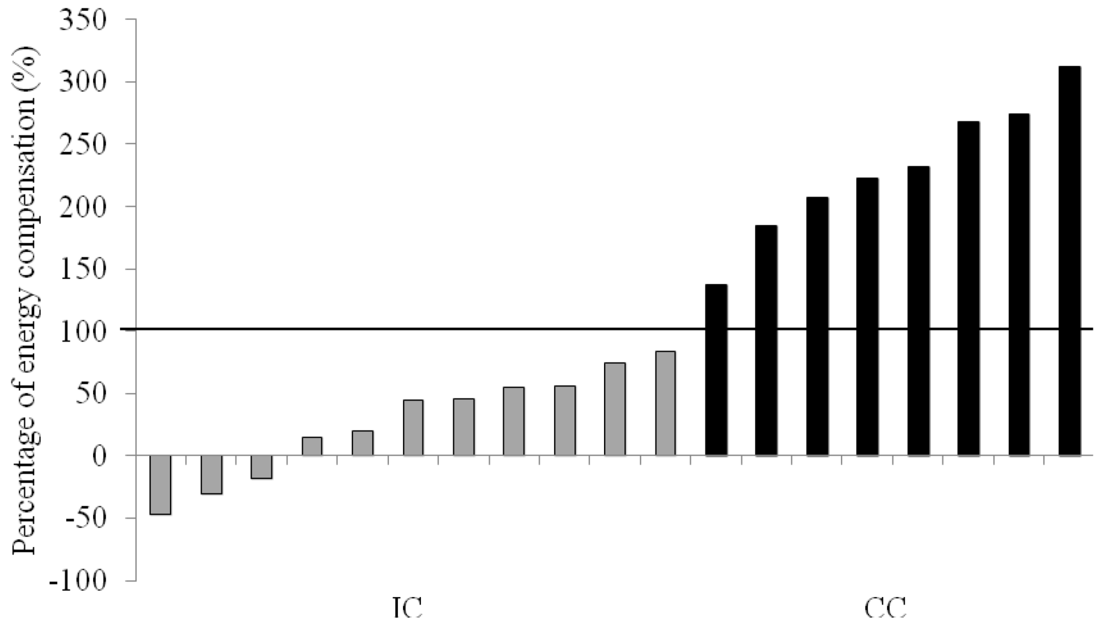



**Figure 1** - Percentage of energy compensation during the exercise intervention

The overall energy compensation is 113±113%
Mean compensation for IC (n=11) and CC (n=8) are respectively 27±43% and 230±55% (p<0.000)

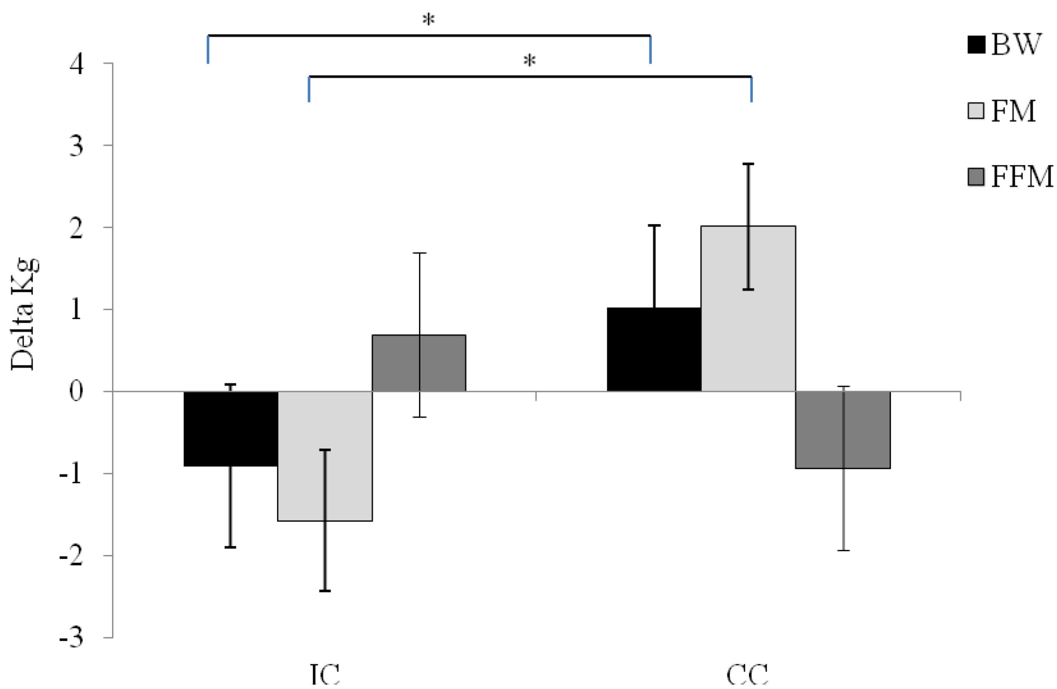



**Figure 2 -** Body weight and composition change for IC and CC across a 3 month intervention

For IC value are -0.91±1.92, -1.58±0.86 and 0.69±1.75 for BW, FM and FFM respectively
Values for CC are 1.03±1.99, 2.01±0.77 and -0.93±2.28 for BW, FM and FFM, respectively

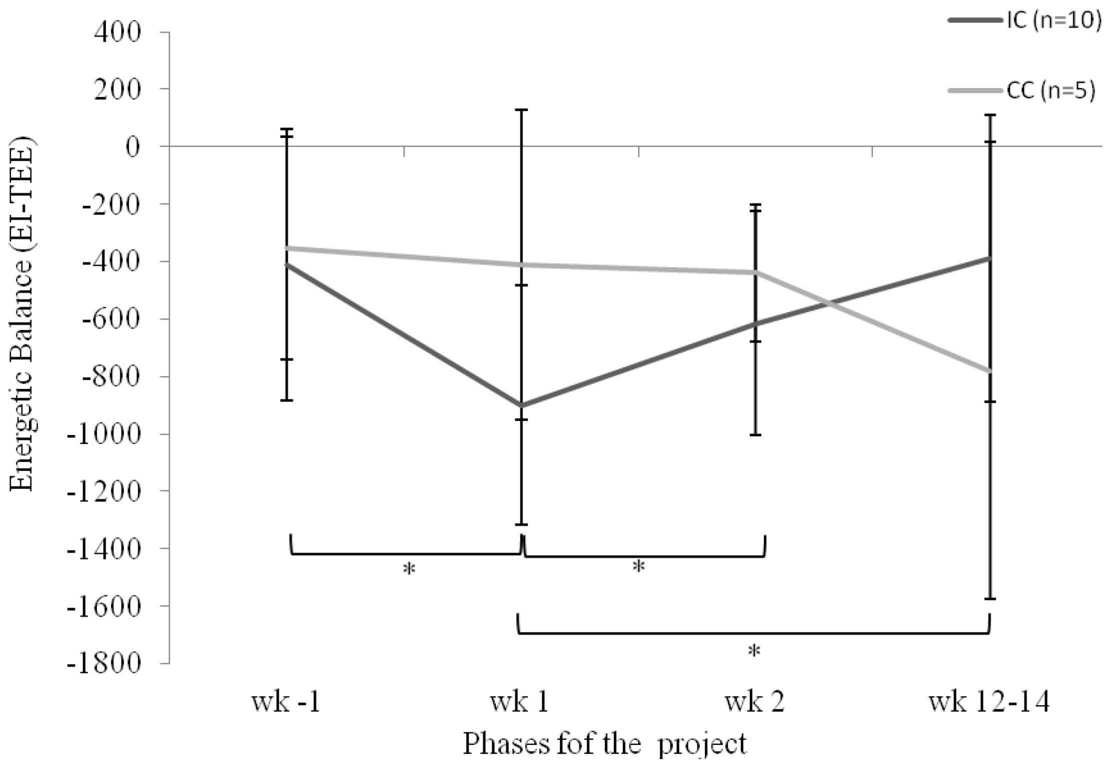



**Figure 3 -** Energy balance for IC and CC across the intervention

* Represents a significant difference

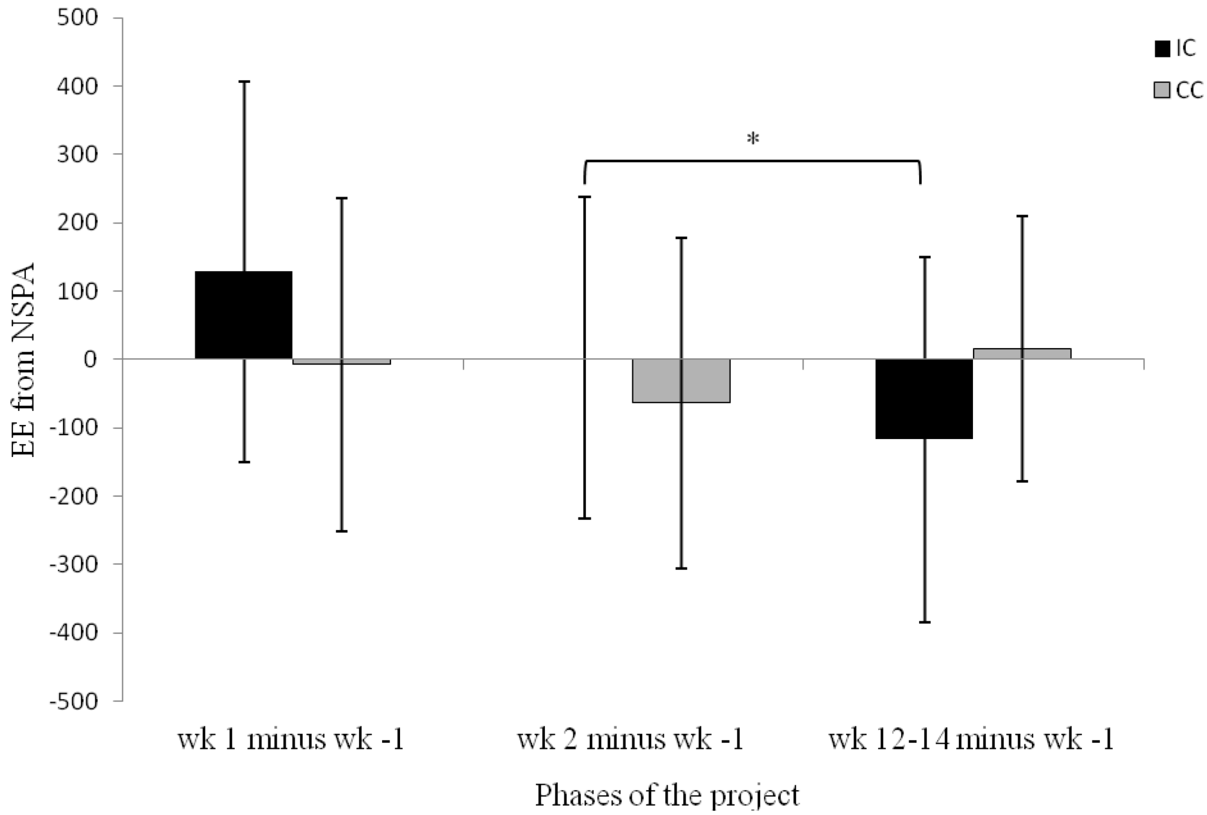
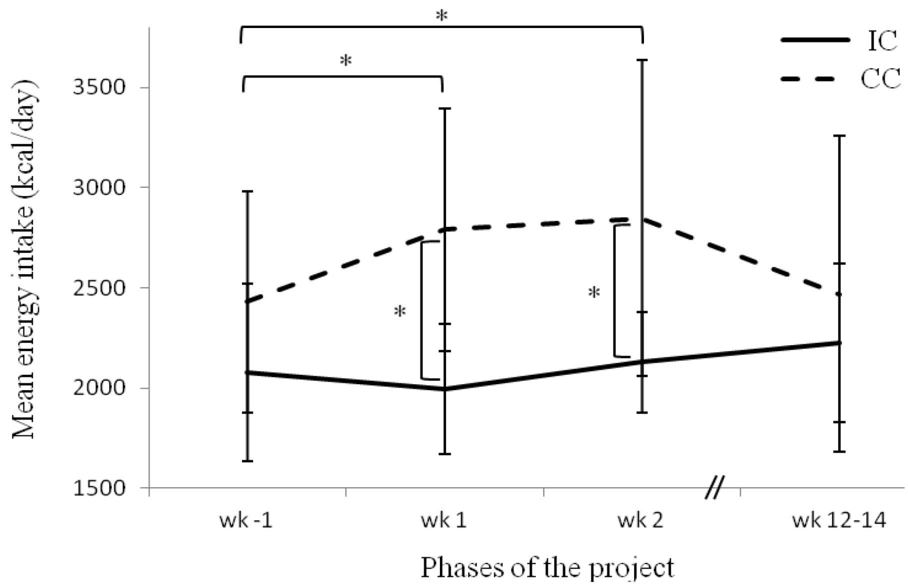



**Figure 4 -** Interaction of Phase by Group for EE from NSPA

* Represents a significant difference

Panel A




Panel B

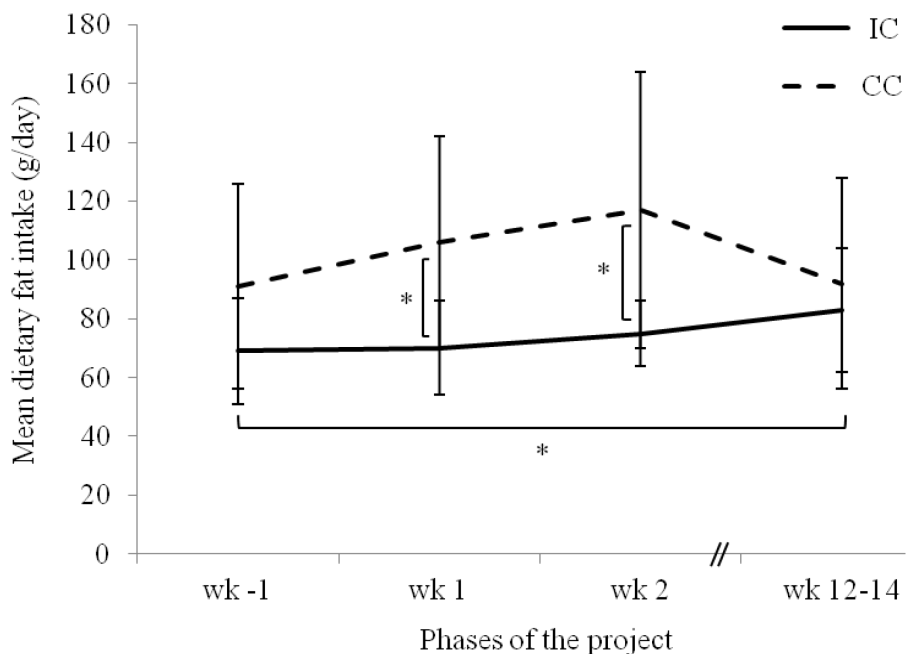



**Figure 5 -** Mean energy intake (panel A) and dietary fat (Panel B) consumed over 7 days

* Represents a significant difference

# Chapter IV

# Discussion

This thesis aimed to better characterize the energy compensation phenomenon. In Study 1, women spending more time performing light-intensity PA were shown to have lower adiposity compared to women spending more time performing moderate- and high-intensity PA. This finding suggests that energy spent exercising at a HI may be offset by EI and/or NSPA. Study 2 demonstrated that following the onset of an exercise intervention, energy compensation is initially below 100%, but approaches complete compensation after a long-term intervention. Objective methods to measure EI and the time spent performing different activities such as lying down, dynamic standing, sitting, walking and running were shown to be valid and reproducible in Study 3 and Study 4. In Study 5, energy compensation in overweight/obese women was shown to be higher after exercise training at a HI compared to LI. Greater energy compensation with HI compared to LI exercise training was explained by lower NSPA, and specifically by greater time spent lying down. In a comparison of overweight/obese CC and IC (Study 6), the last study of the thesis revealed an important contribution of cognitive factors to energy compensation. IC demonstrated lower EI at the onset of the exercise intervention, but it seems that cognitive factors balance EI to offset the energy deficit created by ExEE. Collectively, the findings of this thesis emphasize that: (I) weight loss following exercise is impeded by energy compensation; (II) energy compensation is about 100% after a long-term intervention; (III) the intensity of ExEE impacts energy compensation; (IV) energy compensation demonstrates high inter-individual variability and; (V) EI and NSPA should be sampled more frequently, or maybe through different means over a longer period of time to better capture the variability of these factors in order to ultimately obtain more reliable experimental data.

Changes in body composition following an exercise intervention are the best proxy of changes in body energy reserves. In accordance with the first law of thermodynamics, changes in body energy reserves over time occur with a persistent imbalance between EI and EE. Nevertheless, even in our best attempt to measure EI and EE over the course of the exercise intervention, these changes did not necessarily align with body composition changes. One of the two possible explanations is that the multiple 'snapshots' measurements of EI and EE at baseline, pre-, and post-intervention time-points, most likely do not capture the full extent of the variability in EI and EE. The second explanation is that our measures do not provide a true depiction of the reality. In the end, it is likely a combination of these two scenarios. Measurements of EI may be affected by large day-to-day individual variation[110], participant compliance due to the complexity and difficulty of accurately completing a food diary[38], and the under-reporting of EI[39-42]. Additionally, by virtue of study participation, individuals may be more inclined to increase PA or eat less/differently, and thereby alter their EI and EE. Although measuring EI and EE more frequently may be necessary to obtain a comprehensive and representative picture of EB, more measurements would lead to problems with participant recruitment and commitment and do not circumvent the limits associated with the tools used to measure EI and EE. One potential solution could be the use of mobile applications that monitor participants over a longer period of time without providing participants with any data (*e.g.,* step counts[111]). Use of mobile applications in this fashion may be the ideal approach to measuring EI and EE in different activities with high measurement stability without being too cumbersome and expensive for experimental use. Of course, mobile applications would have to conform to ethical standards to avoid the violation of individual liberties.

The findings presented in this thesis suggest that results obtained from acute or short-term exercise interventions should not be extrapolated to longer-term exercise interventions (~6 months). The systematic review analysis suggests that it is possible to sustain incomplete energy compensation over a short period of time. However, over a longer period of time, complete compensation tends to occur. Also, it has been demonstrated that cognitive factors (*e.g.,* disinhibition), which modulate EI[65], are altered during the exercise intervention. For example, hunger has been shown to modulate EI at the onset of the ExEE intervention for CC but not for IC. Conversely, dietary disinhibition for IC at the end of the intervention negatively changes dietary fat and carbohydrate intake compared to CC. As a result, even if there is no doubt that acute/short-term interventions are less invasive, less expensive, and easier to conduct, this thesis raises the question of whether the knowledge gained with studies performed over acute/short-term exercise should be used to understand weight management as it relates to exercise.

In addition to cognitive factors affecting energy compensation, it is possible that a decrease in motivation could explain an increase in energy compensation over a long-term exercise intervention. Based on results obtained from individuals who adhere to a low-calorie diet[112], increased energy compensation towards the end of the exercise intervention may reflect changes in motivation secondary to early success in weight loss at the beginning of the intervention. In contrast, a lack of weight loss at the onset of the intervention might have increased motivation for weight loss (*e.g.*, eat less, increase PA and NSPA) and thus limit energy compensation. If so, an approach "identifying successful goal-pursuit [...] rather than the outcome level of the goal"[112] could be advocated to increase motivation in an attempt to possibly limit energy compensation. A first step to do this would be to test with an appropriate study design whether motivation influences energy compensation during an exercise intervention.

To reduce the complete compensation observed in the systematic review over long-term exercise intervention, intermittent exercise interventions such as interventions that include several breaks spanning a week across a month-long intervention could be investigated. Even if no significant difference in terms of weight loss was obtained in an intermittent vs. a continuous diet intervention[113], it is possible that an intermittent exercise intervention may reduce energy compensation by increasing NSPA and decreasing the time spent lying down. To validate this idea, adaptation created by the exercise intervention on NSPA should be measured periodically during exercise intervention. Additionally, in order to maintain NSPA during a long-term exercise intervention, a program aimed at increasing NSPA could be added in parallel to the exercise intervention. Emphasis on stairs climbing instead of the use of the elevator and on walking instead of taking the bus are examples that increase NSPA and thus limit energy compensation over a long-term exercise intervention. In order to validate this idea, a longer measurement of NSPA and the time spent performing different activities should be performed in order to understand the impact of an intermittent exercise intervention on energy compensation.

To understand energy compensation following an exercise intervention, exercise compliance of the participants needs to be inspected more closely. Since exercise compliance impacts energy compensation, it is of interest to debate if intervention should strive to achieve close to perfect compliance to prescribed exercise. Would it be better to give individuals freedom as far as exercise compliance is concerned rather than to monitor attendance tightly with the goal of achieving 100% of exercise compliance? In this context, the addition of exercise compliance as a factor in the calculation of energy compensation might not reduce the energy compensation close to 100% observed over a long period of training, as reported in the systematic review included in this thesis. Nevertheless, it would help to better understand energy compensation when individuals are in a free-living context, where it is difficult to perform exercise on a regular basis. In order to provide a higher adherence to the exercise and to give skills to individuals in their desire to lose weight, behavioral treatment with cognitive therapy might be helpful[114]. In essence, by identifying the changes that can be made, or taking small steps rather than huge steps, individuals might be better prepared to follow exercise intervention over time[114].

This thesis also contributed to the development of an equation that calculates energy compensation from ExEE, ΔFM and ΔFFM. With dietary interventions[32], a constant value of 7700 kcal/kg of body weight[115] has been derived from the fact that 30% of FFM and 70% of FM are lost per kg of body weight[45,109,115]. However, the proportion of body composition changes when only considering ExEE is actually unknown[45]. As proposed by Rosenkilde in 2013, the contribution of FM has been shown to be larger during an exercise intervention[45,116]. To account for these differences in body composition changes, energy densities of 1020 kcal/kg (FFM) and 9500 kcal/kg (FM) have also been used[117]. Also to be considered is the fact that the energy required to accumulate a calorie must be different from the energy required to expend one. Example of differences between storing or expending a calorie include the energy needed for the digestion/absorption of the calorie intake and the non absorption of the calorie intake found in the feces[118]. As a result, the calculations performed to obtain energy compensation in this thesis were done while considering that a gain of 1 kg of FM corresponds to 12 000 kcal, while a gain of 1 kg of FFM corresponds to 1780 kcal[119]. In comparison, a loss of 1 kg of FM corresponds to 9417 kcal while a loss of 1 kg of FFM corresponds to 884 kcal[120]. The equivalents used by Rosenkilde in 2012[45] and used in this thesis have been determined from other studies[119,121,122]. As a result, energy compensation specifically accounts for the dynamic change of body composition, such as a gain or loss of FM and FFM. It is however important to acknowledge that because no direct measurements of body energy changes were performed and that we relied on proxies, there could be some variability that is not accounted for in the present thesis as far as body energy changes are concerned. However, we did use DXA for studies performed in our laboratory, which does represent the gold standard for whole body composition measurement.

# Chapter V

# Conclusion

The main objective of this thesis was to characterize energy compensation following ExEE. The finding that the energy compensation is increased with the length of the intervention highlights the difficulty associated with exercise-induced weight loss over a long period of time. Nevertheless, this thesis adds interesting observations to the body of knowledge on weight loss and exercise. Individuals intervening with overweight/obese individuals with the goal of improving weight management should be aware that the response is seemingly greater when training occurs at LI in women. However, when training at HI, NSPA and more specifically the time spent lying down, should be closely followed. This finding therefore leaves room for monitoring NSPA over a long period of time in hopes in improving the resolution potential of exercise intervention on body weight control. For example, participants could strive and should be encouraged to maintain the same number of daily step counts per day over the entire exercise intervention. The results from this thesis also highlight that cognitive factors should be monitored before and during an exercise intervention in order to help individuals who struggle with weight loss. Finally, the results of this thesis emphasize that a better understanding of the impact of ExEE on energy compensation relies on methods that measure EI and EE under unrestricted environment.

# Chapter VI

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# Appendix A

CLIMACTERIC 2014;17:79–86

# Light physical activity is a better determinant of lower adiposity during the menopausal transition

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Key words: PHYSICAL ACTIVITY, ACCELEROMETRY, BODY WEIGHT, BODY COMPOSITION, MENOPAUSE, COMPENSATION

## ABSTRACT

*Objective* To investigate the relationship between time spent performing physical activity (PA) and adiposity across the menopausal transition.

*Methods* Body weight and body composition were analyzed in 65 women (47–54 years old; body mass index 23.2 ± 2.4 kg/m$^2$) in a 5-year prospective study. Time spent in PA of varying intensities (sedentary, light, moderate and vigorous) was determined from 7-day accelerometer measurement and energy intake with a 7-day food diary.

*Results* Significant negative correlations were observed between the time spent in light-intensity PA and fat mass (FM) ($r = -0.38$, $p < 0.005$), central FM ($r = -0.36$, $p < 0.005$), peripheral FM ($r = -0.33$, $p < 0.01$), and percent body fat ($r = -0.42$, $p < 0.001$) at year 1, respectively. No significant correlations were noted between measures of adiposity and time spent performing either moderate or vigorous PA. Analyses using tertiles of time spent in light PA at year 1 showed that FM (20.7 ± 4.0 vs. 20.3 ± 6.6 vs. 16.6 ± 4.6 kg, $p < 0.05$), central FM (10.1 ± 2.6 vs. 10.0 ± 3.8 vs. 7.8 ± 2.4 kg; $p < 0.05$) and percent body fat (34.5 ± 5.1 vs. 32.2 ± 7.7 vs. 28.1 ± 6.2%, $p < 0.01$) were all significantly lower in women in the highest tertile. These differences remained significant after covariate analyses using time spent in moderate- and high-intensity PA and total energy intake. Finally, lower levels of FM, percent body fat, central and peripheral FM persisted in women who spent more time in light PA (highest tertiles) over the 5-year follow-up.

*Conclusion* Our results suggest that the time spent performing light PA may have a greater impact on adiposity than moderate and/or vigorous PA, an observation independent of the menopausal status.

## INTRODUCTION

Exercise interventions have been widely investigated and recommended to prevent obesity or to promote weight loss. However, even if it has been associated with a favorable impact on physiological and psychological well-being[1], the fact remains that the effects of exercise on the reduction in body weight are often much less than anticipated[2,3]. Several reasons have been proposed to explain this observation. These include, but are not limited to, the small doses of prescribed exercise, a reduction of resting energy expenditure, an increased energy intake and/or a decrease in non-exercise activity following exercise[3–5].

In an attempt to provide a clearer picture of the effect of exercise on body weight, studies have manipulated the duration, the amount of exercise per week as well as the intensity of the exercise. In this sense, it has been demonstrated in overweight and premenopausal women with restricted energy

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ORIGINAL ARTICLE

DOI: 10.3109/13697137.2013.810715

Received 09-04-2013
Revised 29-05-2013
Accepted 29-05-2013

intake that a 3-month walking intervention lasting either 30 or 60 min leads to a similar weight reduction when performed 5 times per week[6]. In contrast, it was reported that obese postmenopausal women who performed exercise for longer duration lost a higher amount of weight, independent of the exercise intensity[7]. On the other hand, when taking into consideration intensity of physical activity, it has been suggested by Slentz and colleagues in 2004 that, when physical activity is performed at higher intensity, it has a small and non-significant effect on fat mass when compared to a lower-intensity physical activity, and this is even after controlling for energy expenditure during exercise (14 kcal/kg or 12 miles in both groups)[8]. It has also been proposed that intensity might be more related to a gain in lean body mass rather than to fat mass losses[8], suggesting that duration has a greater impact than intensity as far as weight and fat loss are concerned[7–9]. Similarly, after controlling for energy expenditure during exercise, in an intervention that lasted 3 months, it has been shown that weight loss was greater at lower intensity when compared to weight loss in women who exercised at higher intensity[9,10]. To explain, the authors' assumptions support the idea of a lower energy intake and non-structured physical activity compensation across the intervention for women training at a lower intensity[10].

Considering the above evidence suggesting that the better cocktail to favor weight loss is to perform a physical activity for a longer duration at lower intensity, we, for the first time, investigated whether this cocktail would have a greater impact on body composition across the menopause, which is a critical period that has been shown to be associated with changes in body composition and fat distribution[11,12]. As such, the main objective of this study was to investigate the impact of the time spent (duration) in sedentary physical activity (PA) and PA of varying intensities (light, moderate and vigorous) on body weight and composition during a 5-year follow-up of women going through menopause. It is hypothesized that light PA would be associated with a favorable change in body composition when compared to moderate or high PA. It is also hypothesized that spending more time performing light physical activities would be associated with a lower adiposity at baseline and with a lesser gain in adiposity during the 5-year follow-up.

## METHODS

### Participants

This study was part of one of the MONET (Montréal Ottawa New Emerging Team) studies and details are provided elsewhere[13]. The inclusion criteria were as follows: (1) premenopausal women between 48 and 55 years of age; (2) regular menstrual cycle; (3) non-smoker; (4) body mass index (BMI) between 20 and 29 kg/m$^2$; (5) reported weight stability ($\pm 2$ kg) for $\geq 6$ months before enrolment in the study; (6) no known disease or disability; and (7) no current medications that could influence energy intake or metabolism. Women were also allowed to be on oral contraceptives. Hormone replacement therapy was an exclusion criterion at inclusion. However, women who began this treatment during the study were kept in all analyses ($n = 4$)[13]. A total of 314 women responded to the invitation in the local newspapers of the Ottawa City metropolitan area. As described by Abdulnour and colleagues[13], 102 women were found to be eligible. Among them, 11 dropped out of the study for personal reasons. A total of 91 Caucasian women completed the 5-year longitudinal study with body composition measurements performed each year. However, women without complete accelerometry data ($n = 26$) were not included. Body weight ($60.5 \pm 6.4$ kg ($n = 65$) vs. $61.2 \pm 6.1$ kg ($n = 26$); $p$ not significant) and composition (% body fat, $31.6 \pm 6.9$ ($n = 65$) vs. $29.7 \pm 5.5$ ($n = 26$); $p$ not significant; fat-free mass, $40.9 \pm 4.2$ kg ($n = 65$) vs. $41.8 \pm 4.9$ kg ($n = 26$), $p$ not significant) were not significantly different at baseline and over the course of the study, between those who completed all accelerometry measurements and women who did not. Sixty-five premenopausal women were thus included in this prospective observational study. This study was conducted according to the guidelines laid down in the Declaration of Helsinki and all the procedures involving human subjects were approved by the University of Ottawa ethics committees. Written informed consent was obtained from all subjects.

### Menopausal status

Women were classified, according to the STRAW classification[14], into three groups based on their menopause status at year 5: (1) women who remained premenopausal throughout the study (stable length of cycles) ($n = 2$); (2) women who were classified as perimenopausal (variable cycle length $> 7$ days different from normal and/or $\geq$ two skipped cycles and an interval of $\geq 60$ days of amenorrhea) ($n = 20$); and (3) women who were classified as postmenopausal women during the course of the study (12 months without any menstrual cycles and follicle stimulating hormone (FSH) $> 30$ mIU/ml ($n = 43$)[15]. We combined women who remained premenopausal over the entire course of the study with those who were classified in the menopause transition because their initial weight and body composition revealed no significant differences at baseline (not shown). FSH levels were also measured annually during the early follicular phase to verify the menopausal status. Women who had a hysterectomy were classified using their FSH value ($n = 3$).

### Measurements

All measurements (except for the graded exercise test to exhaustion) were performed on a yearly basis at approximately the same time of the year (within 2–3 months) during the follicular phase (days 1–8), for as long as the women enrolled in this study were still premenopausal. Women who were perimenopausal and postmenopausal were tested during a specific time of the year.

## Body composition measurements

Body weight was measured to the nearest 0.1 kg using a BWB-800AS digital scale, and standing height was measured to the nearest millimeter using a wall stadiometer (Tanita Corporation of America, Inc, Arlington Heights, IL, USA). Waist circumference was assessed in duplicate at the mid-distance between the iliac crest and the last rib margin with a flexible steel metric tape. Body composition and central fat mass (FM) were measured by using dual-energy X-ray absorptiometry (DXA; GE-LUNAR Prodigy module; GE Medical Systems, Madison, WI, USA). In addition, peripheral fat, i.e. FM contained in both arms and legs, was obtained by subtracting central FM (FM contained in the trunk) from total fat measured with DXA. The coefficient of variation and correlation for body fat percentage (% BF) measured in 12 healthy subjects tested in our laboratory were 1.8% and $r = 0.99$, respectively.

## Time spent in physical activity of varying intensities

A 7-day accelerometer measure (Actical; Mini Mitter Co, Inc, Bend, OR, USA) was used to estimate mean time spent in PA of varying intensities. Sedentary intensity was described as an intensity between 1.0 and 1.5 METs, light intensity was higher than 1.5 METs and lower than 3.0 METs, moderate intensity was higher or equal to 3 METs and lower than 6 METs, and vigorous intensity was higher or equal to 6 METs[16]. As described in the Actical software instruction manual, examples of a sedentary activity are sleeping and resting. Examples for light, moderate and high physical activity include walking at a pace lower than 4.8 km/h, lower than 7.2 km/h and higher than 7.2 km/h, respectively[16]. Participants wore the accelerometer upon waking up and took it off just before going to bed. Twenty-four hours of continuous recording was performed by the accelerometers and time spent performing sedentary exercise was also considered when participants were not wearing the device (sleep time). The accelerometer was worn on the right hip (anterior to the iliac crest)[17]. When compared to doubly labelled water, this tool has been shown to be a good predictor of energy expenditure[18]. However, we elected to use the time spent in PA of varying intensities instead of energy expenditure, because time does not have to be controlled for body weight.

## Cardiorespiratory fitness

A progressive exercise stress test to exhaustion was performed to measure participants' peak maximal oxygen consumption ($VO_{2peak}$) on a treadmill at years 1, 3 and 5 of the study. The progressive test consisted of 3-min stages on a treadmill with an increasing workload to the point of exhaustion. For the first 15 min, the speed was at 3.4 mph and the incline increased by 4% every 3 min until 16%. The speed then increased to 4.0, 5.2 and 6.0 mph every two stages, while the incline changed at every stage (14, 16, 12, 15, 14 and 16%). Heart rate, blood pressure and the Borg scale[19] were taken at rest and at the end of each stage during the test. Breath-by-breath samples of expired air were collected through a mouthpiece throughout the test, and measurements of $VO_2$ and respiratory exchange ratio were made automatically using a $V_{max}$ 229 series metabolic cart (SensorMedics Corporation, Yorba Linda, CA, USA). Peak oxygen consumption was considered as the highest $VO_2$ reached during the test.

## Food records

Energy intake and macronutrients were assessed with a 7-day dietary record during the same day where the accelerometer was worn. Subjects were asked to record the type and amount of foods and beverages consumed. The time and place of eating of food were recorded as well. Participants received oral and written instructions on how to record their energy intake. They were asked to be as specific as possible in their description by indicating all main ingredients and the quantity, the brand of products, and the cooking method. Participants were also asked to bring food labels. Recorded data were carefully verified on the return of the food diary to obtain forgotten items or to correct misreported foods. Food Processor SQL software (version 9.6.2; ESHA Research, Salem, OR, USA) was used for analyses.

## Statistical analyses

Statistical analyses were performed using SPSS software (version 11.5; SPSS Inc, Chicago, I, USA). Data are presented as means $\pm$ standard deviations. A one-way repeated-measure analysis of variance (PROC MIXED) was used to determine the main effects of time spent in sedentary PA and PA of varying intensities (light, moderate and vigorous) across the 5 years' follow-up. When significant differences were found, the Bonferroni *post hoc* test were used to determine the differences. Pearson correlations were then used to examine relationships between time spent in PA of varying intensities (year 1) and body weight and composition at years 1 and 5. Participants were then grouped into tertiles based on time spent in light PA at year 1. An ANOVA that compared these groups was then followed by an ANCOVA, controlling for the time spent in other intensities (moderate and vigorous), and total energy intake was used to determine differences in body weight and composition between tertiles at year 1. When significant differences were found, the Tukey *post hoc* test were used to determine group differences. Finally, a three-way repeated-measures ANOVA was used to determine the main effects of time, tertile of light PA (year 1) and menopausal status*time on body composition variables during the follow-up. When significant differences were found, the Tukey *post hoc* test were used to determine group differences. Differences with $p$ values $< 0.05$ were considered statistically significant.

# RESULTS

## Baseline characteristics of participants

The characteristics of the participants at year 1 are shown in Table 1. Although all women had a BMI lower than 30 kg/m$^2$ at baseline, participants in this cohort presented a large range of % BF (18.2–41.7%), FM (9.6–30.0 kg), central FM (3.3–18.3 kg) and peripheral FM (5.0–15.5 kg). As described by Abdulnour and colleagues[13], increases in FM and % BF as well as a decrease in fat-free mass were noted during the 5-year follow-up (data not shown). Times spent in sedentary PA and PA of varying intensities (light, moderate and vigorous) during the 7-day accelerometry measurement were not different over the course of the 5-year follow-up (Figure 1). The only significant difference was observed between years 3 and 4 in PA performed at moderate intensity.

## Correlations with time spent at different intensities

Our data revealed significant and positive relations between the time spent in sedentary PA and central FM ($r = 0.27$, $p < 0.05$) and % BF ($r = 0.26$, $p < 0.05$) at year 1 (Table 2). In contrast, at year 1, the time spent performing light PA was found to correlate negatively with BMI ($r = -0.30$, $p < 0.05$), FM ($r = -0.38$, $p < 0.005$), % BF ($r = -0.42$, $p < 0.001$), central FM ($r = -0.36$, $p < 0.005$) and peripheral FM ($r = -0.33$, $p < 0.01$). Similar correlations were also found at year 5 with FM ($r = -0.29$, $p < 0.05$), % BF ($r = -0.31$, $p < 0.05$), central FM ($r = -0.26$, $p < 0.05$) and peripheral FM ($r = -0.27$, $p < 0.05$). No significant correlations were noted between adiposity and time spent performing either moderate or vigorous PA at years 1 and 5. Energy intake measured at year 1 was correlated with the time spent performing light PA ($r = 0.22$, $p < 0.05$) (data not shown).

## Comparison of body weight and composition between tertiles of time spent performing light PA

Since negative correlations were only found between time spent in light PA and body weight and body composition, we decided to further investigate this issue by grouping women into tertiles of time spent performing light PA at year 1. As presented in Table 3, women in the highest tertile of time performing light PA displayed lower FM ($p < 0.05$), % BF ($p < 0.01$) and higher fat-free mass ($p < 0.05$) when compared to women in the lowest tertile. Similarly, women in this tertile displayed lower central FM ($p < 0.05$) when compared to women in the lower and moderate tertiles. No significant differences were observed for body weight, BMI and waist circumference, while a trend ($p = 0.06$) was observed for peripheral FM. Also, no significant difference was noted for cardiorespiratory fitness.

Because spending more time performing light PA impacts the time spent performing moderate and/or high intensity PA, the same analyses were performed after controlling for the sum of time spent performing moderate and high intensity PA. Differences remained significant for FM ($p < 0.05$), % BF ($p < 0.01$) and fat-free mass ($p < 0.05$), while a trend was noted for peripheral FM ($p = 0.06$) between the highest and lowest tertiles. Finally, even if no significant group differences for time performing light PA were noted for total energy intake at year 1 (total energy intake at lowest tertile of time performing light PA: 1850 ± 377 kcal ($n = 22$); at middle tertile of time performing light PA: 2074 ± 344 kcal ($n = 21$); at highest tertile of time performing light PA: 2053 ± 434 kcal ($n = 22$); $p$ not significant), total energy intake was used as a covariate in all analyses. Results show that most differences remained when corrected for both time spent performing moderate- and high-intensity PA and total energy intake (Table 3).

## Time spent performing light PA and changes in body weight and composition

Repeated-measures ANOVA analyses were performed in order to determine the main effect of time (years 1–5) of tertiles (lowest, moderate and high) on time performing light PA and menopause status. Analyses revealed a main (increase) effect of time (year 1 to year 5) for waist circumference ($p < 0.005$), FM ($p < 0.0001$), % BF ($p < 0.0001$), central FM ($p < 0.0001$), peripheral FM ($p < 0.0001$) as well as a main (decrease) effect for fat-free mass ($p < 0.0001$), while no significant effects were found for weight and BMI (data not shown). Similarly, significant effects were observed between tertiles for FM ($p < 0.01$), % BF ($p < 0.01$), peripheral FM ($p < 0.05$) and central FM ($p < 0.01$) (data not shown). Women in the highest tertile of time performing light PA displayed lower FM, % BF, and central FM when compared to women in the lowest or moderate tertile of time performing light PA. An overview of these findings for % BF, for women who had worn an accelerometer every 5 years ($n = 41$) is presented in Figure 2. No significant difference was noted as far as menopausal status was concerned. Finally, no significant interaction of time by group, time by menopausal status or time by group by menopausal status were noted (data not shown), indicating that adiposity differences between tertiles were not different across

**Table 1** Characteristics of the subjects at baseline ($n = 65$). Data are given as means ± standard deviations

| | |
|---|---|
| Age (years) | 49. 7 ± 1.8 |
| Maximal aerobic power (min/kg/ml) ($n = 62$) | 33.7 ± 6.5 |
| Body weight (kg) | 60.5 ± 6.4 |
| Body mass index (kg/m$^2$) | 23.2 ± 2.4 |
| Waist circumference (cm) | 78.3 ± 7.0 |
| Fat mass (kg) | 19.2 ± 5.4 |
| Fat-free mass (kg) | 40.9 ± 4.2 |
| Body fat % | 31.6 ± 6.9 |
| Central fat mass (kg) | 9.3 ± 3.2 |
| Peripheral fat mass (kg) | 9.9 ± 2.7 |

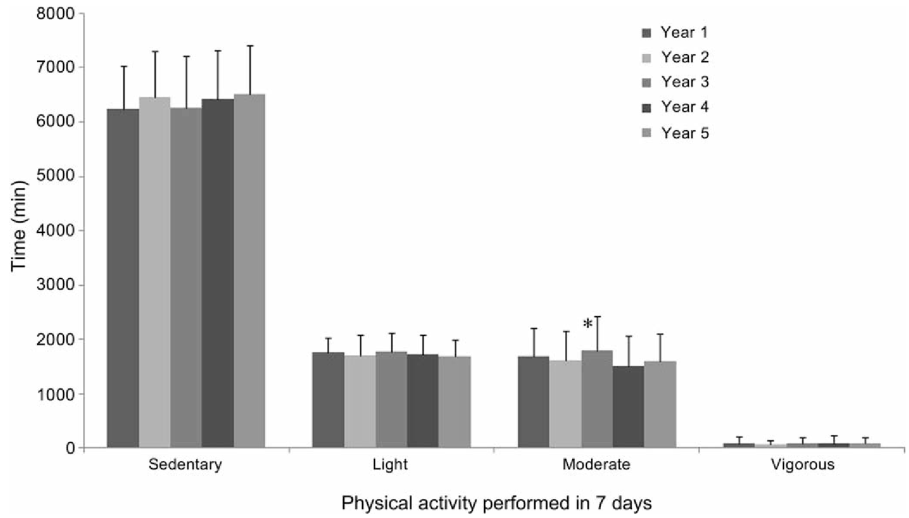


**Figure 1** Time spent in sedentary physical activity (PA) and PA of varying intensities in 7 days across the 5 years of follow-up. *, Significant difference between years 3 and 4 for moderate intensity. For sedentary PA, the times (mean ± standard deviation) are: year 1, 6245.4 ± 785.1 min; year 2, 6464.7 ± 848.4 min; year 3, 6265.2 ± 946.8 min; year 4, 6417.8 ± 906.2 min; year 5, 6521.1 ± 884.7 min; $n = 41$. For light PA, the times are: year 1, 1756.9 ± 265.0 min; year 2, 1711.7 ± 367.0 min; year 3, 1771.4 ± 345.8 min; year 4, 1726.8 ± 357.8 min; year 5, 1681.3 ± 310.3 min; $n = 41$. For moderate PA, the times are: year 1, 1689.0 ± 528.2 min; year 2, 1608.1 ± 540.4 min; year 3, 1795.2 ± 621.3 min; year 4, 1514.3 ± 556.0 min; year 5, 1602.1 ± 498.4 min; $n = 41$. For vigorous PA, the times are: year 1, 84.3 ± 130.3 min; year 2, 68.1 ± 66.0 min; year 3, 86.9 ± 103.6 min; year 4, 76.2 ± 147.4 min; year 5, 81.0 ± 105.1 min; $n = 41$



the 5-year follow-up and regarding the menopausal status. However, it is important to note that, even if women in the highest tertile of time performing light PA displayed lower FM, % BF, and central FM when compared to women in the lowest or moderate tertiles of time performing light PA, they present a similar increase in body weight and body composition across the 5-year follow-up. Last, after controlling for time spent performing moderate and high PA and total energy intake at year 1, adiposity differences between tertiles remained significant across the 5-year follow-up. However, no effect of time was observed after controlling for these variables (data not shown).

## DISCUSSION

Due to reported compensatory effects on energy intake[20] and energy expenditure[4] following a physical activity practise at a higher intensity, we hypothesized that women spending more time performing light PA would have lower body weight and adiposity. In addition, we further hypothesized that spending more time in light PA would attenuate the adiposity gain during a 5-year follow-up. Our data suggest that spending more time doing light PA is associated with lower body weight as well as with some indices of adiposity at the onset of a 5-year follow-up. However, even if spending more time performing light PA was associated with lower adiposity throughout the 5-year follow-up, it was not associated with a reduction of the adiposity gain normally observed with menopause and aging[12,21,22].

Our results showed that the time spent in light PA is associated with lower adiposity, which was not the case for time spent performing moderate or vigorous PA. This would seem to suggest a possible implication for compensatory mechanisms as intensity increases. In fact, it has been shown that PA increases the palatability, pleasantness, as well as the tastiness of foods[23,24]. More recently, it has also been reported that the hedonic value of food is at least partly modulated by exercise[20]. As such, it could be postulated that increased compensation from energy intake might differ in response to the time spent performing light, moderate or vigorous intensity. For example, it has been demonstrated that women have a significantly lower energy intake over 24 h after a bout of low-intensity exercise than they do after a high-intensity exercise bout[25]. However, in this study, light physical activity was positively correlated with energy intake at year 1 while no significant correlation was noticed at year 5. Another explanation as to why women spending more time performing light PA display lower adiposity may relate to energy expenditure after non-structured PA. Results from a study done in elderly individuals who were performing high-intensity exercise revealed that energy expenditure after non-structured PA was decreased by 231 kcal/day[26]. More recently, it was also reported that a moderate-intensity walking program designed to expend 1500 kcal/week during 2 months produced a significant decrease after non-structured PA (22% or 175 kcal/day) in a group of obese women[4]. These findings lend support to the notion that non-exercise activity thermogenesis may be reduced in response to exercise. Whether the magnitude of

**Table 2** Correlation coefficients (*r* values) between time spent in physical activity of varying intensities at year 1 and body weight and composition at years 1 and 5. $n = 65$ unless otherwise stated

| | *Time spent in physical activity of varying intensities at year 1* | | | |
|---|---|---|---|---|
| | *Sedentary* | *Light* | *Moderate* | *Vigorous* |
| *Body weight* (kg) | | | | |
| Year 1 | 0.10 | −0.20 | −0.04 | −0.06 |
| Year 5 | 0.11 | −0.18 | −0.04 | −0.04 |
| *Body mass index* (kg/m²) | | | | |
| Year 1 | 0.19 | −0.30* | −0.12 | −0.08 |
| Year 5 | 0.17 | −0.24 | −0.11 | −0.05 |
| *Waist circumference* (cm) | | | | |
| Year 1 | −0.02 | −0.12 | 0.07 | −0.06 |
| Year 5 ($n = 64$) | −0.01 | −0.02 | 0.07 | −0.09 |
| *Fat mass* (kg) | | | | |
| Year 1 | 0.22 | −0.38** | −0.08 | −0.04 |
| Year 5 | 0.19 | −0.29* | −0.07 | −0.03 |
| *Fat-free mass* (kg) | | | | |
| Year 1 | −0.15 | 0.22 | 0.05 | −0.03 |
| Year 5 | −0.13 | 0.17 | 0.04 | −0.01 |
| *% Body fat* | | | | |
| Year 1 | 0.26* | −0.42‡ | −0.10 | −0.03 |
| Year 5 | 0.23 | −0.31* | −0.09 | −0.01 |
| *Central fat mass* (kg) | | | | |
| Year 1 | 0.27* | −0.36** | −0.15 | −0.08 |
| Year 5 | 0.24 | −0.26* | −0.14 | −0.05 |
| *Peripheral fat mass* (kg) | | | | |
| Year 1 | 0.13 | −0.33† | 0.03 | 0.01 |
| Year 5 | 0.11 | −0.27* | 0.03 | −0.00 |
| *Maximal aerobic power* (min/kg/ml) | | | | |
| Year 1 ($n = 62$) | −0.08 | 0.20 | −0.05 | 0.19 |
| Year 5 ($n = 58$) | −0.13 | 0.21 | −0.01 | 0.18 |

*, $p < 0.05$; †, $p < 0.01$; **, $p < 0.005$; ‡, $p < 0.001$



this decrease is greater when performing exercise at high intensity remains, however, to be determined.

Our analyses also demonstrated that larger amounts of PA performed at a light intensity (highest tertile of time spent in light PA) are associated with lower body weight and with lower indices of adiposity in women going through the menopausal transition. In accordance with results from Jakicic and colleagues, this could be explained by the fact that women performing more minutes of exercise per week (200 min/week) were the ones displaying the largest weight losses when compared to those performing less than 150 min/week, independently of exercise intensity[7]. In summary, time performing light PA is associated with lower adiposity, at least in the sample we investigated. Furthermore, it is also associated with the maintenance of lower body fat over the course of the study period, an effect that is independent of the menopausal status.

BMI at inclusion was $< 30$ kg/m². It is clear that conclusions cannot be extended to the general population. However, it is important to mention that 45% of the women aged between 40 and 59 years in the Canadian population[27] present a BMI between 20 and 29 kg/m². In addition, our findings need to be confirmed in a larger cohort of subjects that should include obese women with a greater age range as well as women with high levels of vigorous physical activity. Nonetheless, it is relevant to note that our conclusions are based on results obtained from objective measures such as DXA and accelerometry. It should also be reiterated that women were investigated across the menopausal transition during a 5-year follow-up and were grouped accordingly (premenopausal, perimenopausal and postmenopausal) for all analyses.

As mentioned previously, our results suggest that women spending more time performing light PA have lower adiposity, an effect that is independent of the menopausal status.

**Table 3** Comparison of tertiles of time spent in light physical activity with body weight and composition at year 1. Data are given as means ± standard deviations. Values that share the same superscript letter are not statistically different using the Tukey HSD *post-hoc* test performed without correction for time spent performing moderate and high intensity physical activity and energy intake

| | *Tertile of light physical activity* | | | | | |
|---|---|---|---|---|---|---|
| | *Low light* ($n = 22$) | *Moderate light* ($n = 21$) | *High light* ($n = 22$) | *p Value* | *p Value corrected** | *p Value corrected*† |
| Time spent (min) | 1451 ± 170 | 1744 ± 73 | 2081 ± 179 | < 0.0001 | < 0.0001 | < 0.0001 |
| *Body composition* | | | | | | |
| Body weight (kg) | 60.3 ± 4.9 | 62.6 ± 7.8 | 58.8 ± 6.1 | 0.16 | 0.16 | 0.14 |
| Body mass index (kg/m²) | 23.5 ± 1.7 | 23.7 ± 3.0 | 22.4 ± 2.0 | 0.11 | 0.15 | 0.13 |
| Waist circumference (cm) | 78.2 ± 7.0 | 79.7 ± 7.4 | 77.1 ± 6.6 | 0.47 | 0.47 | 0.44 |
| Fat mass (kg) | 20.7 ± 4.0$^{A}$ | 20.3 ± 6.6$^{AB}$ | 16.6 ± 4.6$^{B}$ | 0.02 | 0.02 | 0.03 |
| Fat-free mass (kg) | 39.0 ± 2.9$^{A}$ | 41.8 ± 4.3$^{AB}$ | 42.0 ± 4.7$^{B}$ | 0.03 | 0.03 | 0.07 |
| % Body fat | 34.5 ± 5.1$^{A}$ | 32.2 ± 7.7$^{AB}$ | 28.1 ± 6.2$^{B}$ | 0.006 | 0.009 | 0.02 |
| Peripheral fat mass (kg) | 10.6 ± 2.0 | 10.3 ± 3.2 | 8.8 ± 2.7 | 0.06 | 0.05 | 0.07 |
| Central fat mass (kg) | 10.1 ± 2.6$^{A}$ | 10.0 ± 3.8$^{A}$ | 7.8 ± 2.4$^{B}$ | 0.02 | 0.03 | 0.04 |
| *Aerobic fitness* | ($n = 21$) | ($n = 20$) | ($n = 21$) | | | |
| Maximal aerobic power (min/kg/ml) | 33.2 ± 5.8 | 32.6 ± 6.2 | 35.2 ± 7.4 | 0.40 | 0.39 | 0.32 |

*, *p* value corrected for time spent performing moderate and high intensity physical activity; †, *p* value corrected for time spent performing moderate and high intensity physical activity and energy intake

Additionally, the lower adiposity values observed in women performing light PA persist over a 5-year follow-up across the menopausal transition. These findings seem to suggest that women should increase the amount of time spent performing light PA as a potential strategy to maintain lower levels of adiposity.

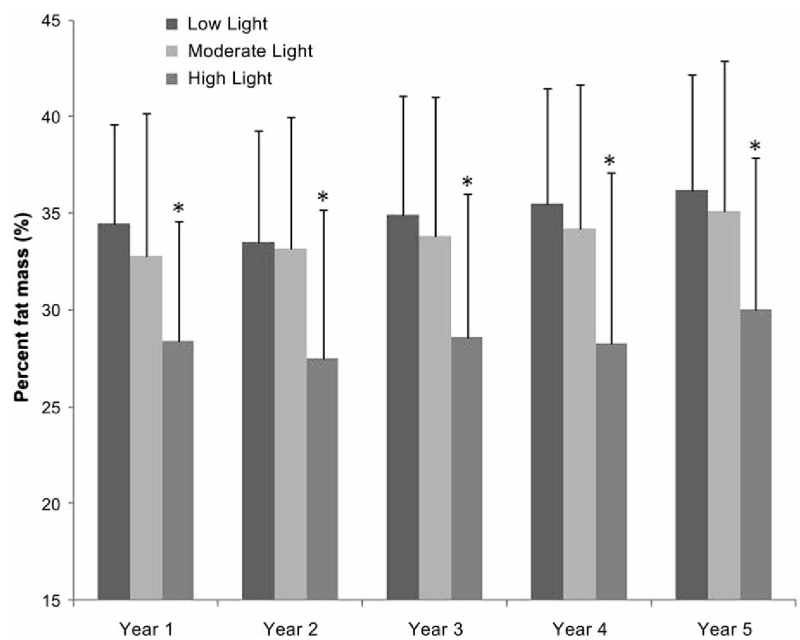


**Figure 2** Tertiles of time spent in light physical activity (PA) (low ($n = 22$), moderate ($n = 20$) and high ($n = 21$)) and percent body fat over the 5-year follow-up. *, Significant difference for percent fat mass in women spending more time performing high light PA and women spending more time performing low or moderate light PA

## ACKNOWLEDGEMENTS

The authors would like to thank the participants for their devoted participation and to the staff of BMRU for their contribution to this study. We especially want to thank the study nurse, Ann Beninato for her significant role in the collection of the data and overall study coordination.

*Conflict of interest* The authors report no conflict of interest. M. E. Riou and É. Doucet analyzed the data and wrote the manuscript while the co-authors J. Abdulnour, M. Brochu, D. Prud'homme and R. Rabasa-Lhoret critically appraised and approved the final version of the manuscript. In addition, D. Prud'homme, M. Brochu, R. Rabasa-Lhoret and É. Doucet participated in the research design. M. E. Riou is a recipient of the Frederick Banting and Charles Best Doctoral Award (CIHR). R. Rabasa-Lhoret is a FRQ-S (Fonds de recherche du Quebec en santé) senior scholar and holds the J-A DeSève chair in clinical research.

*Source of funding* This study was supported by CIHR (Canadian Institute for Health Research) grants: 63279 MONET study (Montréal Ottawa New Emerging Team: DP, MB, RRL and ED).



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# Appendix B

*British Journal of Nutrition* (2012), **108**, 1316–1324
doi:10.1017/S0007114511006672


# Reproducibility of a food menu to measure energy and macronutrient intakes in a laboratory and under real-life conditions

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*(Submitted 4 May 2011 – Final revision received 2 November 2011 – Accepted 4 November 2011 – First published online 16 January 2012)*

## Abstract

Given the limitations associated with the measurement of food intake, we aimed to determine the reliability of a food menu to measure energy intake (EI) and macronutrient intake within the laboratory and under free-living conditions. A total of eight men and eight women (age 25·74 (SD 5·9) years, BMI 23·7 (SD 2·7) kg/m$^2$) completed three identical in-laboratory sessions (ILS) and three out-of-laboratory sessions (OLS). During the ILS, participants had *ad libitum* access to a variety of foods, which they chose from a menu every hour, for 5 h. For the OLS, the foods were chosen from the menu at the start of the day and packed into containers to bring home. There were no significant differences in total EI (6118·6 (SD 2691·2), 6678·8 (SD 2371·3), 6489·5 (SD 2742·9) kJ; NS) between the three ILS and three OLS (6816·0 (SD 2713·2), 6553·5 (SD 2364·5), 6456·4 (SD 3066·8) kJ; NS). Significant intraclass correlations (ICC) for total energy ($r$ 0·77, $P$< 0·0001), carbohydrate ($r$ 0·81, $P$< 0·0001), dietary fat ($r$ 0·54, $P$< 0·0001) and protein ($r$ 0·81, $P$< 0·0001) intakes for the ILS and significant ICC for total energy ($r$ 0·85, $P$< 0·0001), carbohydrate (0·85, $P$< 0·0001), dietary fat (0·72 $P$< 0·0001) and protein (0·80, $P$< 0·0001) intakes for the OLS were noted. The average within-subject CV for total EI was 18·3 (SD 10·0) and 16·1 (SD 10·3) % for the ILS and OLS, respectively, with a pleasantness rating for foods consumed of 124 (SD 14) mm out of 150 mm (83 %). Overall, the food menu produces a relatively reliable measure of EI inside and outside the laboratory. The results also underscore the difficulties in capturing a representative image of food intake given the relatively high day-to-day variation in the amount and composition of foods consumed.

Key words: **Food intake: Food menus: Reproducibility: Free-living: Conditions**

Few studies have attempted to establish the validity of tools that directly measure food intake. The use of an *ad libitum* buffet-style meal has previously been validated to measure energy intake (EI) inside a laboratory setting[1]. This method has been shown to have a very high reliability with an intraclass correlation (ICC) of 0·97 and a within-subject CV (CVws) of 10 % for total EI between two identical experimental sessions in fourteen men[1]. Another study later tested the reproducibility of a slightly different method in fifty-five men who were given *ad libitum* access to one meal item (a mixed hot-pot meal containing pasta, vegetables, minced meat and cream) at lunch time on two separate occasions in a controlled laboratory setting[2]. A slightly lower ICC ($r$ 0·86) with similar CVws (8·9 %) to those reported by Arvaniti *et al.*[1] was noted. In a study using refrigerated vending machines to measure *ad libitum* EI inside a laboratory setting[3], CVws for EI over 1·5 h at lunch time on four separate occasions was found to be 6·3 % in five women[3]. While each one of these methods has shown a good reproducibility, they have only investigated the measurement of energy and macronutrient intakes over a short period of time (one meal) and they do not offer a very large variety of hot meal-type foods, which may be encountered by the participants under free-living conditions.

Although these methods employed to directly measure EI have been shown to be reproducible under controlled laboratory conditions, they have not been evaluated outside of the laboratory setting. Food records have previously been validated in order to measure EI outside of the laboratory setting[4]. However, the complexity and inconvenience related to the description and measurement of each food and beverage consumed is often associated with a poor compliance, and thus may lead to a certain degree of under-reporting and/or under-eating[5]. To make matters more complex, under-reporting has also been found to be associated with

**Abbreviations:** CVws, within-subject CV; EI, energy intake; ICC, intraclass correlation; ILS, in-laboratory session; OLS, out-of-laboratory session.

† Both authors contributed equally to every aspect of the study.

many factors, such as adiposity level, body size, dietary restraint and socio-economic status[6–9]. As such, the limitations associated with self-reporting of energy and macronutrient intakes[5,10] warrant the investigation of tools that are able to capture the volatility of food intake more accurately outside of the laboratory setting. One study has previously attempted to validate and measure *ad libitum* protein intake under free-living conditions in sixty-five obese men and women who were given access to a food store that offered 900 food and beverage items[11]. This study did demonstrate a high level of agreement in protein intake between the first and second half of the intervention. However, even if it was assumed that carbohydrate and dietary fat intakes did not vary much between the two parts of the intervention, this study only objectively captured protein intake.

The objectives of the present study were thus twofold. The first objective was to evaluate the reproducibility of a food menu to measure food intake over several meals (two meals and snacks over 5 h). The second objective was to compare the reproducibility of this food menu between in-laboratory sessions (ILS) and out-of-laboratory sessions (OLS). A secondary objective was to evaluate sex differences in energy and macronutrient intakes because not many studies have investigated the reproducibility of tools that may be used for the measurement of total EI in men and women together. We hypothesised that energy and macronutrient intakes over several meals (two meals and snacks over 5 h) would be reliable and reproducible in men and women.

## Experimental methods

### Participants

A total of eight women and eight men completed three ILS and three OLS testing sessions. Participants were individually interviewed to evaluate whether they met the study's inclusion criteria: (1) over the age of 18 years; (2) stable weight (±2 kg) within the past 6 months; (3) non-smokers; (4) no drug and alcohol abuse. Women were tested during the follicular phase of the menstrual cycle and at least 7 d separated each testing session. The study was conducted according to the guidelines laid down in the Declaration of Helsinki and all the procedures involving human participants were approved by the University of Ottawa Ethics Committee. Written informed consent was also obtained from all participants.

### Body composition

Body weight was measured to the nearest 0·1 kg using a BWB-800AS digital scale and standing height was measured to the nearest centimetre using a wall stadiometer, Tanita HR-100 height rod, without shoes (Tanita Corporation of America, Inc.) before the start of each testing session, when participants were fasting. Body composition was measured using dual-energy X-ray absorptiometry (GE-LUNAR Prodigy module; GE Medical Systems) on one occasion, once all testing sessions were completed. The CV and correlation for the percentage of body fat measured in twelve healthy participants tested in our laboratory were 1·8 % and $r$ 0·99, respectively.

### Design and procedure

Participants were asked to come to the laboratory for six sessions divided into three ILS and three OLS. The order of the sessions was not randomised. In fact, when we started the study, we had initially decided to test our food menu for two consecutive sessions in the laboratory only. Soon after we had begun testing, we slightly modified the study design to include a third ILS and also decided to add the three OLS as well. This is the reason why the sessions were not randomised. It should be noted that no differences in EI were noted across all sessions based on the session at which participants started the study (results not shown). During the ILS, participants were in a room with a desk and a chair, a television and most participants brought and used their own laptop computer. They were allowed to perform any type of sedentary activities while in that room. As for the OLS, no restrictions were given with regard to the amount and types of activities that the participant could perform. However, they were instructed to only eat items that were found in the lunch boxes throughout the 5 h session. The participants arrived at the laboratory following a 12 h overnight fast. They had been instructed not to consume any alcohol or to engage in any type of structured physical activity (e.g. playing sports or training) for at least 24 h before the start of testing.

### Energy intake assessment – in-laboratory and out-of-laboratory sessions

Total energy and macronutrient intakes were measured by the use of an *ad libitum* food menu (Appendix 1). A total of sixty-two items were provided on the menu in order to ensure that a sufficient amount of hot meals, breakfast items, snacks, fruits, vegetables and beverages were made available to the participant. This menu was mainly based on the items provided in the Arvaniti *et al.*[1] buffet, while some breakfast and hot-meal items were added in order to study the reproducibility of this tool over 5 h. During the ILS, this food menu was presented to the participants every hour, for 5 h (08.00–13.00 hours). Every hour, the participants could choose the types of foods and beverages from the menu that they wanted to consume at that time. During the OLS, the participants were given the same food menu at 08.00 hours and were asked to choose the types of foods and beverages that they wanted to consume over the next 5 h (until 13.00 hours). The food items were then packed into plastic containers, while the beverages were packed into plastic bottles. These containers and bottles were then placed into a portable cooler for the participants to bring with them. They were also asked to bring back all leftovers, wrappings and peels and to put them into their original containers when applicable. In both cases, two portions of each of the food and beverage items selected were prepared and served or packed into the portable cooler for the participants. The specific quantity (portions) of each food and beverage item provided/served to the



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participants is presented in Appendix 1. The participants were then given the instructions to 'eat as little or as much as you want'. The chosen and prepared food items were weighed to the nearest gram before serving (ILS) or before being put into coolers (OLS) using an electronic scale (Scout Pro SP2001; Ohaus Corporation), and after the allocated 30 min time period (ILS) or after the coolers were brought back to the laboratory (OLS). The macronutrient composition of foods and beverages consumed was determined and analysed with Food Processor SQL software (version 9.6.2; ESHA Research).

### *Pleasantness of the foods*

During the three OLS, all participants were asked to draw a vertical line on a 150 mm visual analogue scale, reflecting their appreciation for all foods and beverages that they consumed during these experimental sessions. The question asked on each visual analogue scale was: 'How pleasant is the taste of this food?' The pleasantness rating of each item on the food menu was performed in order to determine whether the participants enjoyed/liked the foods and beverages consumed. Lastly, these ratings also served in determining whether items on the food menu should be removed and/or replaced due to low pleasantness ratings for future studies.

### *Statistical analyses*

Statistical analyses were performed using SPSS software (version 17.0; SPSS, Inc.). An independent *t* test was done in order to determine whether any significant differences in participant characteristics existed between men and women. A two-way repeated-measures ANOVA was used (PROC MIXED) to determine the main effects of the sessions (ILS and OLS) and sex on the components of dietary intake (total amount of energy (kJ), protein (kJ), carbohydrate (kJ) and dietary fat (kJ) during the ILS, the OLS as well as for the combination of the six sessions). In addition, a repeated-measure ANOVA was used (PROC MIXED) to determine the main effects of the session on the distribution of total EI (main meal, snack and beverage intakes) over the course of the ILS, OLS and the combination of the six sessions. ANOVA and Bonferroni tests were also used to evaluate where significant differences existed when looking at the distribution of total EI. ICC and CVws were calculated for energy and macronutrient intakes for the ILS, OLS as well as the combination of all six experimental sessions. The pleasantness ratings of the foods consumed are presented as the mean obtained for all foods and beverages chosen and consumed during the OLS sessions for all sixteen participants. Values are presented as means and standard deviations. Differences with *P* values $<$ 0·05 were considered statistically significant.

## Results

### *Characteristics of participants*

The characteristics of the participants are shown in Table 1. As expected, there was a significant difference in body weight, height, percentage of fat mass and fat-free mass between women and men. No significant differences were, however, found between men and women with regard to their age, BMI and fat mass (kg). Body weight was also stable across the six experimental sessions in men (77·0 (SD 7·9), 77·4 (SD 8·4), 76·8 (SD 8·9), 77·5 (SD 8·6), 77·4 (SD 8·5), 77·0 (SD 8·8) kg; *P*=NS) and women (60·0 (SD 6·7), 60·1 (SD 6·4), 60·0 (SD 6·7), 60·1 (SD 6·5), 59·4 (SD 6·3), 59·4 (SD 6·1) kg; NS). Although it is understood that energy balance can be substantially altered before any changes in energy reserves and body weight can actually be picked up, body weight measured at the beginning of each session was used as a gross proxy of weight stability and energy balance.

### *Energy and macronutrient intakes*

Table 2 presents the results for energy and macronutrient intakes across the three ILS and three OLS. No significant differences were noted for total EI, carbohydrate, dietary fat and protein intakes between the three ILS and three OLS. When all six sessions were analysed (three ILS and three OLS), no significant differences were observed for energy and macronutrient intakes. The power for the analyses of energy, carbohydrate, dietary fat and protein intakes over two meals and snacks over 5 h was 0·24, 0·16, 0·33 and 0·11, respectively. Additionally, the estimate of effect size was extremely low for the same analyses (estimate of effect size=0·05, 0·03, 0·06 and 0·02 for energy, carbohydrate, dietary fat and protein intakes, respectively).

No significant interactions were noted between sessions and sex for EI, carbohydrate and dietary fat intakes (data not

**Table 1.** Characteristics of women (*n* 8), men (*n* 8) and all participants (*n* 16)
(Mean values and standard deviations)

| | Women | | Men | | Overall | | |
|---|---|---|---|---|---|---|---|
| | Mean | SD | Mean | SD | Mean | SD | *P* (between women and men) |
| Age (years) | 28·1 | 9·7 | 24·9 | 2·5 | 26·5 | 7·0 | NS |
| Body weight (kg) | 60·2 | 6·8 | 77·0 | 7·9 | 68·6 | 11·2 | $<$ 0·0001 |
| Height (cm) | 162·4 | 5·3 | 178·4 | 4·5 | 170·4 | 9·5 | $<$ 0·0001 |
| BMI (kg/m$^2$) | 22·8 | 1·7 | 24·2 | 3·1 | 23·5 | 2·6 | NS |
| Fat mass (kg) | 17·1 | 3·5 | 13·2 | 8·2 | 15·2 | 6·4 | NS |
| Fat mass (%) | 28·8 | 4·1 | 16·8 | 9·0 | 22·8 | 9·2 | $<$ 0·005 |
| Fat-free mass (kg) | 42·0 | 3·7 | 64·1 | 7·8 | 53·1 | 12·8 | $<$ 0·0001 |

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**Table 2.** Energy (EI) and macronutrient intakes for each session in all participants ($n$ 16)
(Mean values and standard deviations)

| | In-lab session | | | | | | Out-lab session | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Session 1 | | Session 2 | | Session 3 | | Session 4 | | Session 5 | | Session 6 | | | | | |
| | Mean | SD | Mean | SD | Mean | SD | Mean | SD | Mean | SD | Mean | SD | Overall | In-lab | Out-lab | Between sex |
| Total EI (kJ) | | | | | | | | | | | | | | | | |
| Women | 5106·5 | 1440·0 | 5436·7 | 1466·8 | 4629·2 | 1301·6 | 5675·7 | 1769·5 | 5148·5 | 1023·4 | 4716·3 | 1658·8 | NS | NS | NS | 0·02 |
| Men | 7130·8 | 3332·3 | 7920·9 | 2524·2 | 8349·8 | 2552·8 | 7956·3 | 3110·0 | 7958·6 | 2534·0 | 8196·5 | 3237·6 | | | | |
| Overall | 6118·6 | 2691·2 | 6678·8 | 2371·3 | 6489·5 | 2742·9 | 6816·0 | 2713·2 | 6553·5 | 2364·5 | 6456·4 | 3066·8 | | | | |
| Carbohydrate (kJ) | | | | | | | | | | | | | | | | |
| Women | 3358·2 | 1193·4 | 3259·9 | 981·4 | 2892·3 | 554·6 | 3573·7 | 1361·0 | 3357·0 | 1012·6 | 2953·8 | 835·9 | NS | NS | NS | 0·02 |
| Men | 4557·3 | 1812·0 | 5026·8 | 1895·2 | 5289·9 | 1894·5 | 5028·5 | 1670·9 | 5076·7 | 1569·4 | 5439·7 | 2123·6 | | | | |
| Overall | 3957·7 | 1606·3 | 4143·4 | 1719·9 | 4091·1 | 1830·7 | 4301·1 | 1652·8 | 4216·9 | 1554·5 | 4196·8 | 2019·5 | | | | |
| Dietary fat (kJ) | | | | | | | | | | | | | | | | |
| Women | 1063·8 | 386·5 | 1564·0 | 684·2 | 1170·7 | 762·5 | 1475·0 | 809·2 | 1164·8 | 512·1 | 1126·2 | 865·6 | NS | NS | NS | NS |
| Men | 1788·4 | 1327·0 | 1954·5 | 823·1 | 2052·3 | 799·2 | 2070·7 | 1351·0 | 2025·5 | 929·0 | 1855·9 | 1064·7 | | | | |
| Overall | 1426·1 | 1015·6 | 1759·2 | 758·5 | 1611·5 | 881·3 | 1772·8 | 1118·9 | 1595·1 | 850·1 | 1491·1 | 1010·3 | | | | |
| Protein (kJ) | | | | | | | | | | | | | | | | |
| Women | 777·0 | 307·8 | 751·3 | 304·7 | 672·8 | 262·5 | 781·4 | 289·1 | 796·2 | 241·7 | 756·5 | 307·4 | NS | NS | NS | 0·04 |
| Men | 1037·9 | 450·9 | 1105·1 | 279·6 | 1188·3 | 334·9 | 1005·9 | 265·4 | 984·0 | 211·4 | 1112·9 | 341·3 | | | | |
| Overall | 907·5 | 396·6 | 928·2 | 336·4 | 930·6 | 394·2 | 893·6 | 292·1 | 890·1 | 239·8 | 934·7 | 363·8 | | | | |

In-lab, in-laboratory; out-lab, out-of-laboratory.

shown). However, a significant interaction was noted between sessions and sex for protein intake ($P<0·05$) only. As expected, the present results also revealed that total energy, carbohydrate and protein intakes were significantly higher in men when compared with women (Table 2). However, no significant difference was noted for dietary fat intake between sexes.

### *Distribution of energy intake over the course of the six sessions*

The distribution of EI across the experiment was also investigated. We subdivided the foods and beverages found on the menu into main meals, snacks, energy beverages and water. The categorisation of each item is presented in Appendix 1 and is based on the type of food or beverage, and does not take into account the time at which the foods were consumed since participants were able to choose any item on the food menu, at any time. As shown in Fig. 1, no significant differences were noted for EI (kJ) of main meals and snacks during the three ILS, three OLS and all six sessions. However, a significant difference in energy beverage intake was noted across the six sessions ($P<0·01$), even though no significant differences were noted in the latter between the three ILS and three OLS. Indeed, significant differences were found between session 3 of the ILS and sessions 2 ($P<0·05$) and 3 ($P<0·05$) of the OLS. A significant difference was seen for water consumption (g) across the sessions (565·1 (SD 270·0), 517·1 (SD 289·7), 626·7 (SD 356·6), 524·1 (SD 300·0), 528·2 (SD 317·2), 370·8 (SD 271·2) g; $P<0·01$). More specifically, this difference was observed between the last sessions of the ILS and OLS ($P<0·05$). Additionally, a significant difference in water consumption was noted during the OLS ($P<0·05$).

### *Intraclass correlations and CV*

The ICC observed for total EI during the ILS, OLS and over the course of the six sessions are $r$ 0·77 ($P<0·0001$), $r$ 0·85 ($P<0·0001$) and $r$ 0·82 ($P<0·0001$), respectively (Table 3). However, when excluding two participants (one man and one woman) who were outliers based on their high CVws (+2 SD from the mean), the calculated ICC ($n$ 14) for total EI increased to $r$ 0·82 ($P<0·0001$) for the ILS, $r$ 0·89 ($P<0·0001$) for the OLS and $r$ 0·86 ($P<0·0001$) for the six sessions. As for macronutrient intake ($n$ 14), the ICC for carbohydrates, dietary fat and protein intakes were $r$ 0·85 ($P<0·0001$), $r$ 0·56 ($P<0·0001$) and $r$ 0·86 ($P<0·0001$) for the ILS; $r$ 0·88 ($P<0·0001$), $r$ 0·77 ($P<0·0001$) and $r$ 0·81 ($P<0·0001$) for the OLS; and $r$ 0·86 ($P<0·0001$), $r$ 0·70 ($P<0·0001$) and $r$ 0·81 ($P<0·0001$) for the six sessions.

Additionally, when the CVws were investigated, analyses revealed a CVws of 18·3 (SD 10·0) % for the ILS, a CVws of 16·1 (SD 10·3) % for the OLS as well as a CVws of 17·2 (SD 8·0) % for the combination of the six sessions for total EI. As for macronutrient intake, CVws for carbohydrate, dietary fat and protein intakes were, respectively, 17·3 (SD 8·3), 34·8 (SD 15·8) and 17·5 (SD 10·7) % for the ILS; 14·7 (SD 9·4), 34·8 (SD 22·3) and 14·7 (SD 11·4) % for the OLS; 16·3 (SD 6·8),

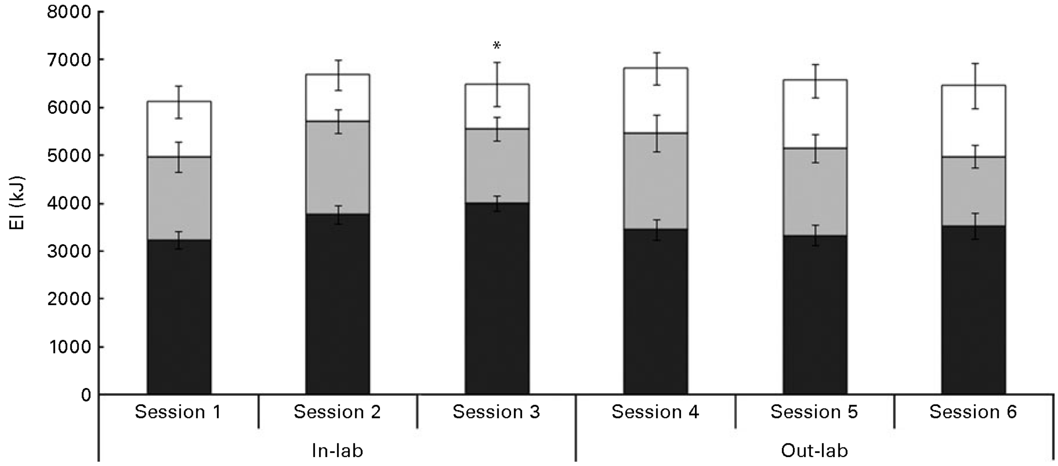


**Fig. 1.** Distribution of energy intake (EI, kJ) as main meals (■), snacks (▩) and energy beverages (□) over the course of each session. Values are presented as means for eight women and eight men, with standard errors of the mean represented by vertical bars. * Mean values were significantly different in energy beverage intake between session 3 and sessions 5 ($P<0·05$) and 6 ($P<0·05$). In-lab, in-laboratory; out-lab, out-of-laboratory.

35·1 (SD 14·1) and 17·4 (SD 7·5) % for the six sessions. When excluding the two outlier participants, the CVws decreased to 16·5 (SD 9·3) % for the ILS, 14·9 (SD 10·0) % for the OLS and 15·8 (SD 7·6) % for the combination of the six sessions for total EI. The CVws for all components of macronutrient intake also slightly decreased after controlling for outliers, where CVws for carbohydrate, dietary fat and protein intakes were, respectively, 16·1 (SD 7·5), 32·0 (SD 14·0) and 16·2 (SD 10·9) % for the ILS; 13·7 (SD 8·0), 30·9 (SD 19·7) and 15·8 (SD 11·7) % for the OLS; 15·2 (SD 6·5), 32·0 (SD 12·1) and 17·3 (SD 8·0) % for the six sessions. Furthermore, the average pleasantness of the foods that were actually eaten and rated by all participants during the three OLS sessions was calculated to be 124 (SD 14) mm on a scale of 150 mm, which represented an average rating of 83 % (Appendix 1).

## Discussion

Given the limitations associated with the measurement of food intake, we aimed to determine the reproducibility of a food menu that includes a large variety of meal-type foods, beverages and snacks (sixty-two items in total) in order to measure total energy and macronutrient intakes during breakfast, mid-morning and lunch for three ILS and three OLS. We hypothesised that the energy and macronutrient intakes over several meals (two meals and snacks over 5 h) would be reproducible in men and women. The present results show no significant differences in our three ILS and three OLS as well as for the combination of these six sessions, as far as EI and macronutrient intakes are concerned. No significant interactions were noted between sex and experimental sessions for EI, carbohydrate and dietary fat intakes, while a significant interaction was found for protein intake between sexes over time. We also reported a good ICC and a relatively good CVws for total EI, while the reproducibility for macronutrient intake, especially dietary fat, was lower. Food items on the menu were overall well appreciated as participants rated them highly on a visual analogue scale (83 %).

The present data show that there are no significant differences for energy and macronutrient intakes over the course of the ILS, OLS and all six sessions. In fact, this suggests that there is no more variation within each environment than there is between them. In addition, when investigating the present data with regard to sex, while significant differences were noted between men and women, where men consumed a larger quantity of food, no interactions, except for protein intake, were noted between sex and each experimental session. Even though a significant interaction was noted between sex and sessions for protein intake only, no significant differences were observed in protein intake over time when analysing men and women separately. This suggests that within the variations shown for this measurement, this tool can be used in men or women as well as within and outside the laboratory setting. When looking at the distribution of EI, even though no significant differences were noted in main meal and snack intakes, significant differences were indeed noted in energy beverage and water intakes across the sessions. Water intake was higher during the last session of the ILS in comparison with the last session of the OLS, while energy beverage intake was higher during the second and third OLS in comparison with the last session of the ILS. Based on these results,

**Table 3.** Intraclass correlations (ICC) in all participants (*n* 16)

| | ICC | | |
|---|---|---|---|
| | In-lab | Out-lab | Overall |
| Total energy intake (kJ) | 0·77† | 0·85† | 0·82† |
| Carbohydrate (kJ) | 0·81† | 0·85† | 0·83† |
| Dietary fat (kJ) | 0·54† | 0·72† | 0·65† |
| Protein (kJ) | 0·81† | 0·80† | 0·78† |

In-lab, in-laboratory; out-lab, out-of-laboratory.
† $P<0·0001$.

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it may be assumed that when participants consumed more water, energy beverage intake was decreased and vice versa. Certain studies[12,13] have noted an increase in total EI when participants consumed more energy from energy beverages. However, the increases in energy beverage intakes during sessions 2 and 3 of the OLS, in comparison with session 3 of the ILS, in the present study did significantly influence total EI values. Finally, it can be hypothesised that a decrease in water intake may be related to an increase in the intake of water contained in foods. This was, however, not analysed because the quantity of water contained in each food was not available from the software that we used.

The present results also demonstrated positive and significant ICC for total EI during the ILS, the OLS and for the six sessions. The ICC values obtained in the present study are lower than the ICC of 0·97 obtained by Arvaniti *et al.*[1] but are similar to the ICC of 0·86 presented by Gregersen *et al.*[2]. It could be argued that the buffet-style meal used by Arvaniti *et al.*[1] was only presented to the participants on one single occasion and this buffet, even if it does provide a wide variety of foods, does not offer any hot food items. Along these lines, Gregersen *et al.*[2] provided a mixed hot-pot meal but, in this case, the EI was only considered for one meal on two separate occasions. A novel aspect of the present study is that nine hot meal-type options were made available from the food menu (Appendix 1) along with most of the items provided in the Arvaniti *et al.*[1] buffet. In addition, our food menu was investigated over several episodes (breakfast, mid-morning and lunch) of feeding as opposed to a single-sitting measure of EI. While we believe that the food menu that was investigated in the present study provides distinctive benefits, we must concede that it is not as reproducible and sensitive as single-sitting measures of EI.

With regard to the CVws values noted in the present study, these are slightly lower than the CVws of 23 % noted by Bingham *et al.*[14], obtained with weighed food records over 4 d on four different occasions (total of 16 d). Studies using direct measurements with single-meal designs have reported CVws between about 6 and 10 %[1–3]. These differences are probably explained by the use of single-meal designs, a lower number of food items offered, and possibly because food intake was measured in the laboratory. Although many studies have measured appetitive and food intake responses to manipulations such as knowledge-based work[15,16], exercise[17] and functional foods[18,19] with single-meal designs, it should be noted that compensation to dietary[20,21] and exercise[22–24] manipulations is often delayed[21]. As such, the validation of a tool that measures food and beverage intake over multiple meals including snacks may provide a more accurate image of the true effect of such manipulations on EI. It is nevertheless important to note that the measurement of energy and macronutrient intakes over the course of multiple meals and multiple days instead of two meals, as in the present study, would have probably been even more revealing. It would thus be ideal to test this food menu for a more prolonged period to determine whether its reliability would increase under such conditions. In considering such a study, it would be important to weigh the logistical aspects of administration and the cost against the added precision of this tool.

Although some studies have provided foods to participants for consumption outside of the laboratory setting[25–28], to our knowledge, none has tried to study the reproducibility of these tools for measurements of total EI and all macronutrient intakes under free-living conditions. Moreover, the investigation of the same tool both inside and outside of a laboratory setting has never been done before, and the results in the present study indicate that the environment in which the participants consumed the foods and beverages provided to them did not greatly affect their total energy and macronutrient intakes. As such, the reproducibility of our food menu outside and inside of the laboratory setting provides convenience and ecological validity to our tool. However, this tool is accompanied by limitations when used outside of the laboratory, including the fact that it does not offer the certainty that only the foods that were provided were eaten, as is the case when it is used in the laboratory. Although not performed in the present study, adding a follow-up questionnaire to verify whether only foods from the lunch boxes were consumed could help control for this possibility. Additionally, the activities performed by the participants during the OLS were not assessed or restricted. As such, adding an objective measure of participants' physical activity participation outside of the laboratory during the measure of food intake could also help to better understand some of the observed differences.

Furthermore, although the reproducibility of carbohydrate and protein intakes from our food menu was relatively good, it was much less the case for dietary fat. As such, certain studies have found higher variation ratios for fat intake, in comparison with carbohydrate and protein intakes[29–32] when measured over time. Cai *et al.*[33] even noted a CVws of 65·3 % in fat intake (g/d) when evaluating data measured over 24 d evenly distributed over 1 year, using 24 h diet recall interviews. This CVws was also higher than the CVws for carbohydrate (29·5 %) and protein (37·5 %) intakes measured over this same time period. When comparing the mean difference in macronutrient intakes using food diaries *v.* food questionnaires, higher differences were also noted in fat intake (25 %), when compared with protein (5 %) and carbohydrate (4 %) intakes[34]. Based on these findings, it may be safe to say that dietary fat intake seems to be more variable than other macronutrients, supporting the idea that dietary fat intake may not be as reproducible over time.

Finally, the present findings are limited to a small normal-weight population, in which case only eight men and eight women were tested. It is thus not surprising to see that the power was low for energy, carbohydrate, dietary fat and protein intakes over several meals. However, as mentioned in the results, the estimate of effect size was also very low for these analyses, indicating that increasing the number of participants would have very likely led to the same results for our primary outcomes. In addition, these results should be interpreted in light of the characteristics of the participants who took part in the present study. Future studies should look into the reproducibility of this tool in populations with different characteristics, such as age and BMI.

Overall, the present results suggest that the food menu investigated in the present study is a reproducible tool that can be used to measure energy and macronutrient intakes under the conditions described in the present study. However, these results also emphasise the difficulties in capturing a stable measure of EI, which is most probably due to the fact that this variable, although relatively stable over long periods of time, presents relatively high day-to-day variations. It is also suggested that both men and women respond similarly with regard to energy and macronutrient intakes, meaning that the reproducibility of this tool is not seemingly affected by the sex of the individual. Future studies should try to find the ideal time frame for the measurement of total EI to obtain stability of the measurement while not making the tool too cumbersome and costly for experimental use.

## Acknowledgements

The authors would like to thank the participants for their devoted participation. É. D. is a recipient of a CIHR/Merck-Frosst New Investigator Award, CFI/OIT New Opportunities Award and of an Early Research Award. M.-È. R. is a recipient of the Frederick Banting and Charles Best Doctoral Award (CIHR). J. M. is a recipient of an Ontario Graduate Scholarship. É. D., M.-È. R. and J. M. designed the research; M.-È. R., J. M., S. C. and S. R. collected the data; M.-È. R. and J. M. analysed the data; M.-È. R., J. M. and É. D. wrote the manuscript. All authors critically appraised and approved the final version of the manuscript. The authors declare that they have no conflict of interest.

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# Appendix C

File Number: h06-10-21 | Date (mm/dd/yyyy): 09/14/2010

# Université d'Ottawa University of Ottawa

Bureau d'éthique et d'intégrité de la recherche | Office of Research Ethics and Integrity

## Ethics Approval Notice

### Health Sciences and Science REB

**Principal Investigator / Supervisor / Co-investigator(s) / Student(s)**

| First Name | Last Name | Affiliation | Role |
|---|---|---|---|
| Éric | Doucet | Health Sciences / Human Kinetics | Principal Investigator |
| Jessica | McNeil | Health Sciences / Human Kinetics | Research Assistant |
| Marie-Eve | Riou | Health Sciences / Human Kinetics | Research Assistant |

**File Number:** h06-10-21

**Type of Project:** Professor

**Title:** Internal Validation and Reliability Test: Structured and Non-Structured Physical Activity and Food Intake

| Approval Date (mm/dd/yyyy) | Expiry Date (mm/dd/yyyy) | Approval Type |
|---|---|---|
| 09/14/2010 | 09/13/2011 | Ia |

**(Ia: Approval, Ib: Approval for initial stage only)**

**Special Conditions / Comments:**
N/A

**File Number:** h06-10-21 **Date (mm/dd/yyyy):** 09/14/2010

Université d'Ottawa University of Ottawa
Bureau d'éthique et d'intégrité de la recherche Office of Research Ethics and Integrity

This is to confirm that the University of Ottawa Research Ethics Board identified above, which operates in accordance with the Tri-Council Policy Statement and other applicable laws and regulations in Ontario, has examined and approved the application for ethical approval for the above named research project as of the Ethics Approval Date indicated for the period above and subject to the conditions listed the section above entitled "Special Conditions / Comments".

During the course of the study the protocol may not be modified without prior written approval from the REB except when necessary to remove subjects from immediate endangerment or when the modification(s) pertain to only administrative or logistical components of the study (e.g. change of telephone number). Investigators must also promptly alert the REB of any changes which increase the risk to participant(s), any changes which considerably affect the conduct of the project, all unanticipated and harmful events that occur, and new information that may negatively affect the conduct of the project and safety of the participant(s). Modifications to the project, information/consent documentation, and/or recruitment documentation, should be submitted to this office for approval using the "Modification to research project" form available at: http://www.rges.uottawa.ca/ethics/application_dwn.asp

Please submit an annual status report to the Protocol Officer 4 weeks before the above-referenced expiry date to either close the file or request a renewal of ethics approval. This document can be found at: http://www.rges.uottawa.ca/ethics/application_dwn.asp

Germain Zongo
Protocol Officer for Ethics in Research
For Dr. Daniel Lagarec, Chair of the Health Sciences and Sciences REB



550, rue Cumberland 550 Cumberland Street
Ottawa (Ontario) K1N 6N5 Canada Ottawa, Ontario K1N 6N5 Canada

**Numéro de dossier:** h10-10-03 **Date (mm/jj/aaaa):** 01/17/2012

Université d'Ottawa University of Ottawa

Bureau d'éthique et d'intégrité de la recherche Office of Research Ethics and Integrity

# Certificat d'approbation déontologique

## CÉR Sciences et science de la santé

### Chercheur principal / Superviseur / Co-chercheur(s) / Étudiant(s)

| Prénom | Nom de famille | Affiliation | Rôle |
|---|---|---|---|
| Eric | Doucet | Sciences de la santé / Activité physique | Chercheur principal |
| Simon | Jomphe-Tremblay | Sciences de la santé / Activité physique | Assistant de recherche |
| Marie-Eve | Riou | Sciences de la santé / Activité physique | Assistant de recherche |

**Numéro du dossier:** h10-10-03

**Type du projet:** Professeur

**Titre:** Compensation - Do Non-Structured Physical Activity and Food Intake Limit Weight Lost during Physical Activity

| Date de renouvellement (mm/jj/aaaa) | Date d'expiration (mm/jj/aaaa) | Approbation |
|---|---|---|
| 01/24/2012 | 01/23/2013 | Ia |

**(Ia: Approbation complète, Ib: Autorisation préliminaire de libération de fonds de recherche)**

**Conditions Spéciales / Commentaires:**
N/A

**Numéro de dossier:** h10-10-03 **Date (mm/jj/aaaa):** 01/17/2012

# Université d'Ottawa University of Ottawa

Bureau d'éthique et d'intégrité de la recherche Office of Research Ethics and Integrity

La présente confirme que le Comité d'éthique de la recherche (CER) de l'Université d'Ottawa identifié ci-dessus, opérant conformément à l'Énoncé de politique des Trois conseils et toutes autres lois et tous règlements applicables de l'Ontario, a examiné et approuvé la demande d'approbation déontologique du projet de recherche ci-nommé. L'approbation est valide pour la durée indiquée plus haut et est sujette aux conditions énumérées dans la section intitulée "Conditions Spéciales / Commentaires".

Lors de l'étude, le protocole ne peut être modifié sans approbation préalable écrite du CER sauf si le sujet doit être retiré en raison d'un danger immédiat ou s'il s'agit d'un changement ayant trait à des éléments administratifs ou logistiques de l'étude comme par exemple un changement de numéro de téléphone. Les chercheurs doivent aviser le CER dans les plus brefs délais de tout changement pouvant augmenter le niveau de risque aux participants ou affecter considérablement le déroulement du projet. Ils devront aussi rapporter tout évènement imprévu et / ou dommageable et devront soumettre toutes les nouvelles informations pouvant nuire à la conduite du projet et/ou à la sécurité des participants. Toutes modifications apportées au projet, aux lettres d'information / formulaires de consentement ainsi qu'aux documents de recrutement doivent être soumises pour approbation à ce Service en utilisant le document intitulé "Modification au projet de recherche" au: http://www.ssrd.uottawa.ca/deontologie/application_dwn_f.asp.

Veuillez soumettre un rapport annuel au Responsable de la déontologie en recherche, quatre semaines avant la date d'échéance indiquée afin de fermer le dossier ou demander un renouvellement de l'approbation déontologique. Le document nécessaire est disponible en ligne au: http://www.rges.uottawa.ca/ethics/application_dwn.asp.

Leslie-Anne Barber
Responsable de la déontologie en recherche
Pour Daniel Lagarec, Président du CÉR en Sciences et sciences de la santé



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