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1 **Refined carbohydrate consumption and facial attractiveness**

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29

30 **Declaration of Conflicting Interests**

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

33

34 **Ethical Statement**

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

40

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52

53 **Abstract**

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

69

70

71 **Keywords**

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

74 **Introduction**

75 Each animal species is adapted to a specific diet (carnivorous, herbivorous, etc.) through a
76 specialised digestive process. Therefore, any rapid change in this diet could result in health problems,
77 revealing that the change has driven the population outside its adaptive peak (Fiennes, 1965). In
78 humans, during the 20th century, a drastic dietary switch occurred in Western populations with the
79 introduction of industrially processed food such as refined products (carbohydrates, oil) and additives
80 (e.g., trans-fatty acids, gluten, sweeteners). In particular, a massive increase in the consumption of
81 refined carbohydrates (primarily sucrose, fibre-depleted gelatinous starches and high sugar corn syrup)
82 occurred in less than three generations (Cordain et al., 2005). As a consequence, these refined
83 carbohydrates currently represent a major element of the modern urban diet (e.g., 36% of total energy
84 in the typical US diet) compared with at most a few percentage points as recently as 200 years ago
85 (Cordain, Eades, & Eades, 2003). Certain detrimental health effects of this new refined carbohydrate-
86 rich food consumption are now well known, such as obesity, insulin resistance, type II diabetes,
87 cardiovascular diseases and dental caries (Hu, Van Dam, & Liu, 2001; Jellinger, 2007; Johnson et al.,
88 2007; Spencer, Appleby, Davey, & Key, 2003; Touger-Decker & Van Loveren, 2003). Many other
89 direct or indirect deleterious effects are also strongly suspected, e.g., Alzheimer's disease,
90 hypertension, inflammatory diseases, cancer, myopia, acne, etc. (Cordain et al., 2002; Cordain, Eaton,
91 Brand Miller, Lindeberg, & Jensen, 2002; Craft, 2007; Johnson et al., 2007; Key et al., 2004; Manzel et
92 al., 2013; Gentreau et al., 2020).

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

97 (Cordain, Eades, & Eades, 2003). Considering that facial masculinity/femininity influences
98 attractiveness (for a review see: Puts, Jones, & DeBruine, 2012), it is possible that an increase in
99 refined carbohydrate consumption has affected facial attractiveness. There are indirect cues that refined
100 carbohydrate consumption could affect attractiveness. For example, Zuniga, Stevenson, Mahmut, &
101 Stephen (2017) showed that carbohydrate intake, mainly food item rich in refined carbohydrate,
102 reduces body odour attractiveness. Also, refined carbohydrates are among the factors suspected to
103 accelerate skin ageing and photo-ageing (Purba et al., 2001; Cosgrove, Franco, Granger, Murray &
104 Mayes, 2007), a trait affecting attractiveness (Buss, 1989). Attractiveness influences a diverse range of
105 critical social outcomes, from mate choice to decisions related to social exchange. For example,
106 physically attractive (relative to unattractive) individuals are evaluated more favourably as romantic
107 partners (Eastwick, Luchies, Finkel, & Hunt, 2014), as students by teachers (Ritts, Patterson, & Tubbs,
108 2016), and even as political candidates (Praino, Stockemer, & Ratis, 2014).

109 In this study, we investigated whether refined carbohydrate consumption affects facial
110 attractiveness in healthy women and men. General predictions on whether attractiveness is increased or
111 decreased as the result of refined carbohydrate consumption are not straightforward. For example,
112 hyperglycaemia could have a possible ageing effect (i.e. increase of apparent age), with the
113 consequence of increasing attractiveness in men and decreasing attractiveness in women (Buss, 1989;
114 Jencks & And Others, 1979). However, hyperglycaemia generates hyperinsulinaemia.
115 Hyperinsulinaemia with insulin resistance have been linked to diseases associated with perturbation of
116 sex hormones (Cordain et al., 2003) and to testosterone levels increased in women and decreased in
117 men (Lutz et al., 2019), thus potentially decreasing attractiveness for both sexes (Puts et al., 2012). As a
118 consequence, for women, it is expected that refined carbohydrate consumption decreases attractiveness.
119 For men, no clear prediction could be unambiguously formulated. Evaluation of attractiveness was
120 based on facial pictures evaluated by raters of the opposite sex. Evaluation of refined carbohydrate

121 consumption was based on total glycaemic load (a proxy of glycaemic and insulinaemic responses) of
122 three mealtimes at-higher glycaemic risk (breakfast, afternoon snack and between-meal snack). The
123 choices of the raters were explained by the diet variables in the presence of potentially confounding
124 variables including apparent age and a femininity/masculinity index.

125

126 **Methods**

127 **Individual measures**

128 Individuals between 18 and 26 years of age were recruited at the University of Montpellier.
129 Possible confounding variables potentially affecting facial attractiveness were collected: sex, year and
130 month of birth, height and weight, socio-economic status (scholarship level coded from 1: no
131 scholarship to 4: highest level), smoking (yes: 1, no: 0) and for women, use of contraceptive pill (yes:
132 1, no: 0, Alvergne & Lummaa, 2010). Facial photographs of all of the individuals were obtained from
133 a frontal perspective at a distance of approximately 1 m using the same digital camera (Canon EOS
134 20D) with a 50-mm focal length.

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

140 **Diet variables**

141 The various daily meals have different nutritional composition and thus they do not bring the
142 same glycaemic response. Indeed, carbohydrates are rarely ingested alone, and their degradation and
143 absorption rates during digestion are modified by the other macronutrients. The glycaemic response

144 will be higher with a meal rich in refined carbohydrates, poor in fat, protein and fibre (Hätönen et al.,
145 2011; Sun, Ranawana, Leow, & Henry, 2014). The order of food macronutrient intake also changes the
146 glycaemic and insulinaemic responses (Sun, Goh, Govindharajulu, Leow, & Henry, 2020). As a
147 consequence, meals such as breakfast, afternoon snack and between-meals snack, which are described
148 as richer in refined carbohydrates and displaying less food items, may be at-higher glycaemic risk
149 (Bellisle et al., 2003; Bellisle, 2014; Bellisle, Hébel, Salmon-Legagneur, & Vieux, 2018). Thus the
150 exhaustive list of the different foods and drinks chronically consumed during these specific times in the
151 same day (breakfast, afternoon snack [“goûter” in French, corresponding to an after-school snack] and
152 between-meals snack) was collected.

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

167 were summed leading to an estimate of total energy intake for breakfast (EI1), afternoon snack (EI2)
168 and between-meal intake (EI3) and corresponding macronutrient compositions.

169 **Apparent age and attractiveness estimation**

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

186 **Femininity/masculinity index**

187 To generate the morphological facial femininity/masculinity index (fem/masc index), a
188 geometric morphometric analysis of the faces was used following the methods described in Dixson,
189 Lee, Sherlock, & Talamas, 2017; Lee et al., 2014; Scott, Pound, Stephen, Clark, & Penton-Voak, 2010.
190 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-landmark 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 (Dixon et al., 2017; Lee et al., 2014; Scott et al., 2010).

203 **Statistical analyses**

204 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 `bgfmer` 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

215 minus right) between the GL1 of the focal and the non-focal subject was calculated, and the same
216 procedure was performed for the GL2 and GL3. These differences were integrated into the model as the
217 variables of interest. Because pairs of subjects were rated by the opposite sex (men rated by women and
218 women rated by men), two models were performed, one for each subject's sex. For both, several
219 control variables potentially affecting facial attractiveness were added: differences between the
220 variables associated with the individuals of each pair (left minus right) for age, age departure from
221 actual age (perceived age minus actual age), facial femininity/masculinity index, BMI (calculated as
222 weight divided by the squared height), scholarship level [-3 to +3], smoking [-1 to +1], and for women,
223 pill use [-1 to +1]). All quantitative variables were centred. The significance of each term was assessed
224 from the model including all of the other variables. The variance inflation factor was computed using
225 the `vif.mer` function adapted from the `vif` function of the R package `rms` (Harrell, 2015; Zuur, Ieno, &
226 Elphick, 2010). Differences between the EI variables associated with the individuals of each pair were
227 not included in the model due to the high correlation of EI1, EI2 and EI3 with GL1, GL2 and GL3
228 respectively (Pearson's correlation coefficient $r > 0.9$ and $P < 10^{-4}$ for all). Rather, the same models
229 were conducted using these variables instead of GL. Because the glycaemic load variables (GL1, GL2,
230 and GL3) could potentially affect certain control variables directly (e.g., age departure from actual age,
231 femininity/masculinity index and BMI), this could indirectly influence the effect of the GL variables on
232 the dependent variable. To evaluate this possibility, structural equation modelling was performed using
233 the control variables from the model displaying $P < 0.1$. An attractiveness index was constructed for
234 each individual, computed as the number of times this individual was chosen over the number of
235 occurrences. An hypothesised path model was constructed for each sex, incorporating four linear
236 regressions with GL3 to explain attractiveness, age departure from actual age, BMI, and
237 femininity/masculinity index for women and incorporating three linear regressions to explain
238 attractiveness, age departure from actual age, and BMI for men (Figure 2).

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

243

244 **Results**

245 A total of 50 female and 49 male Caucasian subjects with fully completed questionnaires were
246 used. Descriptive statistics of their physical characteristics are given in Table 1, and their food
247 consumption for each meal are detailed in Table 2. The proportion of men and women taking a meal
248 were 92% and 90% respectively for breakfast, 63% and 70% respectively for an afternoon snack, and
249 41% and 50% respectively for a between-meal snack. Mean glycaemic load (GL) and energy intake
250 (EI) for each meal are computed considering only consumers (Table 3). According to the general
251 classification (e.g. Eleazu, 2016), the means of GL obtained for each of the three meals studied were
252 high (>20) except for GL3 in women which was medium (value between 11 to 19) (Table 3). GL and
253 EI values were in the same range of variation as those from another study on a French population
254 (Gentreau et al., 2020).

255 Raters were first recruited to assess the perceived age of the subjects. Assessments from
256 unreliable raters (i.e., with more than fifteen years for the sum of the absolute difference between real
257 ages and attributed ages during the three judgements of reliability) were removed, resulting in a final
258 sample of 222 raters (78 men and 144 women, age range: 18-76, mean age \pm s.d.: 36 ± 14 years for
259 men and 37 ± 13 years for women). This process resulted in a total of 834 estimations of men towards
260 women and 1435 estimations of women towards men. The mean number of raters was 28.8 (range: 14-
261 41) for each man and 16.6 (range: 12-25) for each woman. For each individual, the perceived age

262 variable was computed as the average estimated by the raters. Overall, the perceived age was either
263 younger (maximum 3.0 years) or older (maximum 7.8 years) than the chronological age, with a mean \pm
264 s.e.m. of 1.7 ± 0.25 years older.

265 Raters (N = 169) were subsequently recruited to assess the attractiveness of the subjects. The
266 following conservative selection of raters was applied. First, to reduce cultural heterogeneity, only
267 raters from a European ancestry were considered. Second, unreliable raters (i.e., with more than one
268 incorrect answer during the test of judgement reliability) or non-adult raters (less than 18 years old)
269 were removed. A total of 150 raters were retained in the final sample (61 men and 89 women, age
270 range: 18-68, mean age \pm s.d.: 35 ± 10 years for men and 33 ± 13 years for women). This process
271 resulted in a total of 346 judgements of men towards women and 402 judgements of women towards
272 men. The mean number of raters was 17 (range: 8-24) for each man and 14 (range: 6-21) for each
273 woman. The probability that a subject was chosen as the most attractive was significantly influenced by
274 the variable GL3 (men: $\beta = 0.564$, SE = 0.171, $P = 0.001$; women: $\beta = 0.468$, SE = 0.174, $P = 0.007$,
275 see Table 4). Women preferred men, and men preferred women, with the highest between-meal
276 glycaemic load. Some control variables significantly influenced the choice of the raters. For male and
277 female subjects, BMI had a negative effect on the probability of being chosen as the most attractive
278 (men: $\beta = -0.399$, SE = 0.172, $P = 0.021$; women: $\beta = -0.792$, SE = 0.168, $P < 10^{-5}$). A lower BMI was
279 preferred for both sexes. For male subjects, age had a positive effect on the probability of being chosen
280 ($\beta = 0.445$, SE = 0.159, $P = 0.005$), and women preferred men with an older age. The difference in age
281 departure from actual age had a significant impact on attractiveness (men: $\beta = 0.401$, SE = 0.167, $P =$
282 0.015; women: $\beta = -0.415$, SE = 0.191, $P < 0.030$). At equal chronological age, women preferred men
283 with the oldest perceived age. At equal chronological age, men preferred women with the youngest
284 perceived age. Scholarship level, smoking status, femininity/masculinity index, and taking the
285 contraceptive pill (for women) did not have a significant effect on the probability of being chosen ($P >$

286 0.25, for both sexes, except femininity/masculinity index for women, $P = 0.07$). The full model for men
287 explained 9% of the total deviance and the variance inflation factors (VIF) were less than 1.50. The full
288 model for women explained 10% of the total deviance and the VIF were less than 2.50. VIF values for
289 both models indicated that the multicollinearity between covariables was weak and not of concern
290 (Zuur et al., 2010). Models using EI1, EI2 and EI3, gave qualitatively similar results (Table S1). A
291 hypothesised path diagram was constructed for each sex to evaluate a possible direct effect of GL3 on
292 the control variables BMI, age departure from actual age, and femininity/masculinity index (Figure 2).
293 For men, GL3 had a significant effect on age departure from actual age (path coefficient = 0.310, $P =$
294 0.014). A higher between-meal glycaemic load increased appearance towards an older age. For women,
295 GL3 had a marginally significant effect on the femininity/masculinity index (path coefficient = -0.249,
296 $P = 0.056$). A higher between-meal glycaemic load decreased masculinity.

297

298 **Discussion**

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

306 Attractiveness is not independent of the refined carbohydrate content of the food eaten
307 estimated through glycaemic load, although this effect was evidenced from only one (between-meal

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

323 **How chronic between-meal snacks could affect attractiveness**

324 Refined carbohydrate-rich food consumption generates hyperinsulinaemia as a consequence of
325 hyperglycaemia, interfering with growth factors and sex hormones, which themselves modulate
326 morphology and secondary sex characteristics (Cordain et al., 2003). This result occurs because
327 hyperinsulinaemia stimulates androgen synthesis by the ovaries and testes, increasing the quantity of
328 free (and thus active) androgens in the blood. Androgens are the precursors of male and female sex
329 hormones such as testosterone and oestrogen. Hyperinsulinaemia has been linked to diseases associated
330 with significant perturbation of sex hormone levels, such as polycystic ovary syndrome and premature
331 menarche (Cordain et al., 2003). If the influences of a refined carbohydrate-rich diet on other

332 downstream consequences have been poorly studied to date, it is possible that these consequences
333 include the development of secondary sexual traits, typically masculine or feminine facial features. In
334 addition, it has been shown that sex hormones modulate facial femininity/masculinity, which in turn
335 influences attractiveness, with men preferring more feminine faces and women preferring more
336 masculine ones (for a review see Puts et al., 2012). To capture facial secondary sex characteristics, a
337 femininity/masculinity morphological index was computed, for which the difference within each pair
338 was used as a control variable. Structural equation modelling showed that for women, the effect of
339 glycaemic load on attractiveness could be indirectly mediated through a direct effect of the femininity/
340 masculinity index, leading to an increase of femininity. Sexual hormones are possible candidates to
341 explain this effect (Cordain, Eades, & Eades, 2003), although, as it is in the opposite direction than
342 expected, further work is required for a better understanding.

343 Another physiological effect of refined carbohydrate-rich food consumption is
344 hyperglycaemia, which has itself several physiological consequences. For example, hyperglycaemia
345 accelerates glycation, a covalent bonding process that cross-links the amino acids present in the
346 collagen and elastin that support the dermis. Cross-linked collagen fibres are incapable of repair
347 through the usual process of remodelling, directly impacting youthful skin appearance, which relies on
348 flexible and repairable collagen fibres (Danby, 2010). Thus chronic hyperglycaemia generated by
349 chronic between-meal snacks could affect attractiveness because skin ageing directly impacts age
350 appearance (Nkengne et al., 2008), and age affects attractiveness (Samson, Fink, & Matts, 2010).
351 However, this possible effect was controlled for because apparent age was independently estimated,
352 and the difference in age departure from the chronological age within each pair was used as a control
353 variable. Structural equation modelling suggested that for men, the effect of glycaemic load on
354 attractiveness could be indirectly mediated through a direct effect on age departure from actual age.
355 Indeed, an increase in the age difference (chronological or apparent) within each pair increased

356 attractiveness (Table 4), and thus any skin ageing effect, which increases apparent age, also increases
357 attractiveness. This increase in attractiveness with age is generally described for relatively young men
358 in the range 20-50 years old and is classically explained by the correlation between age and
359 characteristics that advertise adequate parental investment in terms of resource and social status (Buss,
360 1989; Jencks & And Others, 1979). For older ages, the correlation between age and attractiveness is
361 reversed, perhaps due to somatic senescence compromising some type of paternal investment, fertility
362 decline, or to higher chances of passing on genetic defects to offspring (Hellstrom et al., 2006; Kong et
363 al., 2012). For women, the ageing effect is the opposite: an increase in the difference in age departure
364 from actual age within each pair decreased attractiveness, i.e., men preferred women that were
365 perceived to be younger (or compared to women evaluated older) (Table 4). Indeed, age supplies a
366 powerful cue related to female reproductive capacity, and men prefer younger women (Buss, 1989).

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

369 Traditional foods with a high level of sugar contents are energetically rewarding, although
370 they are typically seasonal or scarce, such as ripened fruit and honey. Because sugar excess generated
371 by hyperglycaemia is stored as fat, traditional foods that generate hyperglycaemia are sometimes used
372 to intentionally increase fat storage, e.g., the case of the food intake of Japanese sumo wrestlers
373 (Nishizawa et al., 1976) or the fattening sessions described in various ethnic groups before an expected
374 general shortage period (Garine & Koppert, 1990; Garine & Koppert, 1991). Generally, traditional
375 food, i.e., pre-industrial or non-refined, does not generate hyperglycaemia. This is the case for fresh
376 fruits, legumes, traditionally prepared cereals, etc., although there are counter-examples such as honey.
377 Globally, traditional foods that generate hyperglycaemia were not always readily available because they
378 were scarce or expensive. Thus, it is possible that intake of foods that generate hyperglycaemia
379 represents an advantage in certain traditional environments, particularly when food shortages are not

380 uncommon. In such an environment, detection and preference of facial cues that display an ability to
381 find refined carbohydrates sources could constitute an evolutionary advantage for the choice of mating
382 partner. This hypothesis could explain why an increased consumption of such food increases
383 attractiveness. However, in the current industrial dietary environment, foods that generate
384 hyperglycaemia are not limited, and their consumption is not a signal of quality anymore. Therefore, it
385 is possible that the current increased attractiveness associated with the increased consumption of such
386 food is better understood as a maladaptation.

387 **How the other control variables could affect attractiveness**

388 Several other variables potentially affecting attractiveness were controlled for, although only
389 BMI has a significant effect in that a higher BMI decreased facial attractiveness for both men and
390 women (Table 4). Indeed, body weight can be accurately judged from facial images alone (Coetzee,
391 Chen, Perrett, & Stephen, 2010), and cues of adiposity affect social judgements of female and male
392 faces (Coetzee, Perrett, & Stephen, 2009; Han, Hahn, Fisher, Debruine, & Jones, 2016; Re & Perrett,
393 2014).

394 **Limitations**

395 The effect of chronic between-meal snacks on attractiveness could be confounded by a
396 variable not considered in this work. One possibility could be physical activity, which could have the
397 effect of both increasing attractiveness (Faurie, Pontier, & Raymond, 2004; Stephen, Coetzee, Smith, &
398 Perrett, 2009) and increasing between-meal snacks (Kerver, Yang, Obayashi, Bianchi, & Song, 2006;
399 Ovaskainen et al., 2006). Other diet factors not taken into account could affect facial attractiveness,
400 such as fruit and vegetable known to increase skin yellowness (Zuniga, Stevenson, Mahmut, &
401 Stephen, 2017; Appleton et al., 2018). Also, the main and more complex meals, i.e. lunch and dinner,
402 were not included, precluding the computation of an overall diet quality index, which could have
403 possibly captured other aspects of diet influencing attractiveness. However, diet quality indexes are

404 correlated with low-GL food (higher values for an increase of low-GL food, see e.g. Jones et al. 2016;
405 Azadbakht et al. 2016), and thus are partially described by GL measures. Finally, energy intake of each
406 meal was not controlled for in our model due to the high correlation observed with glycaemic load, but
407 gave qualitatively similar results when integrated alone (Table S1). As a consequence, it is unclear
408 whether the associations observed are due to energy intake or to glycaemic load.

409

410 **Conclusion**

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

416

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418 **References**

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424 **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/m ²)	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

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

Food group	Women			Men		
	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

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430 **Table 3.** Descriptive statistics of food consumption for the three meals. Mean and standard deviation (SD) are
 431 given for consumers only. GL1, GL2 and GL3 are the three variables of glycaemic load. EI1, EI2 and EI3 are the
 432 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

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434 **Table 4.** Effects of different variables on the probability of being chosen during the test of attractiveness for
 435 male or female faces. Raters were instructed to choose the individual found to be the most attractive between
 436 two facial photographs. GL1, GL2 and GL3 are the three variables of glycaemic load. For each variable, the
 437 difference between the two individuals presented was integrated into the model. The estimate (β), standard error
 438 of the mean (SE), χ^2 statistic, and corresponding P -value are given. Bold characters indicate significant ($P <$
 439 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

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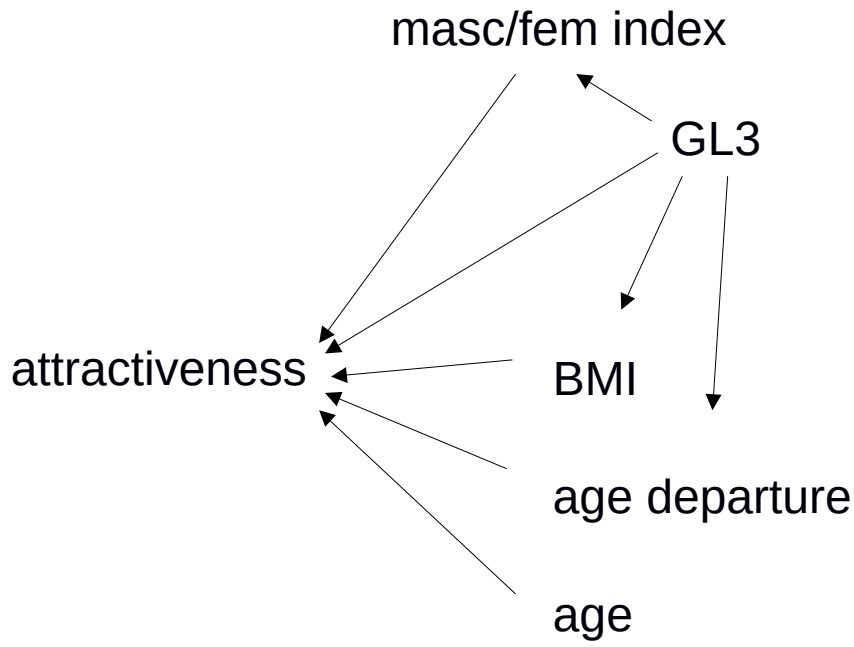


447 **Figure 1.** Example of a pair of faces used during evaluation of women's facial attractiveness by male
448 raters. For each pair of women, the rater was instructed to click on the photograph of the woman that he
449 found the most attractive. Photographs reproduced with permission.

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

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477

478 **Table S1.** Effects of different variables on the probability of being chosen during the test of attractiveness for
 479 male or female faces. Raters were instructed to choose the individual found to be the most attractive between
 480 two facial photographs. EI1, EI2 and EI33 are the three variables of energy intake. For each variable, the
 481 difference between the two individuals presented was integrated into the model. The estimate (β), standard error
 482 of the mean (SE), χ^2 statistic, and corresponding P -value are given. Bold characters indicate significant ($P <$
 483 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

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