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Journal Pre-proof

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Highlights :

- Exercise differently affect energy intake and appetite depending on its timing
- Morning exercise seems to have better effect on energy intake
- The closer exercise is to the meal, the greater are the beneficial effects

Journal Pre-proof

Appetite control and exercise: Does the timing of exercise play a role?

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Abstract

The prevention and management of chronic diseases, particularly overweight and obesity, relies on multidisciplinary strategies mainly combining dietary approaches with physical activity. Recently, the timing of exercise (time of the day as well as delay/position relative to a meal) has been suggested as an important parameter to consider when prescribing physical activity. Some studies have for instance shown the interest of the timing of exercise on the glycemia, sleep and body composition regulation. However, the impact of exercise-timing on appetite control and energy intake remains unclear. This is why, the present paper questions whether physical exercise, depending on its timing during the day and related to a meal, can affect energy intake, appetite sensations and food reward. Although evidences remain actually limited, exercising during the morning; and particularly close to lunch, might have a better impact on overall energy balance through reduced subsequent energy intake, without leading to compensatory intakes at the following meals. Importantly, dealing with the timing of exercise to optimize energy balance (and affect energy intake and appetite) does not only require to consider its time during the day (morning vs. afternoon or evening), but also and maybe mainly its order/position (pre vs. post) and delay regarding meals. While the actual literature remains limited in this area, the present paper tends to highlight the importance of considering the timing of exercise to optimize our impact on the overall energy balance, and to encourage the elaboration of further studies to better understand and determine the potential effect of this timing of exercise, in order to find the best combination between the different exercise characteristics, intensity, duration, modality, to empower these effects.

Introduction

Physical activity programs are nowadays recognized as a core component of multidisciplinary weight loss strategies. Physical activity interventions are elaborated through the selection of the best and adapted exercise's intensity, duration, modality or frequency, among others, in order to optimize their effects. Recently, the timing of exercise (time of the day as well as delay/position relative to a meal) has been suggested as an important parameter to consider when prescribing physical activity

[1]. Some studies have for instance shown a better glycemic control when exercise is performed within one to three hours after food intake in patients with type II diabetes [2–5]. However, a better lipemia response to a meal has been shown when exercise is performed before the meal compared with after [6–8]. Other studies have questioned the interest of the timing of exercise on sleep [9–11], with an evening exercise allowing a better subjective feeling of sleep quality [11], a decrease in daytime sleepiness [11], a relevant sleep phase progression [9] and a better sympathetic regulation (HR and body temperature) [10]. The exercise-meal timing was also investigated in relation to body composition, with regular pre-meal exercise favoring greater weight loss [12,13], decreased BMI and abdominal circumference [12] and then reducing obesity risks [14].

While the effects of exercise, depending on its duration [15,16], intensity [17–19], modality [20–22] or induced-energy expenditure [23] on the control and regulation of appetite and energy intake have received a lot of attention for the last decade, the impact of exercise-timing remains unclear. Since we recently suggested “Timing” as a third “T” to the FITT exercise prescription method (Frequency, Intensity, Time (duration), and Type of exercise) [1], it seems important to further question the potential effects of the timing of exercise on appetite control to optimize the impact of our interventions on both sides of the energy balance (expenditures and intake). In that context, the present commentary tends to highlight the available evidence regarding the potential effects of the exercise timing on appetite control.

Time of the day

Although Maraki et al. were among the first to specifically question the appetitive responses to exercise (1 hour of aerobic + muscle conditioning exercises) depending on its timing during the day (morning vs. afternoon) [24], their results failed to show any effect of both exercise conditions on self-reported energy intake, with a similar increase in hunger and PFC as well as a similar fullness and satiety decline, compared with their non-exercise group, among healthy normal weight women. To date, we found only two studies whose main aim was to compare the acute effect of morning *versus*

afternoon exercises on appetite and energy intake [25,26]. In their work, Alizadeh and collaborators asked adult women with overweight to perform a 30-minute acute bout of exercise (treadmill running) set at their individually determined ventilatory threshold, whether between 08:00 and 10:00 am (morning condition) or 02:00 and 04:00 pm (afternoon condition). Although the authors did not observe any difference between conditions for the subsequent energy intake, they used self-reported dietary recalls whose sensitivity might not be enough to detect significant changes, and that have been also shown to favor under-reporting [25]. Interestingly, the authors found a greater level of satiety in response to the morning session [25], suggesting once more the potential beneficial effect of exercising during the morning when it comes to the control of appetite and energy intake. Moreover, Larsen et al. recently observed a higher ghrelin concentration in inactive men after a 30-minute acute high intensity intermittent cycling exercise performed during the afternoon compared to the same exercise performed in the morning or evening, while perceived hunger and fullness as well as self-reported energy intake appeared unaffected by the timing of the exercise [26].

In their chronic study, Alizadeh et al. (2017) found reduced dietary intake in women with overweight, including carbohydrate and fat consumption in response to a 6-week intervention when exercise (30 minutes treadmill running at the ventilatory threshold, three-times a week) was performed in the morning but not in the afternoon, despite unchanged appetite feelings [12]. These results have been reinforced by later studies who failed to find any energy intake modifications in response to a 12-week program where adolescents girls performed 30 minutes exercise sessions (composed of various activities such as running, cycling, team games, dancing, etc.) between 03:30 pm and 04:30 pm, three times a week [27]. Some authors even observed a 80 to 230 Kcal/day increase in food consumption in response to an afternoon exercise intervention (walking/running on a treadmill), but not when the exercise was set during the morning, in adults with overweight and obesity (noting that these differences did not reach significance) [13]. Such an increase in energy intake after exercise is of main importance to consider since it might decrease the amount of energy expended during the exercise and, in the long term, if the energy expended is overcompensated, this

could favor counterproductive results such as weight gain. Importantly, future studies comparing the effect of morning vs. afternoon exercise should also consider the potential existence of different eating patterns between lunch and dinner, with individuals who might be susceptible to overeat at dinner compare to lunch, independently of exercise.

Exercising before or after a meal?

In 2016, Heden and colleagues questioned for the first time the importance of exercising just before or 45 minute after a meal, to improve appetite control [28]. They then asked patients with type II diabetes to perform resistance exercise (45-minute session) prior or 45-minute following dinner. According to their results, exercising right before a meal favored increased pre-meal perceived fullness, reduced hunger and reduced acylated ghrelin concentrations compared with their post-meal exercise session and control condition [28]. These results are in line with those from Cheng et al. who also obtained decreased appetite, despite increased plasma ghrelin concentrations, when healthy adult males cycled before a meal (50 minutes at 60% of their maximal capacities) compared with after [29]. Interestingly these studies also suggest the interest of exercising after a meal as a way to potentially extend the suppressive effects of meal consumption on appetite [28,29], which definitely warrants further investigations.

In 2017, Mathieu et al. published a well-controlled free-living study designed to compare the effect of two different lunchtime organizations : i) exercise then meal or ii) meal then exercise, on overall energy balance, also considering the importance of the intensity of exercise [30]. Twenty-one primary school children were then asked to exercise for 40 minutes (ball games as well as running and chasing games) right before their lunch meal either at low or moderate-to-high intensity; or to perform the 40-minute moderate-to-high intensity exercise right after their lunch, on three separate occasions. While their results confirm the interest of prescribing higher intensity exercises to benefit from a subsequent transient anorexigenic effect (with a significantly higher energy intake after the low intensity exercise compared with the moderate-to-high intensity one), they failed to observe any

difference in energy intake when exercise was performed before or right after the meal [30]. More recently, similar results were obtained among adolescents with obesity whose energy intake and food reward remained unchanged whether the adolescents performed a 30-minute cycling exercise ($65\%VO_{2\text{peak}}$) right before or after their lunch meal [31]. Pre- and post-meal hunger feelings were however found reduced when the exercise was performed right before the meal [31]. To our knowledge, only one chronic study questioned the effect of exercising right before or after meals among patients with overweight and obesity. In this study, participants were asked to exercise twice a day for 15 minutes at high intensity for 4 consecutive weeks [32]. According to their results, the authors failed to find any effect on energy intake, except a slight increase in the percentage of protein intake when exercise was performed just before meal [32].

Interestingly, Gustafson et al. (2018) highlighted the importance of the cognitive and hedonic control of energy intake that must be considered when comparing pre and post meal exercise [33]. They indeed pointed out that individuals' free food selection differs in quality when realized before or after an acute exercise. According to their study, people show a 33.5% higher probability of choosing healthy food items when the choice is made before exercising; while they are about 39% more likely to select "unhealthy" items after exercise [33]. Although the participants of this later study were proposed apples or brownies only, which certainly composes its main limitation; such hedonic compensatory responses to exercise have to be considered when prescribing exercise before or after a meal in order to avoid any compensatory consumption that might attenuate the beneficial effects of exercise.

The exercise-meal delay

While not specially designed and focused on the effect of the exercise-timing, results from studies using similar exercises and conducted among similar populations tend to suggest potentially different energy intake responses depending on the delay between exercise and the subsequent meal. In their work, Fearnbach et al. for instance showed reduced *ad libitum* energy intake in 12-15 years old

adolescents with obesity 30 minutes after an acute bout of moderate intensity cycling exercise [34,35] while others failed to observe any food consumption modification in a similar population when the same exercise is performed 60 minutes before lunch [36].

Some studies have been specifically conducted to compare some nutritional outcomes in response to exercise depending on its delay with a meal. In their work, Josaphat and collaborators asked healthy men to perform an acute 30-minute exercise set at 70% of their maximal aerobic capacities either 90 minutes or right before a lunch test meal [37]. According to their results, there was no difference between the two conditions regarding total *ad libitum* energy intake, appetite feelings and the taste or smell sensations [37]. Interestingly, using a similar design, Albert et al. observed a reduction of 11% of the post-exercise energy intake (with a 23% decrease in ingested fat) when the exercise (30 minutes treadmill running at 70% VO_{2max}) is performed just before the meal compared with 165 minutes before, with no difference regarding appetite feelings, in normal-weight adolescents [38]. This reduced food intake was moreover not compensated for by an increase of the following snack or dinner intake [38]. Our team recently obtained similar results in adolescents with obesity who show a decrease of their relative energy intake after an acute bout of moderate intensity cycling exercise (65% VO_{2peak}) set 30 minutes before lunch compared with 180 minutes before, without any compensation at the following meal (dinner) [39]. This was accompanied by a significantly reduced intake of proteins and lipids after the control session (rest) or both the control and exercise + 180 minutes sessions respectively [39]. Interestingly, none of the appetite feelings (hunger, fullness, desire to eat and prospective food consumption) were found different between conditions, suggesting an optimized effect on overall energy balance when exercise is realized close to a meal, without creating any food frustration or hunger. These results are in line with those from Panissa et al. (2019) who recently showed that intermittent high intensity exercise performed one hour before an *ad libitum* meal reduces appetite and energy intake in overweight inactive men [40]. Moreover, Fillon et al. showed a significantly lower pre-meal explicit liking for high-fat relative to low-fat foods when the exercise is close to the meal [39]. Importantly, all the studies conducted so far questioned

the potential effect of the exercise-meal delay implementing exercises between 30 to 150 minutes after the breakfast and testing the energy intake response at a fixed meal (usually 12:00pm). However, by doing so, these studies compared the appetitive responses to exercise of different metabolic load and activities. Indeed, it has been showed that performing the same exercise, in terms of duration and intensity, 60 or 180 minutes after a standardized breakfast, leads to different substrate use in children, which in turns can differently affect subsequent energy intake and appetite [41]. In that sense, *ad libitum* energy intake has been compared at a test meal settled 30 or 90 minutes after an acute exercise (30 minutes cycling at 65% $VO_{2,peak}$) fixed 150 minutes after a standardized breakfast on both conditions (modifying then the timing of the lunch meal) [42]. Interestingly, energy intake was found lower on both exercise conditions compared to the control one, with a greater decrease when the lunch was consumed 90 minutes after the exercise, without any difference in terms of food reward [42].

Conclusion

Although the actual literature remains limited to date, available results seems to encourage the consideration of the timing of exercise when prescribing physical activity, as an interesting way to empower energy balance by affecting both energy expenditure and energy intake. The available literature discussed in the present work seems to indicate that regularly exercising during the morning would have beneficial effects on subsequent energy intake when compared to afternoon interventions. While it remains difficult to draw any conclusion regarding the effect of exercising right before or after a meal (due to the reduced and heterogeneous evidences); available results suggest that the closer to the lunch is the exercise, the greater might be the impact on overall energy balance through reduced subsequent energy intake, without leading to compensatory intakes at the following meals, which remains obviously to be confirmed. Importantly, dealing with the timing of exercise to optimize energy balance (and affect energy intake and appetite) does not only require to consider its time during the day (morning vs. afternoon or evening), but also and maybe mainly its

order/position (pre vs. post) and delay regarding meals. These results remain however to be confirmed since the actual body of literature rests on studies that present a high level of methodological heterogeneity, suggesting the need for a more consensual and standardized method to facilitate our actual understanding and help future exercise prescriptions. Similarly, this high degree of methodological disparity limits any interpretation regarding the potential effect of the exercise timing on food preference and macronutrients intake, which should be better considered in future studies. While the present work highlights the importance of considering the timing of exercise to optimize our impact on the overall energy balance, further studies are needed to find the best combination between the different exercise characteristics, intensity, duration, modality, to empower these effects. Further studies questioning the effect of the timing of exercise on food reward are also required since the few available results come from the same research group and were obtained in adolescents with obesity only. Not only the appetitive and behavioral responses to exercise, depending on its timing, should be further explored, future studies should also investigate the potentially involved physiological and neurocognitive mechanisms, including the potential role of some eating traits such as the eating profile (cognitive restriction, disinhibition, food craving, etc.). Indeed, the beneficial effects (and their extent) of the exercise timing might also depend on these parameters (certainly mainly its intensity). Although encouraging results exist in both lean and children with overweight/and obesity, further long-term investigations and especially free-living school-based studies are required. Indeed, while the elaboration of daily schedules that respect the chronobiology of children has created a lots of debate for the last couple of years, especially regarding the introduction and organization of physical education and physical activities, there is a clear need to better explore and understand the exact effects and interests of the exercise-meal timing to improve both our public health prevention strategies and treatment programs.

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