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Acknowledgements

The authors thank the City Hall of Montpellier, Luc Gomel and all staff from the Serre Amazonienne for providing places for rater recruitment and the women and men who participated in this study. This is contribution ISEM 2020-229.

Declaration of Conflicting Interests

The author(s) have declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Ethical Statement

The protocol used to recruit participants and collect data was approved by the French Committee of Information and Liberty (CNIL #1783997V0). For each participant, the general purpose of the study was explained (“a study on the determinants of mate choice”), and written voluntary agreement was requested for statistical use of data (private information and photographs). Data were analysed anonymously.

Funding

The author(s) have disclosed receipt of the following financial support for the research, authorship, and/or publication of this article: Agence Nationale pour la Recherche ‘HUMANWAY’ project (ANR-12-BSV7-0008-01). None of the funding organisations or sponsors played a role in the design and conduct of the study; in the collection, management, analysis, or interpretation of the data; or in the preparation, review, or approval of the manuscript.

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Abstract

Since the second half of the 20th century, a massive increase in the consumption of refined carbohydrates has occurred, generating well-described detrimental health effects such as obesity, insulin resistance, type II diabetes, cardiovascular diseases and dental caries. Certain physiological mechanisms involved, particularly through chronic hyperglycaemia and hyperinsulinaemia, suggest that a non-medical trait such as facial attractiveness could also be affected. To explore this possibility, variation in facial attractiveness was evaluated relative to refined carbohydrate consumption. Attractiveness was assessed from facial pictures as judged by raters of the opposite sex. Estimates of refined carbohydrate consumption were based on the glycaemic load of three mealtimes at-higher glycaemic risk (breakfast, afternoon snack and between-meal snack). In the presence of several control variables, facial pictures of women and men with higher between-meal glycaemic loads were preferred by opposite-sex raters. Structural equation modelling suggests that this result is possibly mediated by an increase in apparent age for men and an increase in femininity for women. The different physiological ecologies of the three meals at-higher glycaemic risk are discussed as well as the interpretation of the results in terms of adaptation or maladaptation to the modern and unique dietary environment.

Keywords

Refined carbohydrates, sugars, evolutionary diet, dietary switch, facial attractiveness, social trait, glycaemic load

Introduction

Each animal species is adapted to a specific diet (carnivorous, herbivorous, etc.) through a specialised digestive process. Therefore, any rapid change in this diet could result in health problems, revealing that the change has driven the population outside its adaptive peak (Fiennes, 1965). In humans, during the 20th century, a drastic dietary switch occurred in Western populations with the introduction of industrially processed food such as refined products (carbohydrates, oil) and additives (e.g., trans-fatty acids, gluten, sweeteners). In particular, a massive increase in the consumption of refined carbohydrates (primarily sucrose, fibre-depleted gelatinous starches and high sugar corn syrup) occurred in less than three generations (Cordain et al., 2005). As a consequence, these refined carbohydrates currently represent a major element of the modern urban diet (e.g., 36% of total energy in the typical US diet) compared with at most a few percentage points as recently as 200 years ago (Cordain, Eades, & Eades, 2003). Certain detrimental health effects of this new refined carbohydrate-rich food consumption are now well known, such as obesity, insulin resistance, type II diabetes, cardiovascular diseases and dental caries (Hu, Van Dam, & Liu, 2001; Jellinger, 2007; Johnson et al., 2007; Spencer, Appleby, Davey, & Key, 2003; Touger-Decker & Van Loveren, 2003). Many other direct or indirect deleterious effects are also strongly suspected, e.g., Alzheimer’s disease, hypertension, inflammatory diseases, cancer, myopia, acne, etc. (Cordain et al., 2002; Cordain, Eaton, Brand Miller, Lindeberg, & Jensen, 2002; Craft, 2007; Johnson et al., 2007; Key et al., 2004; Manzel et al., 2013; Gentreau et al., 2020).

Thus far, the increase in refined carbohydrates consumption has been shown to affect body physiology and health. However, frequent refined carbohydrate-rich food consumption generates chronic hyperglycaemia and thus chronic hyperinsulinaemia, the latter interfering with growth factors and sex hormones, which themselves modulate morphology and secondary sex characteristics

(Cordain, Eades, & Eades, 2003). Considering that facial masculinity/femininity influences attractiveness (for a review see: Puts, Jones, & DeBruine, 2012), it is possible that an increase in refined carbohydrate consumption has affected facial attractiveness. There are indirect cues that refined carbohydrate consumption could affect attractiveness. For example, Zuniga, Stevenson, Mahmut, & Stephen (2017) showed that carbohydrate intake, mainly food item rich in refined carbohydrate, reduces body odour attractiveness. Also, refined carbohydrates are among the factors suspected to accelerate skin ageing and photo-ageing (Purba et al., 2001; Cosgrove, Franco, Granger, Murray & Mayes, 2007), a trait affecting attractiveness (Buss, 1989). Attractiveness influences a diverse range of critical social outcomes, from mate choice to decisions related to social exchange. For example, physically attractive (relative to unattractive) individuals are evaluated more favourably as romantic partners (Eastwick, Luchies, Finkel, & Hunt, 2014), as students by teachers (Ritts, Patterson, & Tubbs, 2016), and even as political candidates (Praino, Stockemer, & Ratis, 2014).

In this study, we investigated whether refined carbohydrate consumption affects facial attractiveness in healthy women and men. General predictions on whether attractiveness is increased or decreased as the result of refined carbohydrate consumption are not straightforward. For example, hyperglycaemia could have a possible ageing effect (i.e. increase of apparent age), with the consequence of increasing attractiveness in men and decreasing attractiveness in women (Buss, 1989; Jencks & And Others, 1979). However, hyperglycaemia generates hyperinsulinaemia. Hyperinsulinaemia with insulin resistance have been linked to diseases associated with perturbation of sex hormones (Cordain et al., 2003) and to testosterone levels increased in women and decreased in men (Lutz et al., 2019), thus potentially decreasing attractiveness for both sexes (Puts et al., 2012). As a consequence, for women, it is expected that refined carbohydrate consumption decreases attractiveness. For men, no clear prediction could be unambiguously formulated. Evaluation of attractiveness was based on facial pictures evaluated by raters of the opposite sex. Evaluation of refined carbohydrate consumption was based on total glycaemic load (a proxy of glycaemic and insulinaemic responses) of three mealtimes at-higher glycaemic risk (breakfast, afternoon snack and between-meal snack). The choices of the raters were explained by the diet variables in the presence of potentially confounding variables including apparent age and a femininity/masculinity index.

Methods

Individual measures

Individuals between 18 and 26 years of age were recruited at the University of Montpellier. Possible confounding variables potentially affecting facial attractiveness were collected: sex, year and month of birth, height and weight, socio-economic status (scholarship level coded from 1: no scholarship to 4: highest level), smoking (yes: 1, no: 0) and for women, use of contraceptive pill (yes: 1, no: 0, Alvergne & Lummaa, 2010). Facial photographs of all of the individuals were obtained from a frontal perspective at a distance of approximately 1 m using the same digital camera (Canon EOS 20D) with a 50-mm focal length.

The subjects were asked to express a neutral face (without a smile) and to remove any glasses or earrings. Photographs of individuals declaring a European origin of their 4 grandparents were further retained. All photographs were processed using Adobe Photoshop CS3 to normalise size (photographs were aligned on the eye position, with a fixed distance between the eyes and chin). The backgrounds were replaced by a uniform grey colour.

Diet variables

The various daily meals have different nutritional composition and thus they do not bring the same glycaemic response. Indeed, carbohydrates are rarely ingested alone, and their degradation and absorption rates during digestion are modified by the other macronutrients. The glycaemic response will be higher with a meal rich in refined carbohydrates, poor in fat, protein and fibre (Hätönen et al., 2011; Sun, Ranawana, Leow, & Henry, 2014). The order of food macronutrient intake also changes the glycaemic and insulinaemic responses (Sun, Goh, Govindharajulu, Leow, & Henry, 2020). As a consequence, meals such as breakfast, afternoon snack and between-meals snack, which are described as richer in refined carbohydrates and displaying less food items, may be at-higher glycaemic risk (Bellisle et al., 2003; Bellisle, 2014; Bellisle, Hébel, Salmon-Legagneur, & Vieux, 2018). Thus the exhaustive list of the different foods and drinks chronically consumed during these specific times in the same day (breakfast, afternoon snack ["goûter" in French, corresponding to an after-school snack] and between-meals snack) was collected.

For each food and drink item, the glycaemic load was evaluated according to the International Tables of Glycaemic Index and Glycaemic Load Values and the corresponding serving size (Atkinson, Foster-Powell, & Brand-Miller, 2008). The glycaemic index refers to the rate of glucose release by measuring the 2 h postprandial glycaemia value after consumption of a food portion containing 50 g of available carbohydrates relative to 50 g of glucose consumption. The glycaemic load (GL) is calculated by multiplying the glycaemic index by the amount of available carbohydrates (g) per serving, divided by 100 (Monro & Shaw, 2008). Compared with low-GL diets, high-GL diets elicit larger glycaemic and insulinaemic responses (Foster-Powell, Holt, & Brand-Miller, 2002). For each subject, the glycaemic load for each item was summed leading to an estimation of total glycaemic load for breakfast (GL1), afternoon snack (GL2) and between-meal intake (GL3). Foods with low carbohydrate content (e.g., meat, fat) were not assigned any glycaemic load value (Bakel et al., 2009). Energy intake (EI) and macronutrients (carbohydrates, fat, protein and fibre) for each item were obtained from the Anses-Ciqual database (www.anses.ciqual.fr) and were calculated for each participant depending on its corresponding serving size (Atkinson, Foster-Powell, & Brand-Miller, 2008). For each subject, they were summed leading to an estimate of total energy intake for breakfast (EI1), afternoon snack (EI2) and between-meal intake (EI3) and corresponding macronutrient compositions.

Apparent age and attractiveness estimation

Volunteer adult raters were recruited in public places in Montpellier, France. For each rater, the sex, age and geographic origin (continent of birth for the rater, parents and grandparents) were recorded. A first set of raters estimated the age of the subjects from their facial photographs. A Delphi-based computer program was generated to present randomly drawn photographs to raters of the opposite sex. Each rater assessed 20 distinct photographs. If the rater knew one of the subjects, the trial was removed. Three photographs randomly chosen among those previously viewed were presented again at the end to estimate judgement reliability. A second set of raters was sampled to make decisions concerning the relative attractiveness of the facial photographs. A Delphi-based computer program was generated to present randomly drawn pairs of photographs to raters of the opposite sex (Figure 1). For each pair, the raters were instructed to click on the photograph depicting the face that they found the most attractive. The position of the photograph on the screen (left or right) was randomly ascribed. Each rater assessed 20 distinct pairs of photographs, corresponding to 40 different randomly chosen subjects. If the rater knew one of the subjects presented for judgement, the trial was removed. Additionally, the first pair of photographs viewed by each participant was not used in the analyses because the task could require a certain amount of habituation. Three pairs randomly chosen from among those previously viewed were presented again at the end to estimate judgement reliability.

Femininity/masculinity index

To generate the morphological facial femininity/masculinity index (fem/masc index), a geometric morphometric analysis of the faces was used following the methods described in Dixson, Lee, Sherlock, & Talamas, 2017; Lee et al., 2014; Scott, Pound, Stephen, Clark, & Penton-Voak, 2010. First, the coordinates of 142 landmarks (anatomical points present in all individuals, e.g., corners of the lips) and semi-landmarks (sliding points positioned along selected anatomical curves, such as the bow of the eyebrow) were delineated for each male and female face. The delineation of the landmarks and semi-landmarks was performed using Psychomorph (Tiddeman, Stirrat, & Perrett, 2005). The R package Geomorph (version 3.0.3) was used to perform Procrustes superimposition of the landmark and semi-land-mark data, which removes non-shape information such as translation, size and rotational effects (Zelditch, Swiderski, & Sheets, 2012). The coordinates were transformed into shape variables via principal component analysis (PCA). The first 10 axes were retained (explaining 75.0% of variance) for further analyses. To compute a data-driven single measure of facial masculinity, an LDA was conducted on the PCA coordinates with sex as the grouping variable. The resulting discriminant function correctly classified 100% of individuals in the two categories. Each individual coordinate on the woman-man axis was used as a facial femininity/masculinity index, with high values indicating a more masculine facial morphology (Dixson et al., 2017; Lee et al., 2014; Scott et al., 2010).

Statistical analyses

For each individual, age estimates were averaged across raters, and the resulting measure was used as the perceived age variable. Logistic regression was used to analyse the rater preferences. The binary response variable corresponded to being chosen or not for the focal subject (arbitrarily, the subject presented at the left position) during the presentation of each pair. Subjects and raters occurred repeatedly (each subject was viewed by several raters, and each rater evaluated several pairs of subjects) and were thus random-effect variables. Therefore, generalised linear mixed models with a binomial error structure were applied. To force the models to fit away from singularities, the Bayesian bglmer function of the blme package for R software was used (Chung, Rabe-Hesketh, Dorie, Gelman, & Liu, 2013). Maximum random effects structure (intercept and slope) was tentatively included according to Barr, Levy, Scheepers, & Tily (2013), but the random slope effect was not included in the final models because it prevented convergence. For each choice made by a judge, the difference (left minus right) between the GL1 of the focal and the non-focal subject was calculated, and the same procedure was performed for the GL2 and GL3. These differences were integrated into the model as the variables of interest. Because pairs of subjects were rated by the opposite sex (men rated by women and women rated by men), two models were performed, one for each subject's sex. For both, several control variables potentially affecting facial attractiveness were added: differences between the variables associated with the individuals of each pair (left minus right) for age, age departure from actual age (perceived age minus actual age), facial femininity/masculinity index, BMI (calculated as weight divided by the squared height), scholarship level [-3 to +3], smoking [-1 to +1], and for women, pill use [-1 to +1]). All quantitative variables were centred. The significance of each term was assessed from the model including all of the other variables. The variance inflation factor was computed using the vif.mer function adapted from the vif function of the R package rms (Harrell, 2015; Zuur, Ieno, & Elphick, 2010). Differences between the EI variables associated with the individuals of each pair were not included in the model due to the high correlation of EI1, EI2 and EI3 with GL1, GL2 and GL3 respectively (Pearson's correlation coefficient $r > 0.9$ and $P < 10^{-4}$ for all). Rather, the same models were conducted using these variables instead of GL. Because the glycaemic load variables (GL1, GL2, and GL3) could potentially affect certain control variables directly (e.g., age departure from actual age, femininity/masculinity index and BMI), this could indirectly influence the effect of the GL variables on the dependent variable. To evaluate this possibility, structural equation modelling was performed using the control variables from the model displaying $P < 0.1$. An attractiveness index was constructed for each individual, computed as the number of times this individual was chosen over the number of occurrences. An hypothesised path model was constructed for each sex, incorporating four linear regressions with GL3 to explain attractiveness, age departure from actual age, BMI, and femininity/masculinity index for women and incorporating three linear regressions to explain attractiveness, age departure from actual age, and BMI for men (Figure 2).

All statistical analyses were performed using R software version 3.5.2 using the packages blme (v1.0-4, Chung, Rabe-Hesketh, Dorie, Gelman, & Liu, 2013), rms (v5.1-4, Harrell, 2015), and lavaan v0.6-3, Rosseel, 2012). The SE values and P values for standardised path coefficients were obtained through the function standardisedSolution in the ‘lavaan’ package.

Results

A total of 50 female and 49 male Caucasian subjects with fully completed questionnaires were used. Descriptive statistics of their physical characteristics are given in Table 1, and their food consumption for each meal are detailed in Table 2. The proportion of men and women taking a meal were 92% and 90% respectively for breakfast, 63% and 70% respectively for an afternoon snack, and 41% and 50% respectively for a between-meal snack. Mean glycaemic load (GL) and energy intake (EI) for each meal are computed considering only consumers (Table 3). According to the general classification (e.g. Eleazu, 2016), the means of GL obtained for each of the three meals studied were high (>20) except for GL3 in women which was medium (value between 11 to 19) (Table 3). GL and EI values were in the same range of variation as those from another study on a French population (Gentreau et al., 2020).

Raters were first recruited to assess the perceived age of the subjects. Assessments from unreliable raters (i.e., with more than fifteen years for the sum of the absolute difference between real ages and attributed ages during the three judgements of reliability) were removed, resulting in a final sample of 222 raters (78 men and 144 women, age range: 18-76, mean age ± s.d.: 36 ± 14 years for men and 37 ± 13 years for women). This process resulted in a total of 834 estimations of men towards women and 1435 estimations of women towards men. The mean number of raters was 28.8 (range: 14-41) for each man and 16.6 (range: 12-25) for each woman. For each individual, the perceived age variable was computed as the average estimated by the raters. Overall, the perceived age was either younger (maximum 3.0 years) or older (maximum 7.8 years) than the chronological age, with a mean ± s.e.m. of 1.7 ± 0.25 years older.

Raters (N = 169) were subsequently recruited to assess the attractiveness of the subjects. The following conservative selection of raters was applied. First, to reduce cultural heterogeneity, only raters from a European ancestry were considered. Second, unreliable raters (i.e., with more than one incorrect answer during the test of judgement reliability) or non-adult raters (less than 18 years old) were removed. A total of 150 raters were retained in the final sample (61 men and 89 women, age range: 18-68, mean age ± s.d.: 35 ± 10 years for men and 33 ± 13 years for women). This process resulted in a total of 346 judgements of men towards women and 402 judgements of women towards men. The mean number of raters was 17 (range: 8-24) for each man and 14 (range: 6-21) for each woman. The probability that a subject was chosen as the most attractive was significantly influenced by the variable GL3 (men: $\beta = 0.564$, SE = 0.171, $P = 0.001$; women: $\beta = 0.468$, SE = 0.174, $P = 0.007$, see Table 4). Women preferred men, and men preferred women, with the highest between-meal glycaemic load. Some control variables significantly influenced the choice of the raters. For male and female subjects, BMI had a negative effect on the probability of being chosen as the most attractive (men: $\beta = -0.399$, SE = 0.172, $P = 0.021$; women: $\beta = -0.792$, SE = 0.168, $P < 10^{-5}$). A lower BMI was preferred for both sexes. For male subjects, age had a positive effect on the probability of being chosen ($\beta = 0.445$, SE = 0.159, $P = 0.005$), and women preferred men with an older age. The difference in age departure from actual age had a significant impact on attractiveness (men: $\beta = 0.401$, SE = 0.167, $P = 0.015$; women: $\beta = -0.415$, SE = 0.191, $P < 0.030$). At equal chronological age, women preferred men with the oldest perceived age. At equal chronological age, men preferred women with the youngest perceived age. Scholarship level, smoking status, femininity/masculinity index, and taking the contraceptive pill (for women) did not have a significant effect on the probability of being chosen ($P >$

0.25, for both sexes, except femininity/masculinity index for women, $P = 0.07$). The full model for men explained 9% of the total deviance and the variance inflation factors (VIF) were less than 1.50. The full model for women explained 10% of the total deviance and the VIF were less than 2.50. VIF values for both models indicated that the multicollinearity between covariables was weak and not of concern (Zuur et al., 2010). Models using EI1, EI2 and EI3, gave qualitatively similar results (Table S1). A hypothesised path diagram was constructed for each sex to evaluate a possible direct effect of GL3 on the control variables BMI, age departure from actual age, and femininity/masculinity index (Figure 2). For men, GL3 had a significant effect on age departure from actual age (path coefficient = 0.310, $P = 0.014$). A higher between-meal glycaemic load increased appearance towards an older age. For women, GL3 had a marginally significant effect on the femininity/masculinity index (path coefficient = -0.249, $P = 0.056$). A higher between-meal glycaemic load decreased masculinity.

Discussion

In this study, we investigated whether refined carbohydrate consumption is related to facial attractiveness in healthy women and men. We found that women and men with the highest between-meal glycaemic loads were preferred by opposite-sex raters, result in the opposite direction than the prediction based on known physiological effects for women. This preference was maintained when controlling for potential confounding effects such as age, age departure from actual age, BMI, scholarship level, smoking status, facial femininity/masculinity index, and for women, whether they took the contraceptive pill.

Attractiveness is not independent of the refined carbohydrate content of the food eaten estimated through glycaemic load, although this effect was evidenced from only one (between-meal snack) of the three mealtimes at-higher glycaemic risk considered. This meal is not the one with the higher mean GL, and is not particularly odd for its macronutrient content as well as carbohydrates, protein, fat and fibre (Table 3). A possible explanation is that these three types of meals could correspond to different ecological food habits that affect subjects differently with different physiological consequences. For example, the usual mid-afternoon eating occasion known in France as the 'goûter' corresponds (for those who usually have one) to a real dietary need. This meal is associated with a pre-prandial decline in plasma glucose and insulin concentration and a high motivation to eat (Chapelot, Marmonier, Aubert, Gausseres, & Louis-Sylvestre, 2004). In contrast, between-meal snacks are often not associated with physiological hunger and are rather motivated by social or other external stimuli, with few resulting effects on satiety and compensation mechanisms (Bellisle, 2014). Therefore, this meal category could better reflect chronic and acute refined carbohydrate consumption. Finally, it is worthy of note that consumers of the between-meal snack were at a frequency around 40-50% (Table 2), allowing more statistical power to detect a difference between two groups, relative to the distribution of consumers for the two other meals (ca. 91% for breakfast, and 63-70% for the afternoon snack).

How chronic between-meal snacks could affect attractiveness

Refined carbohydrate-rich food consumption generates hyperinsulinaemia as a consequence of hyperglycaemia, interfering with growth factors and sex hormones, which themselves modulate morphology and secondary sex characteristics (Cordain et al., 2003). This result occurs because hyperinsulinaemia stimulates androgen synthesis by the ovaries and testes, increasing the quantity of free (and thus active) androgens in the blood. Androgens are the precursors of male and female sex hormones such as testosterone and oestrogen. Hyperinsulinaemia has been linked to diseases associated with significant perturbation of sex hormone levels, such as polycystic ovary syndrome and premature menarche (Cordain et al., 2003). If the influences of a refined carbohydrate-rich diet on other downstream consequences have been poorly studied to date, it is possible that these consequences include the development of secondary sexual traits, typically masculine or feminine facial features. In addition, it has been shown that sex hormones modulate facial femininity/masculinity, which in turn influences attractiveness, with men preferring more feminine faces and women preferring more masculine ones (for a review see Puts et al., 2012). To capture facial secondary sex characteristics, a femininity/masculinity morphological index was computed, for which the difference within each pair was used as a control variable. Structural equation modelling showed that for women, the effect of glycaemic load on attractiveness could be indirectly mediated through a direct effect of the femininity/ masculinity index, leading to an increase of femininity. Sexual hormones are possible candidates to explain this effect (Cordain, Eades, & Eades, 2003), although, as it is in the opposite direction than expected, further work is required for a better understanding.

Another physiological effect of refined carbohydrate-rich food consumption is hyperglycaemia, which has itself several physiological consequences. For example, hyperglycaemia accelerates glycation, a covalent bonding process that cross-links the amino acids present in the collagen and elastin that support the dermis. Cross-linked collagen fibres are incapable of repair through the usual process of remodelling, directly impacting youthful skin appearance, which relies on flexible and repairable collagen fibres (Danby, 2010). Thus chronic hyperglycaemia generated by chronic between-meal snacks could affect attractiveness because skin ageing directly impacts age appearance (Nkengne et al., 2008), and age affects attractiveness (Samson, Fink, & Matts, 2010). However, this possible effect was controlled for because apparent age was independently estimated, and the difference in age departure from the chronological age within each pair was used as a control variable. Structural equation modelling suggested that for men, the effect of glycaemic load on attractiveness could be indirectly mediated through a direct effect on age departure from actual age. Indeed, an increase in the age difference (chronological or apparent) within each pair increased attractiveness (Table 4), and thus any skin ageing effect, which increases apparent age, also increases attractiveness. This increase in attractiveness with age is generally described for relatively young men in the range 20-50 years old and is classically explained by the correlation between age and characteristics that advertise adequate parental investment in terms of resource and social status (Buss, 1989; Jencks & And Others, 1979). For older ages, the correlation between age and attractiveness is reversed, perhaps due to somatic senescence compromising some type of paternal investment, fertility decline, or to higher chances of passing on genetic defects to offspring (Hellstrom et al., 2006; Kong et al., 2012). For women, the ageing effect is the opposite: an increase in the difference in age departure from actual age within each pair decreased attractiveness, i.e., men preferred women that were perceived to be younger (or compared to women evaluated older) (Table 4). Indeed, age supplies a powerful cue related to female reproductive capacity, and men prefer younger women (Buss, 1989).

Ultimately, why is an increase in refined carbohydrate consumption associated with an increased attractiveness ?

Traditional foods with a high level of sugar contents are energetically rewarding, although they are typically seasonal or scarce, such as ripened fruit and honey. Because sugar excess generated by hyperglycaemia is stored as fat, traditional foods that generate hyperglycaemia are sometimes used to intentionally increase fat storage, e.g., the case of the food intake of Japanese sumo wrestlers (Nishizawa et al., 1976) or the fattening sessions described in various ethnic groups before an expected general shortage period (Garine & Koppert, 1990; Garine & Koppert, 1991). Generally, traditional food, i.e., pre-industrial or non-refined, does not generate hyperglycaemia. This is the case for fresh fruits, legumes, traditionally prepared cereals, etc., although there are counter-examples such as honey. Globally, traditional foods that generate hyperglycaemia were not always readily available because they were scare or expensive. Thus, it is possible that intake of foods that generate hyperglycaemia represents an advantage in certain traditional environments, particularly when food shortages are not uncommon. In such an environment, detection and preference of facial cues that display an ability to find refined carbohydrates sources could constitute an evolutionary advantage for the choice of mating partner. This hypothesis could explain why an increased consumption of such food increases attractiveness. However, in the current industrial dietary environment, foods that generate hyperglycaemia are not limited, and their consumption is not a signal of quality anymore. Therefore, it is possible that the current increased attractiveness associated with the increased consumption of such food is better understood as a maladaptation.

How the other control variables could affect attractiveness

Several other variables potentially affecting attractiveness were controlled for, although only BMI has a significant effect in that a higher BMI decreased facial attractiveness for both men and women (Table 4). Indeed, body weight can be accurately judged from facial images alone (Coetzee, Chen, Perrett, & Stephen, 2010), and cues of adiposity affect social judgements of female and male faces (Coetzee, Perrett, & Stephen, 2009; Han, Hahn, Fisher, Debruine, & Jones, 2016; Re & Perrett, 2014).

Limitations

The effect of chronic between-meal snacks on attractiveness could be confounded by a variable not considered in this work. One possibility could be physical activity, which could have the effect of both increasing attractiveness (Faurie, Pontier, & Raymond, 2004; Stephen, Coetzee, Smith, & Perrett, 2009) and increasing between-meal snacks (Kerver, Yang, Obayashi, Bianchi, & Song, 2006; Ovaskainen et al., 2006). Other diet factors not taken into account could affect facial attractiveness, such as fruit and vegetable known to increase skin yellowness (Zuniga, Stevenson, Mahmut, & Stephen, 2017; Appleton et al., 2018). Also, the main and more complex meals, i.e. lunch and dinner, were not included, precluding the computation of an overall diet quality index, which could have possibly captured other aspects of diet influencing attractiveness. However, diet quality indexes are correlated with low-GL food (higher values for an increase of low-GL food, see e.g. Jones et al. 2016; Azadbakht et al. 2016), and thus are partially described by GL measures. Finally, energy intake of each meal was not controlled for in our model due to the high correlation observed with glycaemic load, but gave qualitatively similar results when integrated alone (Table S1). As a consequence, it is unclear whether the associations observed are due to energy intake or to glycaemic load.

Conclusion

The recent dietary change, and particularly the new refined carbohydrate-rich diet, has well-known detrimental health consequences. Non-medical traits also are apparently affected in healthy women and men, as refined carbohydrate consumption seems not independent of facial attractiveness, a trait with important social consequences. Further studies are needed to investigate whether other non-medical traits, but with non-negligible social importance, could also be impacted.

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Table 1. Descriptive statistics of the physical characteristics of the women and men used as stimuli.

	Women (N = 50)			Men (N = 49)		
	Range	Mean	SD	Range	Mean	SD
Age (years)	18-26	20.6	2.0	18-26	21.1	2.0
Perceived age (years)	18-28	22.1	2.1	17-30	23.5	3.0
BMI (kg/m²)	16-30	20.8	3.1	18-31	22.6	3.0
Femininity/masculinity index	-4.56 to -0.44	-2.63	1.02	0.56 to 4.46	2.63	0.97

Table 2. Number of individuals consuming the different food groups for each meal. N indicates the number of consumers among the 50 women, or among the 49 men subjects.

	Women			Men		
Food group	Breakfast (N=45)	Afternoon snack (N=35)	Between-meal snack (N=25)	Breakfast (N=45)	Afternoon snack (N=31)	Between-meal snack (N=20)
Cereals, bread	35	10	1	39	10	6
Biscuits, cakes, pastries	15	27	20	13	25	12
Sweets, chocolate	27	15	4	35	18	10
Sweetened-beverages	22	1	0	27	5	0
Dairy products	19	8	1	15	6	1
Fruits	26	8	2	30	7	6
Eggs, charcuterie	2	2	0	1	1	0
Nuts	0	0	0	0	0	2

Table 3. Descriptive statistics of food consumption for the three meals. Mean and standard deviation (SD) are given for consumers only. GL1, GL2 and GL3 are the three variables of glycaemic load. EI1, EI2 and EI3 are the three variables of energy intake (Kcal).

	Women (N = 50)			Men (N = 49)		
	Range	Mean	SD	Range	Mean	SD
GL1	0-60	28.6	13.2	0-55	30.1	11.3
GL2	0-47	24.3	12.1	0-59	28.6	15.0
GL3	0-45	17.4	9.0	0-48	23.0	12.1
EI1	0-924	344.4	175.7	0-719	353.5	155.3
Carbohydrates(g)	0-136	60.1 (75%)	28.2	0-110	65.3 (78%)	23.1
Fat (g)	0-39	10.5 (13%)	8.0	0-28	10.3 (12%)	7.3
Protein (g)	0-39	9.7 (12%)	7.3	0-29	9.0 (10%)	6.2
Fibre (g)	0-7	3.3	1.72	0-10	3.6	2
EI2	0-722	315.7	177.8	0-797	383.0	195.4
Carbohydrates (g)	0-89	39.4 (65%)	23.1	0-97	49.1 (66%)	25.9
Fat (g)	0-33	14.1 (23%)	8.5	0-39	17.7 (24%)	10.2
Protein (g)	0-21	7.4 (12%)	5.5	0-20	7.2 (10%)	4.8
Fibre (g)	0-7	3.3	1.5	0-6	3	1.4
EI3	0-639	223	128.7	0-989	308.3	231.8
Carbohydrates (g)	0-82	26.2 (65%)	16.3	0-88	37.5 (64%)	23.8
Fat (g)	0-30	10.6 (26%)	6.7	0-64	15.2 (26%)	14.9
Protein (g)	0-7	3.7 (9%)	1.8	0-15	5.3 (10%)	4.2
Fibre (g)	0-6	3.3	1.3	0-8	2.9	2.2

Table 4. Effects of different variables on the probability of being chosen during the test of attractiveness for male or female faces. Raters were instructed to choose the individual found to be the most attractive between two facial photographs. GL1, GL2 and GL3 are the three variables of glycaemic load. For each variable, the difference between the two individuals presented was integrated into the model. The estimate (β), standard error of the mean (SE), χ^2 statistic, and corresponding *P*-value are given. Bold characters indicate significant (P < 0.05) effects.

	Male faces evaluated by female raters				Female faces evaluated by male raters			
	β	SE	χ^2	$P(>\chi^2)$	β	SE	χ^2	$P(>\chi^2)$
Intercept	0.074	0.173			-0.208	0.165		
GL1	0.132	0.148	0.799	0.371	-0.195	0.176	1.228	0.268
GL2	-0.001	0.154	0.001	0.992	0.106	0.170	0.392	0.531
GL3	0.564	0.171	10.79	**0.001**	0.468	0.174	7.226	**0.007**
Age	0.445	0.159	7.843	**0.005**	0.284	0.229	1.539	0.215
BMI	-0.399	0.172	5.359	**0.021**	-0.792	0.168	22.35	**$< 10^{-5}$**
Scholarship level	-0.170	0.147	1.345	0.246	0.105	0.171	0.376	0.540
Smoker	0.273	0.251	0.893	0.345	-0.259	0.252	1.055	0.304
Age departure from actual age	0.401	0.167	5.883	**0.015**	-0.415	0.191	4.708	**0.030**
Femininity/masculinity index	0.069	0.162	0.183	0.669	-0.298	0.168	3.139	0.076
Contraceptive Pill	-	-	-	-	-0.252	0.281	0.800	0.371

Figure 1. Example of a pair of faces used during evaluation of women's facial attractiveness by male raters. For each pair of women, the rater was instructed to click on the photograph of the woman that he found the most attractive. Photographs reproduced with permission.

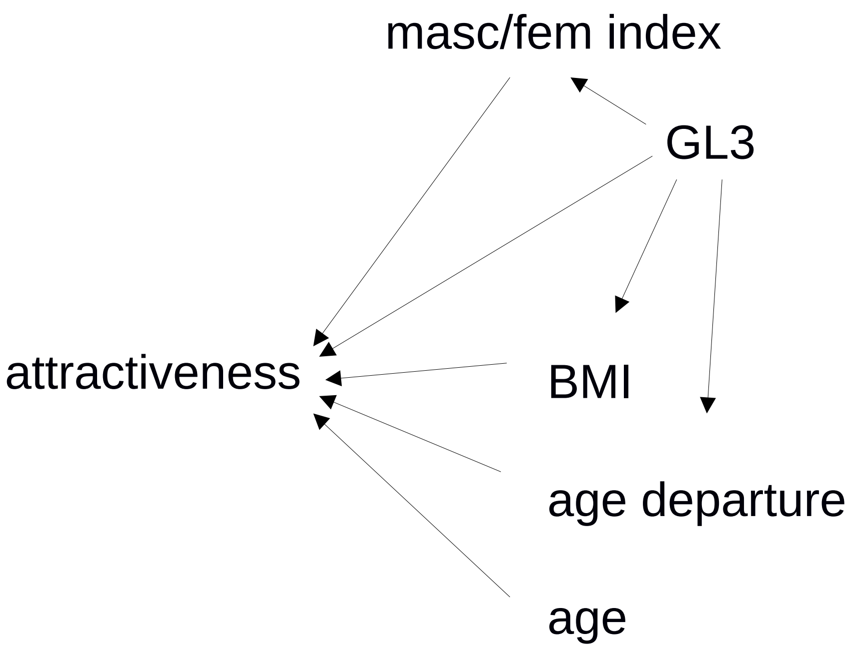

Figure 2. Hypothesised path model to explain attractiveness with the variables of the generalised linear mixed model. Only independent variables displaying $P < 0.1$ are considered. For men, the variable fem/masc index representing the femininity/masculinity index is not present.

Table S1. Effects of different variables on the probability of being chosen during the test of attractiveness for male or female faces. Raters were instructed to choose the individual found to be the most attractive between two facial photographs. EI1, EI2 and EI33 are the three variables of energy intake. For each variable, the difference between the two individuals presented was integrated into the model. The estimate (*β)*, standard error of the mean (SE), χ^2 statistic, and corresponding *P*-value are given. Bold characters indicate significant ($P <$ 0.05) effects.

	Male faces evaluated by female raters				Female faces evaluated by male raters			
	β	SE	χ^2	$P(>\chi^2)$	*β*	SE	χ^2	$P(>\chi^2)$
Intercept	0.093	0.176			-0.233	0.169		
EI1	0.111	0.155	0.518	0.471	-0.147	0.166	0.785	0.376
EI2	0.069	0.142	0.238	0.626	0.050	0.192	0.067	0.795
EI3	0.514	0.141	13.20	**$< 10^{-3}$**	0.648	0.235	7.561	**0.006**
Age	0.544	0.166	10.71	**0.001**	0.277	0.226	1.504	0.220
BMI	-0.393	0.157	5.704	**0.017**	-0.773	0.169	20.96	**$< 10^{-5}$**
Scholarship level	-0.130	0.146	0.797	0.372	0.072	0.180	0.162	0.687
Smoker	0.291	0.248	1.381	0.240	-0.239	0.256	0.871	0.350
Age departure from actual age	0.360	0.157	5.268	**0.022**	-0.444	0.193	5.297	**0.021**
Femininity/masculinity index	0.112	0.160	0.487	0.485	-0.298	0.170	3.065	0.080
Contraceptive Pill	-	-	-	-	-0.214	0.281	0.579	0.44