Human Female Attractiveness: Waveform Analysis of Body Shape

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ABSTRACT

Two putative cues to female physical attractiveness are Body Mass Index (BMI) and shape (particularly the Waist-Hip Ratio or WHR). To determine the relative importance of these cues we asked 23 male and 23 female undergraduates to rate a set of 60 pictures of real women's bodies in front-view for attractiveness. In our set of images, the relative ranges of BMI and WHR favoured WHR. We based these ranges on a sample of 457 women. We did not limit the WHR range, although we kept the BMI range to 0.5 s.d. either side of the sample means. As a result, WHR averaged 1.65 s.d. either side of its sample mean. However, even with these advantages, WHR was less important than BMI as a predictor of attractiveness ratings for bodies. BMI is far more strongly correlated with ratings of attractiveness than WHR (BMI ~ 0.5, WHR ~ 0.2). To further explore the relative importance of BMI and WHR, we deliberately chose a sub-set of these images that demonstrated an inverse correlation of BMI and WHR (i.e. a group in which as images get heavier they also become *more* curvaceous). If WHR is the most important determinant of attractiveness, then the more curvaceous (but higher BMI) images should be judged most attractive. However, if BMI is a better predictor, then the opposite should be true. We found that the more curvaceous (but higher BMI) images were judged least attractive, thereby inverting the expected rating pattern. This strongly suggests that viewers' judgements were influenced more by BMI than WHR. Finally, it is possible that body shape is an important cue to attractiveness, but that simple ratios (such as WHR) are not adequately capturing it. So we treated the outline of the torso as a waveform and carried out a set of three waveform analyses on it to allow us to quantify body shape and correlate it against attractiveness. The waveform analyses address the complexity of the whole torso shape, and pull out innate properties of the torso shape and not shape elements based on prior decisions about arbitrary physical features. Our analyses decompose the waveform into objective quantified elements whose importance in predicting attractiveness can then be tested. All of the components that were good descriptors of body shape were weakly correlated with attractiveness. Our results suggest that BMI is a stronger predictor of attractiveness than WHR.

INTRODUCTION

One of the most fundamental problems for any organism is mate selection. It is vitally important that we are sensitive to the physical cues that honestly signal that one individual is more desirable (i.e. fitter and with a better reproductive potential) than another, and use them to choose the partner who is most likely to enhance our chances of successful reproduction. In women, two potentially critical factors are shape and weight scaled for height (kg/m^2). This latter factor is called the Body Mass Index or BMI (Bray, 1978).

For shape in women, research has focused on the ratio of the width of the waist to the width of the hips (the waist-hip ratio, or WHR). A low WHR (i.e. a curvaceous body) is suggested to correspond to the optimal fat distribution for high fertility (Zaadstra et al., 1993; Wass et al., 1997), and so this shape should be highly attractive. This suggestion is supported by studies that have asked subjects to rate for attractiveness a set of line-drawn figures of women's bodies (Singh, 1993a,b, 1994a,b, 1995; Henss, 1995; Furnham, Tan & McManus, 1997). The line-drawn figures are arranged in three series: underweight, normal and overweight. Within each series, the WHR is varied by altering the torso width around the waist. The problem with this approach is that when the figures are modified by altering the width of the torso around the waist, this not only alters the WHR, but also the apparent BMI. As the value of the WHR rises, so does that of the apparent BMI, and so it is not possible to say whether changes in attractiveness ratings are made on the basis of WHR or BMI, or both (Tovée & Cornelissen, 1999; Tovée et al., 1999). This problem is also found in studies using edited photographic images of women, where their WHR has been artificially altered by thickening or narrowing their torsos (Henss, 2000). Altering the torso width, also altered their apparent body mass. So once again, the WHR and BMI were co-varied.

Multivariate analysis of the attractiveness ratings for unaltered photographic images of real women suggests that although both WHR and BMI are significant predictors of female attractiveness, BMI is a far more important factor than WHR (Tovée et al., 1998, 1999; Tovée & Cornelissen, 2001). It is not simply that this paradigm is insensitive to shape cues, as when women are asked to rate male images in the same format and under the same experimental conditions, the primary determinant of male attractiveness is upper body shape – specifically waist-chest ratio (Maisey, Vale, Cornelissen & Tovée, 1999). The finding that BMI may be the primary determinant of female attractiveness is consistent with the fact that successful female fashion and glamour models all fall within a narrow BMI range (e.g. Tovée et al., 1997). It is well established that changes in BMI also have a strong impact on health (Manson et al., 1995; Willet et al., 1995) and reproductive potential (Reid & Van Vugt, 1987; Frisch, 1988; Lake et al., 1997). So a mate choice strategy based on BMI also favours reproductive success.

However, although these latter results suggest that the primary cue for attractiveness is BMI, the issue is far from clear-cut. The study by Tovee et al (1999) used the widest range of BMI and WHR values available. Therefore, one objection is that the relative ranges of BMI and WHR were unequal, and that the apparent importance of BMI in this study is due to a greater relative variation in this parameter than in WHR. This would exaggerate the relative importance of BMI. To address this problem, in Experiment 1, we use images of female bodies where the range of BMI values is strictly controlled. Based on an opportunistic sample of 457 women, we calculate a sample mean and s.d. for BMI and WHR. We then select stimulus images such that the BMI range was held 0.5 s.d. either side of the sample mean, but the WHR range remained unrestricted. As a result the WHR range was on average 1.65 s.d. either side of its sample mean, thereby giving WHR an advantage in the relative ranges of these two attributes.

Another approach to determining whether BMI is a more powerful determinant of attractiveness than WHR is to disturb the natural relationship between the two, and present raters with a reverse correlated image set. Normally, BMI and WHR tend to be positively correlated in the female population (i.e. women with a higher BMI tend to have a less curvaceous shape). This is reflected in the sets of images used in previous studies (e.g. Tovée et al., 1998; Thornhill & Grammar, 1999) and in the set used in Experiment 1 below. In Experiment 2, we deliberately chose a set of photographic images that demonstrated an inverse correlation between BMI and WHR - i.e. a group in which as the women in the images get heavier, they also become *more* curvaceous. If WHR is the most important determinant of attractiveness, then the more curvaceous (but higher BMI) images should be judged most attractive. However, if BMI is a better predictor, then the opposite should be true. It can be reasonably argued that the BMI and WHR of the women in this set of images are not representative of the population as a whole, but with that borne in mind, the results may be informative as to the relative “strengths” of WHR and BMI in determining judgements of attractiveness.

Finally, one reason why shape cues, such as WHR, seem to be relatively unimportant may be that simple ratios do not adequately capture the complexity of body shape. For example, take the shape of the lower half of the torso. If we think of this as a curve, running from the waist to the top of the thigh, the WHR samples this curve at only two points. This hardly seems an adequate description of the potential variability in the shape of the curve. To more adequately characterise body shape, we took measures of body size at 68 equally spaced positions on the torso and legs. Plots of these size measures against slice position represent body shape as a waveform, which is amenable to analysis by techniques such as Fourier Analysis (FA), Principal Component Analysis (PCA) and Independent Component Analysis (ICA). This can be used to deconstruct the waveform into its constituent parts and their individual role in accounting for attractiveness ratings can be explored.

METHOD

Image measurements

WHR can be measured in two ways. There is the *actual* WHR (or WHR_{actual}), which is the distance *around* the waist divided by the distance around the hips. This is the WHR measure that some studies have correlated with female fertility (Zaadstra et al., 1995; Waas et al., 1997). WHR can also be taken from a woman’s image by measuring the distance *across* the waist and dividing it by the distance *across* the hips (*front* WHR or WHR_{front}). The difference between the two is important. *Actual* WHR is the physical feature that has been linked to fertility; WHR_{front} is just the visual cue to this. If we are trying to correlate physical attractiveness to features that are linked to health and fertility, we must ultimately link attractiveness to WHR_{actual}, rather than its visual cue in the same way that we must link attractiveness to BMI and not one of its visual cues. The same is true of other physical features such as Waist-Chest Ratio. For Experiments 1 and 2, we use both the actual and front-view shape measures to allow comparison of the visual cue and its physical correlate.

We measured of the height and weight of each of the women in the images. From this we calculated their BMI (their weight (kg) divided by the square of their height (m)) (Bray, 1978). When we refer to BMI subsequently in the paper, we do mean the BMI of the women and not one of the visual cues to BMI such as the Perimeter-Area Ratio or PAR (Tovée & Cornelissen, 1999).

Experiment 1: The Restricted BMI Range

We asked 23 male and 23 female undergraduate observers (mean female age: 23.0 years, s.d. 3.1; mean male age 21.4, s.d. 2.7) to rate colour images of 60 real women in front-view. To generate the images, digital photographs were taken of consenting women standing in a set pose at a standard distance, wearing tight grey leotards and leggings in front-view. The faces of the women in our body images were obscured (for examples of the image format used in this study see Tovée at al., 1999, 2000; Tovée & Cornelissen, 2001).

In this experiment we wanted to make sure that the relative range of variation in WHR was considerably greater than the variation in BMI. We therefore used the WHR and BMI data from a sample of 457 women in Newcastle (reported in Tovée et al., 1999) to calculate the sample means and the standard deviations for these parameters. These women were all recruited in Newcastle and the surrounding area, mainly from the staff and students of the Newcastle Medical School. They ranged in age from 18 to 45 (mean age 26.1 years, s.d. 6.7). The BMI and WHR_{actual} ranges from this population is similar to values reported by other population studies such as that by Marti et al. (1991). We then chose images within the BMI range of 0.5 s.d. either side of its sample mean, which corresponds to BMI values of 18.0 to 25.8. We did not constrain the WHR range: it was 0.66 to 0.84, representing 1.9 s.d. below the sample mean and 1.4 s.d. above the sample mean. By weighting the image statistics in favour WHR, we expected that its power to predict attractiveness should be enhanced.

Subjects were encouraged to use the whole range of attractiveness ratings from 0 (least attractive) to 9 (most attractive). The images were rated individually. The 60 body images were presented in a randomised order, and subjects were presented with the entire set twice. The first run through was used to make subjects aware of the range of variability of body features represented in the images. Only on the second run through were subjects asked to rate them.

Experiment 2: Negatively Correlated ranges of WHR and BMI

The BMI values were again restricted to within 0.5 s.d either side of the sample mean and the WHR range left uncontrolled. This produced a WHR_{actual} range of 1.0 s.d. either side of its sample mean (a range of 0.67-0.80 with a mean of 0.73, s.d. 0.03; and a WHR_{front} range of 0.68-0.82 with a mean of 7.38, s.d. 0.03) and a BMI range of 18.4-26.5 (a mean of 21.9, s.d. 2.1). The images showed an inverse correlation of r= -0.66 ($p<0.0001$) between BMI and WHR_{actual} (see fig. 2a), and an inverse correlation of r=-0.39 ($p<0.0001$) between BMI and WHR_{front}. As previously mentioned, the correlation between WHR_{actual} and WHR_{front} is only around 0.6 (in the case of this image set, r=0.61, $p<0.0001$), and so the correlation between BMI and the two forms of WHR will differ. The images were rated by 20 male and 20 female observers (average age male observers 22.8 (s.d. 3.1); average age female observers 21.8 (s.d. 3.2). The procedures were otherwise as in experiment 1.

RESULTS

Experiment 1: The Restricted BMI Range

In this study, we ask to what extent do biometric features, like BMI and WHR predict the attractiveness of individual images. Therefore, the relevant unit of analysis is the mean attractiveness rating for each image. Before pooling the rating data for each image, we confirmed that the data were indeed reliable across all observers: Cronbach's $\alpha = 0.97$ and Winer's reliability for k means is 0.95. Moreover, the Pearson correlation between mean attractiveness ratings for each image, calculated separately from male and female raters was r= 0.93 ($p<0.0001$). This is consistent with our previous studies (e.g. Tovée & Cornelissen, 2001) and suggests that there are no gender difference in the relative ranking of female images.

BMI and mean attractiveness ratings are well correlated (Pearson Correlation, r= -0.53, $p<0.0001$). A plot of this relationship shows that over this range of BMI values the relationship is linear (figure 1b). Attractiveness and WHR_{actual} are not correlated (r=-0.21, p=0.100), but attractiveness and WHR_{front} are weakly correlated (r=-0.32, $p<0.05$). Plots of these relationships are shown in Figure 1c & d. Attractiveness ratings are not significantly correlated with either WCR_{actual} (*actual* Waist-Chest Ratio), or with WCR_{front} (*front* WCR) (at the $P<0.05$ level of significance)].

We used the regression procedure in SAS (SAS Institute Inc., North Carolina, US) to estimate the variance in attractiveness ratings explained by BMI, WHR and WCR. The dependent variable in the multiple regression model was the mean attractiveness rating for each image, as judged by the observers. The same model was run twice, substituting WHR/WCR 'actual' for 'front':

$$y = b1x1 + b2x2 + b3x3 + b3x3 + b4x4 + c$$

Where: y = mean attractiveness rating per image, b1x1 = BMI (centred), b2x2 = WHR (centred), b3x3 = WCR (centred), b4x4 = age of woman in image (centred)

Each model was optimised according to three criteria: 1) Mallow's Cp statistic was minimised, 2) R^2 was maximised and 3) explanatory variables in the model had to be significant at $p<0.05$. The output from the two models is shown in Table 1. In both models the BMI of the women in the images explained 27% of the variance in attractiveness ratings. In contrast, only WHR_{front} had a small (5%) and marginally significant effect.

**************************Table 1 about here ********************************

Although, the main effects of WHR were negligible in these analyses, we nevertheless asked whether WHR_{front} or WHR_{actual} might have a differential effect on attractiveness rating depending on the BMI of the woman in the image. Accordingly, we sought significant interaction terms between BMI and WHR. To do this, we dummy coded BMI, WHR_{front} and WHR_{actual} according to their quartile ranges, and re-ran the models above (excluding WCR) using the GLM procedure in SAS. While these models accounted for 41% (model including WHR_{actual}) and 45% (model including WHR_{front}) of the variance in attractiveness respectively, no significant interaction terms were found. Therefore, we conclude that neither was there a main effect of WHR nor a significant modulation by WHR of the BMI effect.

Experiment 2: Negatively Correlated ranges of WHR and BMI

Across all raters, Cronbach's α =0.95 and the Winer reliability for k means is 0.92, suggesting good reliability at an 'image' level of analysis. Again, there is good agreement on average between male and female observers about which are the most and which the least attractive images ($r = 0.91$, $p<0.0001$), and we have again pooled our male and female data.

BMI and mean attractiveness ratings are well correlated ($r = -0.72$, $p<0.0001$), as can be seen in Fig. 2a. Attractiveness is correlated with WHR_{actual} ($r=-0.60$, $p<0.0001$), and with WHR_{front} ($r=0.32$, $p<0.05$). Figures 2(b) and (c) clearly show that the more curvaceous (but higher BMI) images were judged least attractive, thereby inverting the expected rating pattern. This strongly suggests that viewers' judgements were influenced more by BMI than WHR. Attractiveness ratings are not significantly correlated with either WCR_{actual}, or with WCR_{front} (at the $P<0.05$ level of significance)).

*************************Fig. 2 about here*************************

To quantify these effects, we ran the following multiple regression model twice, once for WHR 'actual' and the second time for WHR 'front':

$$y = b1x1 + b2x2 + b3x3 + b3x3 + c$$

Where: y = mean attractiveness rating, b1x1 = BMI (centred), b2x2 = WHR (centred), b3x3 = age of woman in image (centred)

We used the same procedure to optimise the models as in Experiment 1, and the result is shown in Table 1. The analyses show that the BMI of the women in the images explained most of the variance in attractiveness ratings, and that there were no significant effects of WHR. However, since both WHR_{actual} and WHR_{front} were significantly correlated with BMI, we carried out a communality analysis to identify the unique, as opposed to the shared contributions that BMI, WHR_{actual} and WHR_{front} made to mean attractiveness ratings. For the first model, 15.3% and 3.2% of variance were uniquely explained by BMI and WHR_{actual} respectively. For the second model, 38.2% and 3.2% of variance were uniquely explained by BMI and WHR_{front} respectively. This confirms that BMI of the women in the images overwhelmed any effects of WHR in accounting for attractiveness ratings of the negatively correlated image set.

Experiment 3: Analysis of Body Shape

Measuring Body Shape
To obtain a fuller representation of body shape, for each of the 60 images in experiment 1 we took width measurements of 31 horizontal slices across the torso and 37 slices across the legs. It was critical to ensure that, across all subjects, the relative position of each slice on the torso and legs were comparable. To do this for the torso, we positioned the first slice across the acromioclavicular joints and the last across the top of the legs level with the perineum. We then divided equally the vertical distance between these upper and lower limits and positioned the remaining slices accordingly. For the legs, we pivoted the angle of the slice to the angle of the leg, with one slice at the top of the leg and slice 37 at the ankle joint. We then divided equally the distance between these upper and lower limits and positioned the remaining slices accordingly. We then measured the slice widths from each image. (N.B. Only the left leg, with respect to the image, was measured). The procedure is illustrated in figure 3a.

************ Fig. 3 about here *************

To explore the differences in body shape we first plotted the average width of the most attractive five images and the least attractive five images against slice position (figure 3b & c). We did this for torso and leg separately. The most striking difference between the attractive and unattractive body slice plots is the width of the slices. The unattractive bodies are much wider than the attractive bodies. Previously we have shown that body slice width (particularly lower body width) is highly correlated with BMI (Tovée et al., 1999). This is also true of this set of 60 images. Average torso slice width is correlated with BMI at $r=0.64$ ($p<0.0001$) and average leg width at $r=0.59$ ($p<0.0001$). So body width measurements can be seen as a simple visual proxy for BMI. The slice widths are also highly correlated with attractiveness ratings. Average torso slice width is significantly correlated with attractiveness (female observers $r=-0.55$, $p<0.0001$; male observers $r=-0.64$, $p<0.0001$), but although there is a weak correlation between average leg slice width and attractiveness, it just fails to reach significance (female observers $r=-0.25$, $p=0.051$; male observers $r=-0.22$, $p=0.085$).

Fig. 3 shows that there seems to be comparatively little difference in the shapes of the attractive and unattractive body sets, and this impression is confirmed by normalising the slice widths. To do so, we converted the 31 slice widths on the torsos of each image to Z-scores. Since the mean width for each body is now zero, this process effectively removed differences in size between different bodies. The remaining differences between torsos with different attractiveness ratings are now due to shape. Fig. 3d shows plots of the average Z-score value of the most attractive 5 images and the least attractive 5 images against slice position. It shows graphically that there seem to be no gross changes in body shape between attractive and unattractive torsos, instead any difference seem to be more subtle.

Waveform Analysis of Body Shape

To further explore this issue, we decided to analyse body shape as a waveform. If one considers the plots of body width against slice position, it can be seen that body can be considered as a complex waveform and so be susceptible to waveform analysis. We decided to use three forms of analysis; Fourier Analysis (FA), Principal Components Analysis (PCA) and Independent Component Analysis (ICA). We first used FA, which deconstructs the complex waveform into its sinewave components, each at a particular amplitude, frequency and phase. Different frequency components will be associated with different aspects of body shape, and the power of each component allows us an accurate quantification of different aspects of body curvature. We carried out the FA on the torsos (excluding the neck and shoulders, i.e. using the torso starting from just under the arms down to just above the thighs) for each image in our set of 60 bodies. Fourier component 0 (FC0) corresponds to the average amplitude of the waveform and there is a perfect correlation between the power of FC0 and the average width of the torso slices. As body width is highly correlated with BMI, it is not surprising that the power of FC0 is also highly correlated with BMI (see table 2), and is also highly correlated with the mean attractiveness ratings of the body.

**********************Table 2 about here ******************************

FC1 corresponds to the fundamental frequency in our torso shape, and this reflects the general body outline (i.e. wide at the top of the chest narrowing gradually to the waist and then widening out at the hips). To illustrate this we ran an inverse FA, but minus FC1. This produces a jagged line, with the main shape change associated with the female torso removed (Fig. 4a). There are still “bumps” left in the plot, which correspond to higher frequency components in the body shape. We are pulling it out all possible shape cues, including those not necessarily associated with ratios. Thus the power F! represent a good way of quantifying this aspect of torso shape. We can then plot the result of an inverse FA on FC0 and 1 on their own and, as can be seen in Fig. 4b, this is a sine-wave approximating to the normal torso shape. FC0 represents the width of the torso and is included in this inverse FA to give the curve the right amplitude. FC1 represents the low-frequency change in shape as we move from chest to waist to hips. Thus, the power of FC1 represents a good way of quantifying torso shape. As might be expected, the power of FC1 is highly correlated with measures of shape (WCR_{actual}, WHR_{front} and WHR_{actual}, but not with BMI (see table 2). However, FC1 is not significantly correlated with attractiveness ratings of the body.

************ Fig. 4 about here *************

An alternative way of analysing body shape is Principal Components Analysis (PCA). In order to examine the relationships amongst a set of *p* correlated variables, it is useful to transform the original set of variables to a new set of uncorrelated variables called principal components. These new variables are linear combinations of the original variables and are derived in decreasing order of importance so that, for example, the first principal component accounts for as much as possible of the variation in the original data. The transformation is in fact an orthogonal rotation in p-space. Thus, PCA transforms a set of correlated variables to a new set of uncorrelated variables. It is worth stressing that, if the original variables are nearly uncorrelated, then there is no point in carrying out a PCA. In our case, there is a high degree of inter-correlation between the 31 slice widths in our set of 60 images. Therefore it is justified to use PCA to extract principal components that act as independent descriptors of body shape.

A more recent method for simplifying large datasets is Independent Components Analysis (ICA: Bell and Sejnowski 1995). Like PCA, it is a linear transformation of the original variables, indeed it is usually run after an initial PCA. However, where PCA is driven purely by the variance in the data, ICA looks for "interesting" axes, where interesting is interpreted as a non-normal distribution. It attempts to separate the underlying sources of variation in a set of data. So for these data, if, for example, obesity and sex hormone levels have separate effects on body shape, then ICA might find them. However, unlike PCA, there are many variants of ICA that differ in the non-linearity used and the method of convergence. Furthermore, different runs may produce different results, or the same decomposition but in a different order - unlike PCA, there is no natural ordering of the components produced by ICA. We used the Fast-ICA algorithm (Hyvärinen 1999), with tanh non-linearity and sequential deflation, which did give consistent results for these data.

We first ran a PCA with the 31 factors, without rotation. Figure 5 shows the variations in body shape coded by each of the first four components. Note that the variations shown in the figure are exaggerated in order to make clear the variations. PC1 codes for changes in torso width. This component is highly negatively correlated with BMI and positively with attractiveness - thin bodies are attractive. There is only a weak correlation with WHR. The second and third components represent changes in torso shape, where the waist width is held largely constant. In PC2, the hips alter slightly, and to a lesser extent, so does the chest. But the changes captured by this component are relatively subtle. The third runs from pear-shaped at one end of the range, to a large-chested shape at the other end. It is strongly positively correlated with both WHR and WCR. PC3 shows no correlation with attractiveness. In PC4, waist width is modified, and to some extent, hip width. There are also slight changes in upper chest shape. PC4 produces a narrower waist and a more curvaceous lower torso shape, and is negatively correlated with both WCR and WHR but not significantly with attractiveness.

**********************Fig. 5. about here **

The variations coded by ICA are similar to those from the PCA, though in a different order (see table 2). IC1, like PC2, captures measurement inconsistencies around the neck. IC2 resembles PC3's pear shaped variation. Again it is positively correlated with both WCR and WHR but also weakly so with attractiveness. IC3 resembles PC1, correlating strongly with BMI and attractiveness and weakly with both WHR_{front} and WHR_{actual}. Like PC4, IC4 codes the hourglass variation, correlating very strongly with WHR and WCR and only weakly with attractiveness.

Taken together, the results from our waveform analyses suggest that components of the body shape waveforms that describe aspects of body shape are poorly correlated with attractiveness ratings, whereas components which describe aspects of the waveform that are correlated with BMI are highly correlated with attractiveness ratings.

DISCUSSION

It is an intuitive feeling that female body shape should be an important predictor in determining female attractiveness. However, previous studies using pictures of real women, rather than line-drawings, suggest that BMI is a better predictor, and that shape measures, such as WHR, are comparatively weak predictors (e.g. Tovée et al., 1998, 1999, 2000; Thornhill & Grammar, 1999). To try and determine whether shape, in the form of WHR, can play a role in determining attractiveness, we carried out the set of experiments detailed above. In the first experiment, the relative range of BMI to WHR is controlled to give WHR an "advantage." However, WHR still fails to emerge as a strong determinant of attractiveness. In the second experiment, a set of images were chosen so that there was a strong negative correlation between BMI and WHR. This means that the two putative predictors of female attractiveness were "pitted against" each other. Even though the relative ranges of WHR and BMI should favour WHR in this sample of images, BMI again emerged as the dominant predictor (i.e. women with a low BMI and a high WHR were judged as more attractive, rather than women with a high BMI and a low WHR). In our final experiment, we considered the possibility that simple ratios like WHR were not adequately capturing body shape, and so we were underestimating its importance as a predictor of attractiveness. We therefore treated body shape as a complex waveform and used three methods of waveform decomposition to determine which components are good predictors of attractiveness. The components linked to body size (and BMI) were good predictors, but those that appear to be linked to shape cues (such as WHR) were not. These effects cannot be simply explained by our photographs of women not adequately capturing shape cues. We used pictures of men in the same format, rated by male and female observers in the same experimental protocol, to explore male physical attractiveness (Maisey et al., 1999). Male attractiveness is primarily determined by shape (specifically upper body shape), rather than BMI, demonstrating that shape cues are salient in this format.

An advantage of the waveform analyses is that they address the complexity of the whole torso shape, and are not simply sampling a couple of points on part of the body. Moreover, the analyses pull out innate properties of the torso shape and not elements based on prior decisions about arbitrary physical features. Our analyses decompose the waveform into objective quantified elements whose importance in predicting attractiveness can then be tested. In our Fourier Analysis, FC1 seems to capture torso shape very well and so the power of FC1 should be a good quantified measure of shape. It is highly correlated with other measures of torso shape (such as WCR_{actual}, WHR_{front} and WHR_{actual}), but is still not significantly correlated with the attractiveness ratings of bodies. In our Principal Component Analysis, PC2, PC3 and PC4 also seem to capture these features of body shape, but again, the factor loadings of these two components are weakly, or not at all, correlated with the attractiveness ratings.

Lastly, in our Independent Component Analysis, IC4 was correlated solely with shape features, but again, was only weakly correlated with the attractiveness ratings. In all three sets of analyses, components that correlated with BMI, either solely or sometimes with shape features, were significantly correlated with the attractiveness ratings.

A case can be made for both BMI and WHR being important cues for female health and fertility. BMI in adult women can be very closely correlated with health and fertility (Manson et al., 1995; Reid & Van Vogt, 1987; Frisch, 1988; Brown, 1993; Lake et al., 1997). These studies suggest that the balance between the optimal BMI for health and fertility is struck at around a value of 18-20, which, in this study, is also the preferred BMI for attractiveness (for a detailed discussion of these issues see Tovée et al., 1999). However, Hartz, Rupley and Rimm (1984) found that both BMI and WHR_{actual} are positively related to irregularity in menstrual cycles, and WHR_{actual} is an important predictor of conception in artificial insemination programmes (Zaadstra et al., 1993; Wass et al., 1997). However, this cue may be limited in its utility. For example, there is a considerable overlap in the WHRs of populations of normal women and anorexic patients (Tovée et al., 1997). The latter are amenorrheic. So a woman with an effective fertility of zero can have the same WHR as a woman with normal fertility. However, it should be noted that we did not directly ask subjects to rate the images for fertility or health, although there is a strong correlation between the physical characteristics of the most attractive images and health and fertility (Manson et al., 1995; Reid & Van Vogt, 1987; Frisch, 1988; Brown, 1993; Lake et al., 1997; Wang et al., 2000). The results may have been different had we asked subjects to directly rate the images for health and fertility.

It may be that there is a hierarchy of cues used in partner selection. Features such as WHR may be used to discriminate broad categories, such as male from female or pregnant from non-pregnant women (a between category discrimination), and if we had carried out a study differentiating men and women's bodies, then WHR would probably have played a prominent role. Discriminating within the category of potential partners one may use cues such as BMI, and then use other cues, such as the proportions of the body (like the ratio of the torso/leg length) or possibly some further aspects of body shape, to discriminate between women of very similar BMI. Thus, in the tasks used in this study an observer is likely to be highly sensitive to BMI as an important cue used to assess within category attractiveness, and less sensitive to WHR, which may play a stronger role as a cue to category discrimination. An alternative explanation is that you just don't need to be very sensitive to shape cues. In a normal situation, BMI and body shape are linked. For example in our set of 457 women, BMI and measures of shape are significantly correlated. For example for bodies in the "normal" BMI range (BMI values of 20-24), BMI and WHR are correlated at $r=0.288$ ($P<0.001$), and for the wider range including the "over-weight" and "emaciated categories" (BMI values of 15-30) the correlation is 0.25 ($P<0.001$). This means that on average, a body with a particular BMI will tend to have a particular shape. Although the fact that the correlation of BMI with shape measures is only about 0.25-0.30, it still shows that there is still significant variation of shape with BMI. So a possible search strategy would be to just to find someone of the right BMI, as they would tend to be of approximately the right shape. Under these circumstances one would not need to be very sensitive to shape cues. Of course one could equally employ the alternative strategy of selecting on shape and assuming the BMI will be right, but the weak linkage of shape cues to attractiveness suggests this is not the case.

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FIGURE LEGENDS

Figure 1

(a) An example of the female images used in this study.

(b) A plot of the relationship between the mean attractiveness ratings and the BMI of the images for experiment 1. The relationship is clearly linear, and the two factors are significantly correlated ($r=-0.53$, $p<0.0001$).

(c) A plot of the relationship between the attractiveness ratings and the *front* WHR for experiment 1. The two factors are significantly correlated ($r=-0.32$, $p<0.05$).

(d) A plot of the relationship between the attractiveness ratings and the *actual* WHR for experiment 1. The two factors are not significantly correlated ($r=-0.21$, $p=0.100$).

Figure 2

(a) A plot of the BMI of the women in the pictures against their actual WHR (they are inversely correlated, $r=-0.718$ ($p<0.0001$)) for experiment 2.

(b) A plot of the relationship between the attractiveness ratings and the BMI of the images for experiment 2. The relationship is clearly linear, and the two factors are significantly correlated ($r=-0.76$, $p<0.0001$).

(c) A plot of the relationship between the attractiveness ratings and the *actual* WHR for experiment 2. The two factors are significantly correlated ($r=0.65$, $p<0.0001$)

Figure 3

(a) An example of our body images showing the position of the slices on the torso and legs.

(b) A plot of the average width for the torso of the most attractive 5 images (filled squares) and the least attractive five images (open circles) against slice position

(c) A plot of the average width for the legs of the most attractive 5 images (filled squares) and the least attractive five images (open circles) against slice position

(d) A plot of the average Z-score value of the most attractive 5 images (filled squares) and the least attractive five images (open circles) against torso slice position. There seems to be very little difference in shape between attractive and unattractive bodies.

Figure 4

(b) Plots of actual torso width against slice position (open circles) and the torso shape calculated from Fourier components without FC0 and FC1 (filled squares).

(a) Plots of actual torso width against slice position (open circles) and torso shape calculated by inverse Fourier analysis of the FC0 and FC1) (filled squares)

(c) A plot of the power value of FC0 against BMI.

(d) A plot of the power value of FC1 against *front* WHR.

Figure 5

An illustration of the range of variations in shape coded by the first four principal components (PCs). For each PC, the image on the left correspond to low values of the component and the image in the middle to high values. The variations shown are exaggerated, to make the effects clear. To further clarify the shape changes associated with each component, on the right of figure we superimpose outlines of the two extremes of the range for each PC.

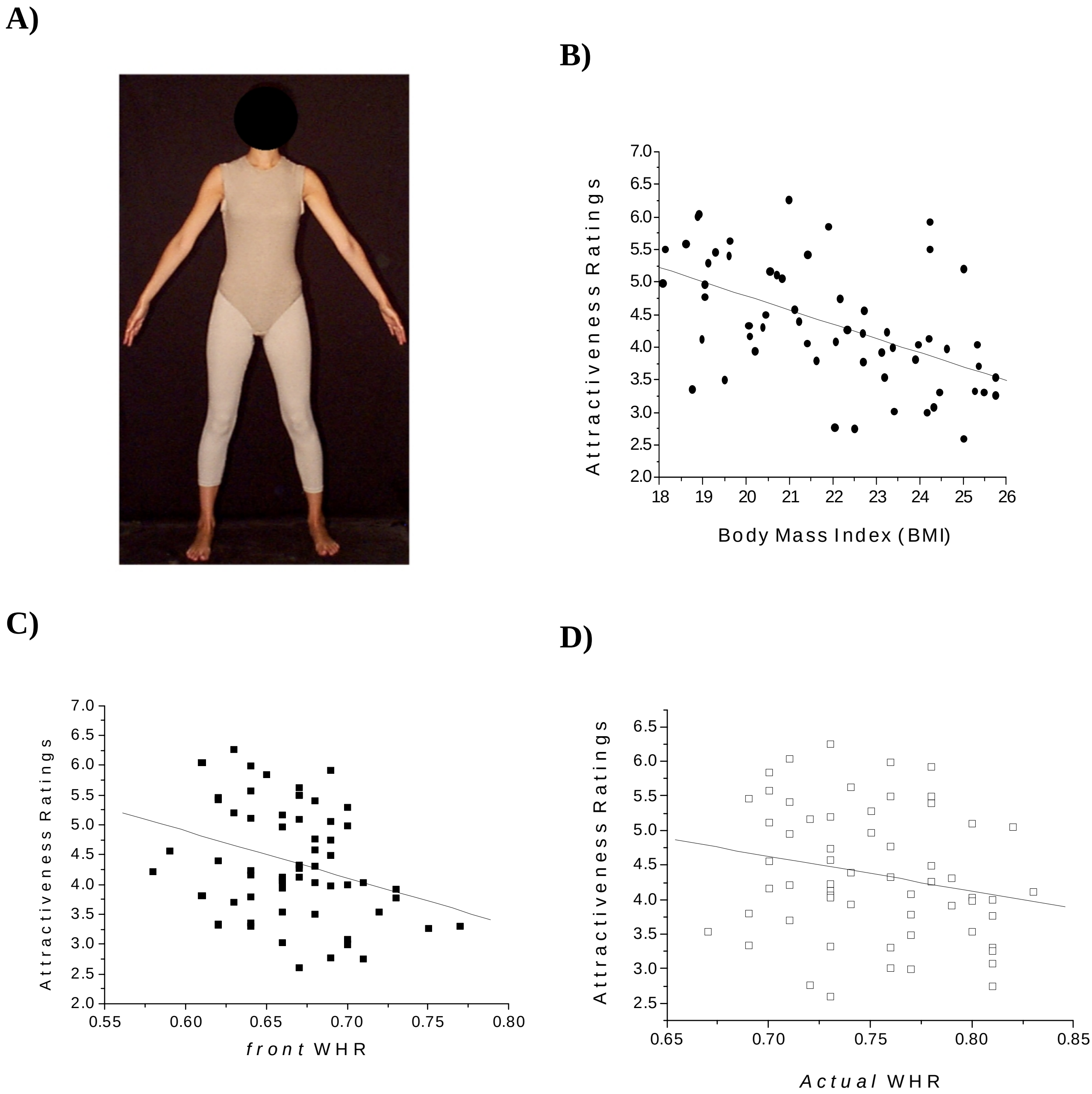
TABLE LEGENDS

Table 1

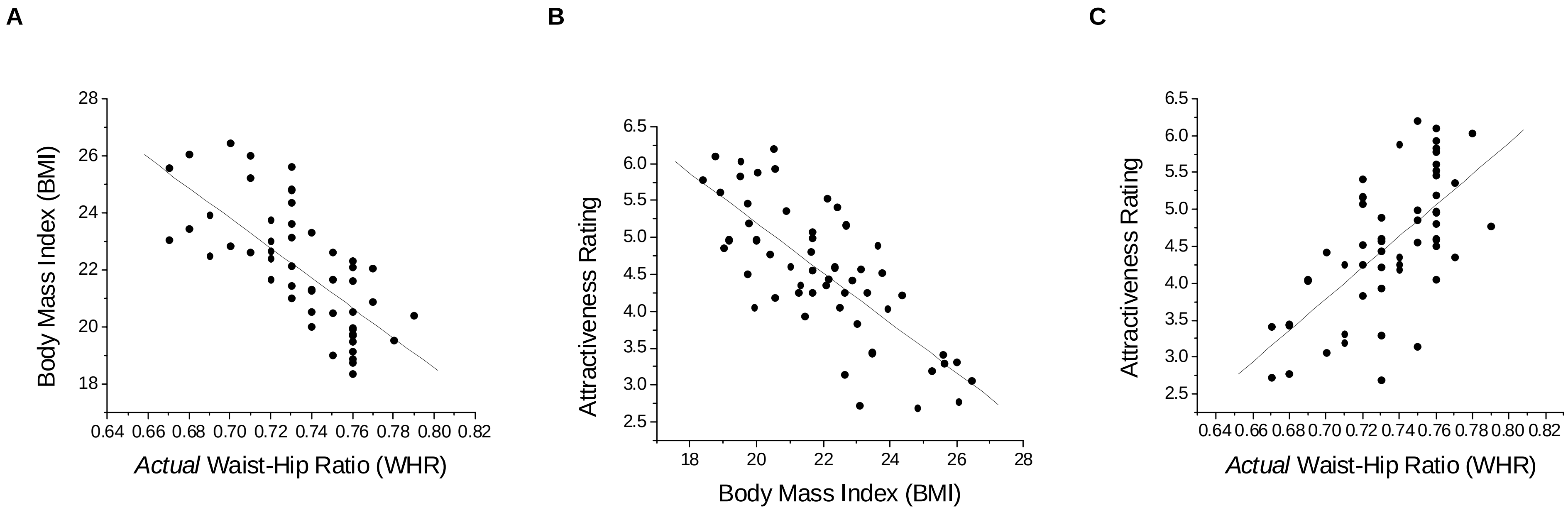
The multiple regression coefficients for experiments 1 and 2.

Table 2

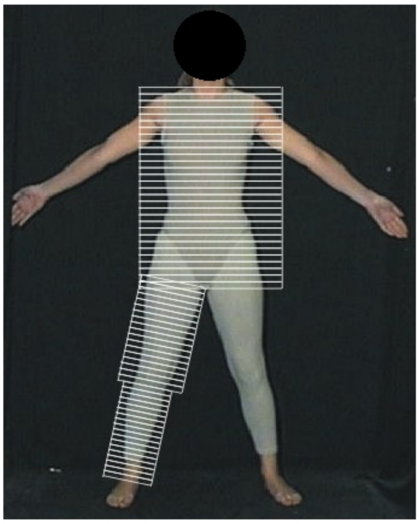
The Pearson correlation values between the Fourier components (FC), the Principal Components (PC) and the Independent Components (IC) with the measures of body shape from our images, and the attractiveness ratings of all our observers (both male and female). (***** indicates a correlation significant at the $P>0.05$ level, ****** indicates a correlation significant at the $P>0.01$ level, ******* indicates a correlation significant at the $P>0.001$ level or better).


A)
B)
Attractiveness Ratings
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
18 19 20 21 22 23 24 25 26
Body Mass Index (BMI)
C)
Attractiveness Ratings
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
0.55 0.60 0.65 0.70 0.75 0.80
front WHR
D)
Attractiveness Ratings
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
0.65 0.70 0.75 0.80 0.85
Actual WHR

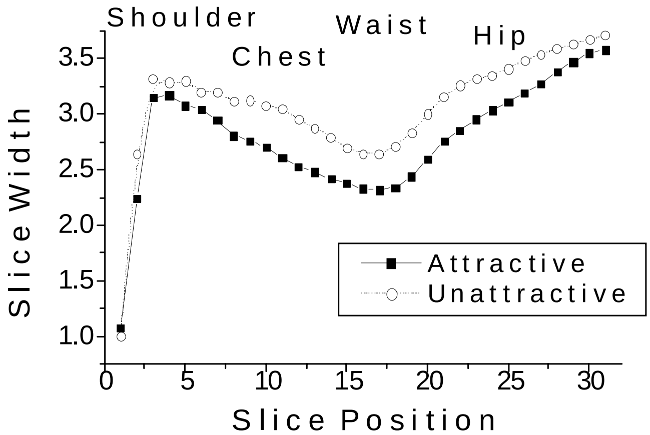
A B C


A
B
C
Body Mass Index (BMI)
Actual Waist-Hip Ratio (WHR)
Attractiveness Rating
Body Mass Index (BMI)
Attractiveness Rating
Actual Waist-Hip Ratio (WHR)

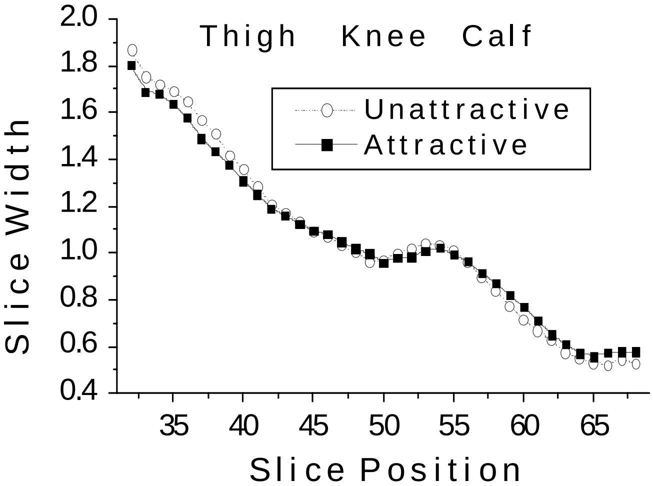
A)



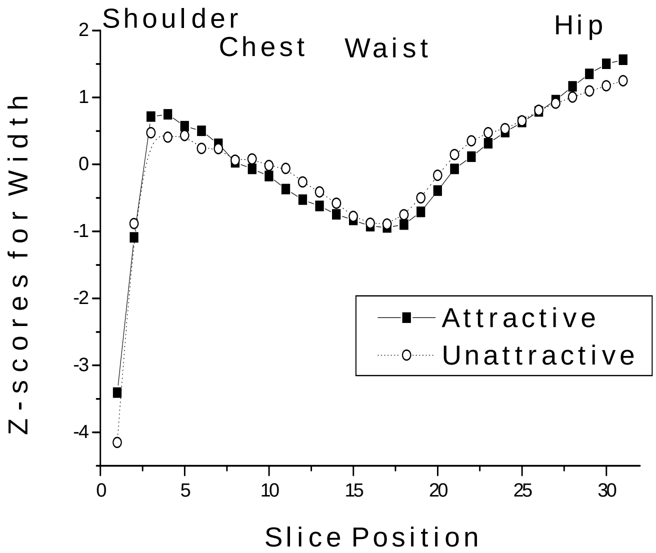
B)

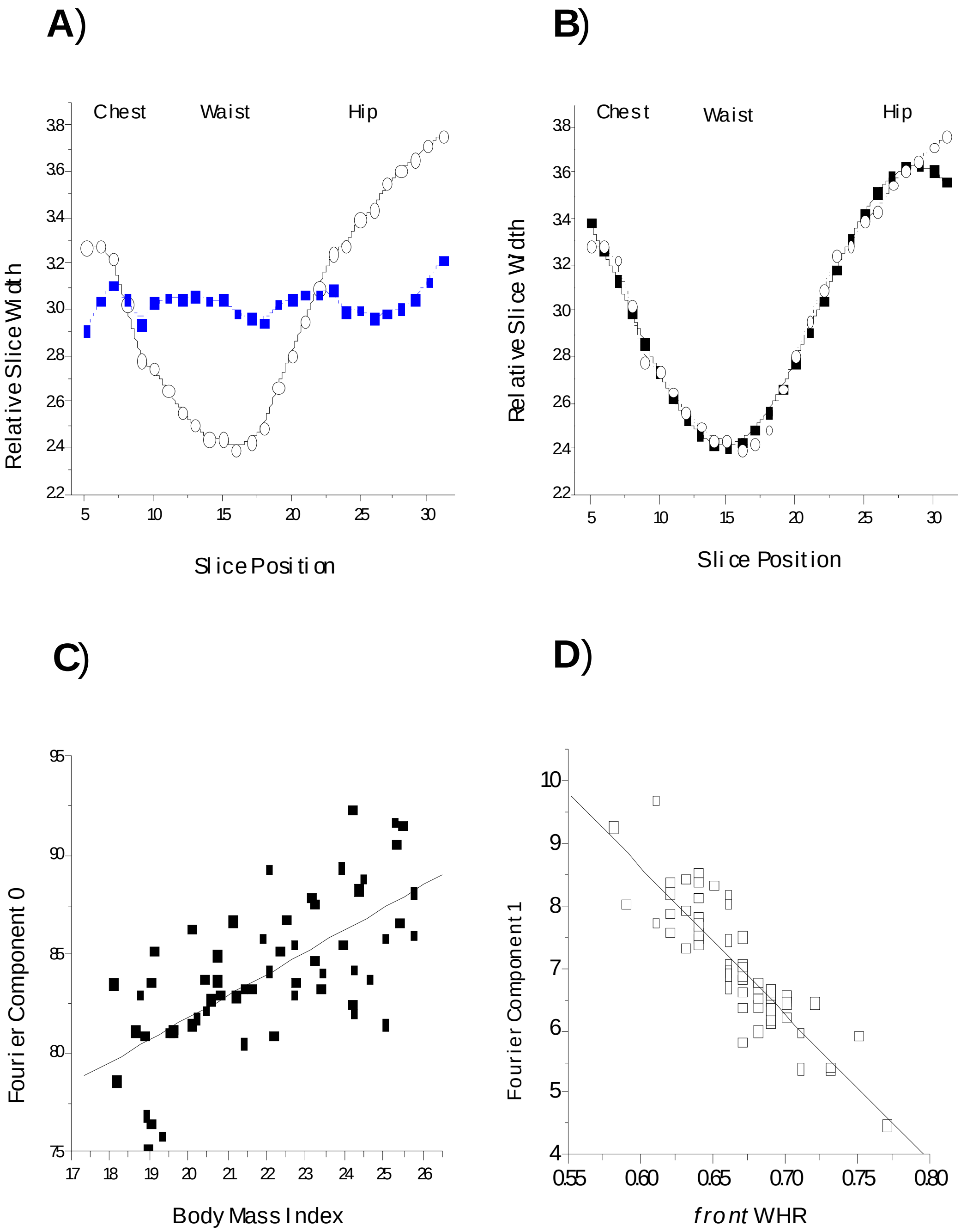

Shoulder
Chest
Waist
Hip
Slice Width
3.5
3.0
2.5
2.0
1.5
1.0
0
5
10
15
20
25
30
Slice Position
Attractive
Unattractive

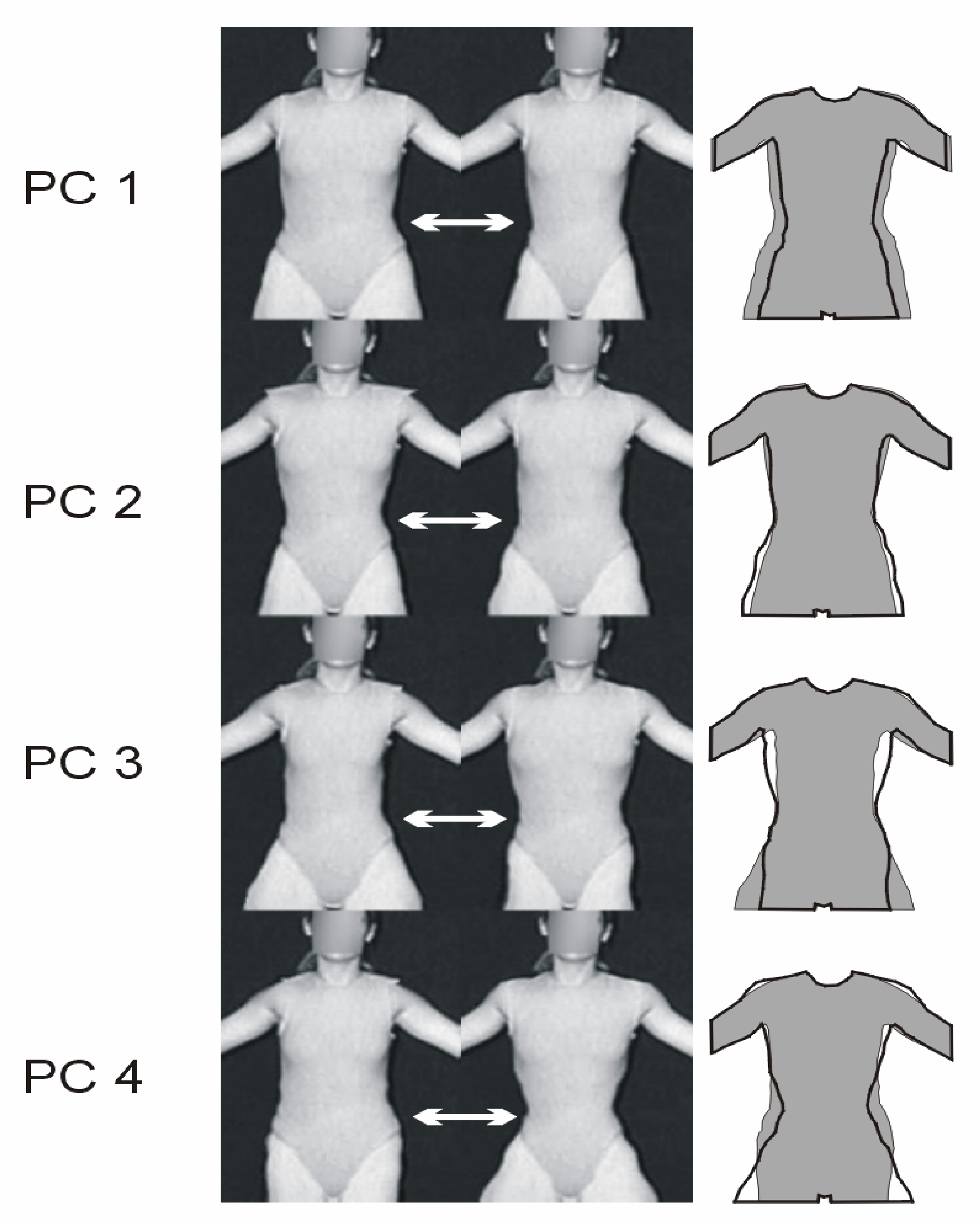
C)


Thigh
Knee
Calf
Slice Width
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
35
40
45
50
55
60
65
Slice Position
Unattractive
Attractive

D)


Shoulder
Chest
Waist
Hip
Z-scores for Width
2
1
0
-1
-2
-3
-4
0
5
10
15
20
25
30
Slice Position
Attractive
Unattractive


A)
Chest
Waist
Hip
Relative Slice Width
Slice Position
B)
Chest
Waist
Hip
Relative Slice Width
Slice Position
C)
Fourier Component 0
Body Mass Index
D)
Fourier Component 1
front WHR


PC 1
PC 2
PC 3
PC 4

Model including:	Explanatory Variable	Regression Coefficient	Standard error	F-ratio	P	% variance explained
Experiment 1						
WHR/WCR_{actual}	BMI	-0.43	0.10	17.96	$p<0.0001$	27%
	Age	-0.21	0.01	4.3	$p<0.05$	3%
WHR/WCR_{front}	BMI	-0.44	0.10	18.98	$p<0.0001$	27%
	WHR_{front}	-0.22	0.10	4.72	$p<0.05$	5%
Experiment 2						
WHR_{actual}	BMI	-0.56	0.12	56.98	$p<0.0001$	52%
WHR_{front}	BMI	-0.56	0.12	56.98	$p<0.0001$	52%

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Analysis	**BMI**	**WHR*actual***	**WHR*front***	**WCR*actual***	**Attractive Ratings**
<u>Fourier</u>					
FC0	0.66***	0.13	0.31*	-0.02	-0.56***
FC1	0.002	-0.74***	-0.87***	-0.71***	0.14
FC2	0.37**	-0.07	-0.13	-0.07	-0.24
FC3	0.28*	-0.06	-0.39**	-0.11	-0.17
<u>PCA</u>					
PC1	-0.66***	-0.10	-0.28*	0.04	0.63***
PC2	0.07	-0.06	-0.06	-0.32**	-0.04
PC3	-0.03	0.60***	0.76***	0.61***	-0.10
PC4	-0.07	-0.46***	-0.46***	-0.32**	0.23
<u>ICA</u>					
IC1	-0.06	-0.05	-0.10	0.18	0.05
IC2	-0.33**	0.28*	0.32**	0.49***	0.26*
IC3	-0.57***	-0.28*	-0.34**	-0.12	0.67***
IC4	0.10	0.73***	0.87***	0.63***	-0.28*