Manuscript accepted for publication in Evolution and Human Behavior on November 30, 2015
http://www.sciencedirect.com/science/article/pii/S1090513815001208

Perception of strength from 3D faces is linked to facial cues of physique

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We thank Bernie Tiddeman for his support with *MorphAnalyser*, Kerry Harcus for her help with a pilot study, Dengke Xiao for his help with the experimental interface, Lesley Ferrier for logistical support, Anne Perrett for proofreading and two anonymous reviewers for their helpful comments and suggestions.

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Word count: 9,024

Abstract

Formidability is an important cue to male intra-sexual competitiveness. While previous studies suggest strength can be accurately perceived from faces, little is known regarding the specific morphological cues that are used to form judgments of strength. Here, we used a set of three-dimensional color- and texture-standardized Caucasian faces to elucidate whether judgments of strength are based on shape cues linked to body physique. We collected facial scans of 50 men and 68 women together with measures of upper-body strength, height, weight and body composition. Upper-body strength was positively correlated with body mass index (BMI) and height. Deriving scores of the face shape associated with BMI and height, we found the face-morphological BMI score explained 27% of the variance in perceived strength. As BMI conflates muscle and fat mass, we also related absolute muscle and fat mass, separately, to actual strength and found a positive association between strength and both muscle and fat mass. We attempted to derive scores capturing the face shape associated with muscle and fat mass, controlling for each other and height. We found that facial scores of male muscle and fat both positively related to perceived strength, explaining 37% of the variance in this judgment. Our findings suggest that perceptions of strength from faces are based on facial cues to body physique. For both sexes, perceptions of strength seem to reflect overall body size or bulk, while for men additional variance was explained by separating facial cues to muscle and fat mass. The differentiation of facial shape associated with relative muscle and fat mass may have implications for the understanding of a variety of interpersonal judgments related to strength, such as dominance and leadership.

Keywords: face perception, physical strength, 3D face shape, muscle, BMI

Perception of male strength is linked to facial cues of men's physique

1 Introduction

A growing body of literature suggests that intrasexual selection pressures amongst men might have played a more important role in shaping men's traits than has been hitherto acknowledged (Puts, 2010; Puts, Jones, & Debruine, 2012; Scott, Clark, Boothroyd, & Penton-Voak, 2012). Intrasexual competitiveness, i.e. the drive to compete with other men and the ability to do so successfully, is linked to higher social status, which in turn has positive fitness payoffs (von Rueden, Gurven, & Kaplan, 2011). Both intrasexual competitiveness and social status have been argued to be partly based on strength, and in particular upper-body strength, which is tightly linked to fighting ability (Sell, Cosmides, et al., 2009). Handgrip strength is a good predictor of upper-body strength (Sell, Cosmides, et al., 2009) and overall muscle strength (Wind, Takken, Helders, & Engelbert, 2010), and has been found to be associated with behavioral tendencies (such as a propensity for anger and aggressive behaviour, e.g., Gallup, White, & Gallup Jr, 2007; Munoz-Reyes, Gil-Burmann, Fink, & Turiegano, 2012; Sell, Tooby, & Cosmides, 2009) as well as to influence interpersonal perception (such as impressions of dominance, e.g., Fink, Neave, & Seydel, 2007).

Sell, Cosmides, et al. (2009) emphasized the importance of being able to assess potential rivals' formidability accurately in order to avoid costs from physical conflicts that cannot be won. Similarly, Puts (2010) and Puts et al. (2012) suggested that men's face shape may have developed to signal the ability to successfully engage in competitive encounters to potential rivals. Although it could also be argued that observers learn any consistent cues to strength, the impact of facial impressions of dominance and strength on interpersonal perception indeed seems to be profound. Oosterhof and Todorov (2008), for example, have argued that faces are assessed on two main dimensions, one of which is based on facial cues to physical strength (i.e. the dominance or power dimension, revealing the ability to inflict damage on others as opposed to the valence dimension, which reveals pro- or antisocial intentions). In line with the proposed importance of visual cues to strength in social interactions, Sell, Cosmides, et al. (2009) showed that observers can judge men's upper-body strength accurately from facial images alone. They did not, however, investigate which facial cues underpin such judgments.

Recent papers have investigated how strength is reflected in face shape, and which facial features might be driving judgments of strength and formidability. By regressing handgrip strength on two-dimensional (2D) face shape, Windhager, Schaefer, and Fink (2011) found that strength is associated with a rounder facial shape, a widening between eyebrows, a shorter nose, broadening of the lower face and pronounced jaw muscles (masseter region). Toscano, Schubert, and Sell (2014) tested which facial features – used by Zebrowitz, Fellous, Mignault, and Andreoletti (2003) and Zebrowitz, Kikuchi, and Fellous (2007) – were associated with the perception of strength and found that faces with a lower eyebrow height, a shorter eye length (i.e. less opened/smaller eyes) and a wider nose were perceived as both stronger and more dominant. Yet, it remains unclear why these features may be related to perceptions of strength and dominance. Recently, Zilioli et al. (2014) identified a face cue that may mediate perceptions of formidability: facial width to height ratio (fWHR) was linked to both actual fighting ability as well as perceived formidability. fWHR may be linked to formidability through an association with physical strength, or through its association with a propensity for aggressive behavior (e.g., Carre & McCormick, 2008; Carre, McCormick, & Mondloch, 2009), although these explanations are not necessarily mutually exclusive given the link of strength and aggression.

Here, we aimed to test whether perceptions of strength might be mediated by facial cues to body physique. That is, instead of pre-defined face features, we investigated whether global variation in face shape linked to body parameters can explain perceptions of strength from faces. If it is adaptive to perceive strength accurately in order to assess fighting ability (Sell, Cosmides, et al., 2009), judgments of strength should be based on facial cues to physical characteristics that predict actual strength. Thus, we investigated whether anthropometric variables that relate to actual strength are reflected in face shape, and hypothesized that face shape associated with physical predictors of actual strength would contribute to the perception of strength.

Four studies were conducted. Study 1a tested whether strength could be perceived accurately from color- and texture-standardized 3D faces, and visualized the facial correlates of actual and perceived strength. Studies 1b and 1c investigated which physical parameters are predictive of strength and how they are reflected in face shape. Study 2 tested whether facial correlates of body physique predict perceived strength.

Most previous studies have investigated anthropometric predictors of strength from a clinical context. Two of the most basic descriptors of body physique that are positively correlated with (handgrip) strength are body mass index (BMI, weight[kg]/height[m^2]) and height (e.g., Balogun, Akinloye, & Adenlola, 1991; Chandrasekaran, Ghosh, Prasad, Krishnan, & Chandrasharma, 2010; Fink, Weege, Manning, & Trivers, 2014; Sartorio, Lafortuna, Pogliaghi, & Trecate, 2002). We have previously shown that facial cues to BMI and height can be relatively simply assessed and used in a model to explain perceptual ratings of masculinity (Holzleitner et al., 2014). In Study 1b, we thus tested whether facial cues to BMI and height are predictors of perceptual ratings of strength.

While BMI is associated with strength, it conflates muscle mass and fat mass. Perhaps counterintuitively, muscle and fat mass are positively correlated. A weight gain due to nutritional intake leads to an increase in both body fat and lean body mass, potentially due to muscle hypertrophy as a result of increased weight bearing (Forbes, 1987, 1993). This increase in lean mass with weight gain appears to be to some extent sex-specific: at least in obese samples, lean mass increased more strongly with increasing weight in men and boys compared to women and girls (Lafortuna, Maffiuletti, Agosti, & Sartorio, 2005; Sartorio, Agosti, De Col, & Lafortuna, 2006; Sartorio et al., 2004). In essence, being heavier results in higher *absolute* strength (Sartorio et al., 2006; Sartorio et al., 2004), reflected in findings that obese participants have higher (anaerobic) strength than a normal-weight control group (Lafortuna et al., 2005), and reflected by the general positive association of weight/BMI and strength (compare weight classes in sporting events).

Despite the correlation of lean and fat mass, underlying body composition in terms of fat and muscle may be a better predictor of strength than BMI for two reasons. First, at a given BMI level, the amount of lean mass can differ. For example, Deurenberg, Yap, and van Staveren (1998) reported that, at the same BMI level, European Caucasians have a higher percentage body fat than American Caucasians. Moreover, while fat and muscle appear to be positively correlated when it comes to nutrition-related weight gains, androgens such as testosterone are associated with an increase in lean body mass, but a decrease in fat mass (e.g., Bhasin, Woodhouse, & Storer, 2003; Forbes, 1993). Hence, despite having the same BMI, men can differ in their muscle mass and thus in their strength. Second, while being heavier will usually result in being stronger in absolute terms, body fat has a negative impact on muscle quality or *relative* strength, i.e. strength scaled to body or muscle mass (Goodpaster et al., 2001; Newman et al., 2003; Vilaca et al., 2014; Zhang, Peterson, Su, & Wang, 2015). Indeed, Sartorio et al. (2002) found that controlling for BMI, lean mass is the best predictor of grip strength in a sample of healthy children, while percentage body fat was negatively related to grip strength. Thus, if two men have the same BMI, but differ in their proportion of lean to fat mass, the man with the higher proportion of muscle mass will be stronger; or, put differently, at the same level of lean mass, having more body fat will negatively affect strength.

In Study 1c, we tested whether facial cues to muscle and fat could be separated and whether they relate to the perception of strength. As muscle mass is positively related to actual strength, we expected to find a positive effect of facial cues to muscle mass on perceptions of strength. Regarding facial cues to body fat, both a negative or positive effect on perceptions of strength was conceivable: body fat has been found to correlate positively with absolute strength, but negatively with relative strength (i.e. strength per unit body mass). We thus tested the non-directional hypothesis that perceptual cues to body fat impact on perceptions of strength.

In summary, Studies 1b and 1c had the following research questions.

(1) Do anthropometric variables (BMI/height, muscle/fat mass) predict strength?

(2) Do these anthropometric parameters relate to face shape?

(3) Do facial estimates of anthropometric parameters predict perceptions of strength?

To our knowledge, muscle and fat mass have not been separately related to 3D face shape before. Study 2 thus tested whether the face shape associated with fat and muscle would be perceived as being related to body fat and body muscularity, and whether these two dimensions would be perceptually distinguishable from each other.

2 General Material and Methods

2.1 Stimulus dataset

2.1.1 3D Images. Participants were recruited through undergraduate, postgraduate and staff mailing lists at the University of St Andrews. Facial scans of 68 Caucasian women (M_{age}±SD=20.9±2.4 years, range 18–32) and 50 Caucasian men (M_{age}±SD =21.2±2.5 years, range 18–32) were taken using a 3D camera (http://www.3dMD.com). An additional 22 participants were photographed but excluded due to poor quality scans (e.g., from beards) and non-Caucasian ethnicity. While strength cues are likely to be independent of ethnicity (Sell, Cosmides, et al., 2009), ethnic variation could introduce noise to perceptual ratings. Participants were photographed with a neutral facial expression, their hair pulled back and at a set distance and relative height to the camera. Faces were delineated in *MorphAnalyser 2.4.0* (Tiddeman, Duffy, & Rabey, 2000) with 49 landmarks (see Figure 1 for an example stimulus face and Table S1 for a verbal description of landmarks). The landmark templates for all digitized head models were aligned in orientation, rotation and scale using Procrustes superimposition, and surface models were resampled in accordance to a standard head delineated with the same set of landmarks (Holzleitner et al., 2014). This process establishes homology of each head model's tessellations across the entire sample. Thus, analyses as well as procedures such as averaging can be conducted on the surface of the head models as a whole instead of being restricted to landmark templates.

2.1.2 Anthropometric measurements. After removing footwear and excess clothing, participants' height was measured and weight and body composition (muscle and fat mass) were assessed barefoot using an electrical impedance scale (Tanita SC-330). Height and weight were recorded for all participants, but body composition measures could not be accurately assessed due to the wearing of tights for 10 of the women. BMI and fat mass were positively skewed. For both variables, log transformations successfully removed the skew. Analyses were thus conducted on these transformed variables. As men are on average taller and have more lean body mass than women (in the current sample, men were 14.7 cm taller, $t(116)=12.08$, $p<.001$, and had 11.9% less body fat, $t(103.2)=9.46$, $p<.001$), height, muscle mass and (log-transformed) fat mass were z-score standardized within sex.

2.1.3 Strength measurements. Two measures of upper body strength were assessed with a hydraulic hand dynamometer (Jamar 5030J1). Handgrip strength was measured following a standard testing protocol three times on the left and the right side with the handle adjusted to a position recommended for testing both men and women (Innes, 1999; Trampisch, Franke, Jedamzik, Hinrichs, & Platen, 2012). Participants were tested seated, with their feet flat on the floor, the elbow flexed at a 90° angle with the arm not touching the side of the body, and the forearm in a neutral position. They were instructed to squeeze the handle as hard as they could in a slow, sustained squeeze. The highest grip strength readings from the left and right hand were averaged (Gallup et al., 2007). To measure inverted grip strength or chest strength, subjects were instructed to hold the dynamometer in front of their chest with two hands and compress inwards (Sell, Cosmides, et al., 2009; Simmons & Roney, 2011). Again, this procedure was repeated three times. Maximum grip strength and maximum chest strength were separately z-scored within each sex and averaged to produce a composite score of actual strength (Cronbach's $\alpha=0.81$).

2.2 Identifying anthropometric variables that are predictive of strength

As a first step, zero-order correlations of BMI and height (Study 1b) and muscle and fat mass (controlling for height, Study 1c) with the strength composite score were calculated to establish whether or not the measured traits were significantly related to actual strength. Literature suggests that the association of BMI, muscle and fat mass might be sex-specific. Thus, a general linear model was used to test for interactions of sex and height/BMI (Study 1b), and sex and height/muscle/fat (Study 1c) in predicting actual strength. If any of the anthropometric traits was found to interact with sex, separate multiple regression analyses were conducted for men and women. Diagnostic regression plots were used to check for normality of residuals, homoscedasticity and outliers. Multicollinearity was considered to be of no concern if tolerance was greater than .10, and the variance inflation factor was less than 3.5.

For one of the women, strength could only be measured for one arm due to an injury; her strength measurements were thus excluded from the analysis. One of the male participants was more than three standard deviations away from the mean height (z-score of 3.1) and was therefore excluded from any analyses involving height.

2.3 Computing, validating and visualizing morphological scores based on group differences

Multiple methods exist in the literature to describe how variables such as attractiveness (Said & Todorov, 2011) or personality (Wolffhechel et al., 2014) are reflected in facial shape. For the current study, we chose a method that conceptually equates to one of the most frequently used methods in studies of face perception: that is, using the difference in average shape between two groups to describe shape changes between them. For example, the difference between men's and women's average face shape has been used to manipulate individual images towards lower or higher masculinity/femininity (Perrett et al., 1998).

While most previous studies have used this vector to *visually* manipulate individual images, the vector can also be used to quantify how much an individual face expresses face shape associated with a specific variable. This method has recently been used in studies quantifying facial masculinity (Komori, Kawamura, & Ishihara, 2011; Valenzano, Mennucci, Tartarelli, & Cellerino, 2006), but can also be extended to variables other than sex. For example, face shape changes associated with height can be quantified by using the difference in face shape between short and tall individuals (Holzleitner et al., 2014). First, all head models of a study population are subjected to a principal component analysis (PCA). Each head model can then be described with a greatly reduced number of principal components (PCs; for a sample of *n* faces, *n* PCs instead of thousands of x-, y- and z-coordinates). Second, two groups are defined, in this example, one subsample of individuals of short height, and one of individuals of tall height. Third, for each of the *n*-1 PCs, the average score of the short subsample is calculated, defining a position in the *n*-1 dimensional space. In the same way, the average principal component scores of the tall subsample are calculated. A "height axis" can then be defined as the direction from the short to the tall average face shape. Fourth, each face in the sample can be projected onto this axis, resulting in a score that expresses the position of an individual face with respect to the short and tall averages (Holzleitner et al., 2014).

Due to the sexual dimorphism in body composition and build, face-morphological scores were separately calculated for men and women. Zero-order correlations of each face score and the variable it was based on were used to test whether face scores captured shape variation associated with the variable of interest (i.e. height, BMI, body fat and muscle mass). In addition, face scores were correlated with each other to test for the independence of face dimensions. All *p*-values reported are two-tailed.

2.4 Face ratings

2.4.1 Participants. Twenty-seven female and 33 male participants (M_{age}±SD=35.7±10.10 years, range 22–63) were recruited from the United States of America through Amazon MTurk (Buhrmester, Kwang, & Gosling, 2011). Participants were paid $2.00 each.

2.4.2 Procedure. To eliminate the influence of hairstyle, clothing and cues to strength from neck circumference on perceptual ratings, all 3D heads were masked to show faces only. As color and textural cues can strongly affect perception (e.g., Jones, Little, Burt, & Perrett, 2004; Said & Todorov, 2011; Scott, Pound, Stephen, Clark, & Penton-Voak, 2010), average male and female face texture images were created using *Psychomorph 4* (Tiddeman, Burt, & Perrett, 2001). All faces were rendered with this sex-specific standardized texture, so that only face shape differed between each of the 3D face models (see Fig. 1).

Prior to the rating, participants were presented with static 2D frontal images of all face models to provide an overview of stimulus variability. The 3D face stimuli were then presented in randomized order, 'bobbing' in a sinusoidal manner from left to right and up and down. For each face, participants were asked "Compared to other men/women his/her age, how physically strong is this person?" Ratings were given on a slider scale beneath each image that ranged from 1-"Very weak" to 100-"Very strong" (numerical values not visible to participants). Stimuli were presented individually against a black background and remained visible until a rating was made.

Female and male faces were presented in two separate blocks; the order of blocks was randomized.

Ratings of strength were z-scored within raters and stimulus sex to account for potential differences in scale use. Ratings were then averaged across participants for each face. Reliability of ratings was calculated using the *R* package *irr* (Gamer, Lemon, Fellows, & Singh, 2012; R Core Team, 2015). Reliability among raters was high for the average measure (Cronbach's α=.92, 95**%** CI [0.90, 0.94]). We note that the intra-class correlation coefficient for the single raters was much lower, though significantly different from 0 (ICC=.16, 95% CI [0.13, 0.20]).

3 Study 1a

As previous studies were based on 2D color photographs, the aim of Study 1a was to test whether strength can be perceived accurately from color- and texture-standardized 3D faces. A general linear model was used to test the predictive value of actual strength on ratings of perceived strength, and to test for an effect of stimulus sex. In addition, composite images of faces scoring low and high on actual and perceived strength were created to visualize differences and similarities in face shape associated with actual and perceived strength.

3.1 Results

Actual strength was found to have a significant main effect on perceived strength ($F(1,113)=4.03$, $p=.047$, $\eta_p^2=.034$). Neither the main effect of sex, nor the interaction of sex and actual strength reached significance (both $F(1,113)\leq 0.19$, $p\geq .666$, $\eta_p^2\leq .002$). Figure 2 shows the association of actual and perceived strength across both men and women.

[Insert Figure 2 about here]

Figure 3 visualizes the face shape associated with actual and perceived strength for men and women. Facial images of the 10 individuals with lowest and highest actual and perceived strength were separately averaged for men and women, resulting in 8 prototypes (2 types of strength [actual, perceived] x 2 levels of strength [low, high] x 2 sexes [male, female], see Table S2). The difference in strength between corresponding low and high strength prototypes was calculated and translated into units of standard deviation observed for the respective variable. *Morphanalyser 2.4* was then used to add and subtract the difference between low and high strength prototypes equivalent to ±5 SD of actual and perceived strength to the mean male and female face shape (see supplementary material SA1 for a short visual demonstration of this process).

[Insert Figure 3 about here]

For men, shape changes from low to high actual strength were subtle – high strength was associated with a slightly higher forehead, more widely spaced eyebrows and eyes, more pronounced cheekbones (greater bizygomatic width), a longer midface, a wider mouth and a narrower mandible (decreased distance between *gonion* and *pogonion;* see supplementary material SA2). For women, high strength was associated with a shorter and rounder face. Compared to women with low strength, women with high strength had a shorter forehead, lower brow height and smaller, deeper-set eyes, a shorter midface, a nose that was wider at the level of the nostrils, a wider mouth with thinner lips, a shorter and wider chin and a wider mandible (increased distance between *gonion* and *pogonion*; see supplementary material SA3).

Perceived strength showed similar facial correlates in men and women (see supplementary material SA2 and SA3). Both men and women's faces that were perceived as stronger had shorter and rounder faces than faces that were perceived as weak. Their foreheads were wider and from a lateral view less bulbous, had a lower brow height, smaller and deeper-set eyes, a shorter midface, a shorter nose (decreased distance between *nasion* and *subnasale*) with a broader bridge and a greater width at the level of the nostrils, a wider mouth, a wider chin and a wider mandible. Men that were perceived as stronger also had a longer and, from a lateral, view more forwardly protruding chin.

3.2 Discussion

In contrast to Sell, Cosmides, et al. (2009) and Toscano et al. (2014), we found only a weak relationship between actual and perceived strength. Further, we found no evidence of strength being more accurately perceived from men's as compared to women's faces. Several methodological differences might partly account for these differences in findings. First, the current study used 3D heads, all of which were rendered with the same average skin texture, while Sell, Cosmides, et al. (2009) used color 2D photographs. Despite the fact that 3D stimuli likely provide a more comprehensive impression of overall face shape, using a standardized skin texture may conceal shape information that is usually gained through shadows on the face. Second, our stimulus sample size was about half the size of that of Sell, Cosmides, et al. (2009). It is therefore likely that actual strength in our study did not vary as much as in Sell, Cosmides, et al. (2009) and thus made it harder to detect differences in true strength. Third, Sell, Cosmides, et al. (2009) included a self-report measure of strength in their composite measure of actual strength, while we focused on whether the perception of strength is linked to physical predictors of strength.

In accordance with the statistical analysis, visualizing the face shape associated with actual and perceived strength showed similarities between actual and perceived strength in women's but not necessarily men's faces. Women who are stronger, and look stronger, were found to have a rounder face, smaller, deeper-set eyes and lower eyebrows, a shorter and wider nose, and the same facial traits were observed to be associated with perceived strength in men, in line with findings by Toscano et al. (2014). Men's actual strength was linked to only subtle variation in face shape; most notably, and in line with Windhager et al. (2011), a widening between eyebrows and a widening between eyes was observed, as well as an increased bizygomatic width, a wider mouth and a narrower mandible. In contrast to Windhager et al. (2011), male handgrip strength in the current sample was not linked to thinner and higher eyebrows, a shorter nose, thinner lips or a shorter midface.

4 Study 1b

The aim of Study 1b was to test whether perceptions of strength can be linked to face shape associated with BMI and height, two physical characteristics that have been previously found to be predictive of (handgrip) strength. We first tested whether BMI and height were related to strength in the current sample (1), then derived face-morphological correlates of BMI and height (2), and finally tested whether these face scores predict the perception of strength (3).

4.1 Are BMI and height predictive of strength?

The composite score of actual strength was found to be positively correlated with BMI ($r(117)=.35$, $p<.001$) and height ($r(116)=.22$, $p=.019$; see Table 1 for an overview of zero-order correlations of the strength composite score and anthropometric measurements, as well as Table S3 for separate zero-order correlations of handgrip and chest strength and anthropometric measurements). A general linear model (between-subjects factor: stimulus sex [male, female]; covariates: height and BMI) showed no significant interaction of sex with BMI or height in predicting actual strength, nor a main effect of sex (all $F(1,110) \leq 0.50$, $p \geq .479$, $\eta_p^2 \leq .005$). The model was re-run omitting the interaction terms. As indicated by the zero-order correlations, effects of BMI ($\beta = .36$, $p < .001$) and height ($\beta = .22$, $p = .016$) on actual strength were significant, while the effect of sex was not ($\beta = .01$, $p < .946$; adj $R^2 = .15$, $F(3,112) = 7.90$, $p < .001$).

[Insert Table 1 about here]

4.2 Computing and validating morphological scores of BMI and Height

Average values for each PC were separately calculated for men and women with low and high BMI, as well as short and tall men and women (see Holzleitner et al., 2014). Faces in the low and high groups were matched so that low and high BMI groups did not differ in height, and those in the low and high height groups did not differ in BMI (all $t(18) \leq 0.78$, all $p \geq .454$; see Table S4). The difference vectors from low to high height and low to high BMI were used to assign scores to each face on the facial correlates of height and BMI, respectively.

Face-morphological BMI scores correlated with actual BMI ($r(118) = .59$, $p < .001$), but not height ($r(117) = .05$, $p = .565$). Face-morphological height scores correlated with actual height ($r(117) = .38$, $p < .001$), but not BMI ($r(118) = .09$, $p = .323$). BMI and height scores were not significantly correlated with each other ($r(118) = -.10$, $p = .297$). Figures 4 and 5 visualize changes in face shape along the BMI and height vector, respectively. Additional analyses regarding the reproducibility of these scores as well as their distributions can be found in the supplementary material.

[Insert Figures 4 and 5 about here]

In both men and women, high BMI was associated with a wider, rounder face, smaller eyes, more closely set eyebrows, a narrower nose bridge and greater width at the height of the nostrils, chubbier cheeks (especially in women), wider but less full lips, and a shorter chin. Being taller was in both men and women associated with a more elongated face shape, lower and more closely set eyebrows, a longer chin and a narrower-angled jaw (shorter distance between *gonion* and *pogonion;* see supplementary material SA4). In men, being taller was also associated with a larger nose (longer, wider and more curved bridge, wider at the level of the nostrils) and fuller lips, while in women being tall was associated with a shorter, more upward pointing nose, less chubby cheeks, an increased distance between nose and upper lip (philtrum height) and a narrower chin (see supplementary material SA5).

4.3 Do facial correlates of height and BMI predict perceived strength?

The face-morphological height scores were neither related to actual ($r(117) = .01$, $p = .943$) nor perceived strength ($r(118) = -.06$, $p = .531$). The face-morphological BMI scores were found to be weakly correlated with actual strength ($r(117) = .18$, $p = .054$), and strongly correlated with perceived strength ($r(118) = .53$, $p < .001$).

A general linear model (between-subjects factor: stimulus sex [male, female]; covariates: face-morphological height and BMI scores) showed no main effect of stimulus sex ($F(1,112) = 0.02$, $p = .897$, $\eta_p^2 \leq .001$), and no significant interaction of stimulus sex with BMI scores or height scores (both $F(1,112) \leq 1.54$, $p \geq .217$, $\eta_p^2 \leq .014$). The model was re-run omitting the interaction terms. Again, a significant effect of BMI scores on perceived strength was found (β=.54, p<.001*),* while height scores and sex were not predictive of perceived strength (both β<.06, p>.498; overall model adj R^2=.27, F(3,114)=15.34, p<.001).

To test whether facial correlates of BMI mediated the effect of actual on perceived strength, the *SPSS* plugin *PROCESS* was used (Hayes, 2012). Actual strength was entered as the independent variable, perceived strength as the outcome variable and the face-morphological BMI scores as the mediating variable. Bias-corrected confidence intervals for indirect effects were calculated through 5000 bootstrap samples. Figure 6 depicts the tested model and results. The completely standardized indirect effect of actual strength on perceived strength (i.e. the mediation effect through the BMI score) was found to be significant (β=.09, Bootstrap SE=.05, 95% CI [0.01, 0.21]). The initially significant direct effect of actual on perceived strength was no longer significant (controlling for BMI scores β=.10, p=.217), confirming the mediation role of facial correlates of BMI in the accuracy of strength perception from faces.

[Insert Figure 6 about here]

4.4 Discussion

In line with previous literature, both actual BMI and body height were found to positively predict strength in the current sample. Based on the difference in the average face shape of men and women scoring low and high on these variables, face-morphological scores of BMI and height were computed. The resulting face scores were related to actual BMI and height, but only BMI scores were also marginally related to actual strength. Finally, the BMI score was found to be a strong predictor of perceived strength, and was mediating the effect of actual strength on perceived strength. Thus, the facial correlates of size (BMI) seem responsible for the accuracy in perceptual judgments of strength from 3D face shape in our sample. In line with previous findings, a high BMI was found to be associated with a wider and rounder (mid-) face (e.g., Coetzee, Chen, Perrett, & Stephen, 2010), as well as lower and more closely set eyebrows, smaller and deeper-set eyes, wider nose at the level of the nostrils, wider (but not fuller) lips and a shorter lower face (Windhager, Patocka, & Schaefer, 2013; Windhager et al., 2011). All of these traits were also found to be associated with perceived strength in Study 1. Analyses showed no significant differences in the tested relationships between men and women, suggesting that facial correlates of BMI explain a significant and similar amount of variance in strength perceived from men and women's faces.

5 Study 1c

As BMI might be an inferior indicator of actual strength compared to underlying body composition, Study 1c tested for the contribution of facial correlates of muscle and fat mass to perceptions of strength. We first tested whether muscle and fat mass were related to actual strength in the current sample (1), then derived face-morphological correlates of muscle and fat (2) and linked them to perceptions of strength (3).

5.1 Are muscle and fat mass predictive of strength?

The composite score of handgrip and chest strength was found to be positively correlated with muscle mass (r(107)=.49, p<.001) and fat mass (r(107)=.25, p=.011; see Table 1). A general linear model [between-subjects factor: stimulus sex (male, female); covariates: height, muscle and fat mass] showed no significant interaction of stimulus sex with height or muscle mass in predicting actual strength (both F(1,98)≤2.25, p≥.137, η_p^2≤.022), but a trend towards an interaction of sex and fat mass (F(1,98)=3.77, p=.055, η_p^2=.037). Thus, separate linear models predicting actual strength using the simultaneously entered covariates, muscle mass, fat mass and height, were run for men and women.

For men, actual strength was found to be significantly and positively predicted by muscle mass (β=0.81, p<.001) and negatively by fat mass (β=–0.35, p=.025). Height was not significantly related to actual strength (β=–0.26, p=.142; adj R^2=.25, F(3,45)=6.44, p=.001). For women, actual strength again was found to be positively predicted by muscle mass (β=0.38, p=.050), but neither height nor fat mass were related to actual strength (both β<0.12, p>.521; adj R^2=.20, F(3,53)=5.63, p=.002).

5.2 Computing and validating morphological scores of muscle and fat mass

As in Study 1, average PC scores were calculated for men and women with low and high absolute muscle mass, as well as men and women with low and high absolute fat mass. Faces in the low and high muscle group were matched so they did not differ in fat mass or height; likewise, faces in the low and high fat group were matched so they did not differ in muscle mass or height (all p≥.461; see Table S5). The difference vectors from low to high fat mass and muscle mass were used to assign scores to each face on the facial correlates of fat and muscle, respectively.

In men, face-morphological muscle scores weakly (but non-significantly) correlated with muscle mass (r(50)=.27, p=.055) but not fat mass (r(50)=.06, p=.666) or height (r(49)=.15, p=.292). Face-morphological fat scores correlated with fat mass (r(50)=.39, p=.005) but not muscle mass (r(50)=.14, p=.348) or height (r(49)=–.09, p=.552). Face-morphological scores of fat and muscle were not significantly correlated with each other (r(50)=–.21, p=.138). Figure 7 visualizes changes in face shape along the muscle and fat vectors in men.

[Insert Figure 7 about here]

Higher muscle mass was visually associated with a steeper forehead, a longer mid- and lower face, lower and more closely set eyebrows and more prominent brow ridges, smaller, deeper-set eyes, wider lips, and a longer chin. In addition, high muscle mass seemed to be associated with more prominent cheekbones (i.e. a wider and more pronounced zygomatic arch). Higher amount of body fat was associated with a rounder and wider face, lower, more prominent and more closely set eyebrows, smaller eyes, a smaller nose, wider and thinner lips, and a shorter chin (see supplementary material SA6).

In women, no significant association of face-morphological muscle scores and muscle mass was found (r(58)=.10, p=.444), although this association was significant when controlling for fat mass (r(55)=.27, p=.040). Muscle scores were not correlated with fat mass (r(58)=–.11, p=.413) or height (r(68)=.01, p=.971). Face-morphological fat scores correlated with fat mass (r(58)=.45, p<.001) and showed a trend to correlate with muscle mass (r(58)=.23, p=.077) but not height (r(68)=–.06, p=.640). Face-morphological scores of fat and muscle were significantly correlated with each other (r(68)=–.52, p<.001), suggesting that we failed to derive separate dimensions of face shape.

5.3 Do facial correlates of muscle and fat mass predict perceived strength?

In women, face scores of fat and muscle were highly correlated with each other but not necessarily with the variables they were based on, indicating that the face shape associated with muscle and fat could not be satisfactorily separated in women. Thus, the subsequent analysis of the association of muscle- and fat-associated face shape with perceptions of strength was restricted to men's faces.

The facial muscle score showed a trend to relate to actual strength ($r(50)=.25$, $p=.082$) but was not related to perceived strength ($r(50)=.11$, $p=.432$). The fat score was not related to actual strength ($r(50)=-.04$, $p=.770$) but was positively related to perceived strength ($r(50)=.58$, $p<.001$). A general linear model with muscle scores and fat scores as predictors of perceived strength showed significant independent effects of both muscle score ($\beta=.25$, $t=2.14$, $p=.037$) and fat score ($\beta=.63$, $t=5.47$, $p<.001$; adj $R^2=.37$, $F(2,47)=15.46$, $p<.001$).

5.4 Discussion

In line with previous literature, the zero-order correlations of actual strength and muscle as well as fat mass showed positive relationships in the current sample. As evidence for an interaction of sex and bodily predictors of strength was found, relationships of fat and muscle were separately investigated for men and women. A multiple linear regression with muscle mass, fat mass and height as predictors of actual strength showed that, for both sexes, muscle mass remained a significant predictor of actual strength when controlling for fat mass and height. In contrast, the relationship of fat and strength differed in the male and female sub-samples when controlling for muscle and height. In women, fat mass was not significantly related to actual strength; in men, fat mass was negatively related to strength. The latter observation is in line with previous findings that fat mass is positively associated with absolute strength, but inversely related to relative strength (i.e. strength per unit muscle mass or strength controlling for muscle mass), although it remains unclear why no such observation was made for women.

As both fat and muscle mass were found to be linked to actual strength, face-morphological scores of muscle and fat mass were derived based on differences in the average face shape of men and women with low and high fat and muscle mass. For men, our results suggested we were successful in describing separate dimensions of face shape associated with muscle and fat mass. The resulting face scores predicted the variable on which they were based (muscle/fat) but were not correlated with the other anthropometric variables (fat and height/muscle and height), or each other. With regards to women, efforts to separate face shape associated with fat and muscle were unsuccessful. Muscle scores were not associated with any of the anthropometric variables, but highly correlated with fat scores. Fat scores, on the other hand, were related to fat mass and showed a trend to correlate with muscle mass. The difficulties in describing separate dimensions of muscle and fat-associated face shape may reflect the stronger correlation of muscle and fat mass in women compared to men (see Table 1). This finding might also reflect a sex difference in sex hormone levels, and in particular testosterone. High testosterone can lead to a greater proportion of lean mass, i.e. a dissociation of fat and muscle, making it easier to separate face shape associated with fat and muscle in men compared to women.

While we defined two dimensions of face shape change related to distinct body composition components in men (fat and muscle mass), their perceptual dissociation remains to be shown. Thus, Study 2 tested whether face shape associated with fat and muscle would indeed represent two perceivably distinct dimensions in two-alternative forced choice tasks.

The face-morphological fat score was not related to actual strength but was positively related to perceived strength. We note that facial correlates of fat were a stronger predictor of perceived strength than facial correlates of muscle, despite the fact that muscle mass is the stronger predictor of *actual* strength. In men, fat mass was negatively correlated with actual strength when controlling for muscle mass. Given this negative relationship of fat mass and actual strength in men, these findings are perhaps counterintuitive. They might be better understood by taking into account that in general, increased weight and therefore increased size means higher absolute strength. In line with previous findings (e.g., Lafortuna et al., 2005), zero-order correlations in the current sample showed that fat mass was positively correlated with actual strength overall. Our findings could be interpreted as evidence that observers, above all, use cues to overall size when judging strength from faces. Together, the two face-morphological scores of muscle and fat, derived from absolute muscle and fat mass, both of which were linked to actual strength, explained close to 40% of the variance in ratings of strength.

6 Study 2: Facial Correlates of Fat and Muscle Mass

Study 1c found that in men (but not women) face shape could be separately related to fat and muscle mass, and two new vectors of male face shape were derived – shape associated with fat mass, and shape associated with muscle mass. Study 2 aimed to validate the structural descriptions of fat and muscle mass perceptually. That is, while we derived face shape vectors associated with distinct aspects of body composition – fat and muscle mass – it remained to be established whether the facial shape dimensions would influence perception in distinct and appropriate ways. Study 2 thus explored whether the two structural descriptions of muscle and fat mass related to the perception of muscle and fat mass. We designed a two-alternative forced-choice experiment that tested the following two predictions.

(1) The defined fat and muscle face shape vectors are perceptually associated with body fat and muscularity. (a) Manipulating faces towards the shape associated with lower and higher fat mass should affect facial judgments of body fat – 'high fat'-faces should be perceived as having more body fat than 'low fat'-faces. (b) Analogously, manipulating faces towards the shape associated with lower and higher muscle mass should lead 'high muscle'-faces to be perceived as having more muscle than 'low muscle'-faces.

(2) Fat- and muscle-associated face shape are separate dimensions. (a) Manipulating fat-associated face shape should have no effect on perceived muscle mass, while manipulating muscle-associated face shape should have no effect on perceived fat mass. (b) Comparing high fat- and high muscle-faces, high fat-faces should be perceived as having more body fat than high muscle-faces, while high muscle-faces should be perceived as having more muscle than high fat-faces.

6.1 Methods

6.1.1 Participants. Twenty-five female and 35 male participants (M_{age}±SD=32.3±8.1 years) were recruited from the United States of America through Amazon MTurk. Participants were paid $2.00 each.

6.1.2 Material. Five male composite faces (each an average of three randomly chosen male faces) were manipulated visually to reflect the face shape associated with low and high levels of muscle and separately fat mass based on the prototypes created in Study 1c (see Table S5). To visualize the face shape associated with muscle mass, the difference in muscle mass between the low and high muscle prototypes was calculated and translated into standard deviation units (SD) for muscle mass observed in the sample (difference between high and low=7.97 kg equating to 1.09 SD). To visualize the face shape associated with having a muscle mass of 1.50 SD below the mean ('low') and 1.50 SD above the mean ('high'), 1.37 times the difference between low and high prototypes was subtracted from or added to each composite face (as 1.5=1.09*1.37). Analogously, the transform amount equivalent of 1.5 SD of fat mass was subtracted and added from each face to create transforms reflecting the face shape associated with 'low' and 'high' fat mass. Figure 8 provides an example of the resulting stimuli.

In total, 20 transforms were generated: five identities x two transform dimensions (muscle and fat) x two transform levels (low and high). These were presented in a two-alternative forced choice task with two different blocks. Participants were asked to choose "which man has more body fat" and "which man has more muscle". In each block, participants were presented with the same 15 face pairs: five pairs of low fat vs high fat, five pairs of low muscle vs high muscle and five pairs of high fat vs high muscle. The order of blocks as well as stimuli within each block was randomized.

6.1.3 Analysis. For each task and stimulus type, the proportion of times a predicted choice was made was calculated. For example, when asked "which man has more body fat", the proportion of trials in which the high fat-face was chosen over the low fat-face was calculated, and separately the proportion of trials in which the high fat-face was chosen over the high muscle-face was calculated. For cross-dimensional choices, such as picking the man with more body fat out of a pair showing low and high muscle transforms, proportions of trials were calculated in which the high transform was chosen over the low transform. As five identities were presented for each stimulus pair combination, the outcome variable could range from 0 to 1, where 0 would indicate that a particular choice was not made once, and 1 would indicate that a particular choice was made for 5 out of 5 identities. Proportions were tested against the null hypothesis of random choice (.50) using one sample t-tests.

[Insert Figure 8 about here]

6.2 Results

(1) Are the defined face shape vectors perceptually associated with muscle and fat?

A one-sample t-test against chance (.50) showed that when asked "which man has more body fat?", high fat-faces were significantly more often chosen than low fat-faces (.87, $t(59)=17.48$, $p<.001$) and high muscle-faces (.74, $t(59)=7.15$, $p<.001$). When asked "which man has more muscle", high muscle-faces were significantly more often chosen than low muscle-faces (.78, $t(59)=8.638$, $p<.001$) and high fat-faces (.69, $t(59)=5.90$, $p<.001$; see Figure 9).

(2) Does the fat- and muscle-associated face shape describe two separate dimensions?

To test whether fat and muscle vectors described two separate dimensions, cross-dimensional judgments were investigated. For the question, "which man has more muscle mass", no preference for high or low fat-faces was observed; high fat-faces were chosen as often as low fat-faces (.50, $t(59)=–0.11$, $p=.913$). Contrary to our prediction, when asked "which man has more body fat", participants chose high muscle-faces significantly less often than low muscle-faces (.39, $t(59)=–2.56$, $p=.013$; see Figure 9).

[Insert Figure 9 about here]

6.3 Discussion

The fat and muscle vector scores computed in Study 3 were found to describe the face shape perceived as being linked to body fat and muscularity, respectively. In addition, we found that these two vectors were perceived as fairly separate dimensions. Men's faces manipulated towards a shape associated with high muscle mass but not high fat mass were perceived as having more muscle. Men's faces manipulated towards a higher fat mass were perceived to have more body fat, although it was found that muscle mass also had an effect on judgments of body fat – face shape associated with lower muscle mass was perceived as having more body fat. These findings suggest that our fat and muscle vectors were successful in describing face shape changes associated with actual fat and muscle mass; they were both correlated with actual fat and muscle mass as well as being perceived as being related to muscle and fat.

7 General Discussion

The presented studies investigated whether facial cues to body physique associated with actual strength can account for perceptions of strength from faces. We found that in a set of masked, color- and texture standardized 3D faces, strength could be assessed with some accuracy. We found BMI as well as body composition (fat and muscle mass) to be linked to both actual strength as well as face shape. The face-morphological correlates of BMI were found to mediate the relationship of actual and perceived strength, explaining close to 30% of the variance in perceived strength. In men, further dissecting weight into muscle and fat allowed the separation of two face shape vectors that together explained close to 40% of the variance in perceived strength.

7.1 Facial cues to height and BMI

Body height and BMI were both found to correlate with actual strength. Visualizing the face shape associated with height and BMI showed that a higher BMI was linked to a rounder/wider face (e.g., Coetzee, Perrett, & Stephen, 2009; Holzleitner et al., 2014), while height was associated with a more elongated face shape (e.g., Holzleitner et al., 2014; Mitteroecker, Gunz, Windhager, & Schaefer, 2013; Re et al., 2013). The computed face-morphological BMI scores were linked to both actual and perceived strength. In contrast, the face-morphological height scores were related to neither actual nor perceived strength. We note that body height was strongly correlated with muscle mass in our sample. The correlation of height and actual strength was no longer significant when controlling for muscle mass, suggesting that it is not height itself that is predictive of strength, but a taller build being associated with a higher amount of lean mass. Visualizing the face shape associated with perception of strength suggested that it is especially the roundness or wideness of a face that drives how strong the face owner looks. We argue that this facial roundness is denoting strength because roundness is a cue to a bulky/heavy body – and on average, heavy means higher strength. We note that this finding might also account for reports that facial width-to-height ratio (fWHR) is linked to perceptions of strength (Zilioli et al., 2014), in line with previous findings that fWHR is correlated with BMI (Coetzee et al., 2010; Lefevre et al., 2012).

7.2 Facial cues to muscle and body fat

Study 1c tried to differentiate facial cues to BMI, or weight, into separate aspects of body composition, muscle and fat mass. Three points are worth noting. First, in men, face shape associated with fat and muscle could be reasonably well separated. Visualizing facial correlates of body fat revealed face shape changes that were closely matched to those associated with BMI. In contrast, the muscle vector revealed overlapping as well as distinct feature changes. For example, high values of BMI/fat and muscle were all associated with more pronounced brow ridges, lower eyebrows and smaller eyes. By contrast, length of mid- and lower face decreased with increasing BMI/fat but increased with increasing muscle mass. Some of the shape changes associated with muscle were reminiscent of shape changes associated with height (such as an overall more elongated face shape, e.g., Holzleitner et al., 2014; Mitteroecker et al., 2013; Re et al., 2013) and as outlined earlier, muscle mass increases with increasing height. We note, however, that the prototypes on which muscle vectors were based were matched for height.

It is possible that the muscle vector may be more generally linked to testosterone. Indeed, the muscle-associated face shape revealed characteristics previously described as "masculine" (such as more protruding brow ridges, deeper-set eyes, pronounced cheekbones and a larger jaw). We suggest that effects of testosterone might mediate the perception of strength. Increased muscle mass itself is unlikely to be directly detectable from the face (strength training is unlikely to show in facial musculature). Yet, high levels of testosterone during development will affect body physique/frame size (and hence attainable strength) as well as facial morphology. Observers may use these aspects of facial architecture as cues to body physique and hence strength. As no hormonal measures were taken, this interpretation remains speculative.

Second, efforts to separate fat- and muscle-associated face shape in women were unsuccessful. We suggest this might be due to the stronger correlation of fat and muscle in women than men, which might be linked to the hormonal differences between men and women. In a larger, more varied sample of women it may also be possible to separate face shape associated with muscle and fat.

Third, the three facial features previous linked to perceptions of strength by Toscano et al. (2014) may all be accounted for by the face shape associated with BMI and/or muscle and fat. Our findings show that brow height may be linked to muscularity, nostril width to a heavier body build, and eye size to both weight and muscularity. As both muscularity and BMI were found to be linked to actual strength, our findings may offer an explanation as to why features identified by Toscano et al. (2014) are associated with perceptions of strength.

7.3 Concluding Comments

The composite measure of grip and chest strength was only weakly linked to perceived strength in the current sample (Study 1a). Visualizing the face shape associated with perceived strength suggests that, for both male and female faces in the current sample, perceptions of strength were based on similar facial cues. Indeed, Study 1b showed that in both sexes a considerable proportion of variance in ratings of perceived strength could be explained by facial cues to BMI or overall mass, such as facial roundness, eyebrows that were narrower and closer together and smaller eyes. Nonetheless, Study 1c demonstrated that even more variance in men's perceived strength could be explained by partitioning facial cues to mass into facial cues associated with fat and muscle. Despite a lack of a relationship of actual and perceived strength in men in the current sample, some of the traits that we found to co-vary with perceived strength (such as more pronounced cheekbones and a longer chin) were found to be linked to higher muscle mass, and facial correlates of muscle were found to be linked to both actual as well as perceived strength.

Sell et al. (2009) found that in three out of four tested samples, measured upper-body strength was a better predictor of men’s perceived strength than body weight. They concluded that judgments of strength from faces track muscularity rather than overall body size. We interpret our findings slightly differently. We agree that muscularity is a cue to strength, yet we note that overall size may be a more effective perceptual cue to strength. Our study is the first to identify facial correlates of muscularity in 3D face shape. By directly testing for the effect of facial shape correlates of muscle mass as well as fat mass and overall mass (BMI), we find that muscularity is a significant predictor of perceived strength. At the same time, facial correlates of overall body size had a stronger effect on perceptions of strength than facial correlates of muscularity. Indeed, and in line with our findings, Sell and colleagues did find that for women and men in their US sample, the effect of body weight was equal to or larger than the effect of actual strength on perceived strength.

Taken together, findings from the current study provide limited support for suggestions that men’s face shape evolved as a signal of formidability (e.g., Puts, 2010). Some aspects of men’s face shape that seem to influence the perception of strength (such as facial adiposity or muscularity) could be a ‘by-product’ of a selection pressure for overall greater body size. These aspects of face shape do not need to have or have had automatic signal value; instead their link to physical characteristics (and hence strength) could be learned. Other, and maybe less physique-dependent aspects of facial shape, could have been selected for. For example, a larger and more robust zygomatic arch might result from benefits associated with a larger masseter muscle and greater bite force. Alternatively, greater robusticity might have been beneficial by providing greater resilience to contact violence (Stirrat, Stulp, & Pollet, 2012; Carrier & Morgan, 2015).

Despite the fact that we found actual strength to be only weakly associated with perceived strength, we have shown that perceptions of strength are likely rooted in facial correlates of physical parameters. Facial correlates of BMI, a rough measure of overall size or bulk were found to be strongly predictive of perceptions of strength in both men and women. Future studies could further investigate the relationship of sex hormone levels, body composition and facial correlates of body composition. If facial sexual dimorphism is partly mediated by dimorphism in body composition, accounting for these sex differences might allow for a more targeted investigation of sexually selected facial traits.

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Table 1. Correlation of actual and perceived strength and anthropometric variables in women (above diagonal) and men (beneath diagonal): actual strength (composite of within-sex z-scored handgrip and chest strength), perceived strength (average rating derived from z-scores), body mass index (BMI, ln(kg m^{-2}), height (z(cm)), muscle mass (z(kg)), fat mass (z(ln(kg)).

	Actual Strength	Perceived Strength	BMI	Height	Muscle Mass	Fat Mass
Actual Strength		.26* (67)	.40** (67)	.24 (67)	.49*** (57)	.42** (57)
Perceived Strength	.13 (50)		.34** (68)	.06 (68)	.34** (58)	.40** (58)
BMI	.27 (50)	.41** (50)		–.07 (68)	.77*** (58)	.87*** (58)
Height	.19 (49)	.15 (49)	.15 (49)		.41** (58)	.30* (58)
Muscle Mass	.50*** (50)	.39** (50)	.73*** (50)	.68*** (49)		.74*** (58)
Fat Mass	.06 (50)	.29* (50)	.82*** (50)	.28* (49)	.55*** (50)	

$p \leq .05$*, $p \leq .01$**, $p \leq .001$***

Figure 1. All 3D images were annotated with 49 landmarks (top row), masked to exclude non-face areas, and rendered with the same standardized skin texture (bottom row).

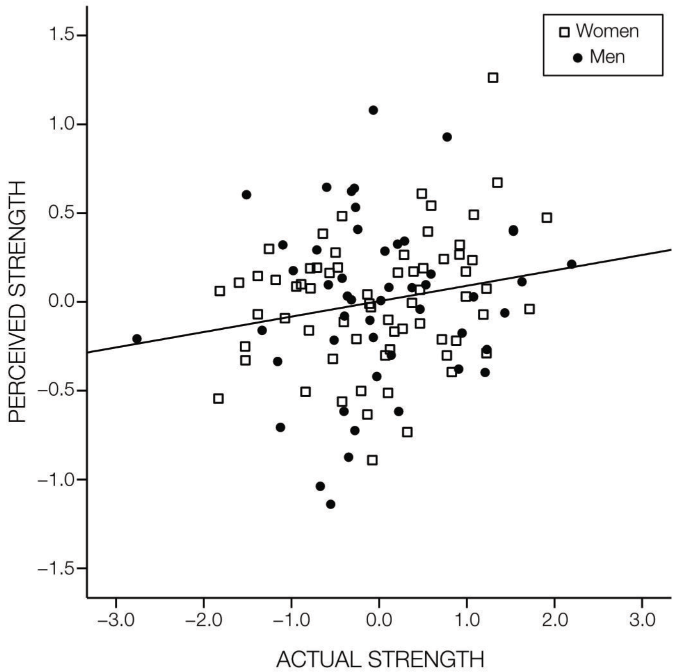

Figure 2. Actual strength (a composite of z-scored handgrip and chest strength) was weakly related to perceived strength (average of z-scored ratings, see main text; R^2=.04). The black line represents the best fit regression line for combined male and female face data. Ratings of men (black circles) and women's strength (open squares) did not differ in their accuracy.

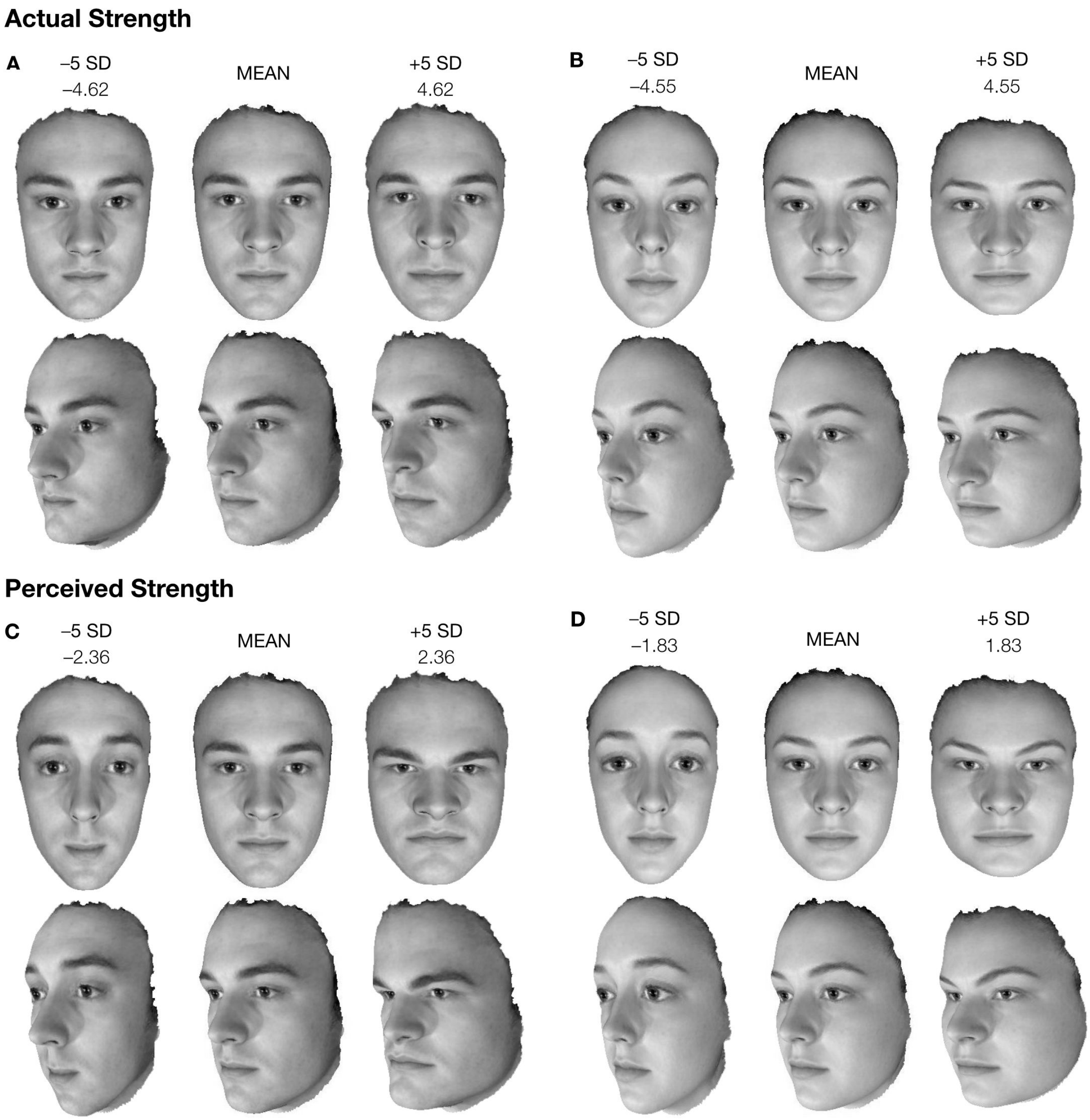

Figure 3. Face shape associated with actual (top row) and perceived strength (bottom row). Visualizations reflect face shape associated with ±5 SD of actual and perceived strength in men and women, based on the difference in face shape between the 10 men (A) and women (B) scoring lowest and highest on actual strength, and the 10 men (C) and women (D) scoring lowest and highest on perceived strength (see Table S2). Supplementary material SA2 and SA3 provide animated views of the visualisations. Please note that the transform amount of ±5 SD was chosen to increase the salience of changes and goes beyond what would be observed in natural faces. Supplementary figure SF1 shows changes associated with ±2.5 SD, i.e. a less extreme transform amount representative of about 5% of the average population.

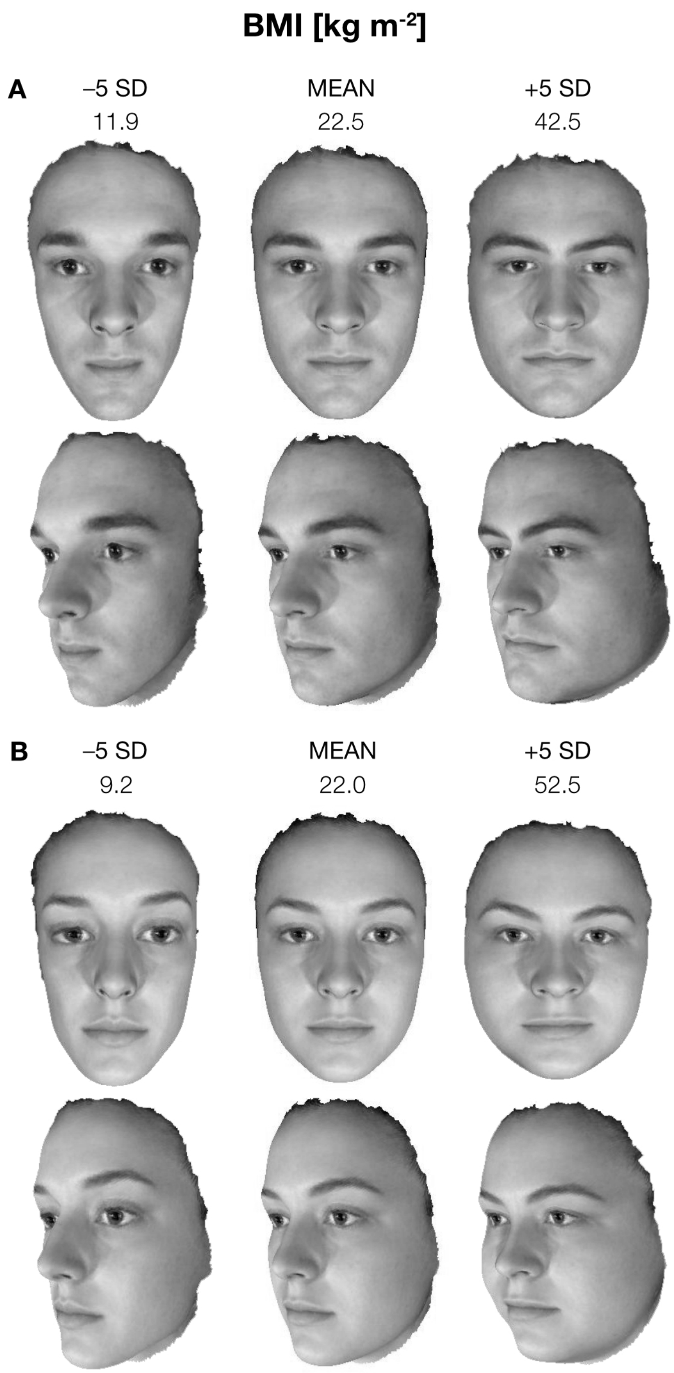

Figure 4. Face shape associated with body mass index (BMI) in men (A) and women (B). Faces were manipulated to reflect face shape associated with the sample mean BMI ±5 SD based on the difference in face shape of the low and high BMI prototypes described in Table S4. Note that while calculations were based on the log-transformed variable, for the figure numerical values are given on the original scale (kg m^{-2}). Supplementary material SA4 provides an animated view of the visualisations, and supplementary figure SF2 shows changes associated with a less extreme transform amount of ±2.5 SD.

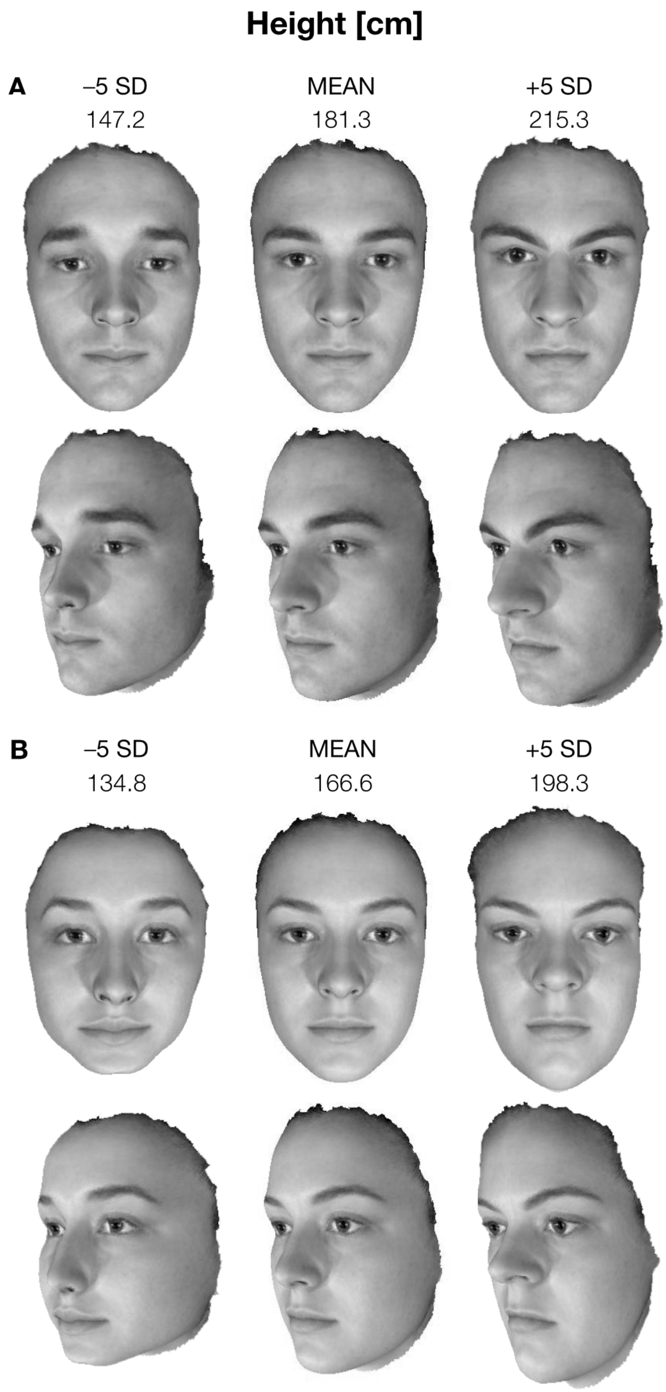

Figure 5. Face shape associated with height in men (A) and women (B) based on the difference in face shape of the short and tall prototypes described in Table S4. Supplementary material SA5 provides an animated view of the visualisations, and supplementary figure SF3 shows changes associated with a less extreme transform amount of ±2.5 SD.

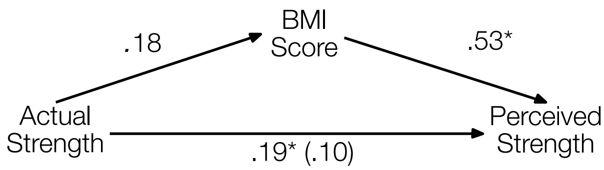

Figure 6. Model testing whether the effect of actual strength on perceived strength was mediated by facial cues to BMI (BMI score). Path weights show standardized regression coefficients. The standardized regression coefficient between actual and perceived strength controlling for facial cues to BMI is in parentheses. **p*<.05

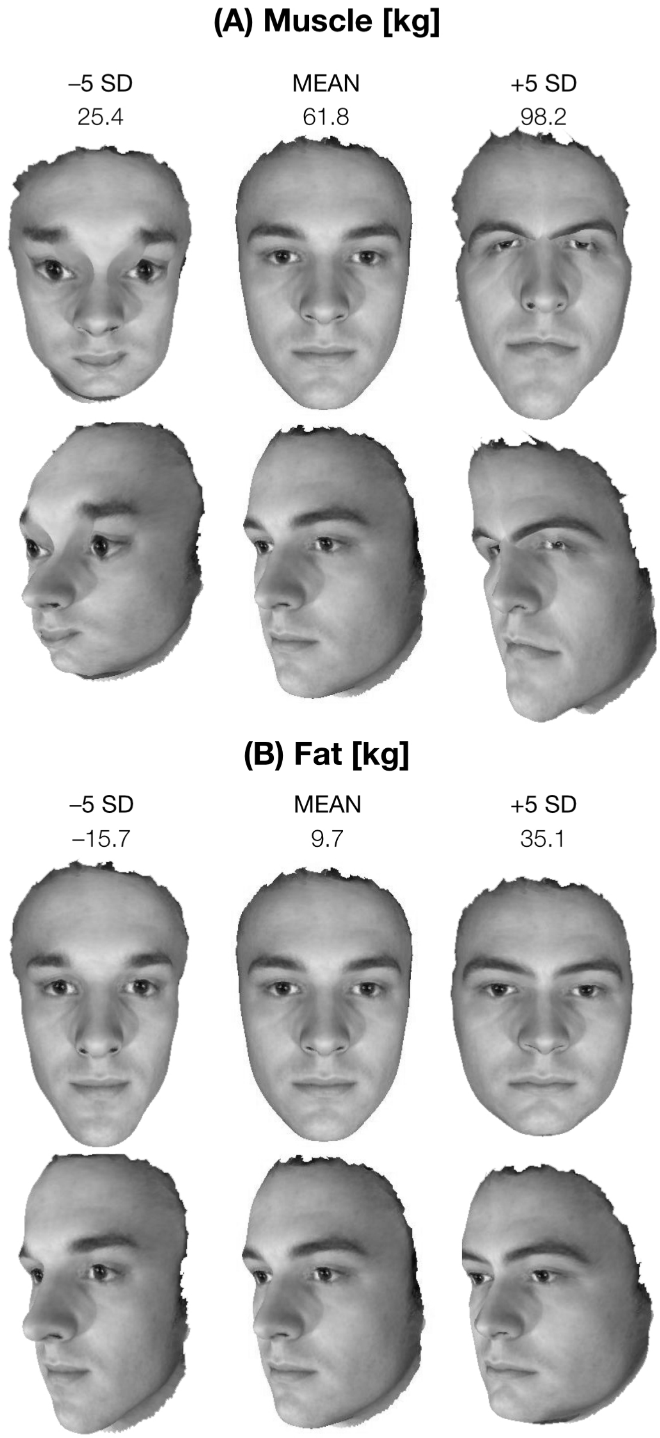

Figure 7. Male face shape associated with muscle mass (A) and fat mass (B) based on the difference in face shape between men with low and high muscle and fat mass described in Table S5. Supplementary material SA6 provides an animated view of the visualisations, and supplementary figure SF4 shows changes associated with a less extreme transform amount of ±2.5 SD.

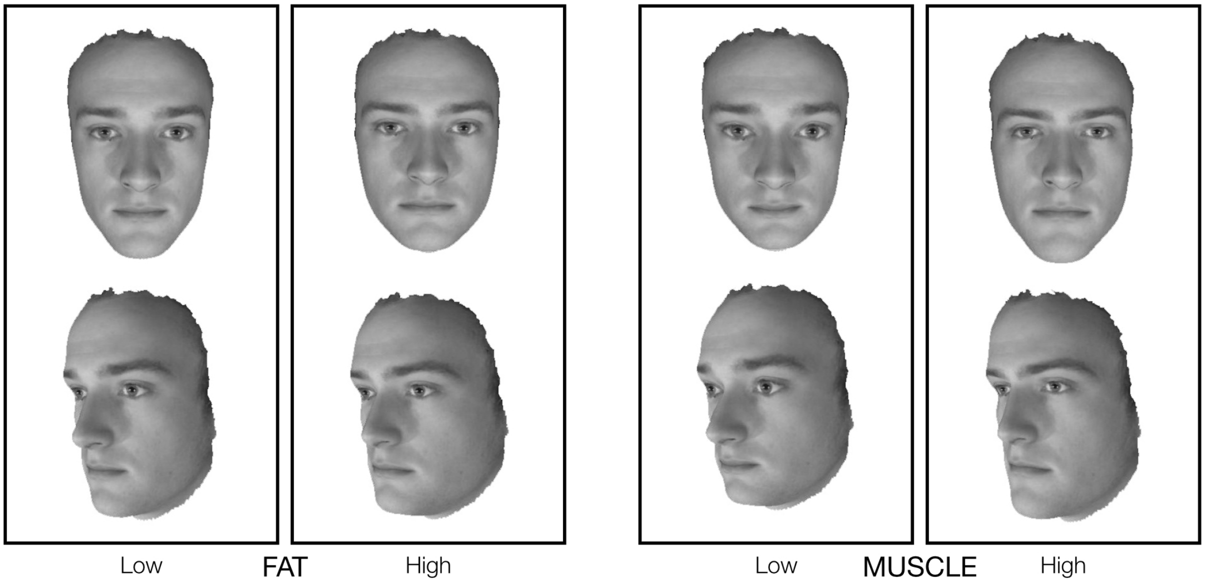

Figure 8. Example of stimuli used in validation task. The first and second column show one of the base faces transformed towards the equivalent of 1.5 SD lower (left) and higher (right) fat mass. The third and fourth column show the same base face transformed towards the equivalent of 1.5 SD lower (left) and higher (right) muscle mass.

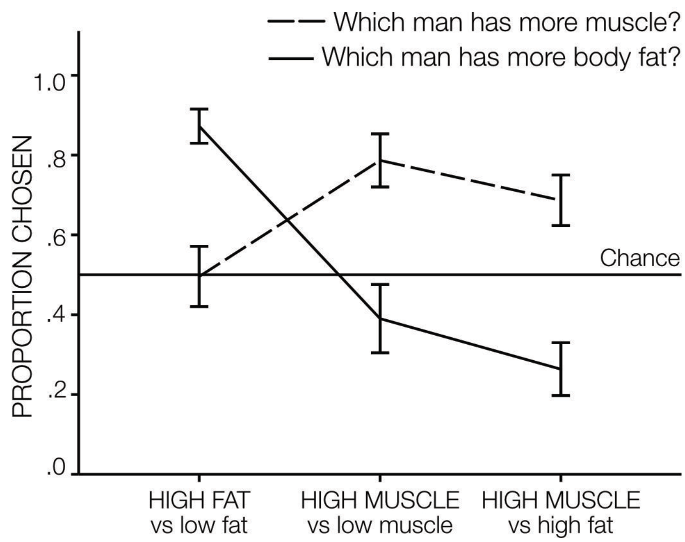

Figure 9. Results of the two-alternative forced choice task. Participants were asked to choose in two separate blocks which man out of a pair had more body fat, and which man had more muscle. Participants were presented with three types of stimulus pairs – high fat vs low fat, high muscle vs low muscle and high muscle vs high fat faces. The y-axis gives the proportion with which the capitalized stimulus face was chosen over the lower case-lettered stimulus face. Error bars represent 95% CI.

SUPPLEMENTARY INFORMATION

Cross-validation of face-morphological height and BMI scores

The face-morphological scores described in the current manuscript were based on the average difference in principal component scores of face shape between groups of individuals, such as short and tall men and women. As principal components (and the resulting principal component scores of each face) are dependent on the set of faces from which they are derived, we tested whether the used face-morphological scores can also provide meaningful descriptions of an independent set of faces.

Based on the principal component analysis of faces described in the current manuscript, we predicted the principal component scores of the 40 male and female faces described in Holzleitner et al. (2014). We then projected this independent face set onto the height and BMI vectors derived in the current manuscript to calculated out-of-set face-morphological height and BMI scores.

Morphological height and BMI scores as derived in Holzleitner et al. (2014), i.e. within-set, and derived from the prototypes in the current manuscript, i.e. out-of-set, were highly correlated (height: Pearson's $r(40)=.84$, $p\leq.001$); BMI: Pearson's $r(40)=.90$, $p\leq.001$). In addition, face-morphological scores derived from the prototypes described in the current manuscript predicted perceived height and weight ratings described in Holzleitner et al. (2014; height: $\beta=.39$, $t=2.63$, $F=6.94$, $p=.012$, $R^2=.13$; weight: $\beta=.82$, $t=7.92$, $F=62.68$, $p\leq.001$, $R^2=.67$). Scores derived from the prototypes in the current manuscript also showed a trend to predict *actual* height ($\beta=.29$, $t=1.85$, $F=3.41$, $p=.073$, $R^2=.06$) and BMI ($\beta=.30$, $t=1.91$, $F=3.67$, $p=.063$, $R^2=.09$) of the individuals in this independent face set. Taken together, these findings suggest that the method we describe provides morphological descriptors that are fairly stable across independent sets of faces.

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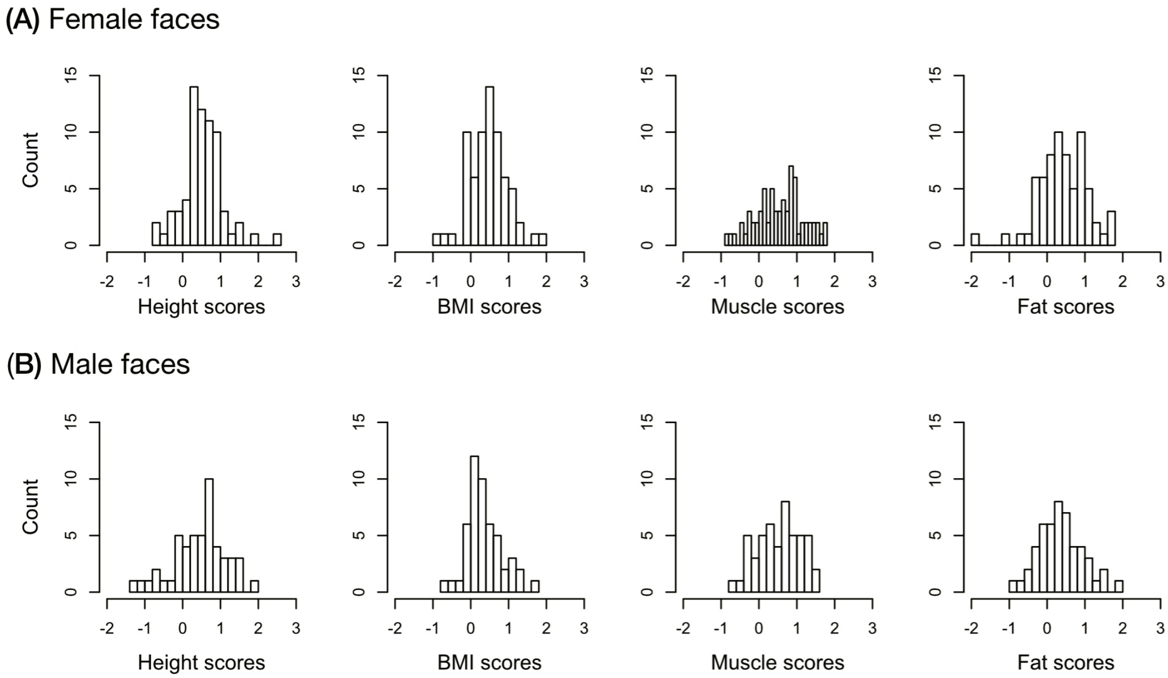
Distribution of face-morphological scores



Supplementary Tables

Table S1. Landmark template used to annotate 3D images (following Farkas, 1994)

1	*Nasion*; on midsagittal plane, in lateral view on lowest point above the nose
2	Centre of right pupil
3	Centre of left pupil
4	*Exocanthion* right; outer corner of the right eye fissure where eyelids meet
5	*Endocanthion* right; inner corner of the eye fissure where eyelids meet
6	Highest point of right iris
7	Lowest point of right iris
8	*Endocanthion* left
9	*Exocanthion* left
10	Highest point of left iris
11	Lowest point of left iris
12	*Alare* right; most lateral point on the right ala
13	*Alare* left
14	*Cheilion* right; right corner of the mouth where the outer edges of upper and lower vermillion meet
15	*Cheilion* left
16	*Labrale superius*; midpoint of the upper vermillion line
17	*Labrale inferius;* midpoint of the lower vermillion line
18	Mid-cleft of upper vermillion
19	Mid-cleft of lower vermillion
20	*Trichion*, midpoint of the hairline
21	*Gnathion*; midpoint of chin
22	Frontal view: right outermost feature of face along the horizontal axis of the mouth Lateral view: turning point of *Ramus mandibulae* and *Corpus mandibulae*
23	Frontal view: left outermost feature of face along the horizontal axis of the mouth Lateral view: turning point of *Ramus mandibulae* and *Corpus mandibulae*
24	*Glabella*; on midsagittal plane, joins the superciliary ridges; lateral view: most protuberant point
25	Tip of the nose; lateral view: most protuberant point on nose

<table>
<tr><td>26</td><td>Subnasale; on the local midline of the junction formed by lower border of nasal septum and cutaneous portion of upper lip</td></tr>
<tr><td>27</td><td>Lateral view: deepest point between lip red and chin</td></tr>
<tr><td>28</td><td>Lateral view: most protuberant point of chin</td></tr>
<tr><td>29</td><td>Lowest point of attachment of right external ear to the face</td></tr>
<tr><td>30</td><td>Lowest point of attachment of left external ear to the face</td></tr>
<tr><td>31</td><td>Superciliare mediale right; most medial point of eyebrow</td></tr>
<tr><td>32</td><td>Midpoint of right eyebrow (horizontally and vertically)</td></tr>
<tr><td>33</td><td>Supercilare laterale right; most lateral point of right eyebrow</td></tr>
<tr><td>34</td><td>Superciliare mediale left</td></tr>
<tr><td>35</td><td>Midpoint of left eyebrow</td></tr>
<tr><td>36</td><td>Superciliare laterale left</td></tr>
<tr><td>37</td><td>Crista philtrum right; right crest of the philtrum, i.e. the vertical groove in the median portion of upper lip, located on the vermillion border</td></tr>
<tr><td>38</td><td>Crista philtrum left</td></tr>
<tr><td>39</td><td rowspan="2">Evenly spaced between 21 and 22 along jaw line</td></tr>
<tr><td>40</td></tr>
<tr><td>41</td><td rowspan="2">Evenly spaced between 21 and 23 along jaw line</td></tr>
<tr><td>42</td></tr>
<tr><td>43</td><td>On midsaggital plane beneath chin</td></tr>
<tr><td>44</td><td>Right intersection of pupil line and hairline</td></tr>
<tr><td>45</td><td>Left intersection of pupil line and hairline</td></tr>
<tr><td>46</td><td rowspan="2">Evenly spaced along hairline between 20 and 44</td></tr>
<tr><td>47</td></tr>
<tr><td>48</td><td rowspan="2">Evenly spaced along hairline between 20 and 45</td></tr>
<tr><td>49</td></tr>
</table>

Note. Italics indicate names of traditional anthropometric landmarks.

References

Farkas, L. G. (Ed.). (1994). *Anthropometry of the Head and Face* (2nd Edition ed.). New York: Raven Press.

Table S2. Actual and perceived strength in the tested sample. The difference in shape between composite head models of the 10 men and women scoring lowest and highest on perceived and actual strength served to visualize face shape associated with strength. Due to the missing strength measurement for one participant, female sample size was 67 for actual strength but 68 for perceived strength. Values are given as M(SD). Actual strength is the average of z-scored measures of handgrip and chest strength. Perceived strength was rated on a slider scale from 1-100, z-scored within raters and stimulus sex, and then averaged for each face (see main text). Significant differences (p<.05) between low and high prototypes are indicated in bold.

	Sex	**Prototype**	**N**	**Actual Strength**	**Perceived Strength**
Actual Strength	Men	Mean	50	0.00 (0.92)	0.00 (0.47)
		Low	10	–**0.92** (0.35)	0.04 (0.50)
		High	10	**1.33** (0.43)	0.11 (0.40)
	Women	Mean		0.00 (0.91)	0.00 (0.37)
		Low	10	–**1.32** (0.37)	–.09 (0.28)
		High	10	**1.13** (0.32)	.21 (0.45)
Perceived Strength	Men	Mean	50	0.00 (0.92)	0.00 (0.47)
		Low	10	–0.11 (0.72)	–**0.65** (0.29)
		High	10	–0.08 (0.81)	**0.62** (0.23)
	Women	Mean		0.00 (0.91)	0.00 (0.37)
		Low	10	–**0.39** (0.82)	–**0.54** (0.18)
		High	10	**0.55** (0.99)	**0.54** (0.28)

Table S3. Correlation of handgrip and chest strength and anthropometric variables in women (above diagonal) and men (beneath diagonal).

	Handgrip strength	Chest strength	Perceived Strength	BMI	Height	Muscle Mass	Fat Mass
Handgrip strength		.65** (67)	.25* (67)	.39** (67)	.36** (67)	.55*** (57)	.47** (57)
Chest strength	.71*** (50)		.21 (67)	.33** (67)	.06 (67)	.33* (57)	.29* (57)
Perceived Strength	.16 (50)	.08 (50)		.34** (68)	.06 (68)	.34** (58)	.40** (58)
BMI	.29* (50)	.20 (50)	.41** (50)		–.07 (68)	.77*** (58)	.87*** (58)
Height	.24 (49)	.11 (.49)	.15 (49)	.15 (49)		.41** (58)	.30* (58)
Muscle Mass	.53*** (50)	.40** (50)	.39** (50)	.73*** (50)	.68*** (49)		.74*** (58)
Fat Mass	.10 (50)	.01 (50)	.29* (50)	.82*** (5 0)	.28* (49)	.55*** (50)	

Table S4. Computing facial correlates of BMI and height (Study 1b). Face-morphological scores of BMI and height were based on the differences in face shape between men/women with low and high BMI, and differences in face shape of short and tall men/women, respectively. Values are given as M (SD); significant differences (*p*<.05) between low and high prototypes are indicated in bold.

	Sex	**Prototype**	**N**	**BMI**		**Height**
				kg m^{-2}	ln(kg m^{-2})	cm
BMI	Men	Mean	50	22.7 (2.98)	3.11 (0.13)	181.3 (6.81)
		Low	10	**19.5** (0.94)	**2.97** (0.05)	181.6 (7.58)
		High	10	**26.9** (2.92)	**3.29** (0.10)	182.1 (7.59)
	Women	Mean	68	22.3 (4.11)	3.10 (.17)	166.6 (6.35)
		Low	10	**17.9** (1.41)	**2.89** (0.08)	167.5 (5.13)
		High	10	**28.7** (2.83)	**3.35** (0.10)	167.7 (4.55)
Height	Men	Mean	50	22.69 (2.98)	3.11 (0.13)	181.3 (6.81)
		Low	10	21.4 (2.78)	3.06 (.13)	**161.7** (2.67)
		High	10	22.3 (2.59)	3.10 (.12)	**173.8** (2.89)
	Women	Mean	68	22.3 (4.11)	3.10 (.17)	166.6 (6.35)
		Low	10	20.7 (2.17)	3.02 (1.0)	**180.8** (4.38)
		High	10	20.4 (2.55)	3.00 (.13)	**190.6** (4.03)

Table S5. Computing facial correlates of muscle and fat mass (Study 1c). Face-morphological scores of muscle and fat were based on the differences in face shape between men/women with low and high muscle mass/fat mass. Values are given as M(SD); significant differences (*p*<.05) between low and high prototypes are indicated in bold.

	Sex	**Prototype**	**N**	**Muscle mass**	**Fat mass**		**Height**	**BMI**
				kg	kg	ln(kg)	cm	kg m^{-2}
Muscle	Men	Mean	50	61.8 (7.28)	9.7 (5.59)	2.12 (0.58)	181.3 (6.81)	22.7 (2.98)
		Low	10	**57.4** (3.66)	7.9 (4.12)	1.96 (0.50)	181.7 (6.61)	**20.8** (2.02)
		High	10	**65.4** (4.25)	8.5 (5.34)	1.95 (0.66)	180.3 (5.48)	**23.7** (1.62)
	Women	Mean	58	43.4 (4.02)	15.7 (8.00)	2.64 (0.47)	166.6 (6.35)	22.3 (4.11)
		Low	10	**40.5** (2.41)	13.4 (4.15)	2.55 (0.33)	167.2 (3.80)	**20.0** (1.74)
		High	10	**46.6** (3.28)	15.3 (6.96)	2.63 (0.47)	167.0 (4.87)	**23.0** (3.00)
Fat	Men	Mean	50	61.8 (7.28)	9.7 (5.59)	2.12 (0.58)	181.3 (6.81)	22.7 (2.98)
		Low	10	61.2 (5.46)	**4.3** (1.24)	**1.41** (0.32)	180.4 (5.34)	**21.1** (1.84)
		High	10	63.1 (5.58)	**15.8** (4.07)	**2.73** (0.23)	181.1 (4.56)	**25.0** (2.04)
	Women	Mean	58	43.4 (4.02)	15.7 (8.00)	2.64 (0.47)	166.6 (6.35)	22.3 (4.11)
		Low	9	42.9 (3.34)	**9.1** (1.84)	**2.19** (0.21)	165.8 (5.43)	**19.7** (1.02)
		High	9	43.8 (2.42)	**21.2** (4.30)	**3.03** (0.20)	167.0 (6.03)	**24.1** (1.21)

Supplementary Figures

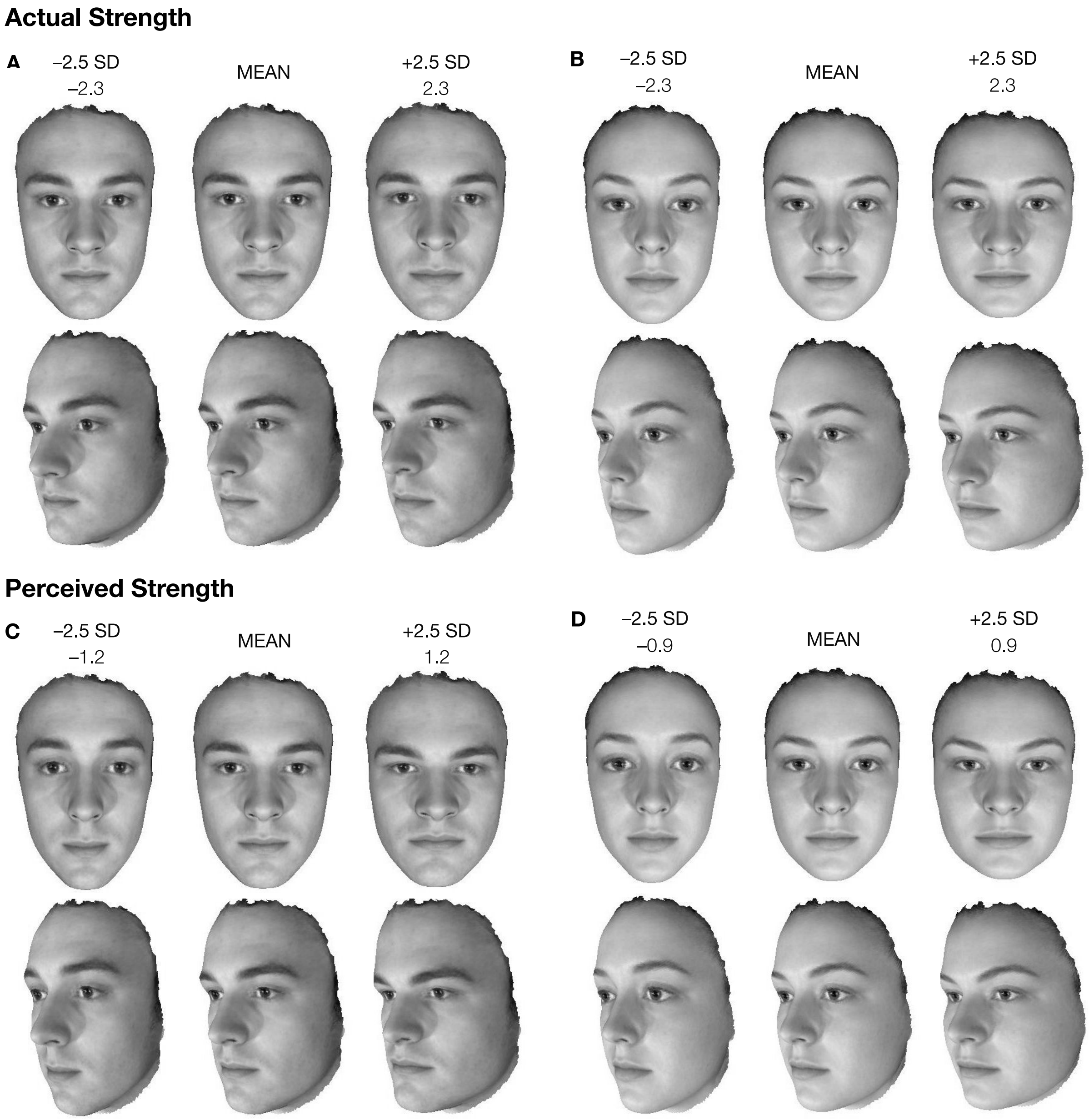


Figure SF1. Face shape associated with actual (top row) and perceived strength (bottom row). Visualizations reflect face shape associated with ±2.5 SD of actual and perceived strength in men and women, based on the difference in face shape between the 10 men (A) and women (B) scoring lowest and highest on actual strength, and the 10 men (C) and women (D) scoring lowest and highest on perceived strength (see Table S2).

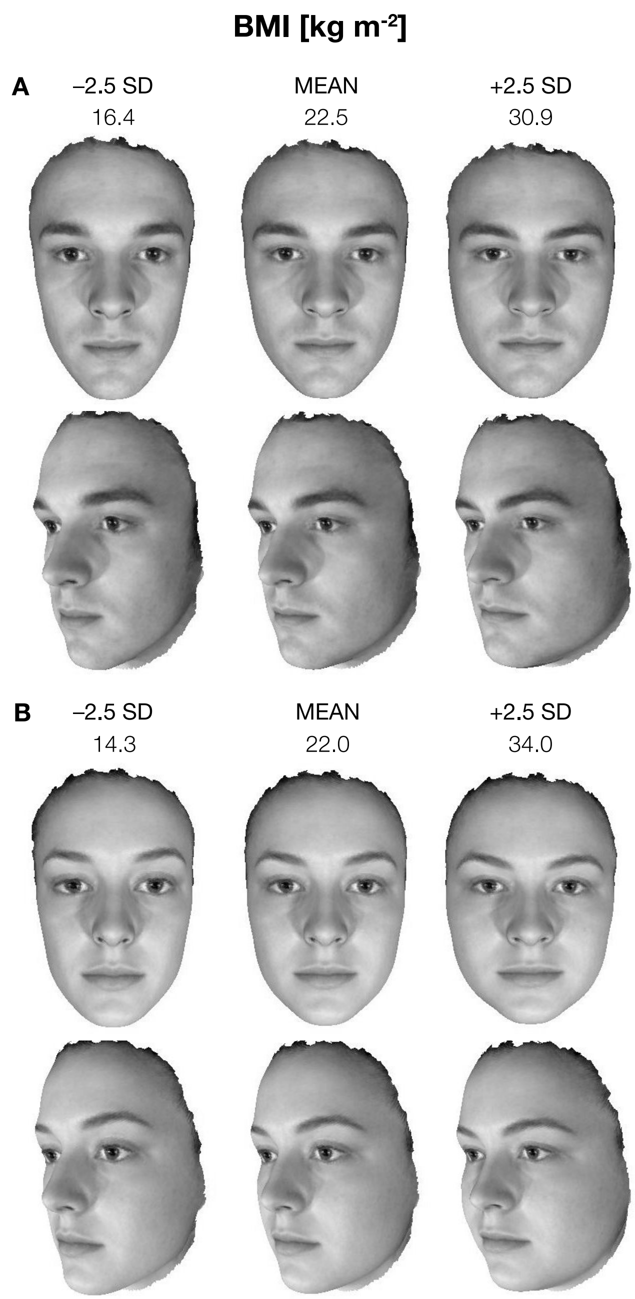


Figure SF2. Face shape associated with body mass index (BMI) in men (A) and women (B). Faces were manipulated to reflect face shape associated with the sample mean BMI ±2.5 SD based on the difference in face shape of the low and high BMI prototypes described in Table S4. Note that while calculations were based on the log-transformed variable, for the figure numerical values are given on the original scale (kg m^{-2}).

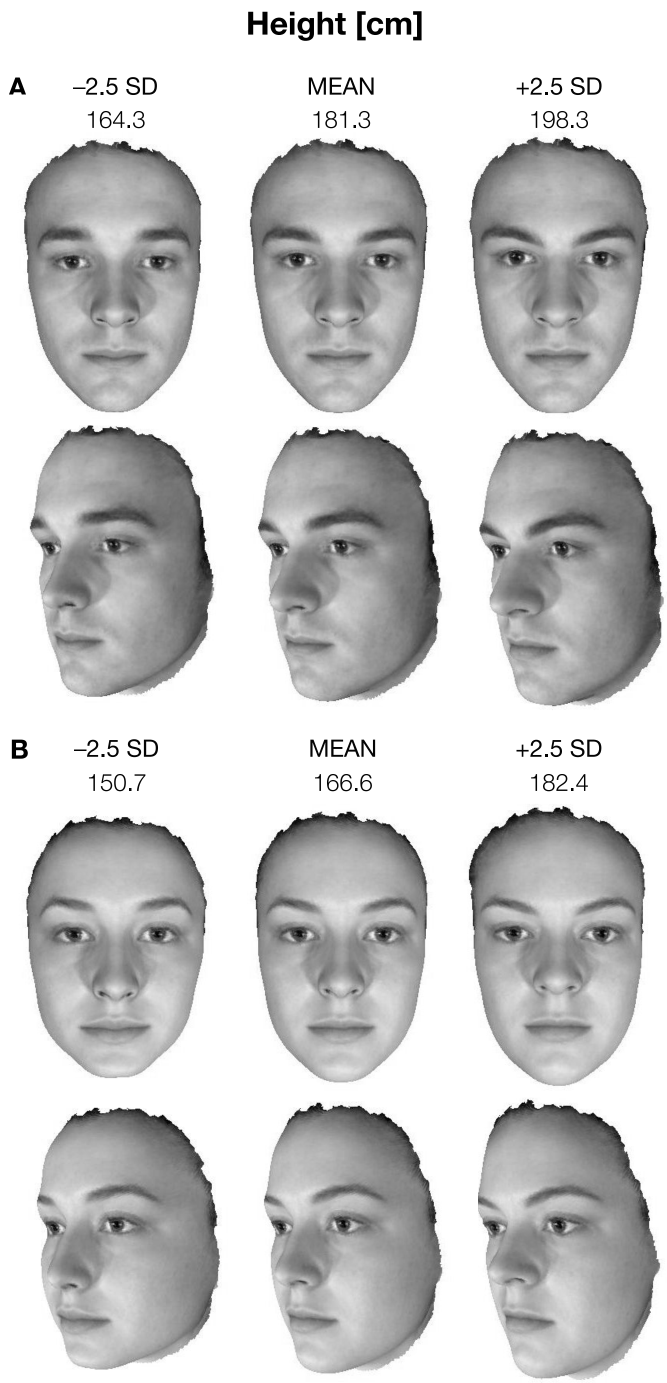


Figure SF3. Face shape associated with height in men (A) and women (B) based on the difference in face shape of the short and tall prototypes described in Table S4.

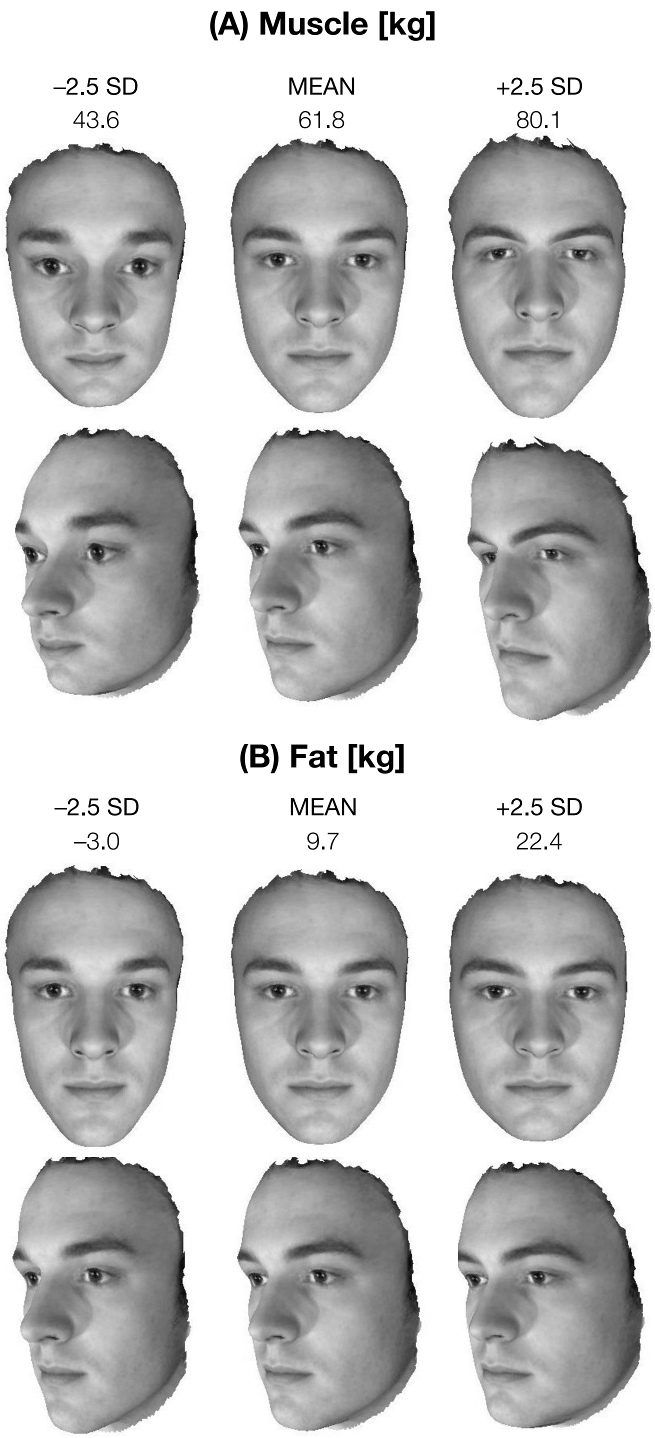


Figure SF4. Male face shape associated with muscle mass (A) and fat mass (B) based on the difference in face shape between men with low and high muscle and fat mass described in Table S5.