Patterns of eye-movements when Male and Female observers judge female attractiveness, body fat and waist-to-hip ratio

P. L. Cornelissen[1], P.J.B. Hancock[2], V.W.Kiviniemi[3], H. R. George[4], & M. J. Tovée[4]*

1. Department of Psychology, University of York, UK
2. School of Psychology, Stirling University, UK
3. Department of Statistics, University of Kuopio, Finland
4. Institute of Neuroscience, Newcastle University, UK.

Corresponding Author: Dr M. J. Tovée, Institute of Neuroscience, Henry Wellcome Building. Newcastle University, NE2 4HH, UK . e-mail: m.j.tovee@ncl.ac.uk

Key Words: eye-movements, attractiveness, waist-hip ratio, body mass index.

To appear in Evolution and Human Behavior

ABSTRACT

Behavioural studies of the perceptual cues for female physical attractiveness have suggested two potentially important features; body fat distribution (the waist-to-hip ratio or WHR) and overall body fat (often estimated by the body mass index or BMI). However none of these studies tell us directly which regions of the stimulus images inform observers' judgments. Therefore, we recorded the eye-movements of 3 groups of 10 male observers and 3 groups of 10 female observers, when they rated a set of 46 photographs of female bodies. The first sets of observers rated the images for attractiveness, the second sets rated for body fat and the third sets for WHR. If either WHR and/or body fat are used to judge attractiveness, then observers rating attractiveness should look at those areas of the body which allow assessment of these features, and they should look in the same areas when they are directly asked to estimate WHR and body fat. So we are able to compare the fixation patterns for the explicit judgments with those for attractiveness judgments, and infer which features were used for attractiveness. Prior to group analysis of the eye-movement data, the locations of individual eye fixations were transformed into a common reference space to permit comparisons of fixation density at high resolution across all stimuli. This manipulation allowed us to use spatial statistical analysis techniques to show: 1) Observers' fixations for attractiveness and body fat clustered in the central and upper abdomen and chest, but not the pelvic or hip areas, consistent with the finding that WHR had little influence over attractiveness judgments. 2) The pattern of fixations for attractiveness ratings was very similar to the fixation patterns for body fat judgments. 3) The fixations for WHR ratings were significantly different from those for attractiveness and body fat.

INTRODUCTION

A basic evolutionary problem is how to choose a partner. We need to be 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 which is most likely to enhance our chances of successful reproduction (Buss, 1987). The wrong choice will have a negative impact on an individual's potential for reproduction, so there should be strong selective pressures to detect cues to health and fertility in potential partners. A number of behavioral studies have attempted to define the physical cues which are used to make attractiveness judgements (e.g. Singh, 1993; Henss, 1996, 2000; Tovée et al., 1998, 2002; Thornhill & Grammer, 1999; Puhl & Boland, 2001; Fan et al., 2004; Smith et al. 2007a; Streeter & McBurney, 2003; Swami et al., 2006). Typically in such experiments, observers are asked to rate a set of images for attractiveness that vary on a number of anthropometric dimensions. Usually, the analysis of such data aims to attribute variance in attractiveness judgments to some combination of the anthropometric features.

Perhaps the two features most frequently used to explain attractiveness judgments are overall body fat, indexed by the body mass index (BMI), the volume height index (VHI) or percent body fat composition (e.g. Tovée et al., 1998; Fan et al., 2004; Smith et al., 2007a) and the specific distribution of fat deposition on the lower body, indexed by the ratio of waist circumference to hip circumference – the Waist-to-Hip Ratio (WHR) (e.g. Singh 1993, Streeter & McBurney, 2007). Changes in BMI have a strong impact on health (Manson et al. 1995; Willet et 1995) and reproductive potential (Reid & Van Vugt 1987; Frisch 1988; Lake et al. 1997), and a low WHR (i.e. a curvaceous body) is believed to correspond to the optimal fat distribution for high fertility (Zaadstra et al. 1993). Additionally, based on a regression analysis of a large set of epidemiological data, Lassek & Gaulin (2008) found a small (2.7% of the variance), but significant role for WHR as a predictor of cognitive skills in females. However, Lassek & Gaulin (2008) did not test the empirical relationship between WHR, intelligence, ratings of perceived intelligence and ratings of attractiveness, so the potential impact of this intriguing finding on studies of attractiveness remains to be assessed.

In principle, a mate choice strategy based on either WHR and/or BMI could plausibly favour reproductive success. However, the experimental data to date do not provide a clear linkage between the physical features visible in stimulus images, anthropometric measures obtained from females in images and the perceptual judgments made about the images themselves. Additionally, there are many anthropometric dimensions which could potentially determine attractiveness judgments, and many of them are significantly correlated with each other. How can we differentiate between these potential cues to find those features which are actually being used to make the judgment?

An obvious solution is to simultaneously record observers' eye-movements while they make perceptual judgments. Although human eyes can attend to a visual field of around 200˚, detailed information can only be received from a central region of around 2˚, corresponding to the fovea (e.g. Levi *et al.*, 1985; Thibos et al., 1987). As a result, the information in a picture can only be sampled in discrete "bite-sized" chunks corresponding to the observer's current fixation position (e.g. Young, 1993; Miller & Bockisch, 1997). Thus by tracking an observer's fixation position, it is possible to gain a direct measure of which regions of an image are being sampled at any one time, and therefore which regions are likely to be contributing information to the perceptual judgments.

Anatomical resolution

A central problem with eye-movement recording experiments is how to compare the locations of fixations across successive stimuli of the same class – in this case human bodies in front view. The co-ordinate system for raw eye-movement recordings is stimulus-centred and is usually defined with respect to the projection system used for viewing the images. However, the co-ordinate system that we want to know about is body-centred. Bodies vary in height, size and shape. So, as far as stimulus-centred co-ordinates are concerned, the positions of the right shoulder and any fixations in this region, for example, will not be aligned across successive stimulus images. What is required is some kind of transformation of the eye fixations into a body-centred co-ordinate frame. A common solution is to pool fixations across (large) areas of interest or AOIs, each of which represents a topologically defined sub-region of the body (e.g. Isaacowitz et al., 2008; Dalton et al., 2005; Guo et al., 2003; van der Geest 2002; Adolphs et al., 2005). However, this approach frequently leads to a considerable loss of spatial resolution and subtle differences in the patterns of eye-movements between conditions may no longer be apparent. Moreover, from a statistical point of view, the same topologically defined AOI in different images may not have the same surface area, thereby introducing a sampling bias.

Here we report a novel method for solving this sampling problem, and its application to the study of human physical attractiveness. First, we morphed all the images in our stimulus set together to produce an average, or reference body image. This was possible because each of the individuals who consented to be photographed for the study stood in a standardized pose at a fixed distance from the camera. The morphing procedure generated a set of co-ordinate transforms which mapped individual pixels in each of the original images in our stimulus set onto the pixels in the reference image, and these co-ordinates are body-centred. By applying the same set of transforms to the horizontal (x) and vertical (y) co-ordinates of our eye-movement records, we were able to transform the eye-movements for each observer into this body-centred spatial framework and coregister the fixation patterns with the reference body image. This allowed us to define grids of equally sized, small AOIs to directly compare the pattern of eye-movements across individual observers and stimulus images, thereby preserving a high degree of anatomical resolution, and eliminating sampling bias. The technique is conceptually equivalent to that used in neuroimaging where 3D patterns of activation in individual brains are warped into a common reference space in order to facilitate statistical comparisons of brain activations across observers.

In summary, we used our new analysis techniques to determine the eye-movements made when male and female observers rated a set of female images for attractiveness, body fat and WHR, and we used the improved spatial resolution of this technique to look for potential differences in the pattern of fixations in the different conditions and between the gender of the observers. It is our hypothesis that if either WHR and/or body fat are used as cues for attractiveness, then observers making attractiveness judgments should include in their fixations, those areas of the body which allow visual assessment of these features. Conversely, if the requirement to extract information about these features is made explicit by directly asking observers to estimate WHR and body fat, we assume that they should look in those same areas. Therefore, we should be able to compare the fixation patterns for these explicit judgments with those for the attractiveness judgments, and infer which features were used to judge attractiveness. By this logic, if the fixation patterns for attractiveness and explicit WHR and/or body fat estimation are very similar, then we can argue WHR and/or body fat do contribute to the assessment of attractiveness. However, if the gaze patterns for attractiveness and WHR and/or body fat estimation are very different, then it is much harder to see a clear role for these features in attractiveness judgments.

Experiment 1: Judgements of Attractiveness, Body Fat and WHR
METHODS

<u>Participants and Procedures</u>

Forty-six Caucasian female volunteers, primarily university undergraduates, (mean age 21.0 years, s.d. 2.4 years) consented to be photographed to provide stimuli for the study. Clothing was standardized, with all women wearing an unsupportive flesh coloured vest and briefs (as in Smith et al., 2007a). Under constant studio lighting, and against a fixed neutral grey backdrop, digital photos were taken of our volunteers as they adopted a standard pose in front view, with feet slightly apart and arms by their sides. The volunteers' faces were then blurred in the digital pictures to ensure anonymity. The volunteers varied in BMI from 18.4 to 26.7 kg/m^2, with an average of 22.3 kg/m^2 (s.d. 2.3 kg/m^2) and in WHR from 0.64 to 0.84, with an average of 0.74 (s.d. 0.04).

The size of the body images on screen varied with the size of the woman depicted, since they were photographed at a uniform distance. They ranged from about 125-150 pixels across the hips, and 640-700 from head to toe. At the screen resolution and viewing distance used, this equates to about 4 to 4.5 degrees of visual field across the hips, and 18-20 degrees in height.

Three groups of female observers and three groups of male observers (10 observers in each group) rated this image set on a scale of 1 to 9, while their eye-movements were being recorded. We used separate observer groups for each condition to minimize image familiarity for the observers (i.e. the observers should be making a judgment about a novel stimulus without a recognition component which might bias their eye-movements towards a different pattern). Observers were asked to rate images either for attractiveness, fatness or WHR. In order to ensure that the observers in the WHR condition were clear on what they were being asked to rate, the observers were told that WHR was defined as "the ratio of the width of the hips to the width of the waist, in other words the curviness of the lower body”. Note that this is inversely related to the standard WHR, where a curvy lower body gives a low value: it was easier to explain to participants this way. For the attractiveness condition, the average age of the male observers was 21.1 years (s.d. 3.7) and the female observers was 19.3 years (s.d. 1.2). For the body fat condition, the average age of the male observers 19.0 years (s.d. 1.5) and the female observers was 19.3 years (s.d. 1.1). For the WHR condition, the average age of the male observers 24.6 years (s.d. 12.2) and the female observers was 22.1 years (s.d. 4.2).

The eye-tracker, a Tobii 1750, was first calibrated for the participant, which takes about 30 seconds. The tracker does not require head restraint and participants sat approximately 1m from the screen, which also contains the camera and infra-red lights. After the initial calibration, there is nothing to remind participants that their gaze is being tracked. Binocular eye gaze position was recorded every 20ms during the rating procedure. Each trial comprised the following sequence. A black fixation cross appeared, its position varying randomly in each presentation between the centre of the image and the four corners. Participants were required to fixate the cross: when they had done so continuously for a second, the system automatically presented the target image, for 2000 ms. The requirement to fixate the cross prevented any anticipatory eye movements. Following image presentation, the observer rated the image on a scale of 1-9 using a keyboard. There was no time limit for rating the image. After making their rating, the fixation cross reappeared and when it had been fixated for a second, the next image displayed.

Generating the reference image

A standard reference image was created from an average of all 46 images using the morphing procedure developed by Hancock (2000). A topologically consistent set of triangles was defined on the body in each individual image from a set of 43 landmark points. For each image, all points were then aligned to a common reference space and the pixel values averaged across images to create the standard, or reference image. In addition, a displacement map was created for each image which provided a look-up table relating each pre-morphing pixel location to its post-morphed pixel location in the reference image. The same look-up table was used to transform the pixel locations of the eye-fixations on the original stimulus images to new ‘morphed’ locations on the reference image, thereby transforming the eye-position data into a body-centred reference frame and permitting the eye-fixations to be co-registered with the reference image.

RESULTS

Behavioral responses

First, to look for consistency across observers’ perceptual ratings, we calculated Winer’s intra-class reliability for k means for attractiveness, body fat and WHR estimations. These were 0.82, 0.94 and 0.82 respectively for the female observers and 0.75, 0.95 and 0.81 for the male observers. These levels of consistency are in line with previous research (e.g. Tovée & Cornelissen, 2001; Tovée et al 2002). The results show a strong correlation between the genders on the ratings of the three conditions (see table 1). This is consistent with previous studies which have also found very similar ratings of attractiveness by both genders (Tovée et al. 1999; Smith et al., 2007a).

Table 1

A Pearson correlation matrix showing the relationship between ratings and anthropometric variables (Female ATT rating = the average attractiveness rating of the images by the female observers, Female FAT estimate = the average body fat estimate by the female observers, Female WHR estimate= the average WHR estimate by the female observers; Male ATT rating, FAT estimate and WHR estimate are the corresponding judgments by the male observers; BMI=body mass index of stimulus images; WHR = the waist-to-hip ratio of stimulus images; WBR = the waist-to-bust ratio of stimulus images).

	Female ATT rating	Female FAT estimate	Female WHR estimate	Male ATT rating	Male FAT estimate	Male WHR estimate	Image BMI	Image WHR
Female ATT rating	-							
Female FAT estimate	-0.58**	-						
Female WHR estimate	0.07	0.33*	-					
Male ATT rating	0.84**	-0.72**	-0.4	-				
Male FAT estimate	-0.58**	0.97**	0.21	-0.74**	-			
Male WHR estimate	-0.22	0.69**	0.82**	-0.35*	-0.61**	-		
Image BMI	-0.59**	0.86**	0.18	-0.69**	0.88**	-0.51*	-	
Image WHR	-0.39**	0.15	-0.47**	-0.31*	0.22	0.19	0.08	-
Image WBR	-0.36**	0.32*	-0.14	-0.35*	0.33*	0.10	0.22	0.41**

***** = p<0.001   * = p<0.05***

The relationship between the perceptual judgments in the three experimental conditions and the different anthropometric variables is illustrated in Table 1. Consistent with Smith et al. (2007a), who used the same stimulus set, we found a strong inverse correlation between attractiveness and BMI as well as moderate inverse correlations between attractiveness, WHR and waist-to-bust ratio (WBR). Reassuringly, given the strong inverse association between attractiveness and BMI in previous studies (e.g. Tovée et al., 1998, 2002), we also found a strong inverse correlation between estimated body fat and attractiveness judgments. The body fat estimates were highly correlated with BMI, but although we found a significant correlation between estimated-WHR and stimulus WHR for female observers, this did not reach statistical significance for male observers although there was a trend. This may be because it is hard to estimate the actual or circumferential WHR of a 3D figure from a 2D image, as much of the fat deposition is on the buttocks which are not visible. Therefore we also calculated front-view WHR (fWHR) for each of the 2D stimulus images (i.e. the ratio as measured across the front of the body). The front-view waist width was measured as the narrowest horizontal distance across the abdomen, and the front-view hip width was measured as the widest horizontal distance between waist and mid thigh. The relationship between fWHR and the observers' estimation of WHR was significant for both the female ($r=-0.61$, $p<0.0001$, negative because our curviness measure is inverse WHR) and male observers ($r=-0.35$, $p<0.05$), suggesting that observers succeeded at making this judgment.

Table 2a

Behavioural Judgement	Beta coefficient for BMI	Beta coefficient for WHR	Beta coefficient for intercept	T-value for BMI	T-value for WHR	T-value for intercept	Unique % variance for BMI	Unique % variance for WHR	Total % variance for full model
Male ATT rating	-0.66	-0.25	-0.07	-6.42**	-2.46*	-0.7	44.4%	6.5%	53.5%
Male FAT estimate	0.88	0.14	-0.01	12.34**	1.96	-0.19	74.9%	1.9%	78.8%
Male WHR estimate	0.51	-0.23	0.003	4.18**	-1.9	0.03	27.7%	5.8%	31.9%
Female ATT rating	-0.56	-034	-0.09	-5.1**	-3.17**	-0.76	32.0%	12.3%	47.2%
Female FAT estimate	0.86	0.08	0.0004	11.12**	1.02	0.01	72.9%	0.6%	74.7%
Female WHR estimate	0.21	-0.49	0.02	1.63	-3.91**	0.13	4.4%	25.5%	28.5%

Table 2b

Behavioural Judgement	Beta coefficient for BMI	Beta coefficient for fWHR	Beta coefficient for intercept	T-value for BMI	T-value for fWHR	T-value for intercept	Unique % variance for BMI	Unique % variance for fWHR	Total % variance for full model
Male WHR estimate	0.56	-0.45	0.02	4.39**	-3.17**	0.15	34.0%	19.0%	45.1%
Female WHR estimate	0.32	-0.68	0.1	2.45*	-4.7**	0.83	10.7%	41.5%	44.6%

***** = p<0.001, * = p<0.05***

Table 2a and b
The regression models for the attractiveness, body fat and WHR estimation for the male and female observers. We have modelled the WHR estimations twice; once using actual WHR as an explanatory variable (Table 2a) and once using fWHR (Table 2b). The degrees of freedom for the T-values are 1, 42 throughout. See text for further details.

To further quantify the relationships between the perceptual judgments of attractiveness, body fat and WHR and the anthropometric measures: BMI and WHR, we ran multiple regression analyses using PROC REG in SAS (SAS Institute, North Carolina, US) and fitted simultaneous models (i.e. the model fits are not dependent on the order of the explanatory variables) of the form: $y = \beta_1.BMI + \beta_2.WHR + intercept$ in Table 2a, and: $y = \beta_1.BMI + \beta_2.fWHR + intercept$ in Table 2b. In both cases y = perceptual judgment. All variables were first converted to z-scores for two reasons. First, this is one of a number of convenient ways to centre the data for regression analysis (Altman, 1991). Secondly, it provides a simple way for the sizes of the regression coefficients to be easily compared and it sets the intercept (close) to zero. The outcomes for the multiple regression models are shown in Table 2a & b. On each row of Table 2a & b, we report the best fit regression model separately for each behavioural judgment (attractiveness, body fat and WHR) for each gender. Column 1 describes the particular behavioural judgment entered as the outcome variable in the model for that row. Columns 2-4 contain the regression coefficients for the best fit model for that row. Columns 5-7 contain the T-values for each estimate and the associated significance level for each term in the model. Column 10 reports the total variance explained by each full model in each row. Columns 8 and 9 report the unique variance explained by BMI and WHR (Table 2a) or BMI and fWHR (Table 2b) respectively for the model in that row. In each case, unique variance was calculated by comparing the r-square for the full model against the r-square for a reduced model. For example, the unique variance in male attractiveness judgments explained by BMI is calculated as the difference in r-square for the full model containing both BMI and WHR as explanatory variables, compared with a reduced model containing only WHR as the explanatory variable.

The regression analyses illustrate that for attractiveness and body fat judgments, the effect size for BMI (based on the estimates of unique variance accounted for) always outstrips WHR by at least a factor of 3. Where WHR does play a significant role in predicting attractiveness and body fat judgments, this effect is stronger for females than males, even though the original argument for the value of WHR as a cue to attractiveness is made with respect to males judging female fertility (Singh, 1993).

Where do observers look when making their judgments?

In order to examine the spatial distributions of fixations, and to compare fixation patterns across observer groups, we constructed a sampling grid of square cells, 20x20 pixels each, and applied it across the entire reference image (800x500 pixels). This cell size (20x20 pixels) represents a compromise between capturing as many fixations per cell as possible to optimize statistical power (which ideally requires large cells) versus retaining good anatomical resolution (which ideally requires small cells). We modeled differences in fixation counts (also known as fixation density) between conditions by applying generalized linear mixed models (GLMMs). To do this we used PROC GLIMMIX in SAS v9.1 (SAS Institute, North Carolina, USA).

For spatially sampled data, we cannot assume that the fixation counts in each cell are statistically independent of each other. Specifically, we must assume that total fixation counts will co-vary across sampling cells, and that the magnitude of this spatial covariation is inversely proportional to the cells' proximity to each other. Therefore, in the statistical models we not only took account of the between groups factor (i.e. attractiveness versus fat estimation versus WHR estimation) as well as the repeated measures factors – i.e. each subject contributed a number of fixations to the sampling grid (defined by row and column indices in the model) for each of the 46 images, but we also controlled for spatial co-variance by incorporating the spatial variability into the statistical models. We assumed the fixation counts to follow the Poisson distribution and consequently a log-link was used as a link function in the models for the outcome. The spatial variability was integrated into the models by specifying a Gaussian spatial correlation model for the model residuals.The GLIMMIX procedure was then used to assess any significant differences between the conditions or genders. Areas of significant difference between conditions or genders are indicated by the black contours ($p<0.05$) in figures 1 and 2, and are based on the estimated marginal means derived from the model parameters. These predicted population margins are compared using tests for simple effects by partitioning the interaction effects.

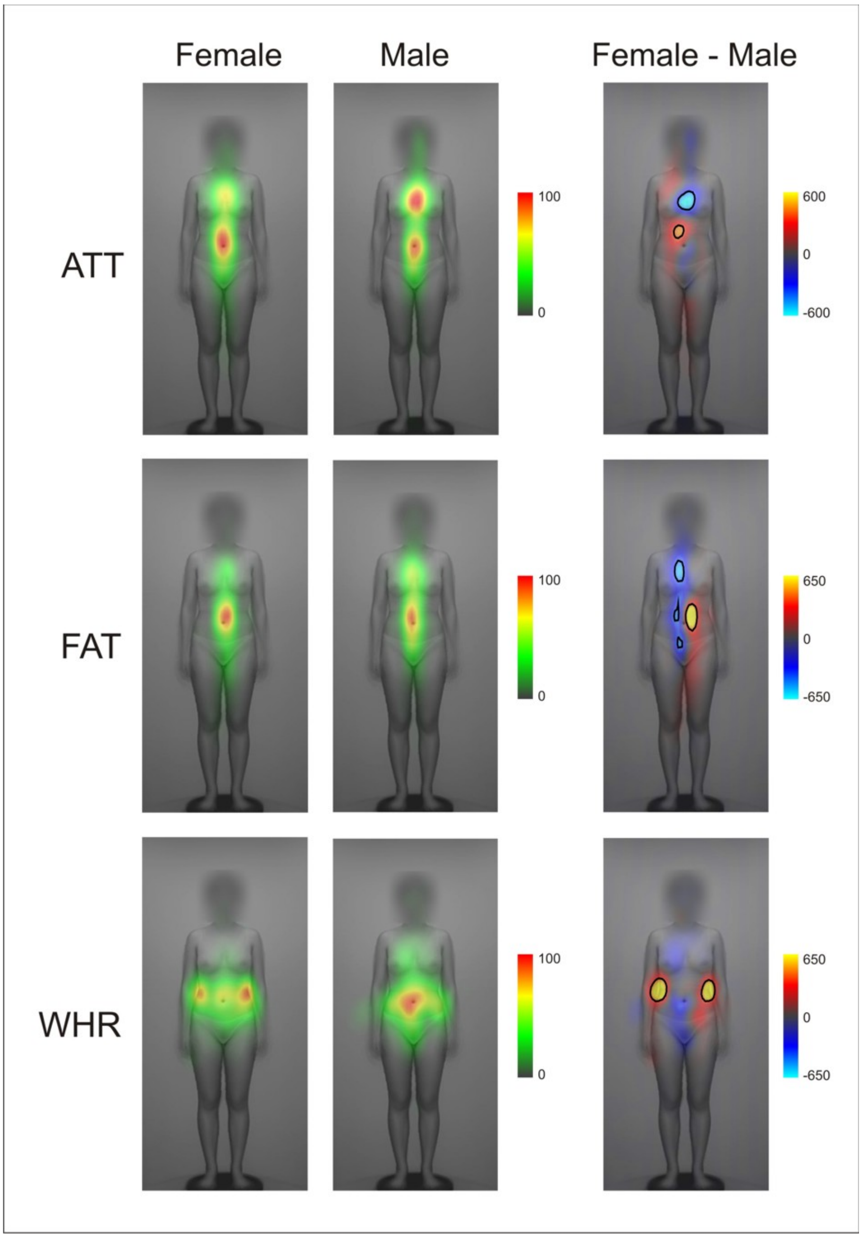

Figure 1 The left and central columns of bodies show contour plots of the fixation distributions for the attractiveness (ATT), body fat (FAT) and WHR estimation conditions for both genders overlaid onto the image of the reference body. In order to facilitate inspection of the data across all conditions, fixation density in the left and central columns has been converted to a percentage score, indicated by colour bars (0-100), with red indicating the highest density. The right column of bodies shows the differences in the fixation density (i.e. differences in raw scores) between the genders for the three conditions. Positive differences are shown as red/yellow colours; negative differences are shown as blue/cyan colours. The black contours demarcate regions within which these differences are statistically significant as determined by the GLMMs.

To illustrate the spatial distribution of fixation counts on the body (i.e. to identify where observers were looking), the fixation distributions for each observer gender and condition were converted to percentage scores and represented as contour plots overlaid on the reference body in the left and central columns of bodies in fig. 1. The far right column of fig. 1 shows contour plots of the differences in fixation density (raw scores) between the two genders for each condition. Both genders show a broadly similar pattern of fixations for a given condition. The attractiveness fixations spread from the stomach up towards the breast and upper chest. However, males tend to look more at the chest than female observers, who tend to look more at the stomach. The same fixation pattern is seen in judgments of body fat, which is consistent with the close correlation of attractiveness ratings and estimates of body fat. However, the pattern of fixations for estimated WHR is markedly different when compared to the other two conditions. Instead of looking *along* the torso, the observers look *across* the torso. The female observers show two peaks of fixation density on either side of the torso on the edge of the waist and upper hips, consistent with sampling the visual information necessary to make this judgment. Although the male observers show the same pattern of fixations across the body, they show less lateral displacement across the torso and their fixations remain within the torso outline in contrast to the high density of female fixations on its edge. This gender difference in fixations seems to be reflected in the accuracy of their estimations; males have a much weaker correlation between their estimated WHR and front-WHR or actual WHR, than those seen for the female observers.

Figure 2 illustrates the differences in fixation patterns (raw scores) between the three experimental conditions. Areas of significant difference between the conditions are again indicated by the black contour lines. For both male and female observers, the differences in fixation density are very similar. Both male and female observers look more at the chest in the attractiveness condition and more at the stomach in the body fat condition. The most striking difference between the conditions, are between WHR and the other two conditions. For both genders, there is a consistent, clear pattern of differences. When estimating WHR, the observers look significantly less along the centre of the torso and significantly more on the edge of the waist and upper hips on each side of the body: logically, the pattern of information required to make the different judgments. Judgments of attractiveness and body fat samples information distributed along the central torso (including the stomach), whereas estimates of WHR requires eye-movements across the body to determine the width of the torso and the curvature of the waist-hip region.

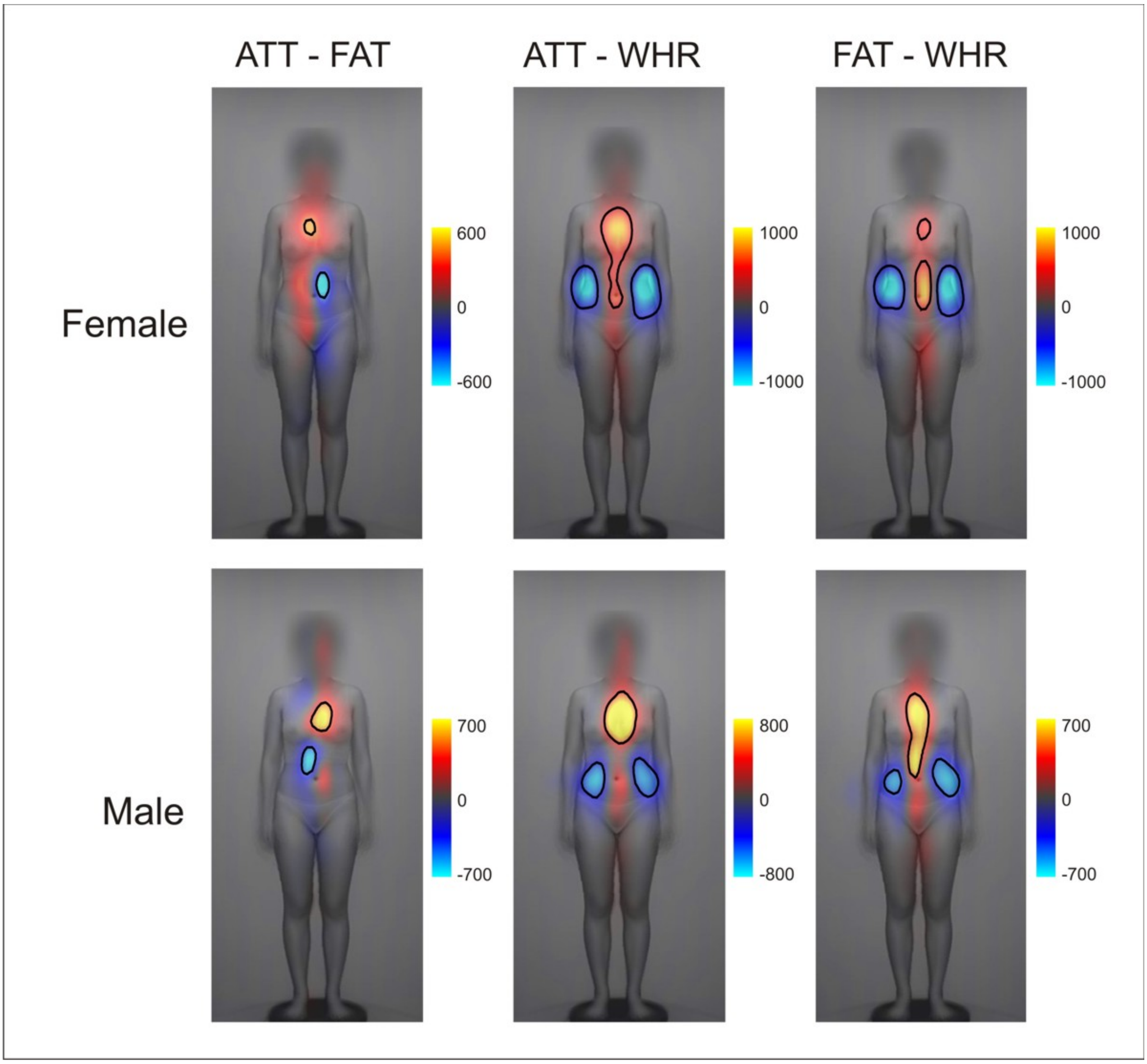

Figure 2 The top row of bodies show the differences in fixation density (i.e. raw scores) between the different conditions for female observers and the bottom row show the differences for the male observers; attractiveness minus WHR fixations (ATT-WHR), attractiveness minus body fat fixations (ATT-FAT) and body fat - WHR (FAT-WHR). Positive differences are shown as red/yellow colours; negative differences are shown as blue/cyan colours. The black contours demarcate regions within which these differences are statistically significant as determined by the GLMMs.

Experiment 2: Estimating WHR and Body Fat when Centrally Fixating the Torso

The results of experiment 1 suggest that during attractiveness judgements, observers do not look in those regions at the edge of the torso which are used to judge WHR explicitly. However, it is possible that the low resolution image information provided by the periphery of the retina is nevertheless sufficient to mediate the discrimination of body shape, and that observers do not need to fixate these edge regions directly. To test this hypothesis, we carried out a further experiment using brief, masked stimulus presentations to observers who were fixating centrally on the torso, confirmed by eye-movement recording.

METHODS

Two groups of 10 observers (each with 5 male and 5 female observers) consented to take part in experiment 2. One set estimated the WHR of the images and the second estimated overall body fat. We did not use separate male and female gender groups as in the previous experiment, where we were looking for differences in fixations patterns between the genders. In this experiment, fixation position was controlled (see below), and so there was no difference. How to judge WHR was explained to the observers as in experiment 1. The average age of the observers in the WHR group was 25.2 years (s.d. 7.3) and in the body fat group was 25.2 (s.d. 10.6).

The stimulus set was the same as in experiment 1. Each trial comprised the following sequence. A black fixation cross appeared, its position corresponded to the centre of the torso at the level of the waist. The observers were asked to fixate the cross, and to not move their eyes during the subsequent presentation of the stimulus image. When they had fixated the cross continuously for a second, the system automatically presented the target image, for 100 ms, immediately followed by a 100 ms-long, pixilated mask. This was derived from one of the body stimuli to give the same average tones and luminance as the stimulus image, but was larger than any of them. The presentations were brief and masked to minimise the possibility of saccades during the presentation and to mimic the pattern of visual activation produced by an individual fixation (Burr et al. 1994; Burr, 2005). We used the eye-tracker to monitor eye-movements and prevent any anticipatory eye-movements. Following mask presentation, the observer rated the image on a scale of 1-9 using a keyboard. There was no time limit for rating the image. After making their rating, the fixation cross reappeared and when it had been fixated for a second, the next image was displayed.

RESULTS

Cronbach alpha for the WHR estimates is 0.75 and for body fat is 0.94. The estimates of WHR were not significantly correlated with the actual WHR of women in the images ($r=0.05$, $p=0.72$) or their fWHR ($r=0.02$, $p=0.93$). We applied the same regression model as detailed in Experiment 1 to these data (see Table 3). For the WHR estimates, neither actual WHR or fWHR are significant predictors. Instead, the observers seem to be defaulting to a judgement of overall body fat. This suggests that it is not possible to accurately estimate the curvature of the lower torso without directly fixating the edge of the torso which corresponds to this shape change. The estimates of body fat were significantly correlated with BMI ($r=0.87$, $p<0.0001$), and the regression analysis indicates that BMI is the primary predictor of this judgement. This suggests that the inability to estimate WHR is not based on the brief presentation time, but on the position fixated.

Table 3

The regression models for the WHR and body fat estimations for the 100msec condition. We have modelled the WHR estimations twice; once using actual WHR as an explanatory variable and once using fWHR. The degrees of freedom for the T-values are 1, 42 throughout.

Behavioural Judgement (100 msec)	Beta coefficient for BMI	Beta coefficient for WHR/ fWHR	Beta coefficient for intercept	T-value for BMI	T-value for WHR	T-value for intercept	Unique % variance for BMI	Unique % variance for WHR/ fWHR	Total % variance for full model
WHR estimate (actual WHR)	0.74	0.004	0.05	7.21**	0.04	0.49	54.9%	0.1%	54.9%
WHR estimate (f WHR)	0.78	-0.12	0.08	6.41**	-0.89	0.59	54.7%	2.2%	57.0%
FAT estimate	0.85	0.09	0.05	11.45**	1.20	0.62	75.0%	2.2%	75.8%

***** = $p<0.001$, * = $p<0.05$***

DISCUSSION

We combined behavioural judgements with a novel analysis of eye-movements that allowed us to make fine spatial discriminations in the pattern of fixations between experimental conditions. For attractiveness judgments, observers demonstrated a typical fixation distribution prior to their rating decision; they looked in a vertical band stretching from the waist towards the upper part of the torso. Therefore, we assume that it is these regions in the images which informed the observers' decisions. We then used this fixation map as a standard for comparison against the fixation patterns for the two explicit estimations. The fixations when judging body fat are the primarily distributed on the stomach. The physical dimensions of the stomach are a good index of the overall body mass (e.g. Wells et al., 2007, 2008; Cornelissen et al., 2009b), and a recent study proposed stomach depth as an index of overall body mass (Rilling et al., 2009). Thus, fixating the central torso would allow the degree of stomach protrusion to be estimated and is an effective way of sampling an information rich area. The fixation patterns are very similar when judging attractiveness and explicitly estimating body fat, which would be consistent with the eye-movements necessary for judging body fat being part of the eye-movement pattern used to judge attractiveness. This is consistent with the behavioural data, which suggest the attractiveness ratings were predicted primarily by overall body fat (indexed by BMI), in line with previous studies using images of real women (e.g. Tovée et al., 1998, 1999, 2002; Fan et al., 2004; Smith et al., 2007a). The attractiveness and body fat fixation distributions are not completely identical, and the body fat fixations form a subset of the fixations made during attractiveness judgements. The more extensive distribution of fixations for attractiveness presumably reflects the fact that overall body fat is only one of a number of features which determine attractiveness judgments.

The similarities in fixation distribution between the attractiveness and body fat conditions are in contrast to the distribution for the explicit estimation of WHR, which shows a clearly different pattern of fixations. The WHR fixations spread across the torso onto the waist and hips at the level of the waist, and do not move up over the chest. If WHR was an important visual feature that was sampled when making attractiveness judgments, one might expect the horizontal spread of fixations seen in the WHR condition, to be incorporated into the pattern of fixations made when attractiveness is assessed. This comparison of fixation distributions suggests that this is not the case. To discount the possibility that a direct fixation is not required, and that the retinal periphery is capable of supporting fine judgements of WHR, in a second set of experiments we constrained observers to fixate the central torso at the level of the waist while judging WHR. Our results in the second set of experiments suggest that the fixations across the body onto the edge of the torso at the level of the waist and hips are necessary to estimate WHR. Centrally fixating on the torso (as the observers do when judging attractiveness) does not allow the observers to sample the information necessary to judge WHR.

These findings are consistent with behavioural studies which suggest that, particularly for male observers, the role of WHR in attractiveness judgments is significantly less than that for body fat. These studies have employed stimulus images of unmodified bodies and take advantage of the natural variation in BMI and WHR. They show that the variance in attractiveness is primarily accounted for by overall body fat (e.g. Tovée et al., 1998, 2002; Puhl & Boland, 2001; Fan et al., 2004; Smith et al. 2007a; Swami et al., 2006, 2008). Those studies which have suggested a key role for WHR have used line-drawings or digitally altered photographs (e.g. Singh, 1993; Henss, 2000). In these studies the method of WHR manipulation also altered the apparent body mass as demonstrated by Tassinary & Hanson (1999) and Tovée & Cornelissen (1999), therefore the relative contributions of these two features to attractiveness cannot be distinguished. To attempt to get around the problem of co-variation between apparent BMI and WHR in manipulated stimulus images, Streeter & McBurney (2003) asked their observers to estimate the body weight of a set of digitally altered photographs as well as rate their attractiveness, so they could factor out perceived body weight in their analyses. In the Streeter & McBurney study, the authors digitally modified a photograph to give a set of images whose WHRs ranged from 0.50 to 1.20. However, when manipulating WHR in this way, it is important to ensure that features across the entire body change in an anthropometrically valid way. If this constraint is not met there is a risk that the resulting image may not be realistic. Having asked observers to rate the Streeter & McBurney images for realism, Bateson et al (2007) showed that attractiveness ratings of the images could be explained by their apparent realism just as well as they could by their WHR. Therefore, while we concede the general principle that a feature which accounts for only a small proportion of the variance in attractiveness judgements may nevertheless provide an important biological signal for this attribute, most of the studies which explore this possibility for WHR appear to co-vary WHR with other anthropometric features. Additionally, it must be borne in mind that epidemiological studies of large populations have consistently reported a link between BMI and WHR (e.g. Health Survey for England, 2003). Cornelissen et al. (2009) have shown how an additive model of subcutaneous fat deposition, whereby fat is added to the waist and hips at a constant rate, captures this correlation between BMI and WHR because with increasing fat, the difference between the waist and hips becomes smaller relative to total width. Using their additive model for Caucasian women in the UK, Cornelissen et al. (2009) show that the explanatory power of WHR may lie primarily in what it reveals about overall body fat.

There are certain similarities in how we process visual information from faces and bodies. For example, our perception of both shows view-inversion effects, selective adaptation and categorical discrimination (e.g. Reed et al., 2003; Winkler & Rhodes, 2005; Tovée, Edmonds & Vong, 2009), and a parallel might be drawn between the eye-movements exhibited in judging bodies and with those seen in face recognition. In judging faces, the key features in a particular perceptual judgement are fixated first and for longest in a predictable scan path (e.g. Henderson et al., 2000; Walker-Smith, Gale, & Findlay, 1977). Observers with deficits in face processing show abnormal patterns of eye-movements which appear to form the basis of their perceptual dysfunction (e.g. Adolphs et al., 2005; Caldara et al., 2005; Pelphrey et al., 2002). In a similar way, observers with deficits in judging bodies also show disturbed fixation patterns. For example, women suffering from Anorexic Nervosa, for whom a distorted body image is part of their diagnostic criteria (APA, 2004), show significant differences in their attractiveness ratings of other women's bodies (Tovée et al., 2000, 2003), and also show a significantly different pattern of eye-movements during this judgement (George et al., 2009).

Consistent with previous reports, our behavioural results suggest a strong similarity between male and female observers in their attractiveness and body fat ratings, but we found some subtle differences in their fixation distributions (e.g. Tovée & Cornelissen, 1999; Tovée et al., 2002; Smith et al., 2007a, b). When rating attractiveness, male observers tend to look further up the body, incorporating more fixations on the bust. A result consistent with the suggestion that the bust-waist ratio may provide a useful cue to reproductive potential, and thus influence attractiveness judgements (Jasienska et al., 2004). Nevertheless, both genders converge on the same behavioural decision for attractiveness. This is predicted by mate selection theory which postulates that an individual will be able to judge not only the attractiveness of members of the opposite sex, but also that they will know their own attractiveness relative to other members of the same sex (e.g. Buss, 1987). This information allows a subject to concentrate on potential partners of the same attractiveness as themselves, thus avoiding both unsuccessful courtship of a more attractive partner (potentially wasteful in time and resources), and accepting a less attractive partner (with a potentially negative impact on future reproductive success). The biggest difference in fixation patterns between the genders was for the estimation of WHR. The female observers showed a significantly higher fixation density on the edge of torso corresponding to the waist and hips than the males, although both genders significantly fixate the edge of the torso at this point more in the WHR estimation condition than in the attractiveness and body fat judgements. This gender difference in fixations for the WHR condition seems to be reflected in the higher accuracy of WHR estimation by the female observers, a finding consistent with the results of experiment 2, which suggest that fixations of this region are necessary to support WHR estimation.

Overall body mass and lower-body fat distribution are just two of the potential cues used to judge attractiveness. Other factors include the torso-leg ratio (TLR), the waist-bust ratio (WBR) and bilateral symmetry (e.g. Sorokowski & Pawlowski, 2008; Jasienska et al., 2004; Brown et al., 2008), and many of them are significantly correlated with each other but spatially separated on the body. The use of this eye-movement analysis potentially allows disambiguation of which cues are used to make judgements about the female body, including attractiveness, health and fertility. It can also be extended to male body judgements, where the relative importance of two potential cues, overall body mass and upper body shape, has been the subject of some debate (e.g. Maisey et al., 1999; Fan et al., 2005; Sell et al., 2008). The technique can also be used in judgements of facially conveyed information, making it possible to make fine distinctions over the features used in social cognition.

In conclusion, our new eye-movement analysis technique has allowed us to determine with great precision where observers look when they rate images of women's bodies. The results suggest that the body fat fixations are very similar to the attractiveness fixations, consistent with body fat being one of the features which are used to judge attractiveness. In contrast, the WHR fixation distribution shows a unique pattern which differs from the attractiveness fixations and whose distribution covers different body features. This suggests that an assessment of WHR may not be directly made during attractiveness judgments. These fixation distributions are consistent with the behavioural responses made during the attractiveness judgments, which suggest that BMI is a stronger predictor of attractiveness ratings.

REFERENCES

Adolphs, R., Gosselin, F., Buchanan, T.W., Tranel, D., Schyns P. & Damasio, A.R. (2005). A mechanism for impaired fear recognition after amygdala damage, *Nature, 433***,** 68–72.

Altman, D.G. 1991 *Practical Statistics for Medical Research*. London: Chapman and Hall.

American Psychiatric Association (APA) 2004 *The Diagnostic and Statistical Manual of Mental Disorders –IV- Text Revision (DSM-IV-TR)*. American Psychiatric Association.

Bateson, M., Cornelissen, P.L. & Tovée, M.J. 2007. Methodological issues in judgements of female body Attractiveness. In A. Furnham & V. Swami, (Eds.), *The Body Beautiful: Evolutionary and Socio-cultural Perspectives* (pp. 46-62) Palgrave Macmillan.

Brown, W.M., Price, M.E., Kang, J., Pound, N., Zhao, Y., Yu, H. 2008 Fluctuating asymmetry and preferences for sex-typical bodily characteristics *Proc. Nat. Acad. Sci. USA* **105,** 12938–12943.

Burr, D. 2005 In the blink of an eye. *Current Biology*, 15, R554-556.

Burr, D.C., Morrone, M.C., Ross, J. 1994 Selective suppresion of the magnocellular visual pathway during saccadic eye movements. *Nature,* 371, 511-513.

Buss, D. M. 1987 Sex differences in human mate selection criteria: An evolutionary perspective. In C. Crawford, M. Smith, & D. Krebs, (Eds.), *Sociobiology and psychology: Ideas, issues and application* (pp. 335–351) Hillsdale, NJ Erlbaum.

Caldara, R., Schyns, P., Mayer, E., Smith, M.L., Gosselin, F. & Rossion, B. 2005 Does Prosopagnosia take the eyes out of face representations? Evidence for a defect in representing diagnostic facial information following brain damage. *Journal of Cognitive Neuroscience* 17, 1652-1666.

Cornelissen, P.L., Toveé, M. J. & Bateson, M. (2009). Patterns of subcutaneous fat deposition and the relationship between body mass index and waist-to-hip ratio: implications for models of physical attractiveness. *J. Theor. Biol.* **256**, 343-350.

Dalton, K.M., Nacewicz, B.M., Johnstone, T., Schaefer, H.S., Gernsbacher, A., Goldsmith H.H., Alexander, A.L. & Davidson, R.J. 2005 Gaze-fixation and the neural circuitry of face processing in autism. *Nature Neuroscience* **8,** 519-526.

Fan, J.T., Liu F., Wu, J. & Dai, W. 2004 Visual perception of female physical attractiveness. *Proc. R. Soc. B* **271**, 347–352.

Fan, J. W., Dai, W., Liu, F. & Wu, J. 2005 Visual perception of male body attractiveness. *Proc. R. Soc. B* **272,** 219–226

Frisch, R. E. 1988 Fatness and fertility. *Sci. Am.* **258**, 88-95.

George, H.R., Cornelissen, P.L., Hancock, P.J.B., Kiviniemi, V.V. & Tovée, M.J. 2009 Differences in eye-movement patterns between anorexic and control observers when judging body size and attractiveness. *International Journal of Eating Disorders* (submitted).

Guo, K., Robertson, R.G., Mahmoodi, S., Tadmor, Y. & Young, M.P. 2003 How do monkeys view faces?—a study of eye movements. *Experimental Brain Research* **150,** 363–374

Health Survey for England 2003 National Centre for Social Research and University College London. Department of Epidemiology and Public Health. UK Data Archive, Colchester, Essex.

Hancock, P.J.B. 2000 Evolving faces from principal components. *Behavior Research Methods, Instruments and Computers* **32**, 327-333.

Henderson, J. M., Falk, R. Minut, S., Dyer, F. C., & Mahadevan, S. 2000 Gaze control for face learning and recognition by humans and machines (Tech. Rep. No. 4, pp. 1–14). East Lansing, MI: Michigan State University, Eye Movement Laboratory.

Henss, R. 1995 Waist-to-hip ratio and attractiveness. A replication and extension. *Pers. & Individual Differences* **19,** 479–488.

Henss, R. 2000 Waist-to-hip ratio and attractiveness of the female figure. Evidence from photographic stimuli and methodological considerations. *Personality & Individual Differences* **28,** 501–513.

Isaacowitz, D.M.,Toner, K., Goren, D. & Wilson, H.R. 2008 Looking while unhappy: Mood-congruent gaze in young adults, positive gaze in older adults. *Psychological Science, 19,* 848-853.

Jasienska, G., Ziomkiewicz, A., Lipson, S.F., Ellison, P.T. & Thune, I. 2004. Large breasts and narrow waist indicate high reproductive potential in women. *Proc. R. Soc. B* **271,** 1213-1217.

Lake, J. K., Power, C. & Cole, T. J. 1997 Women's reproductive health: the role of body mass index in early and adult life. *Int. J. Obesity* **21,** 432-438.

Lassek, W. D. & Gaulin S. J. C. 2008 Waist-hip ratio and cognitive ability: Is gluteofemoral fat a privileged store of neurodevelopmental resources? *Evolution and Human Behavior* **29,** 26-34.

Levi, D.M. Klein, S.A. & Aitsebaomo, A.P. 1985 Vernier acuity, crowding and cortical magnification. *Vision Research* **25**, 963–977

Manson, J. E., Willet, W. C., Stampfer, M. J., Colditz, G. A., Hunter, D. J., Hankinson, S. E., Hennekens, C. H. & Speizer, F. E. 1995 Body weight and mortality among women. *New Engl. J. Med.* **333,** 677-685.

Maisey, D.S., Vale, E.L.E., Cornelissen, P.L. & Tovee, M.J. 1999 Characteristics of male attractiveness for women. *Lancet* **353**, 1500.
Puhl, R.M. & Boland, F.J. 2001 Predicting female physical Attractiveness: Waist-to-hip ratio versus thinness. *Psychol., Evol. & Gender* **3,** 27–46
Pelphrey, K. A., Sasson, N. J., Reznick, S., Paul, G., Goldman, B. D., & Piven, J. 2002 Visual scanning of faces in autism. *Journal of Autism and Developmental Disorders* **32,** 249–261.
Reed, C.L., Stone, V., Bozova, S., & Tanaka, J. 2003 The body inversion effect. *Psychological Science* **14,** 302-308.
Reid, R. L. & Van Vugt, D. A. 1987 Weight related changes in reproductive function. *Fertil. Steril.* **48,** 905-913.
Rilling, J.K., Kaufman, T.L., Smith, E.O., Patel, R. & Worthman, C.M.2009 Abdominal depth and waist circumference as influential determinants of human female attractiveness. *Evolution and Human Behavior* **30,** 21–31.
Sell, A. Cosmides, L., Tooby, J., Sznycer, D., von Rueden, C. & Gurven, M. 2008 Human adaptations for the visual assessment of strength and fighting ability from the body and face. *Proc. R. Soc. B.* **276,** 575–584
Singh, D. 1993 Body Shape and Womens Attractiveness - the Critical Role of Waist-To-Hip Ratio. *Human Nature* **4,** 297-321.
Smith, K. L., Cornelissen, P. L., & Tovee, M. J. 2007a Color 3D bodies and judgments of human female attractiveness. *Evolution and Human Behavior* **28**, 48-54.
Smith, K. L., Tovée, M. J., Hancock, P., Bateson, M., Cox, M. A. A., & Cornelissen, P. L. 2007b An analysis of body shape attractiveness based on image statistics: Evidence for a dissociation between expressions of preference and shape discrimination. *Visual Cognition* **15**, 1-27.
Sorokowski, P. & Pawlowski, B. 2008 Adaptive preferences for leg length in a potential partner. *Evolution and Human Behavior* **29**, 86-91
Streeter, S. A., & McBurney, D. H. 2003 Waist-hip ratio and attractiveness. New evidence and a critique of 'a critical test.' *Evol. & Hum Behav.* ***24***, 88-98.
Streeter, S. A., & McBurney, D. H. 2007. Waist-to-hip ratios and female attractiveness: comparing apples, oranges and pears. In A. Furnham & V. Swami, (Eds.), *The Body Beautiful: Evolutionary and Socio-cultural Perspectives* (pp. 15-28) Palgrave Macmillan.
Swami V. Caprario, C. Tovée, M.J. & Furnham, A. 2006 Female physical attractiveness in Britain and Japan: A cross-cultural study. *Eur. J. Pers.* **20**, 69-81.
Thibos, L.N. Cheney, F.E. & Walsh, D.J. 1987 Retinal limits to the detection and resolution of gratings, *Journal of the Optical Society of America A* **4,** 1524–1529
Thornhill, R. & Grammer, K. 1999 The body and face of woman: One ornament that signals quality? *Evol. & Hum Behav.* **20**, 105–120
Tovée, M.J. Benson, P.J., Emery, J.L. Mason, S.M. & Cohen-Tovée, E.M. 2003 Measurement of body size and shape perception in eating- disordered and control observers using body-shape software. *Brit. J. Psychol.* **94***,* 501-516.
Tovée, M.J. & Cornelissen, P.L. 1999 The mystery of female beauty. *Nature* **399,** 215-216.
Tovée, M. J. & Cornelissen, P. L. 2001 Female and male perceptions of female physical attractiveness in front-view and profile. *Brit. J. Psychol.* **92***,* 391-402.
Tovée, M. J., Edmonds, L. & Vuong, Q.C. 2009 Categorical perception of the attractiveness of female bodies. *European Human Behaviour and Evolution Association* (in press).
Tovée, M.J. Emery, J.L. & Cohen-Tovée, E.M. 2000 The estimation of body mass index and physical attractiveness is dependent on the observer's own body mass index. *Proc. R. Soc. B* **267**, 1987-1997.

Tovée, M. J., Hancock, P. J. B., Mahmoodi, S., Singleton, B. R. R., & Cornelissen, P. L. 2002 Human female attractiveness: waveform analysis of body shape. *Proc. R. Soc. B* **269**, 2205-2213.

Tovée, M. J., Maisey, D. S., Emery, J. L., & Cornelissen, P. L. 1999 Visual cues to female physical attractiveness. *Proc. R. Soc. B* **266**, 211-218.

Tovée, M. J., Reinhardt, S., Emery, J. L., & Cornelissen, P. L. 1998 Optimum body-mass index and maximum sexual attractiveness. *The Lancet* **352,** 548.

van der Geest, J.N., Kemner, C., Verbaten, M.N. & van Engeland, H. 2002 Gaze behavior of children with pervasive developmental disorder toward human faces: a fixation time study. *Journal of Child Psychology and Psychiatry* **43,** 669–678.

Walker-Smith, G., Gale, A. G., & Findlay, J. M. 1977 Eye movement strategies involved in face perception. *Perception* **6,** 313–326.

Willet, W. C., Manson, J. E., Stampfer, M. J., Colditz, G. A., Rosner, B., Speizer, F. E. & Hennekens, C. H. 1995 Weight, weight change and coronary heart disease in women: Risk within the `normal' weight range. *J Am. Med. Ass*. **273,** 461-465.

Winkler, C. & Rhodes, G. 2005 Perceptual adaptation affects attractiveness of female bodies. *Br J Psychol.* **96,** 141-54.

Zaadstra, B. M., Seidell, J. C., van Noord, P. A. H., Velde, E. R., Habbema, J. D. F., Vrieswijk, B., et al. 1995 Fat and fecundity: Prospective study of effect of body fat distribution on conception rates. *British Medical Journal* **306,** 484-487.