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CONSUMPTION OF HIGH FAT AND HOT TEMPERATURE MEALS INDUCES HIGHER SUBJECTIVE SATIETY AND REDUCES HUNGER.

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Abstract

Objectives: We aimed to determine the effects of consumption of three different meal compositions at three temperatures on satiety and palatability. And whether they influence energy intake at subsequent meals.

Setting: Khyber Medical University, Khyber Medical College. Pakistan

Participants: Thirteen healthy young males and females aged 18–35 years, with a body mass index of 18.5-24.5 kg/m^2.

Study Design: In a randomized cross-over study, participants consumed test meals (high carbohydrate, high protein, and high fat) at cold, warm, and hot temperatures (a total of nine meals). A visual analogue scale (VAS) and area under the curve (AUC) were used for satiety score measurements (0–240 minutes). Postprandially palatability scores were checked by a 9-point hedonic scale, and remainder energy intake was also noted.

Results: VAS for hunger, and desire to eat were significantly different between the three compositions of meals at three temperatures ($P < 0.05$) at 240 minutes. Hot temperature meals (high fat and high protein) had higher satiety scores and area under the curve than cold meal groups. The hedonic scale showed that the temperature parameter was highly significant ($P < 0.001$). Among the meals, high-fat meals had the highest ratings for satiety scores, AUC, and pleasantness. However, the remainder energy intake was not statistically different between the test meals ($P > 0.05$).

Conclusion: High-fat and hot temperatures meals can enhance satiety and satiation. However, the effect on satiety and satiation was short-term, and it did not affect remainder of energy intake during the rest of the day.

Key Words: Dietary carbohydrates, diet high fat, diet high protein, food temperature, satiety response, visual analogue scale.

Introduction

Obesity and its associated disorders are epidemic and seriously affect public wellbeing. The World Health Organization (WHO) identifies over weight and obesity as the outcomes of an energy disparity between calories ingested and calories used. [1, 2] The obesity rate has dramatically increased in undeveloped countries, both for males and females, due to a sedentary lifestyle, physical inactivity, and diet. [3] A patient's health is considerably influenced by their nutrition as well as various sociocultural, economic, and ecological factors associated with food accessibility. [4] The capacity to regulate energy consumption and expenditure, as well as intricate physiological functions like controlling hunger and appetite, are essential for survival. [5] The control of appetite involves satiation and satiety. "Satiation is the process that causes one to stop eating" while "satiety is the feeling of fullness that persists after eating." [5] Both processes help limit future food intake. Meals consumed start a stepwise process in the gastrointestinal tract with absorption and digestion. Satiety signals are delivered to specific regions of the brain where sensory and cognitive aspects of food perception are combined. [5,6]

Measuring food intake and inferring satiation and satiety from subjective ratings of appetite are two methods for short-term control of food intake. [7] A useful tool for measuring satiety scores and eating behavior research is the visual analogue scale (VAS),[1,5] which can be used in controlled studies to measure pre- and postprandial hunger, fullness, satiety, desire to eat, and prospective food consumption (PFC).[8] Other factors influencing satiation and satiety include age, gender, body mass index (BMI), physical activity, and sleep. [5-7] Satiety is significantly modified by the composition (protein, carbohydrate, and fat) and energy density of macronutrients. [9] Meals with a high fat content have a higher energy density than those with a high protein or carbohydrate content. [9–11]

The effects of different dietary compositions on satiety vary; some studies have found that protein-based energy is more satiating. [11] Others display that resistant starches are indigestible carbs that reduce appetite and food intake through fermentation in the gut. [12] The serving temperature of food alters perceived intensities, flavors, and acceptance of food as well. [13] The brain has specific regions that detect thermal sensory sensations, pleasantness, flavour, and emotions. [13,14] When the oral cavity is exposed to various oral temperatures, significant neural changes are observed in neuroimaging studies. [14, 15] The single neuron studies and functional magnetic resonance imaging (fMRI) studies show that the oral cavity's somatosensory and thermal inputs play a significant role in food's palatability, affective value, and regulation of appetite. [13-15] Limited research has been done on how food temperature is related to sensory perception and satiety. Understanding the satiation and satiety processes that control food intake, weight gain management, and obesogenic factors necessitates a thorough understanding of food, its energy density, and dietary presentation with varying food temperatures. Thus, the aim of the present study was to assess the hypothesis that different compositions of meals (high carbohydrate (CHO), high fat, and high protein) and different

temperatures of meals (hot, warm, and cold) affect satiety and palatability differently. Moreover, the study also aimed to determine whether the hypothesized effects of different meals were short-term or whether they affected the rest of the day's energy (food) intake.

Material and methods

Participants

Flyers and word-of-mouth recruitment techniques were used to enlist young men and women. The eligible participants were enrolled if they met the inclusion criteria for the study: healthy men and women between the ages of 25 and 35 years of normal weight [BMI: 18.5-24.9 kg/m^2] with no recent weight gain or loss in the past six months. They had not participated in any diet or weight loss program in the past six months. Women had normal menstrual cycles and were not pregnant. Participants were not taking any medications. There was no previous history of metabolic problems, diabetes, thyroid diseases, or neurological conditions. The participants were non-smokers and non-vegetarians. The three-factor eating questionnaire (TFEQ**)** [(6)] was used to exclude any behavioral eating disorder. Sample size and power were calculated with Open Epi software (Center for Disease Control (CDC), Atlanta, Georgia, United States). By keeping the power at 80% and the confidence interval at 95%, the sample size was calculated as 10. [(16)] Randomization in serving different meals was done by Research Randomizer software. A total of 25 voluntary participants were recruited. Screening was done according to study criteria, and out of 25 participants, 15 were eligible and enrolled. Two participants dropped out, and 13 completed the study. The ethical approval was obtained from the Institutional Ethical Review Board (IERB/2022/9303-7) and the Advance Studies and Research Board (AS&RB/EF/001725) on 16 June 2022. The study was registered as a clinical trial (ClinicalTrials.gov Identifier: NCT05822167). Written consent was obtained from all the participants.

Anthropometric measurements

At the screening visit, anthropometric data were collected from the participants. The participants wore light clothes and were barefoot, with no shoes at the time of examination. A stadiometer was used to measure height with 1 mm precision. and weight with an accuracy of 0.05 kg on a weighing machine (height and weight scale ZT-160, China). Body mass index (weight / height (kg/ m^2)) and the BP (systolic and diastolic) (digital blood pressure Omron 3, Kyoto, Japan) were recorded.

Study design and protocol

This study had a randomized crossover design. Three different meals with high protein, high carbohydrate, or high fat content, presented at three temperatures (cold, warm, or hot), resulted in nine groups (nine visits in total). The fasting and postprandial satiety score changes were assessed in these nine groups. Each visit was one week apart to give a washout interval to reduce any carryover impact. At the time of each visit, two experimenters and a nutritionist were present. On each visit, the meals were prepared at the same energy density (500 kcal) but served at three temperatures: cold (25˚C or below), warm (40˚–60°C), and hot (60˚C or above). The food temperature was checked before, during, and after serving using a food thermometer.

Before each study visit, the participants were asked to avoid strenuous exercise. After an overnight fast, the participants reached the research laboratory between 8.00 a.m. and 9.00 a.m. on the experimental day. The laboratory room was a quiet, comfortable room (at 25˚C) with no attendants or distractions. Everyone who participated in the experiment was already acquainted with the day's procedures. Upon arrival at the research facility, a preliminary filling of the VAS for satiety (at fasting) was completed. The fasting participants were served a test meal, and they had 30 minutes to consume it with 250 ml of mineral water. The participants were allowed to eat *ad libitum* to "consume as much or as little as possible until feeling comfortably full." After finishing the test meals, the participants recorded their feeling of satiety by marking a vertical line on the VAS questionnaires every 30 minutes for the next four hours. During the postprandial period, the participants assessed the palatability of the test meal by rating it on the hedonic 9-point scale. Palatability in terms of taste,

appearance, texture, smell, flavor, and temperature was measured using a standard nine-point hedonic scale (1 = dislike extremely and 9 = like extremely). Participants were asked to mark a position anywhere along the scale that matched their perception. [17] Each participant completed a 4-hour testing session. They were allowed to read, watch TV, or use computer games (time was hidden). The remainder of the food consumed throughout the day was recorded by the researchers.

Test meals

Conventional Asian test meals were prepared, including a high carbohydrate meal (chicken biryani rice), a high protein meal (chicken steak with sautéed vegetables), and a high fat meal (paratha roll with minced chicken and fresh mayonnaise). Test meals energy and content are shown in Table 1. The texture, taste, and energy content of each test meal were similar throughout the sessions. Test meals were served at three different temperatures: cold (25˚C or below), warm (40˚- 60˚C), and hot (60˚C and above). [18] The temperature of the test meals was kept constant by serving them on chafing dishes (hot plates). The participants were served in the same setting, with the same-colored dishes, and at the same time of day on each visit. The test meals were weighed before and after being consumed with the digital electronic kitchen weighing scale (TS-200 China, 0.01-2 kg).

Table 1 Energy and contents of test meals (protein, carbohydrate (CHO), and fat)

Content and energy	High protein meal	High CHO meal	High fat meal
Protein (g)	75	31.25	37.5
CHO (g)	12.5	81	12.5
Fat (g)	16.6	5.5	33.3
Protein energy (%)	60	25	30
CHO energy (%)	10	65	10
Fat energy (%)	30	10	60

Satiety measurement visual analogue scale (VAS)

The VAS [8] questionnaires were completed manually on paper, and they included questions assessing "how strong is your feeling of" hunger, fullness, satiety, and desire to eat. It was interpreted as "how much food can you eat right now" with anchors of "not (much) at all" to "extremely/an extreme amount." The visual analogue scale (VAS) has a line of 100 mm, [8] where the participants can place a vertical mark on the horizontal line at a point corresponding to their feelings at that time. The lines were anchored by negative feeling words (I am not hungry at all, 0 mark) on the left and by positive feeling words (never being hungry, 100 mark) on the right. The measurement was quantified by measuring the distance from the left end of the line to the participant's mark. The exact clock time of the VAS was recorded every 30 minutes, 60 minutes, 90 minutes, 120 minutes, 180 minutes, and 240 minutes (watches and clocks were removed from the test area).

Remainder energy intake record

Energy intake for the rest of the day and calories were estimated using the 24-hour recall/multiple pass method in the free-living environment. The participants were inquired about all the food consumed (lunch, snack, and dinner). The food records were analyzed using the Win diet 2005 version by the two researchers (nutritionists), who separately calculated the macronutrients and remainder energy intake.[19] The average mean values of remainder energy intake (kcal) were then considered.

Statistical analysis

Statistical Package for the Social Sciences software version 27.0 (IBM SPSS Statistics for Windows, Version 27.0; Armonk, NY: IBM Corp.) was used to analyze the data. Normality was checked for all continuous variables with the help of Shapiro Wilk test. Descriptive statistical data were presented as means ± standard deviation. Non-parametric Freidman ANOVA was used to compare different time points of data. Satiety scores (VAS) were calculated for hunger, fullness, satiety, and desire to eat.

The total area under the curve (AUC 0-240 minutes) was calculated using the trapezoidal rule. A non-parametric Kruskal-Wallis H test was used to compare differences between nine meal groups (depending on macronutrient composition and food temperature) for VAS, AUC, palatability of test meals, and remainder food intake. Post hoc analysis was done for significant values. Statistical significance was accepted at the 5% level.

Results

In this study, seven male and five female participants with a mean age of 29 ± 2.8 years (range: 18–35 years) and a body mass index (BMI) of 22 ± 0.9 kg/m^2 (range: 18.5-24.5 kg/m^2) were enrolled. Out of 15 participants, 13 (males and females) completed the study. Two dropped out; one participant withdrew due to personal reasons, and another participant had COVID on the study day.

Subjective satiety

The effects of high carbohydrate, high protein, and high fat meals at hot, warm, and cold temperatures on subjective satiety responses are seen in Figure 1. All changes in satiety scores (hunger, fullness, satiety, and desire to eat) were statistically significant at repeated measures within each meal (Friedman ANOVA, $P < 0.001$). Analyses by Kruskal-Wallis H ANOVA (between nine study meal groups) showed that satiety scores were not statistically different between three different meals at three temperatures for hunger, satiety, fullness, and desire to eat ($P > 0.05$) except for hunger and desire to eat at 240 minute ($P < 0.05$). The mean VAS for hunger (0–240 minutes) showed a drop from its peak at 0 minutes postprandially, while the cold food groups (carbohydrates, protein, and fat) induced a rapid 50% return of hunger at 90 minutes ($P = 0.149$). At 180 minutes, hunger scores observed were lowest for hot protein and fat meals (51.85 ± 28.14 mm and 54.08 ± 21.12 mm) as compared to the cold carbohydrate meal (69.92 ± 16.04 mm, $P = 0.186$).

Hunger suppression by hot meals (fat and protein) persisted for 240 minutes ($P < 0.05$). Similarly, the desire to eat was not significantly different at 0-180 minutes ($P > 0.05$) between the three meals at three temperatures. The cold meal groups (carbohydrate, protein, and fat) showed a more progressive increase in desire to eat (30–240 minutes) than the hot meal groups (fat and protein). At 30 minutes, the highest postprandial reduction in desire to eat was seen in cold high protein (9.77 ± 11.31 mm) and hot fat (13.31 ± 12.65 mm) ($P = 0.082$). At 240 minutes, the high fat (cold 69.85 ± 16.34, warm 68.31 ± 23.79, and hot 64.85 ± 24.86) and hot protein meals (63.38 ± 21.01) suppressed the desire to eat more as compared to other meal groups (cold protein 85.08 ± 9.38 mm, and cold CHO 81.31 ± 16.94 mm) ($P < 0.05$).Overall, fat meals suppressed the desire to eat more as compared to other meal groups (protein and carbohydrates). The satiety and fullness scores were not significantly different between the meal groups at three temperatures ($P > 0.05$). The postprandial peaks of satiety and fullness scores were seen at 30 minutes. The hot fat meal had the highest satiety score (86.23 ± 8.98 mm) and fullness score (83.46 ± 10.43) at 30 minutes. Satiety and fullness scores remained higher till 240 minutes in hot protein meals (at 240 minutes, satiety was 39.46 ± 27.49 and fullness was 37.23 ± 27.43) and hot fat meals (satiety was 28.07 ± 2.85 and fullness was 29.38 ± 28.75). During the study period (0–240 minutes), overall high fat meals and especially the hot meal groups (high fat and high protein) had the highest scores for satiety and fullness as compared to other meal groups CHO (hot, cold, and warm) and protein (cold and warm).Post hoc analysis was done for significant values as shown in supplementary Tables 1 & 2.

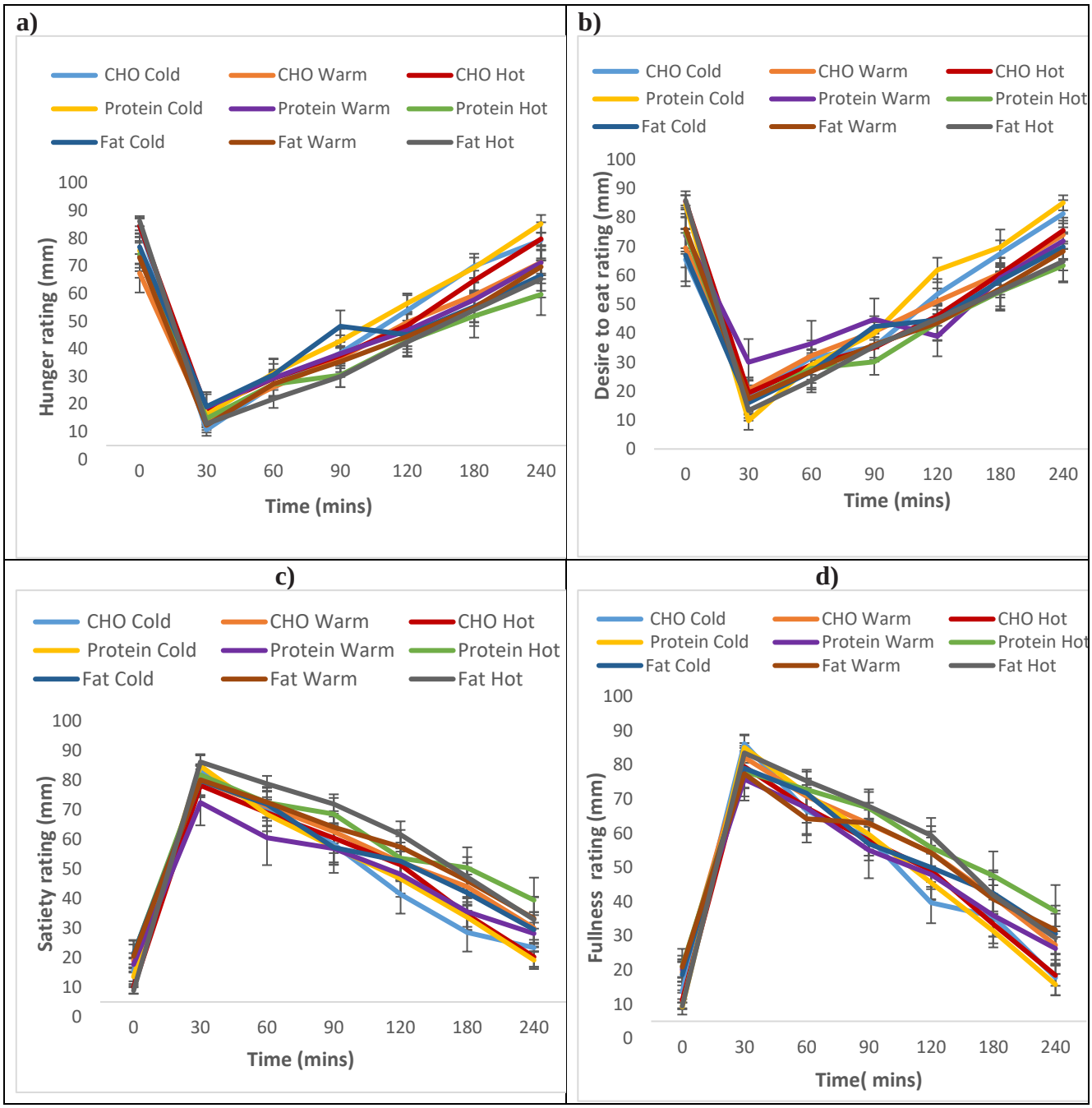

Figure 1 The mean (± SE) changes in responses to satiety scores related parameters: a) hunger (b) desire to eat (c) satiety (d) fullness; from baseline to 240 minutes in three different compositions of meals at three temperatures (n = 13). Analysis by Kruskal-Wallis H ANOVA showed that the differences were not significant for hunger, desire to eat, satiety, and fullness ratings between the three different compositions of meals at three temperatures, except at 240 minutes for hunger and desire to eat ($P < 0.05$).CHO; carbohydrate, mins; minutes

Area under the curve (AUC)

The area under the curve (AUC) for the VAS scores of hunger, satiety, fullness, and desire to eat were compared between three different meal compositions at three temperatures, as shown in Figure 2. The AUC for satiety scores was found to be not significantly different ($P > 0.05$) between the three meals at three temperatures. For hunger, the AUC was reduced in hot fat, hot protein, and hot CHO (10111± 530 mm, 12266± 700 mm, and 10339± 1138 mm, respectively) and increased for cold meals (fat 13088± 706 mm, protein 12542± 838 mm and CHO 11426± 812 mm) ($P = 0.233$). Similar results were seen in the desire to eat; the AUC was attenuated in hot meals (high protein, high CHO, and high fat), while increased in all cold meals. The AUC values increased for satiety in hot meals (high

CHO 13841± 1025 mm, high protein 11378± 932 mm, and high fat 13625± 1173 mm) (P = 0.739) and similarly for fullness (high fat 13347± 1186 mm and high CHO 13011± 1125 mm) as compared to cold meals. The AUC (0-240 minutes) measured resulted in reduced hunger and desire to eat whereas increased satiety and fullness, in hot meals as compared to cold meal groups.

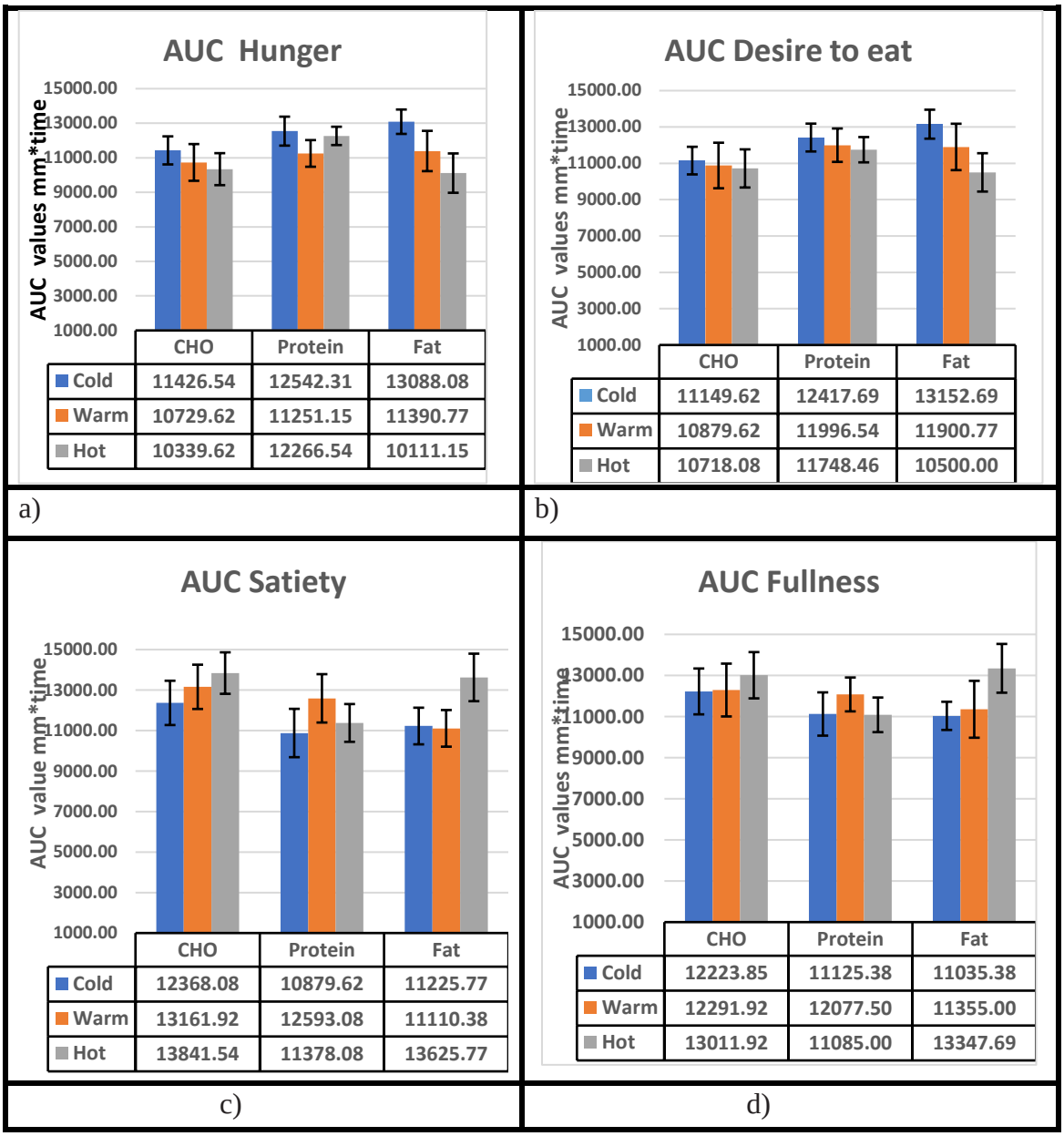

Figure 2 The mean values (± SE) of the AUC for satiety scores are presented as a bar graph. Area under the curve (AUC) in healthy subjects (n = 13) was measured for satiety scores from 0 minutes to 240 minutes. The AUC for satiety scores (hunger, desire to eat, satiety, and fullness) was not significantly different between the three different compositions of meals at three temperatures (P > 0.05). CHO; carbohydrate

Palatability of test meals

The palatability of study meals in terms of temperature, appearance, and texture showed significant differences (P = 0.001, 0.04, and 0.05, respectively) (Table 2). The high fat meals showed the highest palatability scores for all the parameters, as compared to high protein and high carbohydrate meals. The protein meals scored lowest for appearance, texture, smell, and flavors as compared to all other meal groups. Post hoc analysis was done for significant values as shown in supplementary Tables 3,4 & 5.

Table 2 Changes in the palatability parameters of three test meals (CHO, protein, and fat) at three temperatures (cold, warm, and hot) in participants (n = 13)

Parameters	Carbohydrate			Protein			Fat			
	Cold	Warm	Hot	Cold	Warm	Hot	Cold	Warm	Hot	P-value
Appearance	6.77± 1.64	6.00± 2.00	6.38± 1.98	6.00 ± 1.87	5.54± 1.66	6.31 ± 1.88	6.46± 1.26	7.54 ± 1.26	7.08± 1.11	**0.04**
Texture	5.62± 1.85	6.62± 1.71	6.69± 1.49	5.62 ± 1.71	5.62± 1.50	6.69 ± 1.25	6.69± 1.25	7.00 ± 1.29	6.92± 1.18	**0.05**
Smell	6.85± 1.34	6.15± 1.72	6.62± 1.60	5.92± 1.25	5.54 ± 1.76	6.38 ± 1.44	6.00± 0.81	6.85 ± 1.21	6.62± 0.87	0.19
Flavour	6.38± 2.18	6.85± 1.86	6.85± 1.81	5.85 ± 2.19	6.00 ± 2.44	6.62 ± 2.06	6.85± 1.34	7.08 ± 1.70	7.38± 0.87	0.71
Temperature	4.08± 2.06	7.38± 1.32	5.54± 3.01	4.15 ± 1.81	7.62 ± 0.76	6.85 ± 2.19	4.00± 2.19	8.23 ± 1.16	7.38± 1.32	**0.00**

Changes range from 1 = Dislike Extremely to 9 = Like Extremely using 9-point hedonic scale. The temperature, appearance, and texture parameters showed significant differences between the three test meals at three temperatures (Kruskal Wallis H $P < 0.05$).Values are expressed as mean ± SD.

Remainder energy intake

The remainder of the energy intake following three test meals at three different temperatures is presented as a bar graph in figure 3. The rest of the day's food (energy) intake included lunch, snacks, and dinner. There was no statistically significant difference in the remainder of the day's food (energy) intake between the nine meals ($P > 0.05$). Following a hot CHO meal, the subsequent energy intake was the highest (1760.46 ± 571.85 kcal). However, the remainder of the food (energy) intake was lower following cold protein (1201.76 ± 477.51 kcal), hot fat (1277.15 ± 449.23 kcal), and warm fat (1265.23 ± 578.79 kcal) meals.

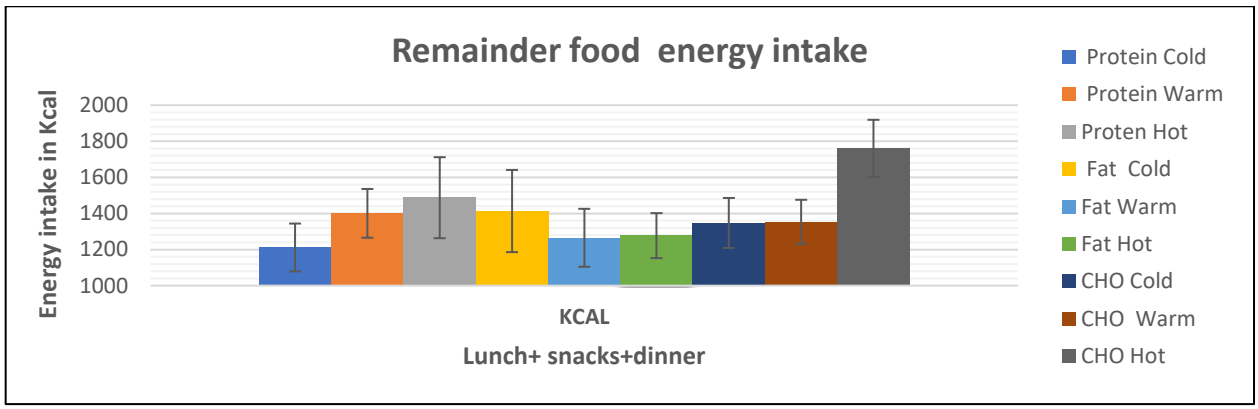

Figure 3 Bar graph presentation of remainder energy intake following three test meals at three different temperatures. There was no significant difference in the remainder energy intake between the three meals at three different temperatures ($P > 0.05$)

Discussion

This is the first study to report the effect of meal consumption with varying macronutrient contents at three temperatures (cold, warm, and hot) on subjective appetite responses, palatability, and remainder-day energy intake in healthy young adults. The purpose of the study was to determine the effect of high-fat, high-CHO, and high-protein meals consumed at different temperatures (cold, warm, and hot) on subjective markers of satiety. In addition, it also determined the energy intake at the subsequent meals. The hypothesis was that different meal compositions at different temperatures would induce higher satiety and reduce remainder energy intake. This was supported in terms of hot temperature meals (fat and protein), as they elicited a greater satiety response compared to cold temperature meals. However, despite greater changes in satiety scores with hot meals and high fat meals, these changes did not translate to decreased subsequent energy intake during the rest of the day. This shows that these short-term changes in subjective satiety perception were not promising for changes in remainder food intake during the rest of the day. The novel finding of this study is that the temperature of food

and different meal compositions have short-lived effects and intake of such meals in the morning have no impact on energy intake later in the day.

Macronutrients have a hierarchical effect on satiety and short-term food intake suppression, according to data from animal and human studies. [9, 20-24] Marmonier. C et al. showed that consumption of nutrient compositions (high protein > high CHO > high fat) delayed dinner but had no impact on the intake of dinner macronutrients. [9] The findings of the current study concur with earlier ones that unsaturated fatty acids improved satiety and had no influence on food intake. [21] Similarly, in young adults, a 240-kcal, high-fat (58% of energy from fat) snack enhanced satiety but had no impact on food intake at dinner. [9] The findings suggested in an acute high-fat meal study were the same as in our study; no significant changes were seen in subjective appetite ratings or remainder energy intake. [20] Contrary to our study, Green S.M. et al. explored that the high-fat and high-CHO test meals with different energy contents and weights did not show any intensification of satiety with the high-fat meals. [22] Instead, recorded hunger was similar after the high-fat and high-CHO test meals. [22] According to Ortinau L. C. et al. [23] high-protein snacks, when compared to high-fat snacks, improved appetite control and fullness and reduced subsequent food intake in healthy women. Others have shown that high protein meals were more satiating than high carbohydrate or high-fat meals when assessed by subjective ratings of satiety. [10, 11, 24] Potier M. et al. study of adults showed that eating each of the three macronutrients one hour prior to lunch did not confirm the greater satiety effect of proteins than of carbohydrates but confirmed the weaker effect of fats as a satiety agent. [25]

Although dietary fat with specific types of composition could influence satiety effects differentially,[20] as in our study, unsaturated, high-fat meals were associated with increased satiety. Due to their high energy density and palatability, studies have shown a favorable correlation between high-fat diets and excessive energy intake from test meals. [26] High dietary fats' satiety effectiveness may be explained by both their high energy density and/or their palatability enhancing effects, including temperature, taste, aroma, and texture. [26, 27] Our study also observed significant differences in palatability parameters among the three meals. Overall, acceptability was more favorable for high-fat meals and meals with higher temperatures. It is notable that the satiety response to the temperature of food is an ignored part of the literature. Higher temperature meals in our study scored higher satiety as well.

Satiety is controlled at both the brain stem and the cortex. [14, 15, 28] Many nuclei in the brain stem are influenced by nutrients (glucose, fats, and amino acids), hormones (cholecystokinin), taste, temperature, and gastric distention signals. These brainstem signals are further integrated with the cerebral cortex and other areas. [15, 28] However, decerebrated (absence of higher cortical regions) animals also showed satiety, showing the independent role of the brain stem in satiety. [28] Food intake affects the reward system in cortical regions; meals with high taste intensity may elicit faster fullness and satiation than meals with low taste intensity. [28] The more appealing the food, the more fullness, which leads to downregulation of the reward center, which reduces or stops further food intake. Moreover, meals with little taste, when eaten quickly, only cause slight oral sensory stimulation and do not initiate a cephalic phase response, leading to little satiation. In our study, high fat had the highest satiety, which may be because fat has higher stimulation of CCK and increased palatability and hedonic stimulation. Moreover, hot temperatures lead to enhanced flavor, aroma, and texture (hedonic response), affecting the brainstem and cortical centers (including the reward center), leading to further increased satiety. [29,30,31] Similar reporting by Ventanas et al. (2010) found that subjects perceived higher flavor intensities from food served at a higher temperature than at a lower temperature. [31]

The remainder of the food intake did not differ significantly between the three meals given at three temperatures in our study. Thus, there was no impact of three different macronutrient meals at three temperatures on self-recorded food intake during the rest of the test days. In several studies, the discrepancies between test meal intake and its related VAS for satiety scores and the remainder of the

day's energy intake have been noted. [8, 32,33,34] Dericioglu D et al. have reported results similar to ours while comparing the effect of preloads high in protein, fat, and carbohydrate on subsequent energy intake and found no significant effect of preload type on energy intake either at the *ad libitum* meal, food intake for the rest of the day, or subjective appetite ratings. [32] Similarly, there was no change in the acute ad libitum energy intake following different preloads in a study of healthy adults employing isovolumetric and isoenergetic fluid preloads but with varied macronutrient compositions. [34] On the contrary, Sharafi M. et al. showed that a high protein and high fiber beverage preload reduced hunger and desire to eat and tended to reduce subsequent food intake. [35]

Fallaize R et al. also supported the reduction of subsequent energy intake at lunch and evening meals after consuming three isocaloric breakfast meals. [36] Although these are all speculative at this moment, there are several potential explanations for the disconnect in our study. According to Blundell et al. (2010), it is unclear how specific changes in visual analogue scale ratings correspond to changes in later caloric consumption. [6] Although the VAS is considered a common and valid measure for examining subjective appetite, there are still concerns about its ability to predict eating behavior. [10] Secondly, the availability of non-standardized food to our study participants at home (with no restriction on quantity) in a free environmental setting may have affected the remainder of the day food intake. [5] Moreover, we relied on participant memory recall of type and quantity of food, and this may lead to biased reporting and miscalculation of macronutrients and calories. [5] Thirdly, ad libitum meal intake during the rest of the day had a high degree of day-to-day variability. Lastly, choosing meals with the hedonic attributes of liking and wanting meals rich in sugar, salt, and fat during the rest of the day. All these may have reduced the impact of higher satiety scores of high fat and hot meals on remainder food intake in our study.

There is a need for large samples for further research into the effects of different diet compositions with different food temperatures on satiety scores and rest-of-day food intake. These investigations will yield corroborating data and additional mechanistic insight on the temperature of food and different meal compositions. The study's limitations included sampling only normal weight and healthy participants. The results may differ in obese and diabetic subjects and need exploration. It was a short-term study to see changes in satiation, satiety, and subsequent energy intake, which may not be informative; a longer-term study with more robust outcomes such as weight, waist circumference, and body composition can be planned. Without weighing the subsequent food intake at home, it led to misreporting and miscalculation of macronutrients for the remainder of the food intake. Moreover, under tightly controlled laboratory conditions, there were difficulties in unmasking the effect of dietary components on eating behavior.

Conclusion

The present study demonstrates that high fat meals and hot food temperatures can modify satiety and satiation. However, the short-term consumption of hot temperature food and high fat meals did not affect the subsequent food intake during the rest of the day.

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Mann Whitney Post hoc VAS score for satiety

Supplementary Table 1 Post hoc of hunger scores (at 240min) in three study meals at three temperatures.

	CCHO	WCHO	HCHO	CPRO	WPRO	HPR0	CFAT	WFAT	HFAT
CCHO		**0.051**	0.174	0.959	0.174	**0.026**	**0.04**	0.081	**0.035**
WCHO			0.247	**0.007**	0.59	0.456	0.608	0.878	0.719
HCHO				**0.057**	0.457	0.15	0.09	0.199	0.208
CPRO					0.106	**0.009**	**0.011**	**0.029**	**0.004**
WPRO						0.27	0.521	0.898	0.369
HPR0							0.572	0.538	0.700
CFAT								0.426	0.959
WFAT									0.959
HFAT									

Cold Carb vs. warm carb, hot protein, cold fat, and hot fat were significant ($P < 0.05$). Warm carb vs. cold protein was significant (P0.05). Hot carb vs. cold protein was significant ($P< 0.05$). Cold protein vs hot protein, cold fat, warm fat and hot fat were significant ($P < 0.05$).

CCHO; cold carbohydrate, WCHO warm CHO, HCHO; hot CHO, CPRO; cold protein, WPRO; warm protein, HPRO; hot protein, CFAT; cold fat, WFAT; warm fat, HFAT; hot fat.

Supplementary Table 2 Post hoc of desire to eat scores (at 240min) in three meals at three temperatures.

	CCHO	WCHO	HCHO	CPRO	WPRO	HPR0	CFAT	WFAT	HFAT
CCHO		0.100	0.174	0.857	0.19	**0.02**	0.065	0.151	**0.035**
WCHO			0.857	0.100	0.837	0.137	0.472	0.59	0.247
HCHO				**0.048**	0.98	0.077	0.227	0.521	0.281
CPRO					0.117	**0.004**	**0.01**	0.048	**0.019**
WPRO						0.248	0.608	0.700	0.293
HPR0							0.489	0.538	0.700
CFAT								0.857	0.898
WFAT									0.837
HFAT									

Cold Carb vs. hot protein and hot fat were significant ($P < 0.05$). Hot carb vs. cold protein was significant ($P < 0.05$). Cold protein vs. hot protein, cold fat and hot fat were significant ($P < 0.05$).
CCHO; cold carbohydrate, WCHO warm CHO, HCHO; hot CHO, CPRO; cold protein, WPRO; warm protein, HPRO; hot protein, CFAT; cold fat, WFAT; warm fat, HFAT; hot fat.

Mann Whitney Post hoc VAS score for Palatability

Supplementary Table 3 Post hoc of temperature palatability parameter in three meals at three temperatures

	CCHO	WCHO	HCHO	CPRO	WPRO	HPR0	CFAT	WFAT	HFAT
CCHO		**< 0.001**	0.204	0.855	**< 0.001**	**0.004**	0.794	**< 0.001**	**< 0.001**
WCHO			0.175	**< 0.001**	0.805	0.854	**< 0.001**	**0.039**	0.869
HCHO				0.234	0.143	0.284	0.170	**0.023**	0.200
CPRO					**< 0.001**	**0.006**	0.795	**0.000**	**< 0.001**
WPRO						0.770	**< 0.001**	**0.030**	1.000
HPR0							**0.004**	0.089	0.872
CFAT								0.524	0.690
WFAT									**0.030**
HFAT									

Cold Carb vs. warm carb, warm protein, hot protein, warm fat, and hot fat were significant ($P < 0.05$). Warm carb vs. cold protein, cold fat and warm fat were significant ($P < 0.05$). Hot carb vs. warm fat was significant ($P < 0.05$). Cold protein vs. warm protein, hot protein, warm fat, and hot fat were significant ($P<0.05$). Warm protein vs. cold fat and warm fat were significant ($P < 0.05$). Hot protein vs. cold fat was significant ($P<0.05$). Warm fat vs. hot fat was significant ($P < 0.05$).
CCHO; cold carbohydrate, WCHO warm CHO, HCHO; hot CHO, CPRO; cold protein, WPRO; warm protein, HPRO; hot protein, CFAT; cold fat, WFAT; warm fat, HFAT; hot fat.

Supplementary Table 4 Post hoc of texture palatability parameter in three meals at three temperatures

texture	CCHO	WCHO	HCHO	CPRO	WPRO	HPR0	CFAT	WFAT	HFAT
CCHO		0.121	0.124	0.979	0.958	0.122	0.121	0.049	0.062
WCHO			0.957	0.063	0.066	0.852	0.831	0.670	0.872
HCHO				0.086	0.072	0.851	0.850	0.688	0.873
CPRO					0.937	**0.059**	0.093	**0.019**	**0.015**
WPRO						0.062	0.079	**0.021**	**0.020**
HPR0							0.979	0.541	0.706
CFAT								0.524	0.690
WFAT									0.808
HFAT									

Cold protein vs. hot protein, warm fat, and hot fat were significant ($P<0.05$). Warm protein vs. warm fat and hot fat were significant ($P < 0.05$).
CCHO; cold carbohydrate, WCHO warm CHO, HCHO; hot CHO, CPRO; cold protein, WPRO; warm protein, HPRO; hot protein, CFAT; cold fat, WFAT; warm fat, HFAT; hot fat.

Supplementary Table 5 Post hoc of appearance palatability parameter in three meals at three temperatures

Appearance	CCHO	WCHO	HCHO	CPRO	WPRO	HPR0	CFAT	WFAT	HFAT
CCHO		0.308	0.731	0.247	0.056	0.636	0.528	0.131	0.707
WCHO			0.466	1.000	0.402	0.560	0.674	**0.022**	0.156
HCHO				0.455	0.114	0.850	0.709	0.087	0.543
CPRO					0.400	0.459	0.545	**0.009**	0.088
WPRO						0.129	0.149	**0.002**	**0.013**
HPR0							0.853	0.035	0.424
CFAT								**0.022**	0.283
WFAT									0.124
HFAT									

Warm carb vs. warm fat was significant ($P<0.05$). Cold protein vs. warm fat was significant ($P<0.05$). Warm protein vs. warm fat .and hot fat were significant ($P<0.05$). Cold fat vs. warm fat was significant ($P<0.05$).

CCHO; cold carbohydrate, WCHO warm CHO, HCHO; hot CHO, CPRO; cold protein, WPRO; warm protein, HPRO; hot protein, CFAT; cold fat, WFAT; warm fat, HFAT; hot fat.