



## Original article

# Skin temperature response to a liquid meal intake is different in men than in women



Borja Martinez-Tellez <sup>a, b, \*, 1</sup>, Lourdes Ortiz-Alvarez <sup>a, 1</sup>, Guillermo Sanchez-Delgado <sup>a</sup>, Huiwen Xu <sup>a</sup>, Francisco M. Acosta <sup>a</sup>, Elisa Merchan-Ramirez <sup>a</sup>, Victoria Muñoz-Hernandez <sup>a</sup>, Wendy D. Martinez-Avila <sup>a</sup>, Miguel A. Contreras-Gomez <sup>a</sup>, Angel Gil <sup>c, d</sup>, Idoia Labayen <sup>e</sup>, Jonatan R. Ruiz <sup>a</sup>

<sup>a</sup> PROFITH (PROmoting FITness and Health through Physical Activity) Research Group, Department of Physical Education and Sport, Faculty of Sport Sciences, University of Granada, Granada, Spain

<sup>b</sup> Department of Medicine, Division of Endocrinology and Einthoven Laboratory for Experimental Vascular Medicine, Leiden University Medical Center, Leiden, The Netherlands

<sup>c</sup> Department of Biochemistry and Molecular Biology II, Institute of Nutrition and Food Technology, Centre for Biomedical Research, University of Granada, Granada, Spain

<sup>d</sup> CIBEROBN, Biomedical Research Networking Center for Physiopathology of Obesity and Nutrition, Carlos III Health Institute, Madrid, Spain

<sup>e</sup> Department of Health Sciences, Public University of Navarra, Pamplona, Avda. Barañáin s/n., 31008, Spain

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## SUMMARY

**Background & aim:** The thermic effect of food (TEF) refers to the increase of the metabolic rate and body temperature in response to a single meal. To date, most of the studies have focused to determine the TEF in terms of energy expenditure, but little is known about which is the response in terms of skin temperature. The aim of this study was to analyze whether the thermic effect of food (TEF) on the skin temperature with a standardized and individualized liquid meal test is different in young adult men than in young adult women.

**Methods:** A total of 104 young adults (36 men and 68 women, age: 18–25 years old) consumed a standardized and individualized liquid meal (energy intake: 50% of measured basal metabolic rate, 50% carbohydrates, 35% fat, 15% protein). The skin temperature was measured by means of 17 iButtons during 3 h and 20 min. The mean, proximal, distal, and supraclavicular skin temperature, as well as the peripheral gradient, were determined as a proxy of a peripheral vasoconstriction. The participants reported the thermal sensation of the whole body, clavicular, feet, and hands zones. The body composition was measured by dual X-ray absorptiometry.

**Results:** The overall, mean, proximal, and supraclavicular skin temperature significantly increased after the meal intake (all  $P < 0.05$  vs. the baseline temperature). There was a postprandial peripheral vasoconstriction right after the meal intake and over the first hour and a peripheral vasodilatation during the second and third hour. Women had a higher increase in all skin temperature parameters in comparison to men (all,  $P < 0.05$ ), whereas there were no sex differences in the proximal skin temperature ( $P = 0.279$ ). The pattern of thermal sensation was similar between sexes, but women always felt colder than men. All of the results persisted after adjusting the analyses for body composition or menstrual cycle.

**Conclusion:** A standardized and individualized liquid meal test increases the skin temperature in young adults, being the thermic effect higher in women than in men.

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**Abbreviations:** AEE, Activity energy expenditure; ANOVA, Analyses of variance; AUC, Area under the curve; BAT, Brown adipose tissue; BMI, Body mass index; CCM, CCM Express (Medgraphics Corp, Minnesota, USA); DEXA, Dual Energy X-ray Absorptiometry; DIT, Diet-induced thermogenesis; FMI, Fat mass index; IC, Indirect calorimetry; LMI, Lean mass index; MGU, Ultima Cardio2 (Medgraphics Corp, Minnesota, USA); POA, Preoptic anterior hypothalamus; RMR, Resting metabolic rate; SNS, Sympathetic nervous system; TEF, Thermic effect of food; TRP, Transient receptor potential; VAS, Visual analog scales.

\* Corresponding author. Department of Physical Education and Sport, Faculty of Sport Sciences, University of Granada, Ctra. de Alfacar s/n, C.P. 18071, Granada, Spain. Fax: 0034 958244369.

E-mail address: [borjammt@gmail.com](mailto:borjammt@gmail.com) (B. Martinez-Tellez).

<sup>1</sup> These authors share first authorship.

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## 1. Introduction

Obesity is considered a pandemic disease that has increased exponentially during the last decades [1]. A study conducted in 19.2 million participants from 200 countries indicated that, by 2025, global obesity prevalence will reach 18% in men and surpass 21% in women [1]. In simple terms, obesity is caused by an energy imbalance where energy intake exceeds the total energy expenditure resulting in an increase in energy storage in the body as fat mass [2]. Thus, new insights on the regulation of energy balance regulation can provide additional information about the development of obesity and possible treatments to face it [3].

In thermoneutral conditions, the total energy expenditure can be divided into resting metabolic rate (RMR), activity energy expenditure (AEE), and diet-induced thermogenesis (DIT) [4]. The latter represents between 7 and 12% of the total energy expenditure [5]. DIT is the energy expenditure required for the digestion, absorption, and storage of food that derives energy throughout a day [2]. Meal-induced thermogenesis or the thermic effect of food (TEF) refers to the increase of the metabolic rate and body temperature [6] in response to a single meal, and it lasts from 3 to 6 h after the meal intake [2,6].

The TEF is influenced by the macronutrient composition of the diet [7–9] as well as by the form of the meal (i.e. solid or liquid) [10,11]. The TEF is higher after a liquid meal intake [10] than after a solid meal intake [11] while keeping the same nutritional composition. Liquids, which are emptied from the stomach faster than solids, are, therefore, expected to be absorbed more quickly [10,12].

The digestion and absorption of nutrients increases body temperature, yet the physiological responses regulating the process are still unclear [6]. Moreover, whether the thermic effect of a liquid meal intake is different in men than in women remains to be investigated. In the 90's, Westerterp-Plantenga et al. [13] reported an increase of the skin temperature in women after a solid meal. It is known that women feel a higher thermal discomfort than men, whereas, in men, the skin temperature of their limbs seems to be slightly lower in thermoneutral conditions [14]. This could be partially explained because women have less blood flow in their hands [15] while men's core temperature [16] seems to be higher [14,17].

To date, most of the studies have focused to determine the TEF in terms of energy expenditure, but little is known about which is the response in terms of skin temperature. Therefore, the aim of the

current study was to determine whether the TEF with a standardized and individualized liquid meal on skin temperature is different in young adult men than in young adult women.

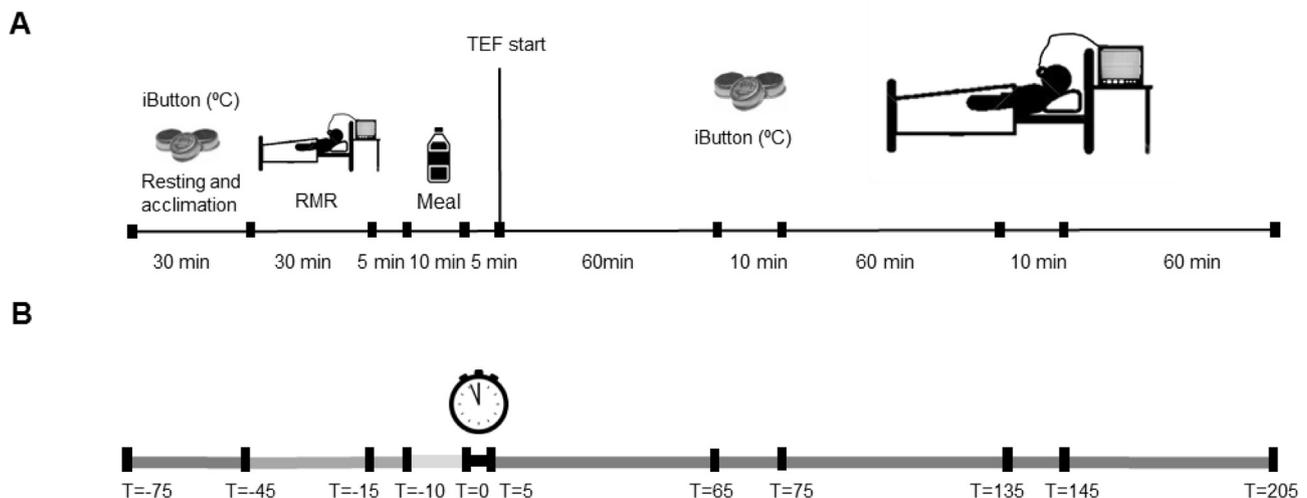
## 2. Material and methods

### 2.1. Participants

A total of 104 (36 men and 68 women) white Caucasian healthy adults aged 18–25 years old, and with a body mass index (BMI) range of 17.5–33.7 kg/m<sup>2</sup>, participated in the present study. The participants were enrolled in the ACTIBATE study [18], an exercise-based randomized controlled trial (Clinical Trials.gov ID: NCT02365129). All participants were non-smokers, were not enrolled in a weight loss program, had a stable body weight (body weight changes <3 kg) over the last 3 months, were not physically active (<20 min on <3 days/week), did not take any medication, had no acute or chronic illness, and were not pregnant. The study was conducted between October and November in 2015 and 2016 in Granada (Southern Spain). The study protocol and informed consent were performed in accordance with the Declaration of Helsinki (revision of 2013), and they were approved by the Human Research Ethics Committee of both University of Granada (n° 924) and Servicio Andaluz de Salud (Centro de Granada, CEI-Granada). A written informed consent was obtained from all the participants.

### 2.2. Design

The measurements started between 8.30 and 9.30 AM. The participants arrived at the research center by car or bus, avoiding any physical activity after waking up, and in a fasted state (12 h after their last meal). The night before taking the measurements, the participants had a standardized meal (tomato sauce with boiled rice and a one-egg omelet). Moreover, prior to the study day, they were instructed to refrain from drinking alcoholic or caffeine-containing beverages (24 h before the testing day), to not do any moderate or vigorous physical activity (48 h before the testing day), as well as to sleep as usual. The tests were carried out in a quiet room with dim lighting. The ambient temperature and humidity were 22.9 ± 0.7 °C and 44.6 ± 6.3%, respectively. During the testing day, the participants lay down on a reclined bed, on a supine position, and were covered with a sheet. They wore standardized



**Fig. 1.** Thermic effect of feeding (TEF) test. **A:** Procedures; **B:** Accumulative timeline. RMR: Resting metabolic rate.

clothes (shorts, standardized T-shirt, and were barefoot, Clo value = 0.20 [19]). Before starting the measurements, the women reported their menstrual cycle phase (menstrual, follicular, ovulatory, or luteal phases). The participants were instructed to breathe normally, and not to talk, fidget, cross their arms or legs, or sleep.

**Resting and acclimation period:** At the beginning of the testing day, the participants entered the room, the above-mentioned conditions were checked, and the iButtons were attached [20]. Then, an acclimation and a resting period were performed in order to obtain more stable measurements of the RMR and skin temperatures (see Fig. 1 A and B, respectively).

**Baseline period:** The RMR and skin temperatures were measured during 30 min. The RMR was measured by indirect calorimetry (IC) (Ultima CardiO2, MGU, Medgraphics Corp,

Minnesota, USA; and CCM Express, CCM) [21]. The participants wore a neoprene face-mask without external ventilation or face-vent mask depending on the metabolic cart used. We performed calibrations following the manufacturer's instructions before every IC measurement. The last 5 min of the baseline period were averaged for further analyses.

**TEF period:** Once the participants had completed the liquid meal test, the skin temperature parameters were registered during 3 h and 20 min. The participants had a 10-min 'rest' every hour (also referred to as period), resulting in three periods of 1 h. During these breaks, the participants were allowed to sit up, go to the toilet, or drink water, if needed. Moreover, they reported the thermal sensation of the whole body, feet, clavicular, and hands zones using visual analog scales (VAS). The VAS consisted in a line of 100 mm in length with words anchored at each end (0 mm = "No cold at all", 100 mm = "Maximum tolerable cold") [22].

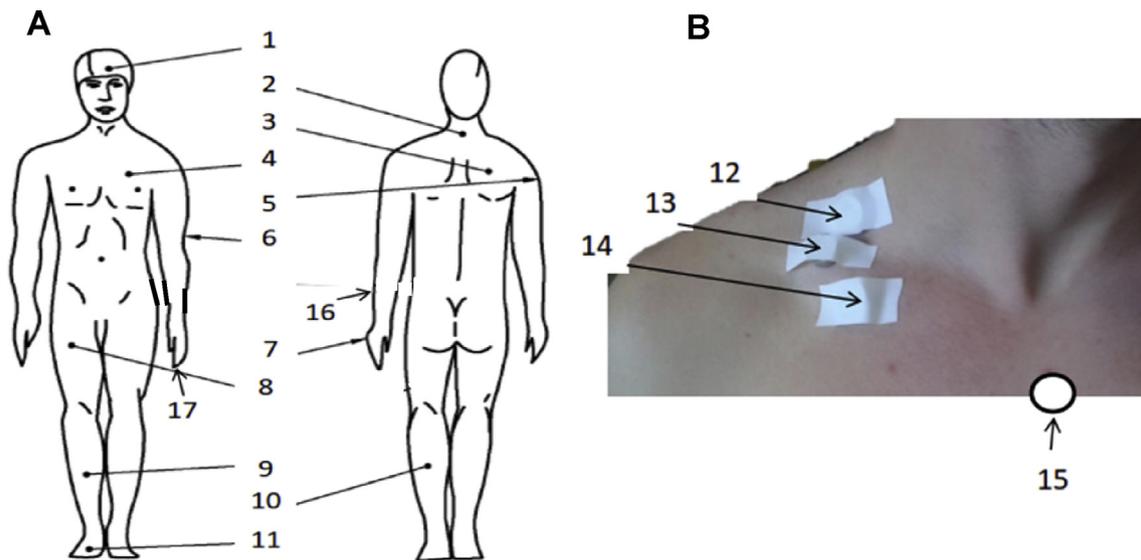
**Table 1**  
Descriptive characteristics of the study participants.

	Men (n = 36)	Women (n = 68)	P
Age (years)	22 ± 2.2	21 ± 2.1	0.174
BMI (kg/m <sup>2</sup> )	27 ± 5.7	23 ± 3.7	<b>0.001</b>
RMR (kcal/day)	1583 ± 498.2	1288 ± 423.8	<b>0.002</b>
Liquid meal (g)	494 ± 155.7	402 ± 132.4	<b>0.002</b>
Fat mass (kg)	25 ± 11.9	24 ± 7.5	0.526
FMI (kg fat mass/m <sup>2</sup> )	8 ± 3.8	9 ± 2.6	0.393
Fat mass (%)	30 ± 7.7	38 ± 5.9	<b>&lt;0.001</b>
Lean mass (kg)	53 ± 7.0	36 ± 4.9	<b>&lt;0.001</b>
LMI (kg lean mass/m <sup>2</sup> )	17 ± 2.0	13 ± 1.3	<b>&lt;0.001</b>
Lean mass (%)	65 ± 7.1	57 ± 5.4	<b>&lt;0.001</b>

Data are mean ± standard deviation. BMI: Body mass index, RMR: Resting metabolic rate, FMI: Fat mass index, LMI: Lean mass index. Bold means significant differences.

**2.2.1. Meal test**

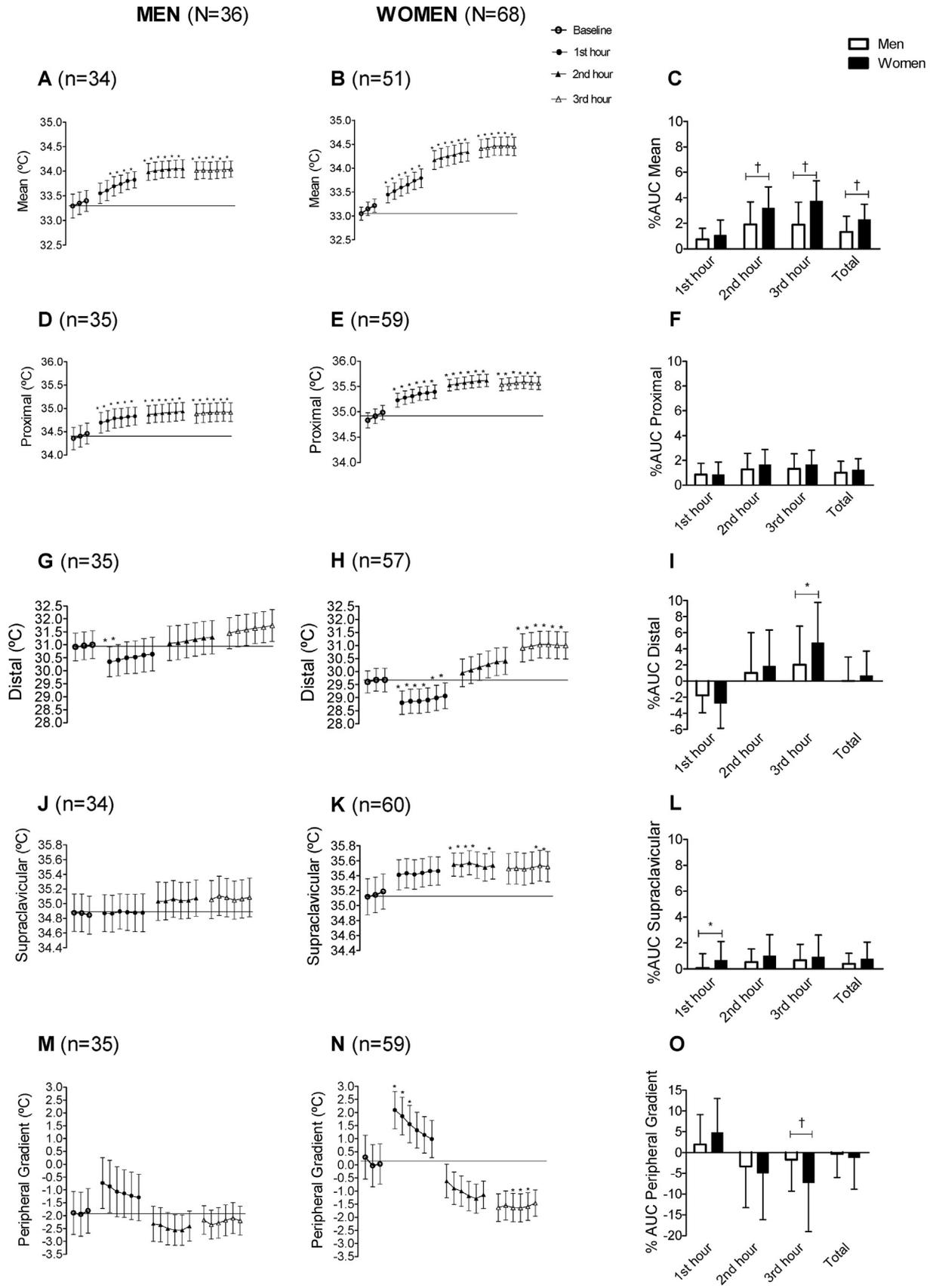
After the baseline measurements, the participants consumed a standardized and individualized liquid meal refrigerated at approximately 4 °C. The amount of the liquid meal was adjusted to 50% of each participant's RMR (i.e.: 1583 ± 498 kcal and 1288 ± 423, men and women respectively, see Table 1). The meal test (T- Diet Energy, Vegenat®) had a density of 1.186 g/ml and a caloric density of 1.6 kcal/ml. The percentage of the energy derived from the nutrients was as follows: 15% proteins, 47% carbohydrates, and 35% fats, of which 25% were saturated, 50% monounsaturated, and 25% polyunsaturated, and with a content of 3% of fiber.



**Fig. 2.** Anatomical position of 17 iButtons. **A:** Distribution of the iButtons over the body. **B:** Distribution of the iButtons on the right clavicular site [20].

**Table 2**  
Equations to measure the skin temperature.

Outcome	iButtons (n)	Anatomical positions. Figure 2	Equation	Reference
Mean skin temperature	8	1,3,4,5,6,7,8,10	(Forehead*0.07)+(Right Scapula*0.175)+(Left Chest*0.175)+(Right Deltoid*0.07)+(Left Elbow*0.07)+(Left Hand*0.05)+(Right Thigh*0.19)+(Left Gastrocnemius*0.2)	8 ISO 9886-2004 [30]
Proximal skin temperature	3	3,4,15	(Left Chest + Right Scapula + Upper Breastbone)/3	Martinez-Tellez et al. [20]
Distal skin temperature	2	7, 11	(Left Hand + Right Instep)/2	Kräuchi et al. [31]
Supraclavicular	1	12	Right Supraclavicular	Boon et al. [32]
Peripheral temperature Gradient	2	16, 17	(Left Forearm-Left Top of forefinger)	Adapted to Sessler et al. [29]



**Fig. 3.** Kinetics of skin temperature parameters. The graphic bars represent sex differences expressed as area under the curve (AUC). The measurements of the skin temperatures during the first 30 min of each period were excluded from the analyses. Kinetics of the skin temperature are presented as the mean of every 5 min and upper and lower limits of the interval of confidence (95%). Analysis of variance with Bonferroni comparisons regarding the last 5 min of the baseline period. A., D., G., J., and M. refer to the mean, proximal, distal, supraclavicular, and peripheral gradient (as a proxy of the peripheral vasoconstriction) temperatures in men, respectively. B., E., H., K., and N. refer to the mean, proximal, distal, supraclavicular, and peripheral gradient (as a proxy of the peripheral vasoconstriction) temperatures in women, respectively. Open circles: Baseline defined as the last 15 min of measurement before the intake of the standardized individualized liquid meal. Black circles: First hour in response to the thermic effect of feeding (1st hour). Black triangles: Second hour in response to the

### 2.3. Procedures

#### 2.3.1. Skin temperature and equations

We measured the skin temperature with 17 iButtons [20] (DS-1922 L, Thermochron; resolution: 0.0625 °C; Maxim, Dallas, USA), which are valid and reliable devices to measure skin temperature in humans [23,24]. We attached the iButtons to the skin with adhesive tape (Fixomull, Beiersdorf AG, Hamburg, Germany) at different body sites (see Fig. 2) [23,25–28]. We recorded the skin temperature at 1-min intervals, and we calculated the averages for every 5 min in order to analyze the data [20]. The mean, proximal, distal, and supraclavicular skin temperature parameters were estimated (see equations in Table 2). Moreover, a peripheral gradient was calculated as a proxy of a peripheral vasoconstriction (forearm-fingertip) [29]. All data registered by the devices and equations were analyzed by the Temperatus® software [20] (<http://profitth.ugr.es/temperatus>). The measurements of the skin temperatures during the first 30 min of each period were excluded from the analyses.

#### 2.3.2. Body composition

The body composition was measured by Dual Energy X-ray Absorptiometry (DEXA) scan (HOLOGIC, Discovery Wi). We measured the participants' weight and height without shoes and wearing the standard clothes using a SECA scale and stadiometer (model 799, Electronic Column Scale, Hamburg, Germany), and we calculated the BMI (kg/m<sup>2</sup>). The fat mass index (FMI) was calculated as kg of body fat divided by height in m<sup>2</sup>. Similarly, we calculated the lean mass index (LMI) as lean body mass in kg divided by height in m<sup>2</sup>.

### 2.4. Statistical analysis

The data are presented as mean and standard deviation, unless otherwise stated. Sex differences were determined using the T-test for independent samples. We conducted an analysis of variance (ANOVA) for repeated measurements with Bonferroni adjustments for post-hoc comparisons to compare the 5-min average of the skin temperature in response to the consumption of the liquid meal with the 5-min average of the baseline period (before the intake). The analyses were conducted by periods (baseline, first hour, second hour, and third hour). We calculated the area under the curve (AUC) for each period using the trapezoidal rule for the VAS and as a percentage of increase of the baseline period for the skin temperature. The total AUC was calculated as the weighted sum of the AUC of the three periods of the TEF. To compare the thermal perception of each period with the basal thermal perception, we conducted ANOVA for repeated measurements with Bonferroni adjustments for post-hoc comparisons. We repeated all the analyses including BMI, FMI, LMI or menstrual cycle in the model as co-variable. All analyses were conducted using the Statistical Package for Social Sciences (SPSS, v. 22.0, IBM SPSS Statistics, IBM Corporation), and the level of significance was set at <0.05.

## 3. Results

### 3.1. Characteristics of participants

Table 1 shows the participants' characteristics. Women had lower BMI and RMR than men ( $P < 0.01$ ), and men were leaner and had lower levels of fat mass than women (all  $P < 0.01$ ).

### 3.2. Mean, proximal, and distal skin temperatures

We observed a significant increase of the mean skin temperature after the liquid meal intake had peaked in men in the 2nd h (Fig. 3A) and in women in the 3rd h (Fig. 3B). Overall, women had a higher increase of the mean skin temperature after the liquid meal intake than men ( $P \leq 0.01$ , Fig. 3C).

Figure 3D and E shows the TEF on the proximal skin temperature in men and women, respectively. There was a significant increase after the liquid meal intake in all measurement points, which was similar in both men and women [Fig. 3F, (1st h:  $P = 0.958$ ; 2nd h:  $P = 0.175$ ; 3rd h:  $P = 0.206$ ; and Total period:  $P = 0.279$ )].

Figure 3G shows the TEF on the distal skin temperature in men. There was a significant decrease between the 35th and 40th minute of the 1st h. In women, the distal skin temperature significantly decreased after the liquid meal intake (1st h, all  $P \leq 0.05$ ), yet it significantly increased at the 175th minute and continued increasing until the end of the test (Fig. 3H). In men we did not find any significant increase (Fig. 3G). Sex differences were observed in the 3rd h after the liquid meal intake, being higher in women than men ( $P = 0.012$ , Fig. 3I).

### 3.3. Supraclavicular skin temperature

Figure 3J shows the TEF on the supraclavicular skin temperature in men, which was constant throughout the test. In women, there was a significant increase of the supraclavicular skin temperature in the 2nd hour, as well as in the last 10 min of the 3rd hour (all  $P \leq 0.05$ , Fig. 3K). Women had a significantly higher supraclavicular skin temperature after the liquid meal intake in the 1st h than men ( $P = 0.027$ , Fig. 3L).

### 3.4. Peripheral gradient as a proxy of peripheral vasoconstriction

Figure 3M shows the TEF on the peripheral gradient in men, which did not change during the test. In women, the peripheral vasoconstriction significantly increased from the 35th to the 45th minute in the 1st h (all  $P \leq 0.05$ , Fig. 3N). However, we did not find any significant difference in the 2nd h compared with the baseline measurement (all  $P > 0.05$ ). In the 3rd h, the peripheral vasoconstriction significantly decreased ( $P \leq 0.05$ ).

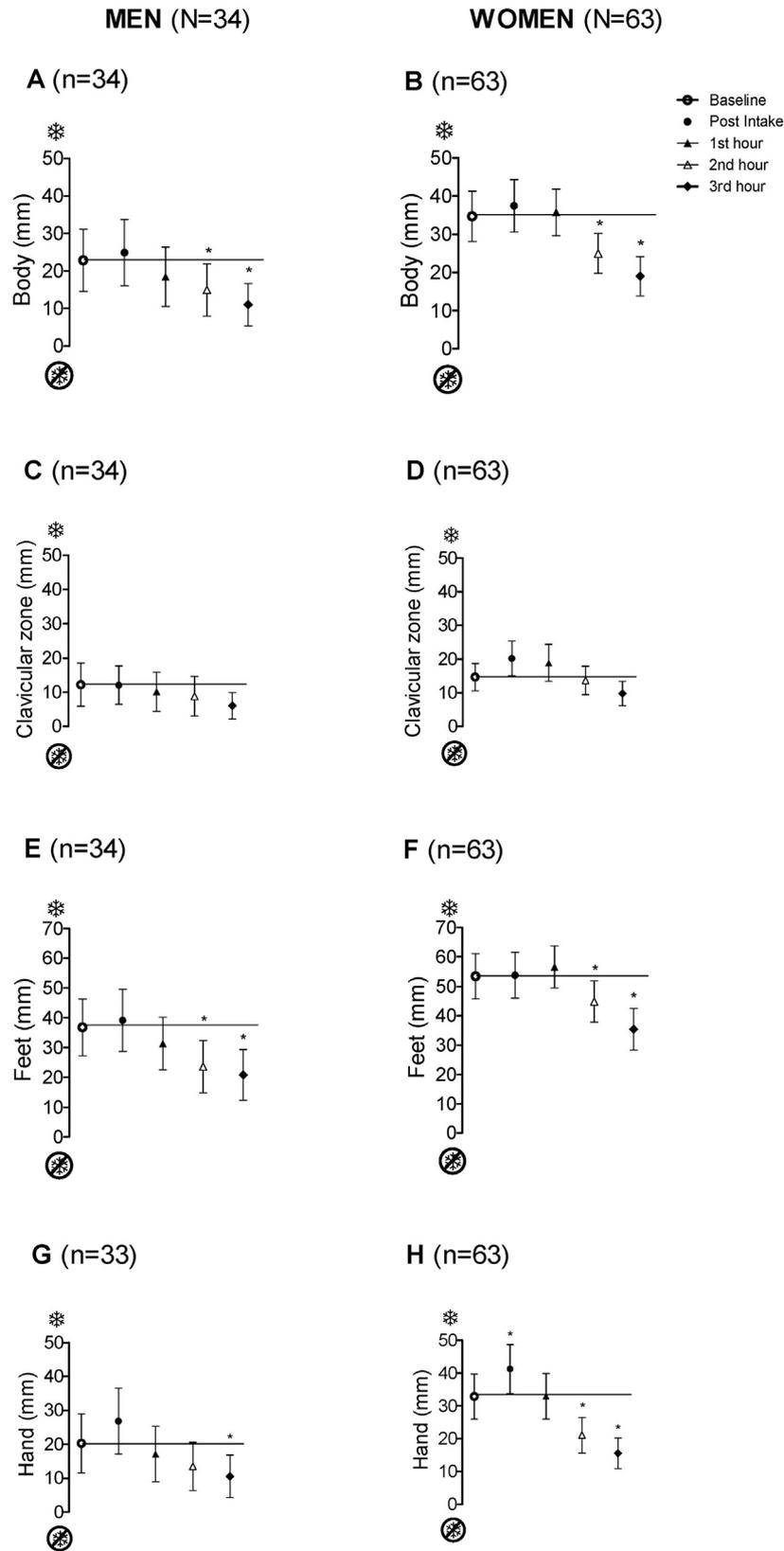
### 3.5. Thermal perception: VAS measurements

Figure 4A shows the TEF on the whole body thermal perception in men. Men felt less cold in the 2nd and 3rd h ( $P = 0.029$  and  $P \leq 0.01$ , respectively). Women showed a similar pattern to men in the same hours ( $P \leq 0.01$ ) see Fig. 4B. Regarding to the thermal perception in the clavicular zone, we did not find any change over the test in either men or women (Fig. 4C and D, respectively).

Figure 4E and G shows the TEF on thermal perception in the feet and hands zone in men, who felt less cold after the 2nd and 3rd h with respect to baseline. Moreover, we observed a similar trend in women's feet and hands (Fig. 4F and H, respectively). However, women felt their hands colder after the intake ( $P \leq 0.01$ ), and they felt their feet and hands less cold after the 2nd ( $P \leq 0.01$ ) and 3rd h ( $P \leq 0.01$ ), whereas men did not feel any cold during the test.

All of the analyses were repeated adjusting by BMI, FMI, or LMI, and the results persisted (all  $P$  for trend  $\leq 0.05$ ). Furthermore, there

thermic effect of feeding (2nd hour). Open triangles: Third hour in response to the thermic effect of feeding (3rd hour). C, F, I, L, and O. refer to percentage of increase respect to the baseline in terms of area under the curve for each period: First hour in response to the thermogenic effect of feeding, 2nd hour: Second hour in response to the thermogenic effect of feeding, 3rd: Third hour in response to the thermogenic effect of feeding. Total: It is the weighted sum of the 3 h in response to the thermogenic effect of feeding in the mean, proximal, distal, and supraclavicular skin temperature, and the peripheral gradient, respectively. The parallel bars indicate significant sex differences. \* $P \leq 0.05$ , † $P \leq 0.001$ .



**Fig. 4.** Kinetics of thermal perception: VAS measurements. The sex differences are represented as graphic bars between the areas under the curve (AUC). Kinetics of thermal perception is presented as the mean of every period and upper and lower limits of the interval of confidence (95%). Analysis of variance with Bonferroni comparisons in relation to the baseline period. A., C., E., and G. refer to the body, clavicular area, feet, and hand thermal perceptions in men, respectively. B., D., F., and H. refer to the body, clavicular area, feet, and hand thermal perceptions in women, respectively. Open circles: Baseline defined as the period before the intake of the standardized individualized liquid meal. Black square: Post intake, this is the moment just after the intake of meal. Black triangles: First hour in response to the thermic effect of feeding (1st hour). Open triangles: Second hour in response to the thermic effect of feeding (2nd hour). Black diamond: Third hour in response to the thermic effect of feeding (3rd hour). In the upper extreme of axis “y”, refers to “maximum tolerable cold”, and in the lower extreme of axis “y”, represents “do not feel any cold”.

were no differences in the TEF or the thermal sensation by menstrual phases (follicular,  $n = 19$ ; ovulation,  $n = 5$ ; luteal,  $n = 28$ ; and menstrual,  $n = 9$ ) (all  $P$  for trend  $\leq 0.05$ ). We conducted linear regression analyses with the AUC of parameters of skin temperature (i.e. mean, proximal, distal, etc.), and the AUC of thermal perceptions (body, clavicular, feet and hands). We did not find any significant relationship (Fig. S1). The results persisted when the sample was divided into BMI categories and sex (all  $P \leq 0.05$ ).

#### 4. Discussion

The present study shows an increase of the mean, proximal, and supraclavicular skin temperature after the intake of a standardized and individualized liquid meal test in young adults, being this thermoregulatory effect higher in women than in men. We also observed that the distal skin temperature decreased during the first hour and then increased during the second and third hour in both, being significant in women. In addition, there was a postprandial peripheral vasoconstriction during the first hour and a later vasodilatation during the second and third hour only in women. Overall, the TEF was higher in women than in men in all skin temperature measurements, except in the proximal skin temperature, which was similar in men and in women. Women always felt colder than men, especially in the first postprandial hour. Of note is that these findings persist after controlling for body composition and were independent of the menstrual phases. To date, most published studies have focused on the increase of energy expenditure after a meal intake, and little is known about which is the response of the skin body temperature after a meal intake. Therefore, the findings of the present study shed light on this topic and show that temperature response after a liquid meal intake is different in men than in women.

##### 4.1. Components of thermic effect of feeding (TEF)

It is well known that the TEF stimulates an increase in metabolic rate which is accompanied by an increase of the body temperature [6]. This increase in metabolic rate in response to a meal seems to be regulated by the parasympathetic nervous system, among others, but it is unknown if the autonomic nervous system regulates the increase of body temperature [6]. Regarding the increase in the metabolic rate, it seems that it is higher in men (21%) in comparison to women after the intake of different meals, even adjusting by age, BMI, or waist circumference [33]. Davidson et al. [34] reported that the sympatho–adrenal activity was higher in men than women. Vaz et al. [35], on the other hand, found that the increase of energy expenditure was linked to postprandial sympatho–adrenal activity, albeit this relationship seems to be attenuated because women had less sympathetic nervous system (SNS) activity, regardless of the body composition.

##### 4.2. Thermoregulatory system: skin temperature

The thermoregulatory system seems to be regulated by the SNS [36]. In our study, women experienced a higher increase of the skin temperature parameters than men. Moreover in our sample, body composition did not explain these sex differences, which are in agreement with others [33]. Of note is that the SNS activity after food intake is lower in women than men [34]. Why does this phenomenon occur?

The thermoregulatory system is mainly controlled by the pre-optic anterior hypothalamus (POA), the homeostatic control of which is separated from the sensation of temperature [37,38]. It is well known that human skin has cold and warm-sensitive POA neurons as peripheral receptors. However, all thermoregulatory

responses could be triggered by either the activation of one class of the temperature-sensitive neurons (cold vs. warm) or the inhibition of the others. Previous studies showed that different stimulus may change the activity of the cold or warm-sensitive POA neurons [37,39]. Studies in animal models observed that females [40] have a larger amount of warm than cold-sensitive POA neurons in comparison to males. Vries & Södersten [37] proposed that the nucleus and POA was bigger in men than in women, and that the supra-chiasmatic nucleus, which is involved in the reproduction cycle, was larger in women than in men [41]. Therefore, it is biologically plausible that the size of the different parts of the hypothalamus could modulate the different physiological responses. This may partially explain why the skin temperature response to a liquid meal is higher in women than in men. However, if women have more warm-sensitive POA neurons than men and whether it is associated with the size of the different parts of the hypothalamus is not known.

Moreover, there are other sex differences that could explain the differences between the thermal responses after a meal intake. For instance, the cutaneous vascular anatomy is different in women than in men [14]. Women seem to have less vascularization in the distal parts of the body and therefore have less blood flow in their hands [15]. The thermoregulatory system goal is to keep the core temperature constant, being more important in women than men because their bodies are prepared to shelter life [42]. To our knowledge, there is only one study which focused on the increase of skin temperature after a meal intake, but the aim was not to study sex differences [13].

Body composition may have affected the measurement of the skin temperature by iButtons, because of its insulation effect [43], yet we found no body composition effect over the skin temperature response after a meal intake. This finding could be driven by the fact that in our experiment design we individualized the meal intake to the RMR, which indeed is body composition dependent. Therefore, we have indirectly adjusted the meal intake to the individual's body composition, and this may partially explain why we did not find any significant differences in terms of skin temperature by BMI.

Several studies suggested that brown adipose tissue (BAT) plays a role in DIT [44,45], yet the results are contradictory [46,47]. We observed slight changes in the supraclavicular skin temperature after a liquid meal intake in women. The supraclavicular skin temperature has been used as an indirect marker of BAT volume and activity [25,32]. We do not know, however, whether the supraclavicular skin temperature response to a liquid meal represents BAT activity. More studies with objective measurements of BAT are needed to understand the role of BAT in the thermoregulatory response to a meal intake.

##### 4.3. Peripheral thermoreception

A recent study investigated the molecular mechanisms of the cutaneous thermoreception suggesting that the transient receptor potential (TRP) family mediates thermal sensation across a broad physiological range of skin temperatures [49]. Nevertheless, none of these TRP channels have been identified as a molecular thermoreceptor, and we do not know if the prevalence of these TRP channels differ by sex, as occurs in other species [50]. Therefore, it would be reasonable to find different amounts of the TRP family in males and females, which could modulate the different thermal sensations [38]; unfortunately, there are no previous studies in humans.

Controversy exists on whether the skin temperature responses to a liquid meal are related to the thermal sensations in humans [48]. Thermal sensation in women is different than in men.

Karjalainen [14] reported that women express more dissatisfaction than men in the same thermal environments, whereas in neutral temperature these differences disappear. They also reported that women are less satisfied than men in cooler conditions. Similarly, Schellen et al. [24] showed that women feel more uncomfortable and dissatisfied than men under the same cold conditions. Furthermore, they reported that the local sensation and skin temperature of the extremities (hands and arms) are of high importance for whole body thermal sensation, whereas this is less important in men. These findings concur with our results.

#### 4.4. Limitations

The present study has several limitations that should be highlighted. It is known that the skin temperature follows a diurnal biorhythm [26,51], but the most stable skin temperature period is between 10 AM and 2 PM [52], the period when our experiments were conducted. The room temperature was slightly low, and therefore it will be of interest repeat the experiment with a higher room temperature. We have no control group; our control condition was the baseline period. Moreover, more studies are needed to understand the differences in terms of increase of the skin temperature after a meal intake between sexes, including participants with the same BMI, albeit it seems that body composition did not influence the skin temperature response in the present study.

#### 4.5. Conclusions

Our findings show that a standardized and individualized liquid meal intake increases the skin temperature in young adults. Women presented a higher increase of skin temperature parameters than men in response to a meal intake, regardless of their body composition and menstrual cycle. Furthermore, our data suggest that the thermoregulatory system is more effective in women than in men: Women are able to reduce the temperature of the distal zones faster during the first hour (distributing the blood flow to the digestive system), and they are able to produce a higher and faster vasodilatation (distributing blood to the distal areas to carry the nutrients) without any alteration in the mean and proximal skin temperature.

#### Conflict of interest

None.

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#### Appendix A. Supplementary data

Supplementary data related to this article can be found at <https://doi.org/10.1016/j.clnu.2018.05.026>.

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