Perception, 2010, volume 39, pages 51 – 61

doi:10.1068/p6560

Deciphering faces: Quantifiable visual cues to weight

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Received 24 August 2009, in revised form 6 November 2009; published online 12 January 2010

Abstract. Body weight plays a crucial role in mate choice, as weight is related to both attractiveness and health. People are quite accurate at judging weight in faces, but the cues used to make these judgments have not been defined. This study consisted of two parts. First, we wanted to identify quantifiable facial cues that are related to body weight, as defined by body mass index (BMI). Second, we wanted to test whether people use these cues to judge weight. In study 1, we recruited two groups of Caucasian and two groups of African participants, determined their BMI and measured their 2-D facial images for: width-to-height ratio, perimeter-to-area ratio, and cheek-to-jaw-width ratio. All three measures were significantly related to BMI in males, while the width-to-height and cheek-to-jaw-width ratios were significantly related to BMI in females. In study 2, these images were rated for perceived weight by Caucasian observers. We showed that these observers use all three cues to judge weight in African and Caucasian faces of both sexes. These three facial cues, width-to-height ratio, perimeter-to-area ratio, and cheek-to-jaw-width ratio, are therefore not only related to actual weight but provide a basis for perceptual attributes as well.

1 Introduction

Mate choice is undoubtedly one of the most critical decisions any individual will be faced with during lifetime. Choosing a good quality partner greatly improves the number and quality of offspring we can produce. But how do we identify good quality partners? Selection favours individuals who choose partners based on physical cues that honestly signal fitness (Ryan 1997). Fitness is defined as the extent to which an organism is adapted to or able to produce offspring in a particular environment. A fitter partner will therefore enhance the individual's own reproductive success, be it through fertility, health, or parental investment. Previous research focused on four facial cues related to attractiveness: symmetry (Grammer and Thornhill 1994; Penton-Voak et al 2001; Rhodes et al 2001), averageness (Rhodes et al 2007), sexual dimorphism (Perrett et al 1998; Penton-Voak et al 2001), and skin colour/texture (Fink et al 2001; Jones et al 2004; Matts et al 2006; Stephen et al 2009). Unfortunately, the relationship between these facial cues and health is more tenuous. None of the facial cues mentioned has been consistently related to both perceived and actual health (for discussion see Coetzee et al 2009).

In a recent study, we identified the perception of weight in the face as a fifth cue to attractiveness (Coetzee et al 2009). Not only is perceived facial weight a cue to attractiveness, it is also a valid cue to health. We showed that perceived facial weight in young adults is significantly associated with both perceived and actual health, as measured by respiratory infections, use of antibiotics, and blood pressure (Coetzee et al 2009). We also showed that people are fairly accurate at judging weight using facial cues alone, with BMI explaining 43% of the variance in facial weight judgments (Coetzee et al 2009).

The question now remains, what are the proximate facial cues people use to judge weight? We specifically want to identify quantifiable facial cues to weight that are available in images. Throughout this study, weight is defined as weight scaled for height and measured by the body mass index (BMI). BMI is a widely used measure of weight, and is significantly related to attractiveness (Tovée et al 1998, 1999; Thornhill and Grammer 1999; Swami and Tovée 2005a, 2005b), health (Pi-Sunyer 1993; Manson et al 1995; Must et al 1999; Brown et al 2000; Wilson et al 2002; Mokdad et al 2003; Flegal et al 2005; Ritz and Gardner 2006), and reproductive potential (Frish 1987; Lake et al 1997). Three components contribute to BMI: fat mass, lean mass (mostly muscle mass), and frame size (Garn et al 1986).

Identifying any quantifiable cue in a 2-D facial image can be a formidable task. Potential visual cues in 2-D images are always limited, especially for weight which is essentially volumetric in nature. These limitations are amplified in the face because of the localised nature of fat distribution. A large percentage of the facial fat is localised in the buccal fat pads located in the cheek (Tostevin and Ellis 1995; Kahn et al 2000). Despite these constraints in 2-D faces, it should be possible to find quantifiable visual cues for weight, since weight is readily perceived.

1.1 *Perimeter-to-area ratio*

Previous literature offers several viable candidate cues for measuring weight in the face. Tovée et al (1999) identified the perimeter-to-area ratio as an accurate, quantifiable, cue for BMI in female bodies. They measured the perimeter-to-area ratio of 2-D female bodies (excluding the head), in front view, and found that the perimeter-to-area ratio explained more than 70% of the variance in BMI. The effect of weight on perimeter-to-area ratio can be visualised as follows: a perfectly round circle has the smallest perimeter for a given area of any 2-D shape, therefore the lowest possible perimeter-to-area ratio. Similarly, as the body increases in volume with excess weight, the area increases more than the perimeter, decreasing the perimeter-to-area ratio. Tovée et al also tested the association between BMI and eleven parallel width measures distributed evenly across the length of the torso. Most of the width measures, especially the waist width, showed a significant association with BMI in female bodies.

1.2 *Cheek-to-jaw-width ratio*

One of the most widely used facial relative width measures is cheekbone prominence. Cunningham et al (1990) defined cheekbone prominence as the difference between the width of the face at the cheekbones (cheekbone width) and the width of the face at the mouth (jaw width), divided by the length of the face. They showed a significant correlation between cheekbone prominence and attractiveness in three male Caucasian populations. A later study by Scheib et al (1999) simplified the measure of cheekbone prominence to cheekbone width divided by jaw width. They did not report individual correlates of cheekbone prominence, but instead combined cheekbone prominence with lower face length to produce a masculinity index. This masculinity index correlated significantly with attractiveness and symmetry in male faces (Scheib et al 1999). Facial measures of sexual dimorphism could be related to BMI as sex hormones influence fat, muscle, and bone ratios (Malina 2005; Blouin et al 2008). Penton-Voak et al (2001) used the same measure as Scheib et al (1999) to measure cheekbone prominence in both males and females, but did not find a significant association between cheekbone prominence, symmetry, and attractiveness in males. Crucially, however, they noticed that cheekbone prominence is smaller (ie less prominent) in males than in females. This is not to say that men do not have wider cheekbones than women. On an absolute scale, adult men do have wider cheekbones than adult women (Enlow and Hans 1996; Weston et al 2007). Cheekbone prominence, as defined by Scheib et al (1999), is a ratio measure that calculates the ratio of cheekbone width to jaw width.

Jaw width itself is a sexually dimorphic feature as adult men have wider jaws than adult women even after controlling for allometric differences in face size (Gangestad and Thornhill 2003; Thornhill and Gangestad 2006). Thus, in essence, cheekbone prominence as defined by Scheib et al is more an inverse measure of how square the face is than cheekbone prominence per se. A smaller ratio would therefore indicate a squarer face (ie smaller difference between cheekbone width and jaw width) than a larger ratio.

1.3 *Width-to-height ratio*

Another relative width measure frequently mentioned in the literature on faces is width-to-height ratio. Penton-Voak et al (2001) defined the facial width-to-height ratio as the cheekbone width divided by the lower face height (vertical distance between the outer corner of the eye and the bottom of the chin). In their study, the width-to-height ratio did not correlate significantly with symmetry or attractiveness in male faces, but was significantly different between the sexes. Women had significantly larger width-to-height ratios than men (Penton-Voak et al 2001). Gangestad and Thornhill (2003) adapted the width-to-height ratio by dividing the cheekbone width by the vertical distance between the hairline and the bottom of chin. They did not find a significant difference in this measure between the sexes. The two studies differed not only in their measure of facial height, but also their sample sizes, ethnicities, age range, and standardisation methods. In both studies the height measure included the entire lower face (including the lower jaw). Since men have significantly longer lower jaws than women (Enlow and Hans 1996; Gangestad and Thornhill 2003; Thornhill and Gangestad 2006), the height measure cannot be used to standardise cheek width.

In a recent study, Weston et al (2007) described a new width-to-height ratio from the morphometric analysis of hominin skulls. They defined the ratio as the cheekbone width divided by the upper face height (distance between the nasion and the prosthion; Weston et al 2007). This upper face region can be roughly envisioned as the distance between the upper eyelids and the most superior point of the upper lip. Unlike the lower jaw region, the upper face region is not sexually dimorphic (Enlow and Hans 1996; Weston et al 2007) and can therefore be used to standardise cheekbone width, thus providing a method of measuring relative cheekbone width (ie cheekbone width scaled for absolute size). Weston et al (2007) showed a significant difference in the width-to-height ratio between the sexes, indicating that men have significantly wider faces than women after controlling for upper face height. A later study by Carré and McCormick (2008) adapted the facial width-to-height ratio for use in 2-D facial photographs. Owing to the difficulty in identifying the prosthion and nasion in real facial photographs, they changed the upper facial height used by Weston et al (2007) to the distance between the most superior point of the upper lip and the most inferior point of the eyebrow.

The aim of study 1 is to test whether three quantitative cues (perimeter-to-area ratio, width-to-height ratio, and cheek-to-jaw-width ratio) relate to body weight (as measured by BMI). To test the universality of the relationship between these three quantitative visual cues and BMI we use both Caucasian and African images. We propose that the perimeter-to-area ratio will be inversely related to BMI, as both the buccal fat volume and the muscle volume (specifically masseter muscle volume) increase with increased weight. The cheek-to-jaw-width ratio should also inversely relate to BMI, as the increased buccal fat and masseter muscle volume should also increase the jaw width. The width-to-height ratio should increase along with BMI, as heavier individuals should also have a bigger frame size. In study 2 we want to test if these quantifiable cues relate to the perception of weight.

2 Study 1: Identification of quantifiable facial cues for weight

2.1 *Method*

2.1.1 *Participants*

Caucasian data set A. We recruited forty-three female (age: mean = 20.9 years, range = 18–24 years; BMI: mean = 22.6, range = 17.8–31.5) and forty-one male (age: mean = 21.3 years, range = 18–27 years; BMI: mean = 23.3, range = 18.4–33.4) Caucasian participants from the University of St Andrews, Scotland.

Caucasian data set B. We recruited fifty-two female (age: mean = 19.9 years, range = 18–22 years; BMI: mean = 22.3, range = 17.9–30.5) and fifty-four male (age: mean = 20.4 years, range = 18–24 years; BMI: mean = 23.4, range = 18.1–30.0) Caucasian participants from the University of St Andrews. The male participants were recruited at two different time points (first: thirty males; second: twenty-four males).

African data set A. We recruited fifty-one female (age: mean = 19.8 years, range = 18–26 years; BMI: mean = 22.1, range = 16.3–37.6) and forty-five male (age: mean = 21.2 years, range = 18–26 years; BMI: mean = 20.0, range = 16.4–29.4) African participants from the University of Pretoria and the University of the Witwatersrand, South Africa.

African data set B. We recruited forty-eight female (age: mean = 19.6 years, range = 18–24 years; BMI: mean = 24.3, range = 17.4–40.0) and forty-seven male (age: mean = 19.9 years, range = 18–29 years; BMI: mean = 20.9, range = 15.9–28.1) African participants from the University of Pretoria.

2.1.2 *Procedure*

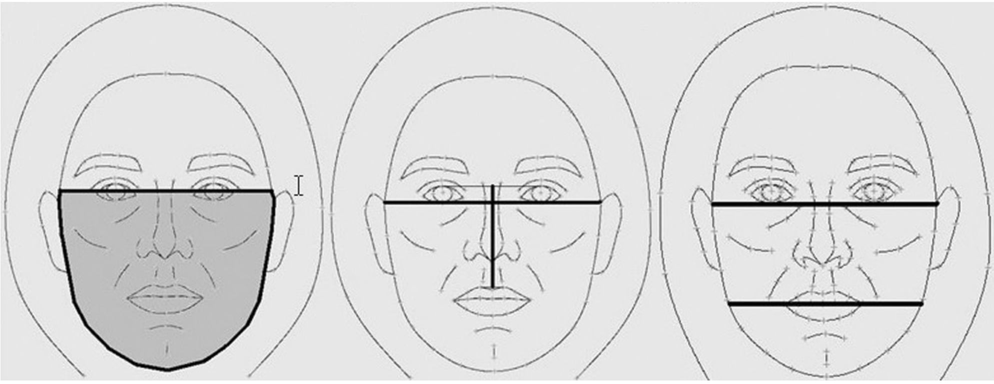
All studies were approved by the local University ethics committees, as appropriate.

All data sets. The four data sets were collected at different time points under slightly different conditions. We took facial photographs of all the participants in full colour and under standard lighting conditions. Participants were seated a set distance from the camera, asked to maintain a neutral expression, and had their hair pulled back. Each participant gave informed consent to take part in this study, completed a questionnaire containing questions on gender, age, and ethnicity, and had his/her weight and height measured. Weight and height measures were used to calculate BMI [(weight in kilograms)/(height in metres)^2] and BMI categories were assigned according to WHO (1999) criteria. BMI data were missing for one female participant in Caucasian data set A and one male participant in African data set B.

Each facial image was manually delineated by defining 179 feature points, and aligned according to interpupillary distance in PsychoMorph 8.4.7.0 (Benson and Perrett 1993). This procedure standardises for head size.

2.1.3 *Shape cue assessment*

All data sets. Perimeter-to-area ratio was calculated for the lower half of the face for each image by using in-house software. We specifically focused on the lower half of the face because the buccal fat pads are located in this region (Tostevin and Ellis 1995; Kahn et al 2000). The perimeter was thus defined as the path along the horizontal line connecting the pupils and the perimeter of the face below the intersection with the interpupil line (figure 1a). The area was defined as the area within this boundary (figure 1a). The second measure, width-to-height ratio, was calculated as the horizontal distance between the two most lateral facial points (bizygomatic width or cheekbone width) divided by the vertical distance between the most inferior point of the upper eyelid and the most superior point of the upper lip (upper facial height; figure 1b). This measure is similar to the width-to-height ratio defined by Carré and McCormick (2008) and measures the relative width of the face. The third measure, cheek-to-jaw



(a) (b) (c)

Figure 1. Measures used to calculate facial cues. (a) Perimeter-to-area ratio: the perimeter is indicated in bold and the area as the shaded area within the perimeter. (b) Width-to-height ratio: cheekbone width divided by upper facial height (both indicated in bold). (c) Cheek-to-jaw-width ratio: cheekbone width divided by jaw width.

width, was calculated as the cheekbone width divided by the horizontal distance between the lateral points of the face along the midline of the lips (jaw width; figure 1c). We were unable to identify the necessary landmarks for perimeter-to-area ratio measurements in six individuals (Caucasian A: five male; Caucasian B: one male) and cheek-to-jaw-width ratio measurements in seven individuals (Caucasian A: two female; Caucasian B: one female, three male; African B: one male) because of facial hair covering the facial contours or slight lateral tilting of the face. These individual measures were therefore excluded from the study.

2.2 *Results*

2.2.1 *Female images.* Each female data set was analysed separately. Skewness and kurtosis were low for all measures ($-0.7 <$ skew and kurtosis > 1.1), except for: the BMI measures of Caucasian data set B (skew 1.2, kurtosis 2.4) and African data set A (skew 1.6, kurtosis 2.1); the perimeter-to-area ratio measures of African data set A (kurtosis 2.3); the width-to-height measures of African data set A (kurtosis 2.3); and the cheek-to-jaw-width measures of Caucasian data sets A (kurtosis 1.3) and B (kurtosis 1.9). Conventional logarithmic and square-root transformations could not successfully normalise the non-normal distributions, but reverse coding and power transformation (power 3) successfully normalised all the non-normal distributions ($-0.7 <$ skew and kurtosis > 0.8), except for the perimeter-to-area ratio and width-to-height measures of African data set A, so Spearman's correlations were used for this data set. Pearson's correlations were used for all other analyses. All correlations were two-tailed. For ease of interpretation, we report the sign of the correlation coefficient, appropriate to original data, in cases where there was reverse coding. We identified four influential outliers (leverage > 0.2). Throughout this study, results are reported both before and after the removal of outliers in cases where their removal influenced the statistical significance.

Width-to-height ratio correlated significantly with BMI in three of the four female data sets (table 1). In the fourth data set, African A, width-to-height ratio correlated with BMI before ($r_{51} = 0.31$, $p = 0.028$), but not after the removal of one influential outlier, although a trend was evident (table 1). The perimeter-to-area ratio did not correlate significantly with BMI in any of the data sets. The cheek-to-jaw-width ratio correlated significantly with BMI in two of the four populations, while it tended to correlate with BMI in the third population (table 1).

Table 1. Correlations showing the relationship between BMI and the three quantifiable facial cues in four populations. The bottom section reports the results for the meta-analyses. Significant correlations are indicated in bold. All correlations are two-tailed. $^{\delta}p \leqslant 0.1$; $^{*}p \leqslant 0.05$; $^{**}p < 0.01$; $^{***}p < 0.001$; $^{****}p < 0.0005$.

Population	Female images			Male images		
	width-to-height	perimeter-to-area	cheek-to-jaw-width	width-to-height	perimeter-to-area	cheek-to-jaw-width
Caucasian A	**0.48*****	−0.10	**−0.48****	**0.33***	**−0.38***	−0.31$^{\delta}$
Caucasian B	**0.39*****	0.09	−0.11	0.12	−0.08	−0.11
African A	0.27$^{\delta}$	−0.23	**−0.33***	0.15	**−0.31***	−0.10
African B	**0.33***	−0.23	−0.25$^{\delta}$	0.10	−0.16	**−0.31***
Meta-analyses	**0.36******	−0.12	**−0.29******	**0.17***	**−0.22****	**−0.20****

To test the overall association between these three measures (width-to-height ratio, perimeter-to-area ratio, cheek-to-jaw-width ratio) and female BMI we performed fixed model meta-analyses in Comprehensive Meta-analysis v2.2.048 (Borenstein et al 2005). Data sets were weighted by their respective sample sizes. The meta-analyses indicated that overall both width-to-height ratio and the cheek-to-jaw-width ratio correlated significantly with BMI, while the perimeter-to-area ratio did not (table 1). The degree of multicollinearity between the three measures was fairly low (condition index < 2) with high tolerance values (width-to-height: 0.75; perimeter-to-area: 0.83; cheek-to-jaw-width: 0.67), indicating a high degree of independence between the three measures. Heavier women therefore had significantly wider (ie larger width-to-height ratio) and squarer (ie smaller cheek-to-jaw-width ratio) faces than lighter women. The heavier women did not have significantly rounder lower faces (ie smaller perimeter-to-area ratio) as expected, but a trend was evident.

2.2.2 *Male images.* Skewness and kurtosis were low for all measures ($-0.7 <$ skew and kurtosis > 1.1), except for: the BMI measures of Caucasian data set A (skew 1.2, kurtosis 3.5) and African data set A (skew 1.3, kurtosis 2.1); and the width-to-height measures of African data set A (skew 1.8, kurtosis 5.7) and African data set B (kurtosis 3.0). Reverse coding and power transformation (power 3) successfully normalised all non-normal distributions ($-0.8 <$ skew and kurtosis > 0.8). Pearson's correlations were used for all four data sets. All correlations were two-tailed.

The results were less straightforward for the males than for the females. Width-to-height ratio correlated significantly with BMI in only one of the four male populations (table 1). The perimeter-to-area ratio correlated significantly with BMI in two of the four populations (table 1), while the cheek-to-jaw-width ratio measure correlated significantly with BMI in only one population and showed a tendency to correlate with BMI in another (table 1). Despite the lack of significance, width-to-height ratio, perimeter-to-area ratio, and cheek-to-jaw-width ratio did show a consistent direction of relationships with BMI in all four populations (table 1).

All three measures significantly correlated with male BMI in the meta-analyses (table 1). Low multicollinearity (condition index < 2.2) and high tolerance values (width-to-height: 0.72; perimeter-to-area: 0.57; cheek-to-jaw-width: 0.75) indicated a high level of independence between the three measures. Heavier men therefore had significantly wider and squarer faces, with significantly rounder lower faces than lighter men.

2.3 *Discussion*

The aim of this study was to find quantifiable cues to BMI, in 2-D facial images. Perimeter-to-area ratio, width-to-height ratio, and cheek-to-jaw-width ratio relate to BMI in both Caucasian and African faces. In the females, width-to-height ratio and cheek-to-jaw width ratio consistently, and significantly, relate to BMI, with heavier women having significantly wider and more square faces than lighter women. Perimeter-to-area ratio did not significantly relate to female BMI in the meta-analyses, although it did show a consistent, albeit not significant, relationship with BMI in three of the four populations. It might therefore be slightly premature to exclude perimeter-to-area ratio as a weak cue to BMI in female faces. The relationship between these three quantifiable cues (width-to-height ratio, perimeter-to-area ratio, and cheek-to-jaw-width ratio) and BMI was more irregular in the individual male populations than in the individual female populations, but overall all three measures were significantly related to BMI in the combined meta-analysis. Similar to the females, heavier men therefore also have significantly wider and squarer faces than lighter men. In addition, heavier men have significantly rounder lower faces than lighter men. Both the African and Caucasian populations showed similar associations between these measures and BMI, indicating that these might be cross-culturally invariant facial cues to BMI. In the next study we test whether these cues relate to perceptual judgments of weight.

3 Study 2: The role of facial cues in the perception of weight

3.1 *Method*

3.1.1 *Participants*

Raters of Caucasian set A. Twenty-six Caucasian participants (fourteen female; mean age = 22.6 years, range = 21–24 years; twelve male; mean age = 23.0 years, range = 20–28 years) previously unfamiliar with the images rated each female image for perceived weight on a seven-point Likert scale (0 = very underweight; 3 = average weight; 6 = very overweight). Another group of twenty-nine Caucasian participants (seventeen female; mean age = 20.7 years, range = 19–23 years; twelve male; mean age = 20.8 years, range = 19–26 years) rated each male facial image for weight on the same scale. Participants were shown all the images before rating commenced to make them aware of the range and variability of the images. Images were presented in a randomised order and participants were asked to indicate whether or not they knew the rated individual; if they did, rating data were excluded (5.8% of ratings). We recorded the time it took the participants to rate each image and excluded all participants with an average time of less than 1.65 s per question, for two or more images (three females). The threshold value was defined by the maximum time it took the experimenter to select random answers as quickly as possible and included submission time. Full details on the ratings of Caucasian set A are available in Coetzee et al (2009). Perceived weight ratings did not differ significantly between male and female raters for male ($\rho = 0.98$) and female images ($\rho = 0.48$). Data from both sexes were therefore combined in the analysis. Inter-rater reliability was very high (Cronbach $\alpha = 0.91$). Given the consistency of ratings, the scores were averaged across participants for each of the 84 images.

Raters of Caucasian data set B. Since we observed no significant difference in weight ratings between the sexes in the previous population, we recruited a new convenience sample of thirty-five participants (thirty-one female; four male; mean age = 19.7 years, age range = 18–22 years) from the University of St Andrews to rate the female images and the first thirty male images for weight. A further thirty-five participants were recruited (thirty-one female; four male; mean age = 19.65 years, age range = 18–22 years) from the University of St Andrews to rate the remaining twenty-four male images for weight. The methods were identical to those used in the previous data set. We excluded six participants who fell below the threshold value for time. Inter-rater reliability was high (Cronbach $\alpha = 0.86$).

Raters of African data set. We recruited another thirty-three participants (twenty-six female; seven male; mean age = 20.2 years, age range = 18–27 years) from the University of St Andrews to rate the data set for weight. The methods were identical to those described for Caucasian data set A. We excluded three participants who fell below the threshold value for time. Inter-rater reliability was very high (Cronbach $\alpha = 0.94$).

All three studies were approved by the University of St Andrews ethics committee. African data set B was not rated for perceived weight.

3.2 *Results*

3.2.1 *Female images.* Each female data set was analysed separately. Skewness and kurtosis were low for all perceived weight distributions ($-0.4 <$ skew and kurtosis > 0.5); the other measures were treated as in study 1. We identified four influential outliers (leverage > 0.2). Throughout this study, results are reported both before and after the removal of outliers in cases where their removal influenced the statistical significance.

Width-to-height ratio correlated significantly with perceived weight in all three female populations (table 2). Perimeter-to-area ratio also correlated significantly with perceived weight in all three populations (table 2). The cheek-to-jaw-width ratio correlated significantly with perceived weight in two of the three populations (table 2).

Table 2. Correlations showing the relationship between perceived weight and the three quantifiable facial cues in four populations. The bottom section reports the results for the meta-analyses. Significant correlations are indicated in bold. All correlations are two tailed. $^{\delta}p \leqslant 0.1$; $^{*}p \leqslant 0.05$; $^{**}p < 0.01$; $^{***}p < 0.001$; $^{****}p < 0.0005$.

Population	Female images			Male images		
	width-to-height	perimeter-to-area	cheek-to-jaw-width	width-to-height	perimeter-to-area	cheek-to-jaw-width
Caucasian A	**0.50*****	**−0.34***	**−0.61******	**0.49*****	**−0.38***	**−0.44****
Caucasian B	**0.30***	**−0.33***	−0.14	0.25$^{\delta}$	**−0.29***	**−0.34***
African	**0.50******	**−0.43****	**−0.70******	**0.52******	**−0.41****	**−0.52******
Meta-analyses	**0.43******	**−0.37******	**−0.51******	**0.43******	**−0.36******	**−0.43******

To test the overall association between these three measures (width-to-height ratio, perimeter-to-area ratio, and cheek-to-jaw-width ratio) and perceived weight we performed fixed model meta-analyses in Comprehensive Meta-analysis v2.2.048. The meta-analyses indicated that overall all three measures correlated significantly with perceived weight (table 2). Low multicollinearity (condition index < 2.0) and high tolerance values (width-to-height: 0.75; perimeter-to-area: 0.60; cheek-to-jaw-width: 0.82) indicated a high level of independence between the three measures. Women with relatively wider, squarer faces, and rounder lower faces, were perceived as being more overweight than women who did not have these characteristics.

3.2.2 *Male images.* Skewness and kurtosis were low for all perceived weight measures ($-0.5 <$ skew and kurtosis > 0.7); the other measures were treated as in study 1. We identified one influential outlier (leverage $= 0.42$).

Width-to-height ratio correlated significantly with perceived weight in two of the three male populations, while it tended to correlate with perceived weight in the third population (table 2). The perimeter-to-area ratio correlated with perceived weight in all three populations (table 2), while the cheek-to-jaw-width ratio measure also correlated with perceived weight in all three populations (table 2).

The meta-analyses indicated that overall all three measures correlated significantly with perceived weight (table 2). Low multicollinearity (condition index < 2.3) and fairly high tolerance values (width-to-height: 0.67; perimeter-to-area: 0.57; cheek-to-jaw-width: 0.75) indicated a high level of independence between the three measures. Men with relatively wider, squarer faces, and rounder lower faces, were perceived to be more overweight than men without these characteristics.

3.3 *Discussion*

In this study we showed a strong association between the three quantifiable shape cues identified in study 1 (width-to-height ratio, perimeter-to-area ratio, and cheek-to-jaw-width ratio) and perceived weight. People use these cues, or highly related ones, to judge weight. In both males and females individuals with wider, squarer faces and rounder lower faces are judged to be heavier than individuals with narrower, less square faces and less round lower faces. Interestingly, perimeter-to-area ratio is not significantly related to BMI in female faces, yet people still use it to judge weight. One plausible explanation for this is that people over-generalise by taking cues which are relevant elsewhere (ie in the body) and using them in the face.

4 General discussion

There were two main aims in this study. First, we wanted to identify quantifiable shape cues to BMI in 2-D facial images. Second, we wanted to determine if these cues are used in the perception of weight. We accomplished both aims.

In study 1, we identified three largely independent quantifiable cues that are closely related to BMI in African and Caucasian faces. Two of the cues, width-to-height ratio and cheek-to-jaw-width ratio, were significantly related to BMI in both male and female faces. The third cue, perimeter-to-area ratio, was significantly related to weight in male, but not in female, faces. We predicted that perimeter-to-area ratio and cheek-to-jaw-width ratio will decrease with increased BMI owing to the increased buccal fat and masseter muscle volume. We also predicted that heavier individuals will have bigger frame sizes and therefore increased width-to-height ratios than lighter individuals. As a whole, our results support these predictions, but future studies should test the associations between buccal fat volume, masseter muscle volume, frame size, and BMI directly.

In study 2, we showed that people use these cues, or highly related ones, to judge weight. All three cues, width-to-height ratio, perimeter-to-area ratio, and cheek-to-jaw-width ratio, were very closely related to people's perception of weight in men and women, African and Caucasian. In fact, these cues were more closely related to perceived weight than to real weight. There are two plausible explanations for this. First, perceived weight might be based more on the percentage body fat while BMI is defined by body fat, muscle mass, and frame size. If these cues are more closely related to body fat than to muscle mass and frame size, one would expect perceived weight to be more closely correlated with percentage body fat than BMI. Second, individuals might be using these shape cues because they are more easily processable than other potential volumetric weight cues (shading for instance).

Our study focuses on facial cues to weight. In real life, body and facial information occur in conjunction, which may restrict generalisation from the results presented here. Ratings of female images without clothing or with standardised clothing indicate that bodily and facial cues to attractiveness intercorrelate (Thornhill and Grammer 1999; Peters et al 2007), but that the face and body cues provide independent contributions to overall attractiveness in both sexes (Peters et al 2007). Since the cues from the face and body contribute independently to overall attractiveness, it is not unreasonable to study them separately. Of course, in normal situations cues from the body are obscured by clothing, whereas for faces such confounds are reduced.

In summary, we identified three quantifiable facial cues that are both significantly related to actual weight and are used to judge weight. Two of these cues, cheek-to-jaw-width ratio and width-to-height ratio, were described as facial measures of sexual dimorphism by past research. BMI might therefore explain at least part of the interaction between sexual dismorphism and attractiveness observed in previous studies.

Acknowledgments. We thank Lesley Ferrier for her help with data collection and Anne Perrett for proofreading the manuscript.

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ISSN 0301-0066 (print) ISSN 1468-4233 (electronic)

PERCEPTION

VOLUME 39 2010

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