

1 Self-reported Health is Related to Body Height and Waist Circumference in
2 Rural Indigenous and Urbanized Latin-American Populations

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20 **Abstract**

21 Body height growth is a life history component. It involves important costs for its expression and
22 maintenance, which may originate trade-offs on other costly components such as reproduction or
23 immunity. Although previous evidence has supported the idea that human height could be a sexually
24 selected trait, the explanatory mechanisms that underlie this selection is poorly understood. Moreover,
25 despite the association between height and attractiveness being extensively tested, whether immunity
26 may be linking this relation is scarcely studied, particularly in non-Western samples. Here, we tested
27 whether human height is related to health measured by both, self-perception, and relevant nutritional and
28 health anthropometric indicators in three Latin-American populations that widely differ in
29 socioeconomic and ecological conditions: two urbanized samples from Bogota (Colombia) and Mexico
30 City (Mexico), and one isolated indigenous population (Me'Phaa, Mexico). Using Linear Mixed Models,
31 our results show that, for both men and women, self-rated health is best predicted by an interaction
32 between height and waist, and that the costs associated to a large waist circumference are differential for
33 people depending on height, affecting taller people more than shorter individuals in all population
34 evaluated. The present study contributes with information that could be important in the framework of
35 human sexual selection. If health and genetic quality cues play an important role in human mate choice,
36 and height and waist interact to signal health, its evolutionary consequences, including its cognitive and
37 behavioral effects, should be addressed in future research.

38

39 **Introduction**

40 In modern Western societies, it has been seen that while women usually show a marked
41 preference for men significantly taller, over significantly shorter, than average [1,2], men are more
42 tolerant in choosing women who are taller or shorter than average [3]. This is consistent with the idea
43 that male height can be adaptive [4] and that sexual selection favors taller men, possibly because it
44 provides hereditary advantages, such as genetic quality for the offspring [5,6], or direct benefits,
45 provisioning resources and protection for women and their children [7]. This because height has been
46 proposed as an indicator of resource holding potential (RHP), in terms of social dominance and
47 deference [8,9], and socioeconomic status [5,10].

48 Supporting this idea, it has been found a direct linear relationship between male height and
49 reproductive success, which would not apply to women, and suggest unrestricted directional selection,
50 that would work to favor even very tall men, but not to very tall women [11]. In fact, it has been
51 reported that taller men (but not extremely tall men) are more likely to find a long-term partner and have
52 several different long-term partners [12], while the maximum reproductive success of women is below
53 female average height [13]. Furthermore, heterosexual men and women tend to adjust the preferred
54 height of hypothetical partners depending on their own stature [14]. In general, heterosexual men and
55 women prefer couples in which the man is taller than the woman, and women show a preference for
56 facial cues that denote a taller man [15].

57 Although previous evidence has supported the idea that human height could be a sexually
58 selected trait, the explanatory mechanisms that underlie this selection is poorly understood.

59 One possibility can be addressed in the framework of the Life-History theory [16], and the
60 immunocompetence handicap hypothesis (ICHH [17–19]). Body height growth is a life history

61 component [1,20], that involves important costs for its expression and maintenance, which may originate
62 trade-offs on other costly components such as reproduction [21] or immunity [22].

63 The costs in height can be measure in terms of survival and physiological expenditure [22]. For
64 example, it has been shown that shorter people are more likely to be more longevous and less likely to
65 suffer from age-related chronic diseases [22,23]. With some exceptions, we have a limited number of
66 cell replications during our lifetimes. A minimal increment in body height necessary involves more
67 cells, maybe trillions, and more replications during the life. This higher number of cell replications
68 demands greater number of proteins to maintain taller, larger bodies [22], which together with an
69 increase on free radicals generated by the corresponding energy consumption, may lead to greater
70 likelihood of DNA damage [24], thus increasing the incidence of cancer and reducing longevity [22].

71 Trade-offs between these life-history components could be mediated by sexual hormones. Trade-
72 off with reproduction occurs because at the beginning of sexual maturity sexual hormones are
73 responsible to reallocate energetic and physiological resources to this function, instead of somatic
74 growth. For instance, an increment in estrogen production leads to the onset of menstrual bleeding in
75 women, but also slows the process of growth, and eventually causes it to cease [25]; estrogen stimulates
76 mineral deposition in the growth plates at the ends of the long bones, thus terminating cell proliferation,
77 and resulting in the fusion of the growth plates to the shaft of the bone [26, see also 27]. In turn, trade-
78 off with immunity occurs because the same increment in sexual steroids , usually has suppressive effects
79 on several immune components [17]. For example, testosterone may increase the severity of malaria,
80 leishmaniasis, amebiasis [28], and perhaps tuberculosis [see 29,30].

81 Therefore, as consequence of these life-history trade-offs, height could be considered as a
82 reliable indicator of individuals' condition in terms of (1) the amount and quality of nutritional resources
83 that were acquired until sexual maturity, (2) the RHP to obtain resources for the somatic maintenance in

84 adult stage, and (3) the current immunocompetence to afford the immune cost imposed by sexual
85 steroids. Thus, according with ICHH height can be used for potential partners to receive information
86 about the quality of potential mate; only high-quality individuals could afford to allocate resources to
87 better immunity and attractive secondary sexual traits simultaneously [18], which would result in
88 increased sexual preference towards taller individuals.

89 Despite the association between height and attractiveness being widely tested, whether immunity
90 might be linking this relation is poorly studied. Moreover, most studies have been done using high-
91 income developed populations (often samples characterized as Western, Educated, and from
92 Industrialized, Rich, and Democratic [WEIRD] societies [31]), which has led to a lack of information of
93 what is occurring in other populations with important socio ecological differences. Considering these
94 ecological pressures is important because although genetic allelic expression could be the main factor
95 that determines individual height differences [25], height is also the most sensible human anatomical
96 feature that respond to environmental and socioeconomic conditions [21,32]. For instance, variation in
97 height across social classes is known to be greater in poorer countries [33], but much reduced where
98 standards of living are higher [34]. Economic inequality not only affects population nutritional patterns,
99 which are especially important during childhood to stablish adult height, but also the presence of
100 infectious diseases [35]. Childhood disease is known to adversely affect growth: mounting an immune
101 response to fight infection increases metabolic requirements and can thus affect net nutrition, and hence
102 reduce productivity. Disease also prevents food intake, impairs nutrient absorption, and causes nutrient
103 loss [36,37]. Therefore, comparing with high-income, developed populations, habitants from sites with
104 stronger ecological pressures imposed by pathogens, or greater nutritional deficiencies, would face
105 greater costs to robustly express this trait, and in consequence could show a stronger sexual selective
106 pressure over height, since it would more accurately signal growth rates, life-history trajectories, and

107 health status. This phenotypic variation is described as developmental plasticity, which is a part of the
108 phenotypic plasticity related to growth and development, in response to social, nutritional, and
109 demographic conditions, among others [38]. In fact, during the last century, and given a general
110 improvement in nutrition, height has increased around the world [39], but maintaining the level of
111 dimorphism in favor of men.

112 Colombia and Mexico are two of the most socioeconomically heterogeneous countries in the
113 world; although both countries have a high Human Development Index [40], and have relatively good
114 health compared to global standards, attaining respective scores of 68 and 66 in the Healthcare Access
115 and Quality (HAQ) Index [41], Colombia and Mexico have GINI coefficients of 50.8 and 43.4,
116 respectively, making them the 12th and 43th most unequal countries in the world (GINI index – World
117 Bank estimate; <https://data.worldbank.org/indicator/SI.POV.GINI>). These national-level statistics,
118 however, hide important within-country differences. In particular, in Latin-America people in rural areas
119 tend to be poorer and have less access to basic services such as health and education than people in
120 urban areas.

121 According to data from the World Bank and the Colombian National Administrative Department
122 of Statistics, in 2017 Colombia was the second most unequal country in Latin-America after Brazil; in
123 rural areas 36% of people were living in poverty, and 15.4% in extreme poverty, while in urban areas
124 these values were only 15.7% and 2.7%, respectively [for a summary, see 42].

125 In addition to rural communities, in Latin-America, indigenous people tend to have high rates of
126 poverty and extreme poverty [43], and have poorer health [44] less susceptible to improve by national
127 income growth [45]. In Mexico, there are at least 56 independent indigenous peoples, whose lifestyle
128 practices differ in varying degrees from the typical “urbanized” lifestyle. Among these groups, the
129 Me’Phaa people, from an isolated region known as the “Montaña Alta” of the state of Guerrero, is one

130 of the groups whose lifestyle most dramatically differs from the westernized lifestyle typical of more
131 urbanized areas [46]. Me'Phaa communities are small groups, composed of fifty to eighty families, each
132 with five to ten family members. Most communities are based largely on subsistence farming of legumes
133 such as beans and lentils, and the only grain cultivated is corn. Animal protein is acquired by hunting
134 and raising some fowl, but meat is consumed almost entirely during special occasions and is not part of
135 the daily diet. There is almost no access to allopathic medications, and there is no health service,
136 plumbing, or water purification system. Water for washing and drinking is obtained from small wells.
137 Most Me'Phaa speak only their native language [47]. In consequence, these communities have some of
138 the lowest income and economic development in the country, and the highest child morbidity and
139 mortality due to chronic infectious diseases [46].

140 These three Latin-American populations can provide an interesting indication about how
141 regional socioeconomic conditions, and the intensity of ecological pressures by pathogens, may
142 modulate the function of height as an informative sexually selected trait of health and individual
143 condition. Therefore, the aim of the present study was to evaluate whether human height is related to
144 health measured by both, self-perception, and relevant nutritional and health anthropometric indicators
145 in three Latin-American populations that widely differ in socioeconomic and ecological conditions: two
146 urbanized samples from Bogota (Colombia) and Mexico City (Mexico), and one isolated indigenous
147 population (Me'Phaa, Mexico).

148 **Materials and Methods**

149 **Ethics Statement**

150 All procedures for testing and recruitment were approved by El Bosque University Institutional
151 Committee on Research Ethics (PCI.2017-9444) and National Autonomous University of Mexico
152 Committee on Research Ethics (FPSI/CE/01/2016). All participants read and signed a written informed
153 consent.

154 **Participants**

155 A total of 251 (120 women and 131 men) adults took part in the study. They were from three
156 different samples: (1) Mexican indigenous population, (2) Mexican urban population, and (3)
157 Colombian urban population. Me'Phaa indigenous participants from "La Montaña Alta" were recruited
158 and participated in this study between January and March 2017, while Participants did it between May
159 and June 2017. In Colombia, data collection took place between October and December 2018.

160 The first sample consisted of 75 subjects (mean age \pm SD = 33.60 \pm 9.51 years old) from the
161 small Me'Phaa community – "*Plan de Gatica*" from a region known as the "*Montaña Alta*" of the state
162 of Guerrero in Southwest Mexico. In this group, 24 participants were women (33.46 \pm 8.61) and 39 were
163 men (33.74 \pm 10.41), who were participating in a larger study about immunocompetence. Both sexes
164 were aged above 18 years old. In Mexico, people from this age are considered adults. We collected all
165 measurements in the own community. Me'Phaa communities are about 20 kilometers apart, and it takes
166 about three hours traveling on rural dirt roads to reach the nearest large town, about 80 km away.
167 Mexico City is about 850 kilometers away and the trip takes about twelve hours by road. This
168 community has the lowest income in Mexico, the highest index of child morbidity and mortality by
169 gastrointestinal and respiratory diseases (children's age from 0 to 8 years old, which is the highest
170 vulnerability and death risk age; [46]), and the lowest access to health services. These conditions were

171 determined by last 10 years of statistical information obtained from the last record of the national system
172 of access to health information in 2016 [46].

173 The second sample consisted of 66 subjects (20.67 ± 2.32) over 18 years old of general
174 community from Mexico City, of whom 36 were women (20.2 ± 2.27) and 30 were men (21.13 ± 2.36).
175 Participants from both Mexican populations were aged 18 to 60 years old. Finally, the third sample
176 consisted of 122 undergraduate students with ages ranging from 18 to 30 years old (30.23 ± 4.27), 60
177 were women (20.2 ± 2.27) and 62 were men (21.13 ± 2.36) from Bogota, Colombia. All urban
178 participants were recruited through public advertisements.

179 Participants from both urban population samples were taking part in two different, larger studies
180 in each country. In Colombia, all data were collected in the morning, between 7 and 11 am, because
181 saliva samples (for hormonal analysis), as well as voice recordings, odor samples, and facial
182 photographs, were also collected as part of a separate project. Additionally, for women in the Colombian
183 sample were not hormonal contraception users, and all data were collected within the first three days of
184 their menses.

185 Participants who were under allopathic treatment, and hormonal contraception female users from
186 both countries were excluded from data collection. All participants completed a sociodemographic data
187 questionnaire, which included medical and psychiatric history. No women were users of hormonal
188 contraception. Although no participant reported any endocrinological or chronic disease, these health
189 issues were also considered as exclusion criteria.

190 Given that indigenous community of “Plan de Gatica” consists of 60-80 families, each with five
191 to seven members, the final sample for this study could be considered as semi-representative of a larger
192 “Me’Phaa” population habiting in the same community. Nevertheless, the total of Me’Phaa people
193 habiting in the region called “Montaña Alta” is comprised of 20-30 communities with almost the same

194 number of families than “Plan de Gatica”. Therefore, our sample size cannot be considered
195 representative of the total “Me’Phaa” people habiting in the region “Montaña Alta”, but from the
196 specific “Plan de Gatica” community. Most participants from the “Mexico City” and “Bogota” samples,
197 however, were recruited at the National Autonomous University of México, and El Bosque University
198 campuses, respectively. Therefore, these samples are comprised mostly of bachelor and graduate
199 students, and cannot be considered representative of a larger population from their respective whole city,
200 which is comprised of about 12 million adult persons in the case of Mexico, and about 5 million adults
201 in Bogota.

202 **Procedure**

203 All participants signed the informed consent and completed the health and background
204 questionnaires. For participants from the indigenous population, the whole procedure was carried out
205 within their own community, and participants from the urban population attended a university laboratory
206 from each country on individual appointments.

207 Participants from Mexico City and Bogota were recruited through public advertisements in social
208 media, and poster boards located along the central campus of National Autonomous University and El
209 Bosque University. While in Mexico City, participants received either 1 partial course credit or a
210 payment equivalent to \$5 dollars as compensation for their participation, in Bogota all participants were
211 given academic credits for their participation.

212 For the indigenous groups, recruitment was done through the Xuajim Me’Phaa non-
213 governmental organization named, which is dedicated to the social, environmental and economic
214 development of indigenous communities of the region (see video from this organization,
215 http://youtu.be/In4b9_Ek78o). Xuajin Me'Phaa has extensive experience in community-based fieldwork

216 and has built a close working relationship with community authorities. This trust and familiarity with
217 community customs and protocols have previously led to successful academic collaborations [48,e.g.
218 49]. Therefore, Xuajin Me’Phaa served as a liaison between Mexican research group and communities
219 for the present study, offering mainly two important factors to collecting data: the informed consent of
220 community members and participants, and two trained interpreters of Me’Phaa and Spanish language of
221 both sexes.

222 First, participants were asked to complete the health and sociodemographic data questionnaires.
223 Subsequently the anthropometric measurements were taken.

224 **Self-reported health**

225 The Interpreters provided by Xuajin Me’Phaa organization administered the SF-36 Health survey
226 in the Me’Phaa Language. Interpreters use Spanish as second language, and are thoroughly proficient in
227 speaking and reading Spanish. We used the validated SF-36 survey for urban and rural Mexican
228 populations [50] for interpreters to translate from Spanish to the Me’Phaa language. Given the ethnical
229 customs of Me’Phaa culture, and to avoid bias in participant responses, participants were always
230 interviewed by an interpreter of their same sex; i.e. men were interviewed by a male interpreter and
231 women by a female interpreter. The same interpreter interviewed all participants of its corresponding
232 sex.

233 Indigenous participants only answered items that define dimension of general health (i.e. Item
234 number 1, 33, 34, 35, 36) with the exception of the item 35. This item informs about the expectation of
235 future health. However, because grammatical compositions of Me’Phaa language does not consider
236 “infinitive” and “future” as verbal tense [51], interpretation of this question was not possible for
237 Me’Phaa people, and this item was excluded.

238 In Colombia, we used a Spanish language validated version of the SF-36 questionnaire [52],
239 which was validated in Colombia [53]. The SF-36 produces eight factors, calculated by averaging the
240 recoded scores of individual items: 1) Physical functioning (items 3 to 12), 2) Role limitations due to
241 physical health (items 13 to 16), 3) Role limitations due to emotional problems (items 17 to 19), 4)
242 Energy/fatigue (items 23, 27, 29 and 31), 5) Emotional well-being (items 24, 25, 26, 28 and 30), 6)
243 Social functioning (items 20 and 32), 7) Pain (items 21 and 22), and 8) General health (items 1, 33, 34,
244 35 and 36).

245 To calculate this factors, all items were recoded following the instructions on how to score SF-36
246 [52]. We calculated final factor averaging the recoded items. To make this data compatible with the
247 Mexican database, and because item 35 cannot be answered by the Mexican Indigenous population, this
248 item was excluded and the health factor was calculated averaging only items 1, 33, 34, and 36.

249 **Anthropometric measurements**

250 All anthropometric measurements were measured three times, consecutively, and then averaged
251 (for agreement statistics between the three measurements of each characteristic, see section 1.3 on S1
252 File). All participants were in light clothes and had their shoes removed. The same observer repeated the
253 three measurements.

254 We measured the body height in centimeters, to the nearest millimeter, using a 220cm Zaupe
255 stadiometer, with the participant's head aligned according to the Frankfurt horizontal plane and with feet
256 together against the wall.

257 Anthropomorphic measurements also included waist circumference (cm), weight (kg), fat
258 percentage, visceral fat level, muscle percentage, and BMI. Circumference of waist was measured in
259 centimeters using a flexible tape, midway between the lowest rib and the iliac crest, and was recorded to

260 the nearest millimeter. These anthropomorphic measures have been used as an accurate index of
261 nutritional status and health, especially waist circumference. Metabolic syndrome is associated with
262 visceral adiposity, blood lipid disorders, inflammation, insulin resistance or full-blown diabetes, and
263 increased risk of developing cardiovascular disease [54,55, for a review see 56], including Latin-
264 American populations [57]. Waist circumference has been proposed as a crude anthropometric correlate
265 of abdominal and visceral adiposity, and it is the simplest and accurate screening variable used to
266 identify people with the presence of the features of metabolic syndrome [58,59]. Hence, In the presence
267 of the clinical criteria of metabolic syndrome, an increased waist circumference does provide relevant
268 pathophysiological information insofar as it defines the prevalent form of the syndrome resulting from
269 abdominal obesity [55].

270 Weight (kg), fat percentage, visceral fat level, muscle percentage and BMI were obtained using
271 an Omron Healthcare HBF-510 body composition analyzer, calibrated before each participant's
272 measurements were obtained.

273 **Statistical analysis**

274 To test the association between height and health, we fitted general a Linear Mixed Model
275 (LMM). The dependent variable in this model were the self-reported health factor and the predictor
276 variables included participant sex, age, population (indigenous, urban), height and waist as fixed, main
277 effects, as well as anthropometric measurements (hip, weight, fat percentage, BMI and muscle
278 percentage). Interactions between height and population, height and sex, and height and waist
279 circumference were also included. Country was always included as a random factor, with random
280 intercepts.

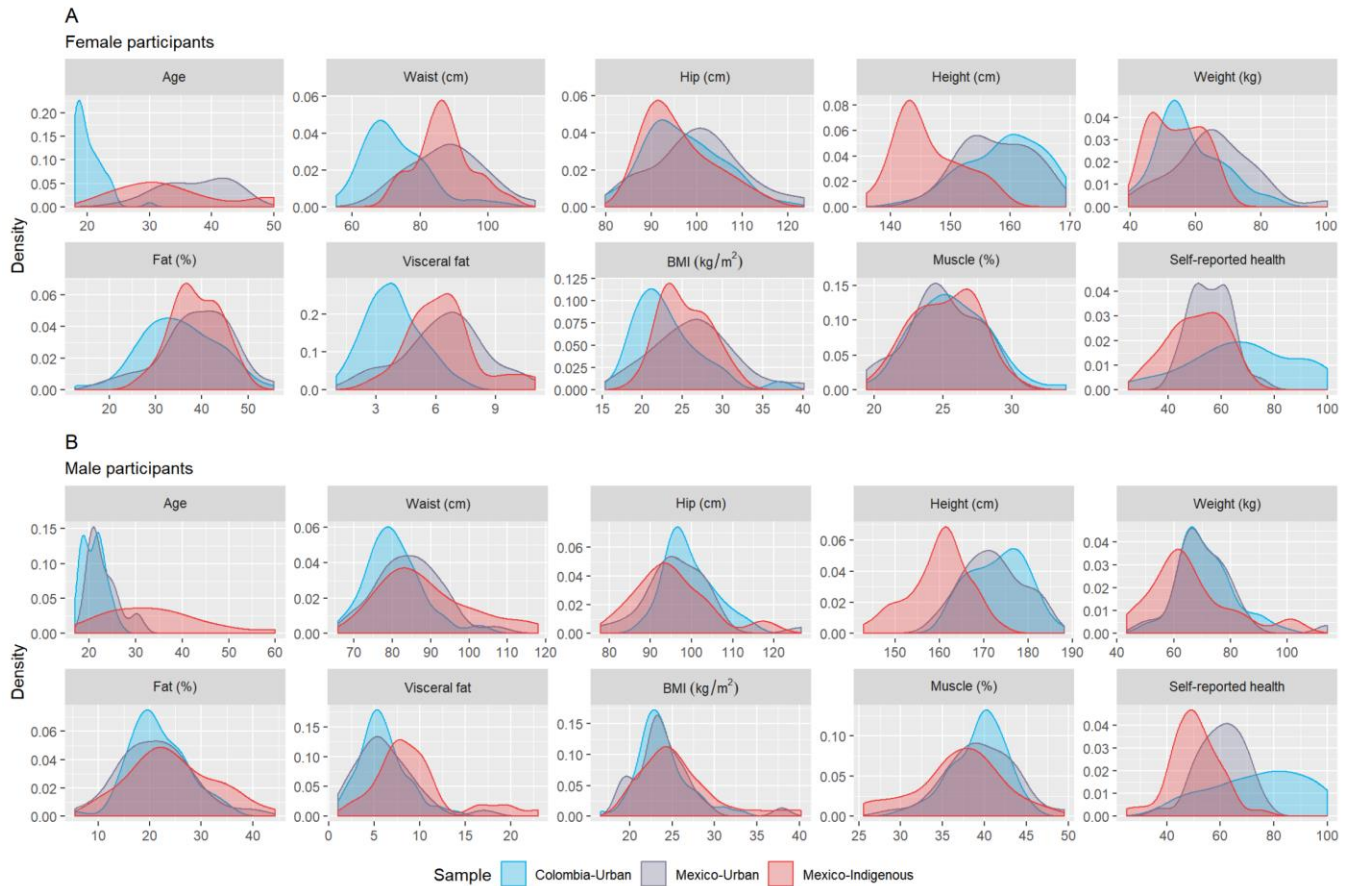
281 Although allowing slopes to vary randomly is recommended [60], we only included random
282 intercepts in the models because there is only one data-point per subject. Population (indigenous, urban)
283 was always included as a fixed effect because while there are important differences in health (and self-
284 reported health) between indigenous and urban populations in Latin-America, while no such differences
285 were expected by country. General LMM were fitted to test residual distribution. In all cases, residuals
286 were closer to a normal or gamma (inverse link) distribution, for each population/country. Models was
287 fitted using the *lmer* function from the *lmerTest* package [61;
288 <https://www.rdocumentation.org/packages/lmerTest>] in R, version 3.5.2 [62].

289 The most parameterized initial model was then reduced based on the Akaike Information
290 Criterion (AIC) and the best supported model (i.e. the model with the lowest AIC with a Δ AIC higher
291 than 2 units from the second most adequate model) is reported [see 63]. To accomplish this, we
292 implemented the *ICtab* function from the *bbmle* package [64;
293 <http://www.rdocumentation.org/packages/bbmle>]. Once a final model was selected, model diagnostics
294 were performed (collinearity, residual distribution, and linearity of residuals in each single term effect;
295 see section 3 in S1 File).

296 **Results**

297 All analysis, data manipulation, tables and figures, as well as the code to produce them, can be
298 reproduced and explored in more detail using *R* scripts in *Markdown* format (S2 File) using the are
299 available as Supplementary Files, as well as the output, S1 File (in HTML format), where all
300 Supplementary tables and figures can also be found. All data are available at the Open Science
301 Framework (<https://doi.org/10.17605/OSF.IO/KGR5X>).

302 Figure 1 shows the distribution of age, waist, height, visceral fat and self-reported health, which
303 strongly varies in both women (Fig 1A) and men (Fig 1B), sex, population (indigenous, urban) and
304 country (Colombia, Mexico).



305

306 **Fig 1. Distribution of all measured variables by sex, population and country.** (A) Female participants. (B) Male

307 participants. For descriptives (mean, SD, median, minimum, and maximum values), see S2 Table (female participants) and

308 S3 Table (male participants), of the Supplemental Material.

309

310 To establish the relationship between height and self-reported health, we fitted three mixed

311 models (Table 1).

312

313 **Table 1. Results of separate linear mixed models testing effects of independent variables on self-**
 314 **reported health.**

	Model 1			Model 2			Model 3		
	Estimate	<i>df</i>	<i>p</i>	Estimate	<i>df</i>	<i>p</i>	Estimate	<i>df</i>	<i>p</i>
(Intercept)	-97.01	226.83	0.520	-166.17	233.81	0.198	-181.41	234.65	0.153
Age	0.07	224.16	0.660	0.11	231.11	0.488	.	.	.
BMI (kg/m ²)	-0.03	226.02	0.990	.	.	.	.	.	.
Fat (%)	-0.21	226.00	0.650	.	.	.	.	.	.
Height (cm)	1.13	226.58	0.240	1.49	233.27	0.064	1.59	234.01	0.043
Height:PopulationUrban	0.30	226.00	0.300	.	.	.	.	.	.
Height:SexMale	0.02	226.01	0.930	.	.	.	.	.	.
Height:Waist	-0.02	226.37	0.180	-0.02	233.25	0.064	-0.02	234.00	0.041
Hip (cm)	-0.05	226.98	0.830	.	.	.	.	.	.
Muscle (%)	-0.32	226.81	0.570	.	.	.	.	.	.
PopulationUrban	-38.67	226.02	0.400	8.42	233.98	0.009	8.24	234.38	0.010
SexMale	3.18	226.09	0.940	6.01	233.07	0.034	5.82	234.00	0.039
Waist (cm)	2.60	226.19	0.220	2.66	233.18	0.094	2.91	234.01	0.061
Weight (kg)	0.03	226.06	0.970	.	.	.	.	.	.

315 *Note.* Indigenous population and females were used as reference for categorical predictors. Significant effects are in bold. For
 316 a full version of this table, including standard errors and *t*-values, see S7 Table, and for an ANOVA-like table of random
 317 effects, see S8 Table in the Supplemental Material, available online.
 318

319 In the first model we included, as predictors, all measured variables as main effects, as well as
 320 the interactions between height and population, height and sex, and height and waist. In the second
 321 model, we included age, height, population, sex, waist, and the interaction between height and waist. For
 322 the final, third model, we removed age since this predictor did not have any influence on self-reported
 323 health factor in the previous models.

324 These three models were compared using the Akaike Information Criterion (AIC) as well as
 325 Akaike weights (w_i AIC), and Δ AIC (Table 2). The analyses revealed that Model 3 is not only the most
 326 parsimonious model, but has a lower AIC and higher Akaike weight [see 63] than the previous two
 327 models; in fact, Model 3 is 5.66 times more likely to be the best model compared to Model 2, and more

328 than 4000 compared to Model 1 (in comparison to Model 1, Model 2 is close to 750 times more likely to
329 be the best model).

330

331 **Table 2. Performance criteria of LME models.**

Model	AIC	Δ AIC	<i>df</i>	$w_i(\text{AIC})$
Model 3	1981.4	.	8	0.85
Model 2	1984.87	3.47	9	0.15
Model 1	1998.09	16.69	16	<0.001

332 *Note.* Models are in descending order from the best, to the worst fitting. Δ AIC is the change in AIC between each model and
333 the previous. Akaike weights $w_i(\text{AIC})$ are conditional probabilities for each model being the best model [63].

334

335 Nevertheless, for Model 3 (the minimum adequate model), Variance Inflation Factors (VIF)
336 revealed extreme collinearity for height, waist, and the interaction between height and waist (VIF > 75
337 in those cases; S9 Table). This problem, however, has solved after centering and rescaling both height
338 and waist measures (VIF < 3 in all cases; S10 Table). In addition, this centered and rescaled version of
339 Model 3 had no issues regarding its residual distribution (i.e. for all samples it resembled a normal
340 distribution) or linearity of residuals (see S2 Fig), and each single term predictor was linearly related to
341 self-rated health (see S3 Fig).

342 Furthermore, the final, centered and rescaled version of Model 3, had a lower AIC than model 3
343 (1962 vs 1981), and was over 1400 times more likely to be the best model, as revealed by Akaike
344 weights (see S11 Table).

345 The final model (Table 3; Fig 2) showed a significant, negative main effect waist circumference
346 ($t = -3.01$, $\beta = -3.27$, $p < 0.001$), as well as a significant effect of population (urban samples rated their
347 health 8.24 points higher than indigenous participants; $t = 2.60$, $p = 0.01$), and sex (men rated their
348 health 5.82 points higher than women $t = 2.07$, $p = 0.039$). In addition, this model (Table 3) revealed that
349 Colombians reported better health than Mexicans (Fig 2B).

350

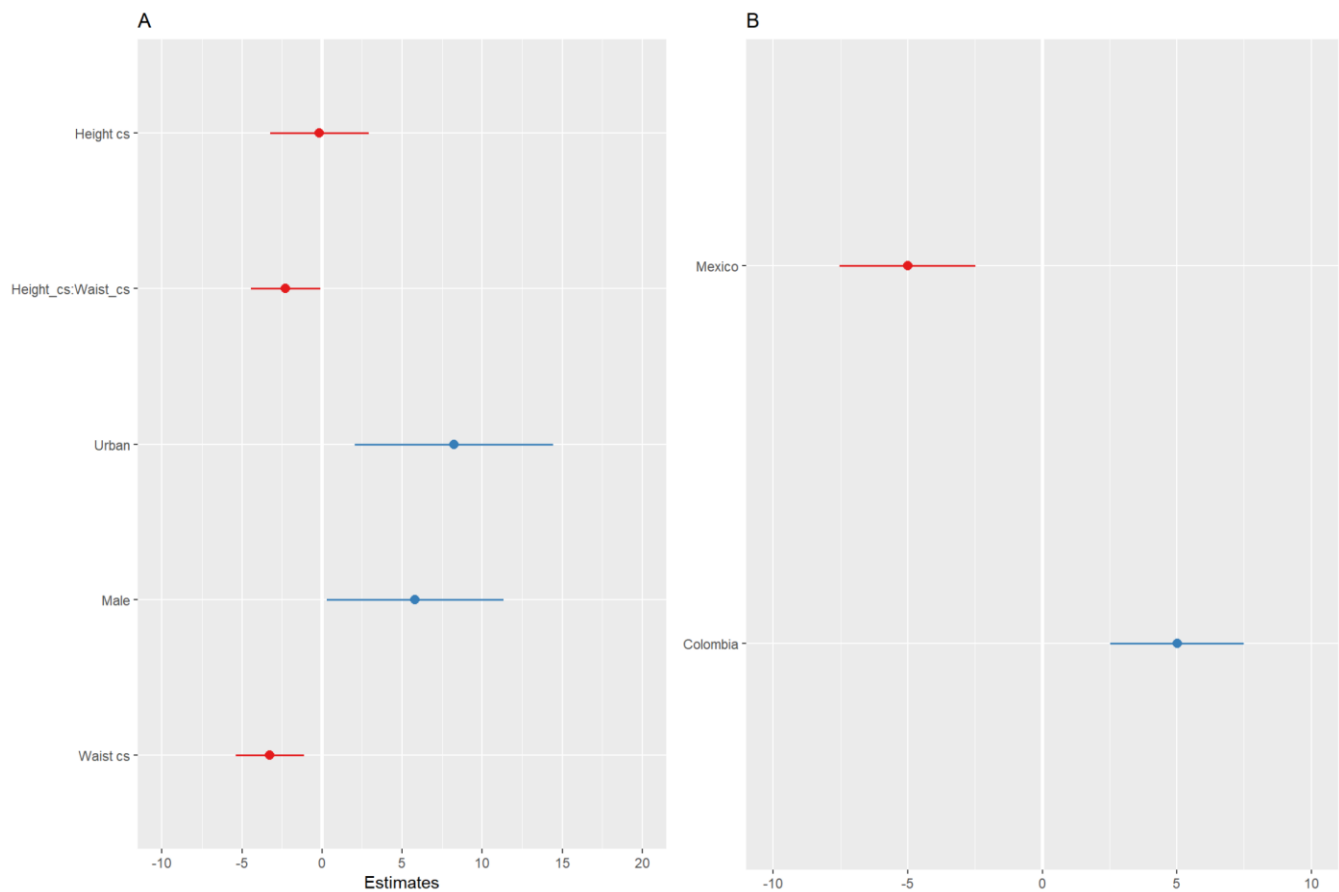
351 **Table 3. Results of the final linear mixed model testing effects of independent variables on self-**
 352 **reported health**

	Estimate	SE	df	t	p
(Intercept)	53.64	6.2	1.88	8.65	0.016
Height_cs	-0.17	1.57	234.16	-0.11	0.914
Waist_cs	-3.27	1.08	234.29	-3.01	0.003
SexMale	5.82	2.81	234	2.07	0.039
PopulationUrban	8.24	3.17	234.38	2.6	0.01
Height_cs:Waist_cs	-2.28	1.11	234	-2.06	0.041

353 *Note.* Indigenous population and females were used as reference for categorical predictors. Significant effects are in bold.

354 Both waist and height were centered and rescaled (identified by the suffix _cs).

355



356

357 **Fig 2. Final model estimates.** Forest-plot of estimates for each fixed factor with 95% CI. (A) Fixed effects. (B) Random

358 effects. For categorical fixed predictors, indigenous population and female participants were used as reference. Both waist

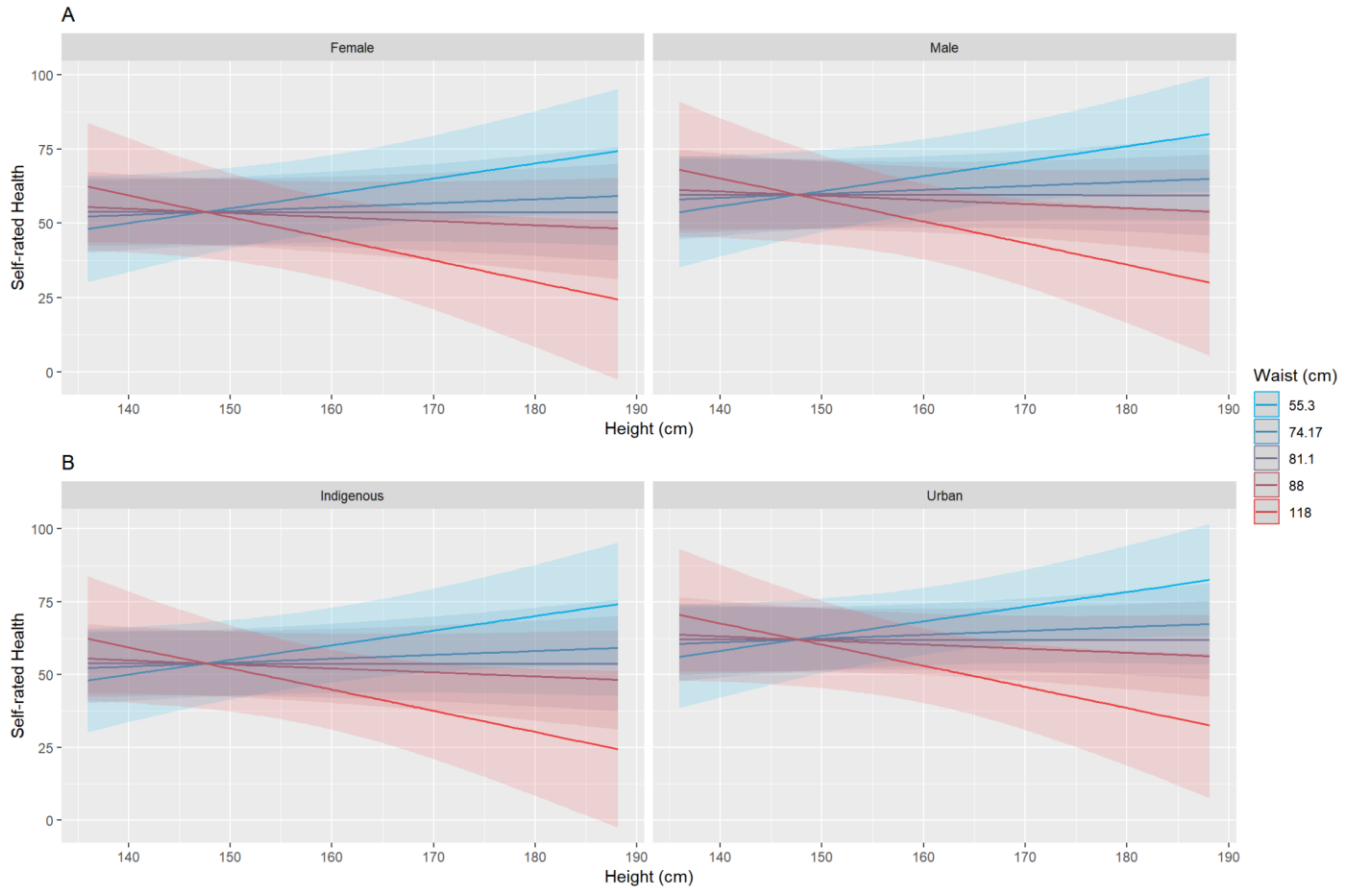
359 and height were centered and rescaled (identified by the suffix _cs).

360

361 Moreover, a significant interaction between waist and height (Table 3; $t = -2.06$, $p = 0.041$) was
362 exposed, indicating that the associated health costs of a larger waist circumference were different for
363 people of different heights (Fig 3); the best predicted self-rated health was for tall participants with small
364 waists, and the worst was for (again) tall participants, but with large waist circumferences. The model
365 also revealed that for shorter people, there are no predicted significant associated costs of having a large
366 waist. In other words, the association between height and self-rated health is positive for people with
367 small waist circumferences, but negative for people with large waists.

368 In addition, age, waist circumference, height, visceral fat, BMI, and muscle percentage, were
369 significantly correlated with self-rated health ($r > 0.20$, in all cases), for men and women (for bivariate
370 Pearson correlations between all measured variables see S4 Table for all participants combined, S5
371 Table for women, and S6 Table for men).

372



373

374 **Fig 3. Interaction between height and waist.** Model predictions were split by (A) sex, and ((B) population. To simplify
375 interpretation, raw (instead of centred and rescaled) values of height and waist were used. As waist reference, minimum,
376 quartiles (lower, median and upper), and maximum waist circumference values were used, showed on a blue to red colour
377 scale. For an interactive 3D plot of the interaction between height and waist, see S4 Fig, or the 3D animated version
378 contained in S1 File.

379 Discussion

380 The present study provides new insights into the nature of the relationship between height and
381 health, in both men and women, by studying three Latin American samples, which included urban and
382 indigenous populations with marked differences in access to basic needs and services like food and
383 health.

384 Contrary to our initial hypothesis, we did not find height by itself to be a significant predictor of
385 self-perceived health but by an interaction with waist circumference in all populations studied. Most
386 results in favor of a direct relationship between height itself and health were carried out more than
387 twenty years ago, in small samples, from modern societies, and in specific Western ethnic groups. New
388 studies with non-traditional population groups have failed to verify the positive relationship between
389 height and health, especially associated with cardiovascular and autoimmune diseases [65,66]. For
390 example, studies in groups of Native Americans, Japanese, Indians and Pakistanis showed that lower
391 people had a lower prevalence of cardiovascular disease than the highest people in each group [66].
392 These findings were similar in a group of inhabitants of Sardinia, a European population with the lowest
393 physical stature recorded in Europe in recent years [65].

394 Interestingly, our results suggest that although there is a main effect of waist size on self-
395 perceived health, the associated costs of a large abdominal circumference are differential depending on
396 stature; this is, waist circumference predicted self-reported health differently for people of different
397 heights: while being taller predicts better self-rated health for taller people with relatively small waists,
398 being taller was found to be associated with poorer perceptions of their health in people with larger
399 waist circumferences. Furthermore, while there is a cost of abdominal and visceral adiposity for tall
400 people, there is no predicted cost for shorter persons. Therefore, these results argue the importance of
401 consider a phenotypic integration of different human features that could be involved in health or
402 physiological condition, when a possible sexually selected trait is being evaluated as a signal of
403 immunocompetence.

404 On the other hand, given that height is the most sensible human anatomical feature to
405 environmental and socioeconomic conditions [21,32], we expected stronger relation between health and
406 height for indigenous population, where the cost to produce and maintain this costly trait is greater than

407 for habitants from urbanized areas. Nevertheless, we did not find inter-population differences in the
408 magnitude of this relation; urban populations reported better health than the indigenous sample, and the
409 shortest participants tended to be from the indigenous Me'Phaa sample. These results could in fact
410 suggests different life history strategies. In harsh environments, compared to modern Western societies,
411 different life strategies could take place [67], like investing relatively less energy in growth and
412 reallocating it towards reproduction [21]. In addition, a relative increase in the intensity or number of
413 infectious diseases (including child disease, like in the case of the Me'Phaa) and a tendency to early
414 sexual maturity, could have negative effects on growth, resulting in lower average height [68,69]. These
415 trends could be a compensation between life history components [25]. Finally, fast and prolonged
416 growth imply high costs for the organism [1]; rapid growth seems to influence mortality risk [70], and
417 growing for a longer time, delays the onset of reproduction, increasing the risk of dying and producing
418 fewer offspring [1]. This perspective of life strategies allows us to understand the relationship between
419 height, health, and reproduction. It suggests the importance of addressing factors such as ethnicity,
420 socio-economic status, level of urbanization, especially in populations where there is great heterogeneity
421 of access to food, health and pressure resources for pathogens, as in Latin American populations in
422 which this relationship has barely been directly explored.

423 Although our study did not directly evaluate any immunological marker but a self-perception of
424 health, the implementation of a physiological immune indicator of adaptive immune system appears to
425 be consistent with our results. It has been found that men but not women show a curvilinear relationship
426 between antibody response to a hepatitis-B vaccine and body height, with a positive relationship up to a
427 height of 185 cm, but an inverse relationship in taller men [19]. In our three populations, the maximum
428 height was lower than 185 cm, which could explain the linear but not curvilinear association we found.
429 In addition, the fact that self-perception in our study and antibody response in previous studies are both

430 positively associated with body height could contribute to the knowledge about the reliability of self-
431 perception of health as an indicator of immunological condition.

432 Finally, in relation with sex differences, women reported lower health in average than men in all
433 communities, which is concordant with reports and normative SF-36 data in other populations, and
434 especially in younger people [e.g. 71,72]. These results could add support to the idea that height is a
435 reliable signal of health in men [25], while for women it could reflect reproductive success [73] in terms
436 of labor and birth, and to a lesser extend function as an indicator of health [74]. It has been seen that
437 taller women experience fewer problem during this process, because of a lower risk of a mismatch
438 between fetal head size and the size of the birth canal [74]. Nevertheless, this idea is only speculative
439 and more studies comparing health, reproductive success and female height need to be done.

440 It is important to take into account that the mode of survey administration might be a limitation
441 in our study, and it could have lead confounding effects. For example, it is possible that indigenous
442 people have different understanding and thresholds about their general health perception, which we were
443 unable to evaluate without previous validation of translated items, and it could have explained the lowest
444 values of general health of indigenous people. Nevertheless, it could also be reflecting the real health
445 conditions in these Me'Phaa communities and not a misunderstanding of the survey. Other National
446 indicators of health, such as morbidity and mortality by gastrointestinal and nasopharyngeal infectious
447 diseases, have reported that Me'Phaa communities also present the lowest values in Mexico [46], which
448 is consistent with our results. In fact, items for the dimension of General Health Perception have the
449 lowest standard deviation and coefficient of variation of the entire SF-36 survey, in both validated
450 Spanish [50,53], and English versions [75], which makes this dimension the most understandable one.

451 In addition, in order to consider obvious differences in language and perception of health,
452 statistical models in this study assumed these inter-population variations *a priori*. Random effects for

453 countries were considered in all performed linear mixed models. We found that although urban
454 populations differ considerably from indigenous populations, the relations between height, waist
455 circumference and self-perceptions of health were observed in the same direction for all populations.

456 The present study contributes with information that could be important in the framework of
457 human sexual selection. If health and genetic quality cues play an important role in human mate choice
458 [e.g. 76], and height and waist interact to signal health, its evolutionary consequences, including its
459 cognitive and behavioral effects, should be addressed in future research. This could be done by studying
460 the interaction between waist circumference and height, in relation to reproductive and/or mating
461 success, as well as mate preferences and perceived attractiveness, in samples with both Westernized and
462 non-Westernized lifestyles.

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656 **Supporting Information**

657 **S1 File. HTML output for R Markdown.** This file contains the script and output for all analyses, data
658 manipulation and compilation, tables and figures. This file was created using R scripts in Markdown
659 format (Rmd file) to promote transparency and ensure reproducibility.

660 **S2 File. R Markdown source file for HTML output.** R Markdown file used to generate S1 File.

661 **S1 Table. Intraclass correlation of anthropometric characteristics measurements.**

662 **S2 Table. Descriptive statistics of measured variables of female participants.**

663 **S3 Table. Descriptive statistics of measured variables of male participants.**

664 **S4 Table. Correlations between measured variables for all participants**

665 **S5 Table. Correlations between measured variables for female participants**

666 **S6 Table. Correlations between measured variables for male participants**

667 **S7 Table. Results of separate linear mixed models testing effects of independent variables on self-
668 reported health.** Full table including standard errors and *t*-values.

669 **S8 Table. ANOVA-like table with tests of random-effect terms.**

670 **S9 Table. Variance Inflation Factors of Model 3 predictors.**

671 **S10 Table. Variance Inflation Factors of the Final Model (Model 3 centered and rescaled)
672 predictors.**

673 **S11 Table. Information criteria for Model 3 and Model 3 (centered and rescaled).**

674 **S1 Fig. Sexual dimorphism of height, waist and health for all samples** (A) Self-perceived health. (B)
675 Height. (C) Waist. Comparisons between female and male participants for each sample, were performed
676 using *t*-tests, adjusted for multiple tests. **** $p < 0.0001$.

677 **S2 Fig. Model diagnostics.** (A) Residual distribution for each sample. (B) Linearity in each (single
678 term) fixed factor. Centered and rescaled variables are identified by the suffix `_cs`.

679 **S3 Fig. Single term predictor slopes.** Slope of coefficients for each (single term) fixed predictor,
680 against self-rated health (linear relationship between each model term and response). For Population, 1 =
681 Indigenous, and 2 = Urban. For sex, 1 = female, and 2 = male. For simplicity, raw (instead of centered
682 and rescaled) values of height and waist were used.

683 **S4 Fig. Interaction between height and waist (interactive, animated 3D version).** For simplicity, raw
684 (instead of centered and rescaled) values of height and waist were used. Click and drag the plot to
685 change its orientation. Scroll to zoom. In S1 File, where this figure is also included, you can also use the
686 buttons below the figure to control the animation.