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# A computer-based method for the assessment of body image distortions in anorexia nervosa patients

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## Abstract

A computer-based method for the assessment of body image distortions in anorexia nervosa and other eating-disordered patients is presented. At the core of the method is a realistic pictorial simulation of lifelike weight-changes, applied to a real source image of the patient. The patients, using a graphical user interface, adjust their body shapes until they meet their self-perceived appearance. Measuring the extent of virtual fattening or slimming of a body with respect to its real shape and size, allows direct, quantitative evaluation of the cognitive distortion in body image. In a preliminary experiment involving 33 anorexia-nervosa patients, 70% of the subjects chose an image with simulated visual weight gain of between 8% and 16% as their “real” body image, while only one of them recognized the original body image. In a second experiment involving 30 healthy participants, the quality of the weight modified images was evaluated by pairwise selection trials. Over a weight change range of -16% to +28%, in about 30% of the trials, artificially modified images were mistakenly taken as “original” images, thus demonstrating the quality of the artificial images. The method presented is currently in a clinical validation phase, towards application in the research, diagnosis, evaluation and treatment of eating disorders.

## 1 Introduction

Anorexia nervosa (AN) is a psychiatric disorder, characterized by low body weight (less than 85% of the minimally normal weight for age and height), refusal to gain weight, an intense

fear of gaining weight or becoming obese, amenorrhea (absence of the monthly period) and perceptual distortions or disturbances of body image or weight [1]. Disordered patients may also exhibit bulimic behaviors such as ingesting large quantities of food, sometimes followed by purging habits that try to compensate for the ingestion of large amount of calories by voiding it through self-induced vomiting, intensive physical activities and abuse of laxative drugs. Bulimia may deplete the body of fluids and of potassium, adversely affecting heart function. The disorder, therefore, involves high incidence of both mental and physical morbidity and high rates of mortality (5-18% of known AN patients) [18].

Body image distortion is a major symptom of AN and other eating disorders. It is relatively resistant to treatment and can be perceived as a cognitive and perceptual core of the disorder [20]. The assessment of body image is, therefore, a central and reliable diagnostic measure, and is also important for the assessment of the changes during treatment [21]. Since the perceptual distortion allows a reliable representation of the pathology, a way of documenting and quantifying the perceptual distortion is of major necessity [30]. Evaluating the existence and severity of the distortion as a direct measure for the perceptual pathology, is also important for research purposes. It may contribute to the understanding of the etiology and the cognitive basis of the disorder, to the evaluation of different treatment methods and to research on the epidemiology of the disorder. For instance, quantifying the distortion in body image at different time points along the course of treatment will give a valid indication for the efficiency of the treatment used. A sensitive measure of body image distortions may be used for early detection, where a clinical intervention may avoid potentially chronic effects of adapting to eating disorders habits (as in anorexia and bulimia nervosa) and other cases of sub-clinical eating disorders.

The increasing incidence of eating disorders and the rising acknowledgment of the central role of the perceptual distortion of the body, lead to the development of various methods for the assessment of body size self-estimation in AN. The first to be employed was the *movable caliper* or *visual size estimation* method, which involved the manual adjustment of the distance between two markers until it was perceived to match the particular body part size to be estimated [24]. Various methods, based on the same principle of estimating body part widths, are referred to as *body part* or *body-site* methods.

Askevold [2] developed the *image marking* procedure in which participants draw their perceived body size on a sheet of paper attached to a wall. Ruff and Barrios [22] suggested the *body-image detection* device with which participants are required to adjust the distance between two lights to match their perceived size. With the *adjustable light beam apparatus* introduced by Thompson and Spana [25], participants adjust the width of a light beam projected on the wall to match the perceived body part size. One drawback of these methods is that body parts are considered in isolation and the context of the whole body is missing. Furthermore, in these methods an external mediator is involved in conducting the measurements. This can adversely affect the reliability of quantitative measurement of the subject's self-perception and self-assessment.

Other methods focus on estimating the body as a whole. In the highly popular method of *silhouette cards*, participants have to select the silhouette that best represents themselves from a series of silhouettes varying from a thin body figure to an obese body figure [3]. In other *whole body* methods, the participant views a real-life image and adjusts its size until it matches his or her view of his or her body size [14]. Among the best known procedures is the *distorting mirror* in which an adjustable mirror distorts the whole body [29]. The *distorting*

*photograph* technique entailed projecting a slide with a distorted version of the person's body. Participants were requested to adjust the distorted image on the screen using an anamorphic lens, until it corresponded with their perceived body size [15]. With the *video distortion* techniques, participants adjust the horizontal dimension of their distorted video images to match their perceived size. The video images can be projected onto a retroprojection life-size screen, allowing the subjects a direct confrontation with their life-size image as if they are looking in a mirror [13, 19]. These whole body distortion methods lead, in most cases, to unnatural, unrealistic images. The distortion level is technically limited and the distortion of specific body parts cannot be controlled.

Computer-based techniques that involve body part and whole body distortions were presented in [12, 23]. Both methods provide body outlines or silhouettes, not a realistic recognizable image of the participant.

In this paper we present a new diagnostic tool that facilitates evaluation of the self perception of the subject's body image and provides a quantitative measure of body image distortion. Starting with a real image of the subject, highly realistic fattened and slimmed images are synthesized. Body parts are independently modified while maintaining the natural appearance and global characteristics of the body shape. User interactivity is simple and friendly, allowing direct manipulation by an untrained subject without an external mediator.

## 2 The algorithm for weight-change simulation

Fattening and slimming processes have different effects on different body parts. The body weight-change simulation algorithm first subdivides the body image into principal body-parts, that have different patterns of shape-change, when a weight gain or loss process takes place. Each body part is separately and independently processed. Then, the altered body parts are merged back into a whole body, with special attention to joint areas. The whole process is based on a method developed for the representation of biological shape modifications (such as growth and evolution) in living organisms.

### 2.1 Image acquisition and preprocessing

The subjects (eating disorders patients) are dressed in close-fitting, uniform pink or purple colored full-body leotards. Front-view body images are captured with a Sony digital still camera (model MVC-FD73), with the subjects' arms raised by about  $25^\circ$ , having their fists clenched and their legs parted by about 50cm. A uniform matte blue screen is used as background. The pixel resolution is 640x480.

The identification of body parts is semi-automatic. The user points at seven different landmarks on the source body image. Slightly misplaced landmarks are corrected automatically. These seven landmarks are used by the algorithm to isolate ten different body parts (left hand, right hand, head, upper chest, lower chest, belly, hips, pelvis, left leg, and right leg as shown in Fig. 1). Each body part is processed independently, according to its shape-change characteristics.

The extraction of the body figure from the background of the image is automatic. First

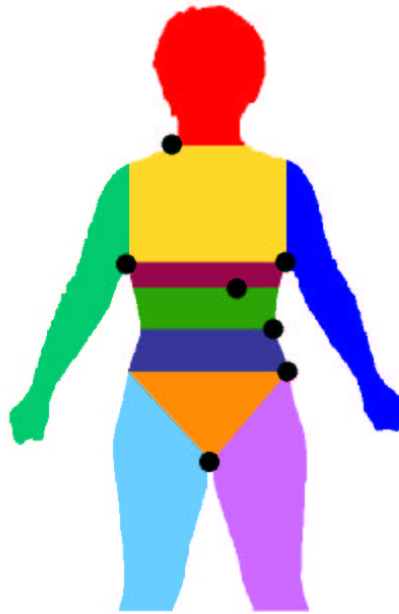


Figure 1: The seven landmarks provided by the user are used to isolate ten different body parts from the extracted body image. The landmark locations are (top to bottom): neck, left armpit, right armpit, lower chest, hips, pelvis and crotch.

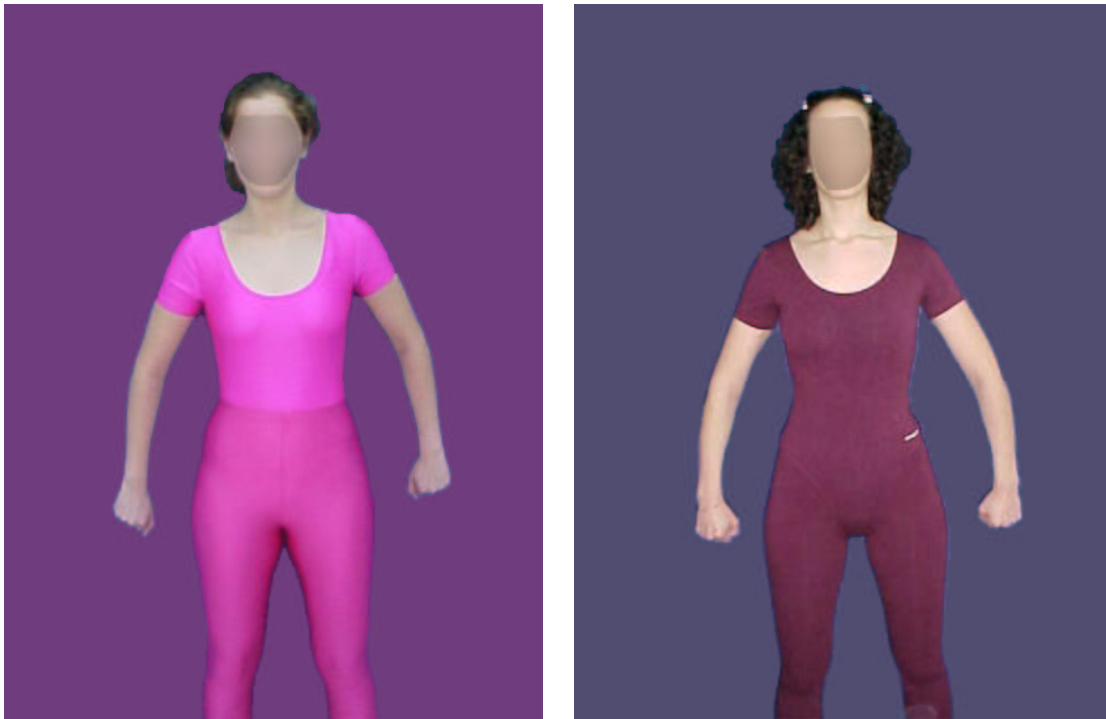


Figure 2: Body images of two anorexia-nervosa patients, extracted (segmented) from the original images. The left patient is referred to as 'A', the right as 'B'.

the image is transformed from the RGB color space to the HSV (Hue, Saturation, brightness Value) color space. Since the background is uniform matte blue, adaptive hue-thresholding (supported by an adaptive saturation threshold for reliable segmentation of hair) allows sharp and exact extraction of the body figure from the source image (see Fig. 2). The segmented body shape, together with the seven user marked landmarks, is used to create a binary mask for each of the ten different body parts. These masks are essential for the shape transformation algorithm, which is applied to each body part independently.

## 2.2 The method of transformation grids

There exist several techniques and methods for the representation of shape and shape change. However, most of these techniques refer to shapes as still objects (in contrast to living organisms) and to shape changes as partial displacements governed by external forces. Since in our case the shapes to be modified are human body parts, that have their own pattern of growth and deformation, a special kind of shape change method is required. Such a method was presented by Bookstein [6] who has found, in his research, a way to express biological shape differences using a mathematical approach based on D'Arcy Thompson's distorted grid graphs [28].

Thompson invented the method of *transformation grids* to represent the relationship between a pair of *homologous* shapes throughout their interiors. A *homology* between two organisms is defined to be a “maximally inclusive scheme of pairs of parts, organs or structures that manifest the same positional relations among themselves in both organisms” [6]. Thompson has drawn grid intersections at roughly homologous points on two organisms, and then showed how the square grid for one was distorted to produce the grid of the other. He



suggested to interpret the pair of diagrams as a transformation of the whole picture plane which maps the points of one diagram into corresponding points in the other, while varying smoothly in between [6]. Thompson has set two conditions: "... that the form of the entire structure under investigation should be found to vary in a more or less uniform manner, after the fashion of an approximately homogeneous and isotropic body ..., and that our structure vary in its entirety, or at least that 'independent variants' should be relatively few" [28]. These requirements accorded with his belief that constituent parts of an organism could never evolve quite independently [6].

While exploring a mathematical model to produce Thompson's distorted grids, Bookstein postulated that "the lines of growth are biologically invariant" (in the sense that growth can be extrapolated), and in effect declared that "nothing really bends. All apparent curving and rotating is produced by differential growth along axes fixed unbendingly at 90°" [6]. Furthermore, Bookstein argued that Thompson was wrong in the construction of pairs of diagrams which were unsymmetrically specified: a rectangular grid on one diagram and an unrestricted grid on the other. Instead, Bookstein suggested the use of biorthogonal grids for the transformation as a representation of general lines of growth. He produced a canonical coordinate system which reduces all change of shape to gradients of differential directional growth [6], enabling the measure of shape change without measuring shape at all. In computing the biorthogonal curve systems, Bookstein assumed correspondence between boundaries and extended it to the interiors. His strategy was to describe the homology between two images by discrete pairs of homologous landmarks. He chose a complex biharmonic function, with only isolated "sources" and "sinks" of distortion as a convenient model for the homologous correspondence between the two images, from which the mapping function could be

defined. Considering a mapping of a small patch, Bookstein defined the *roughness* of the transformation as the squared distance between the mapping of the centroid of the patch and the centroid of the mapped patch. Further, he has shown that if the *roughness* of the transformation is minimized, the non-linear mapping function will be uniquely defined, and the biological characteristics of the shape will be preserved [6, 7, 8].

Formally, suppose we are given a shape  $\mathcal{P}$  that should be transformed into a shape  $\mathcal{Q}$ . Let  $\{P_i = (X_i, Y_i)\}$  be a subset of  $N$  points on the outline of  $\mathcal{P}$ , and suppose that their corresponding points on the outline of  $\mathcal{Q}$  are respectively  $\{Q_i = (U_i, V_i)\}$ . Based on these homologous (corresponding) pairs, Bookstein [6] defines the following transformation from *any* point  $P = (X, Y) \in \mathcal{P}$  to a point  $Q = (U, V) \in \mathcal{Q}$ :

$$\begin{aligned} U &= a_u \cdot X + b_u \cdot Y + c_u + \sum_{i=1}^N \omega_i^u \cdot F\{d(P_i, P)\} \\ V &= a_v \cdot X + b_v \cdot Y + c_v + \sum_{i=1}^N \omega_i^v \cdot F\{d(P_i, P)\} , \end{aligned} \quad (1)$$

where  $d(P_i, P)$  is the Euclidean distance between  $P_i$  and  $P$  and  $F(d) \equiv d^2 \cdot \log(d^2)$ .

This transformation is parameterized by  $2N + 6$  parameters, namely  $a_u, b_u, c_u, \{\omega_i^u\}_{i=1}^N, a_v, b_v, c_v, \{\omega_i^v\}_{i=1}^N$ . The transformation can be made unique by requiring that its *roughness* be minimized, where the roughness  $R$  is defined as

$$R = \iint [(\nabla^2 U)^2 + (\nabla^2 V)^2] dX dY \quad (2)$$

Minimizing the roughness  $R$  leads to the following six constraints on the parameters:

$$\begin{aligned}
\sum_{i=1}^N \omega_i^u &= \sum_{i=1}^N \omega_i^v = 0 \\
\sum_{i=1}^N \omega_i^u \cdot X_i &= \sum_{i=1}^N \omega_i^v \cdot X_i = 0 \\
\sum_{i=1}^N \omega_i^u \cdot Y_i &= \sum_{i=1}^N \omega_i^v \cdot Y_i = 0
\end{aligned} \tag{3}$$

Substituting the  $N$  corresponding pairs  $P_i \rightarrow Q_i$  in Eqs. 1 and Eqs. 3 yields  $2N + 6$  equations from which the unknown parameters can be obtained. Using these parameters, the transformation given by Eqs. 1 can now be applied to all points  $P \in \mathcal{P}$ .

### 2.3 Body shape transformation

The outcome of the preprocessing steps (subsection 2.1) are a segmented body image and the shapes of the ten body parts represented by binary masks. In order to simulate weight-change in each body part according to Bookstein's model, there is a need for pairs of corresponding landmarks in the original and modified shapes.

For each body part, a set of three arbitrary points  $P_i = (X_i, Y_i)$ , located far from each other on the outline, is selected. These three points are mapped to points  $Q_i = (U_i, V_i)$  on the outline of the modified shape by scaling the magnitudes of the vectors connecting them to the centroid (Fig. 3). The outline radius-change ratio is specific to the body part and proportional to the required body area change ratio.

Substituting for the three pairs of points  $P_i \rightarrow Q_i$  and for  $N = 3$  in Eqs. 1 and Eqs. 3, yields 12 independent linear equations, from which the coefficients  $a_u, b_u, c_u, \{\omega_i^u\}_{i=1}^3, a_v, b_v, c_v$ , and  $\{\omega_i^v\}_{i=1}^3$  can be obtained. Using these coefficients, Eqs. 1 are now used to transform

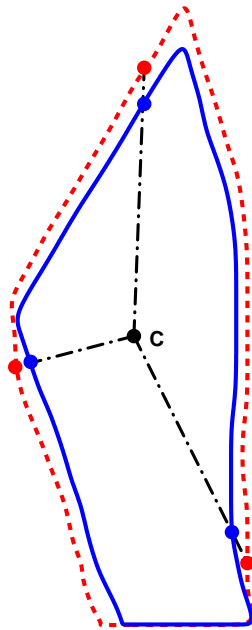


Figure 3: Three points on the original right leg outline (blue) are mapped to points on the outline of the modified right leg (red) by scaling the vectors connecting them to the centroid (black).

the complete outline of the original body part into a weight modified outline. Repeating this procedure for all body parts, yields a set of independently transformed outlines.

The next step is to merge the modified outlines of all the body-parts into a single outline of a whole body. Adjacent pairs of body parts are merged, subject to constraints that preserve the natural appearance of the modified body shape and global characteristics such as body height and skeleton integrity (Fig. 4).

Having obtained the whole outline of the weight-modified body,  $N$  pairs of corresponding points from the original and modified outlines are selected ( $N$  is about 25% of the total number of points on the outline). Substituting for these pairs of points in Eqs. 1 and Eqs. 3, we obtain  $2N + 6$  equations that uniquely define the coefficients in Eqs. 1. These coefficients specify the transformation of the whole body. Eqs. 1 can now map *all* points  $(X, Y)$  in the original body image onto points  $(U, V)$  in the weight modified body image.

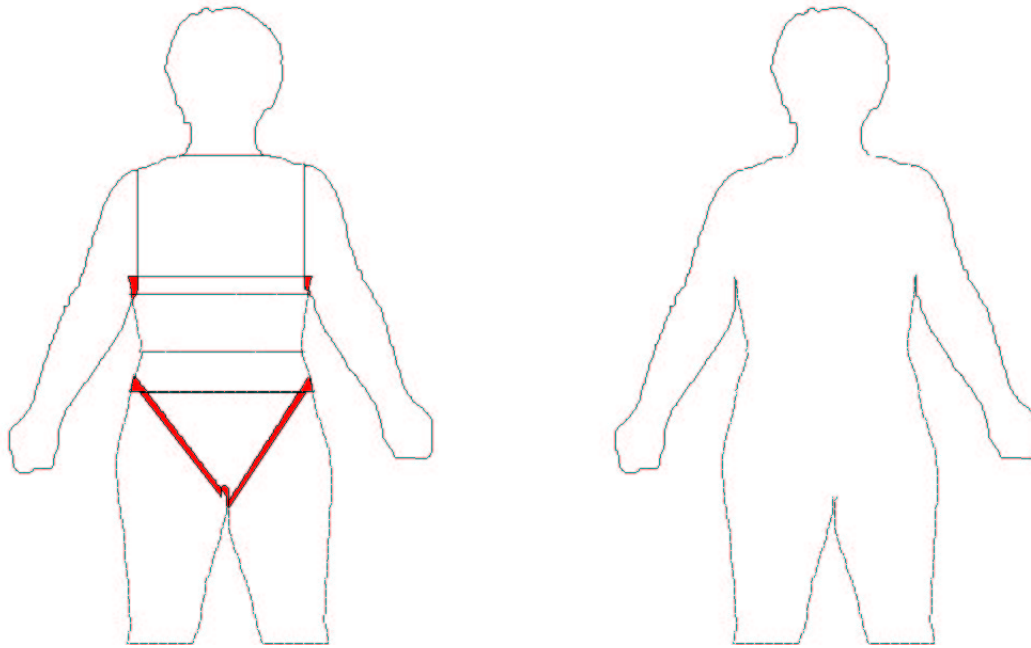


Figure 4: *Left*: Weight-modified body parts. Overlaps are shown. *Right*: The merged outline of the whole body. Overlaps are discarded.

The ratio between the 2-D body areas in the modified and original images is not a good descriptor of the apparent weight change. Using a cylindric approximation for the 3-D structure of body parts, and assuming that body weight is roughly proportional to its volume, the simulated weight change ratio is approximated by the square of the ratio between the areas of the modified and original body images. A better approximation could be obtained by monitoring the weight and 2-D body-shape area of humans during weight change processes.

## 2.4 Postprocessing

The non-linear transformation maps each point in the original body image onto the target image plane. Due to discretization effects, some points in the modified body image have no corresponding source points in the original image, and therefore lack color properties



Figure 5: Due to discretization effects and the nonlinearity of the shape transformation, points on the thin white lines in this fattened body image have no color attributes. From another perspective, these lines visually demonstrate the preservation of body shape characteristics.

(Fig. 5).

Using  $3 \times 3$  median-based color interpolation around colorless pixels eliminates color discontinuities in the modified body image. This procedure may create some artifacts on the external side of the body outline. These are masked using the (known) modified outline. The result is a clear, sharp and realistic color body image, in which the body figure is fatter or slimmer as required. Typical results are shown in Fig. 6.

### 3 Implementation and performance evaluation

The suggested method for the assessment of body image distortions in eating-disordered patients is implemented in the MATLAB environment, and is executable on computers with



Figure 6: *Top:* Computer-generated body images of patients ‘A’ and ‘B’ with about 10% weight loss. *Bottom:* Computer-generated body images of patients ‘A’ and ‘B’ with about 15% weight gain.

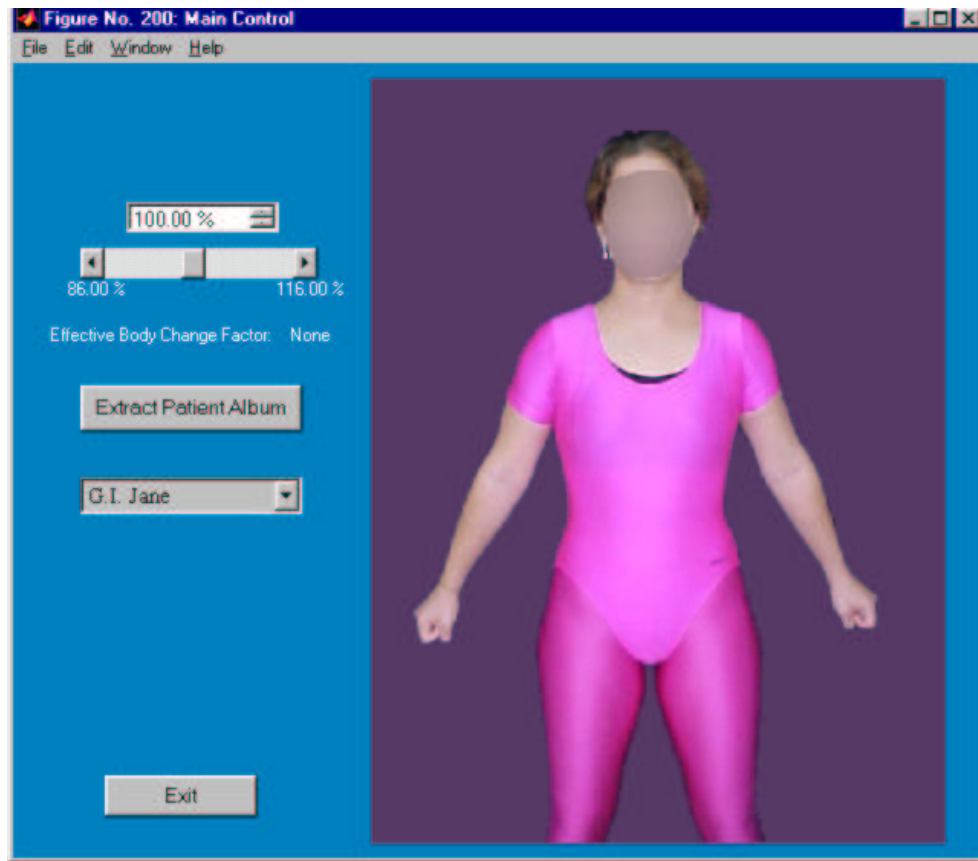


Figure 7: The image browser is used for immediate retrieval and display of weight-modified body images. Note that weight change limits can be modified, percentage values can be hidden and the display sequence can be made arbitrary, as dictated by the experimental methodology or clinical requirements.

a wide variety of operating systems. For each subject, a set of weight-modified body images is generated offline and stored as a virtual album. Following brief initiation by the user (no special training is required), the album generation process is fully automatic. The creation of a 24 image album is unattended and takes about three hours on a 300MHz Pentium II PC.

Convenient access to the stored images is facilitated by a graphical browser, allowing immediate retrieval and display of the weight-modified body images. (Fig. 7). This can be done by the patient, without an external mediator. Note that, to eliminate geometric distortions common in CRT displays, liquid crystal TFT displays were used in this research.





Figure 8: The performance evaluation interface. Can you tell which is the original body image?

To evaluate the quality of the weight modified images, an experiment was conducted among 30 healthy people (not suffering from eating disorders). The purpose of the experiment was to determine whether the simulated body images were realistic enough, to confuse an original body image with an artificially generated one.

The experiment consisted of 45 trials. In each two body images were presented: an original image and an artificial one. A total of 15 simulated image albums of anorectic female teenagers and young adults were used in the experiment. The simulated weight change of the artificial image in each trial was chosen in the range  $\{-16\%, +28\%\}$ . The position (right/left) of the two images on the screen was random. In each trial the subject was asked to choose which of the two displayed images was the original body image. A graphical user interface was used to control the experiment and store its results automatically (Fig. 8).

The results of the experiment show that in trials with a simulated weight change ratio of up to  $\pm 8\%$ , the subjects confusingly chose the artificial body image as the “original” one in 44% of the cases. This proves that the artificially generated body images are highly realistic. As could be expected, larger simulated weight changes appear less natural and are easier to detect. Over the full simulated weight change range of  $\{-16\%, +28\%\}$  the error rate of subjects was about 30%.

## 4 Discussion

We presented a method for the assessment of body image distortions in eating disorders patients, that improves upon previous techniques. Realistic simulation of the human body weight-change process is achieved via independent manipulation of separate body parts, followed by the presentation of the subject’s natural-looking weight-modified body image. Special attention, beyond the scope of the currently suggested method, should be given to facial weight gain or loss, due to the high density of independent body parts in a small space.

The weight change simulation algorithm is based on a unique biological shape modification technique presented by D’Arcy Thompson and Bookstein [28, 6]. Other methods for shape deformation and modification do exist. *Snakes* or *active contour models* are energy-minimizing splines guided by external constraint forces and influenced by image forces that pull them toward features such as lines and edges [16]. Some active-contour based models suggest shape deformation by making the shape’s contour behave like a balloon which is inflated by an additional force [10]. An active contour model with expansion “balloon” forces was used to simulate the changes in shape and cross-sectional area occurring during

the contraction of isolated muscle fiber [17].

*Caricaturing* algorithms [9, 26] exaggerate features on the shape's contour. The resulting shapes resemble the original ones but are not natural looking. Image *morphing* techniques [11, 27] are defined between at least two shapes or objects. However, in the case of weight change simulation only the original body image is given, hence we remain with the problem of creating a synthesized target body image to which the metamorphosis process can be targeted. Image warping algorithms do not require a target image, but the compatibility of the warping with physiological weight change processes has to be addressed.

Based on facial image caricaturing [5], an interesting method for the study of body size perception and body types was recently presented [4]. Using clinical categories of body types (BMI - Body Mass Index) as prototypes, two approaches to changing the body shape were considered. The first approach alters the body shape by exaggerating or minimizing differences of feature points on the original body and its corresponding prototype. The second approach alters the body shape by referring to all prototypes simultaneously, following evolutionary paths of feature points among the prototypes. A large image-database (hundreds of images) is necessary for the extraction of stable prototypes with minimal variability within each prototype and with similarity between the BMI category prototypes [4]. The user is required to manually delineate hundreds of feature points, used by the system to locate and extract the body and the different body parts, and to refer to the category prototypes.

The proposed body image distortion assessment tool is currently being deployed and tested at the Eating Disorder Center of Sheba Medical Center. A group of 33 admitted patients suffering from AN participated in an experiment, in which they were asked to choose an image from a 24-picture album of their body (at various simulated weight-change

levels), that corresponds to their body size as they perceive it. A high percentage of the subjects (70%), both youth and young adults, chose an image in which a body weight gain ratio of between 8% and 16% was simulated, as their “real” body image. None of them recognized their true source body image. In contrast, preliminary results obtained in an ongoing experiment with a control group of healthy female teenagers, indicate that they are able to choose an image that is either the original one or very close to it in terms of simulated weight change.

The method presented here was developed as the first phase of a two-phase project. In the current phase of the project, the body-image distortion as assessed by the method presented, is compared with the distortion as assessed by several common and clinically validated assessment tools, such as: (a) structured interview of anorexia and bulimia syndromes, (b) eating disorder inventory, and (c) body shape questionnaire. In addition, the algorithm’s assessment results are compared to common clinical measures of diagnosis and follow-up: (a) body weight and BMI, (b) menstrual cycle, and (c) stage of therapy. In order to assess the sensitivity of the presented measure to treatment effects on body image and body perception, the patients are assessed during the first week following their hospitalization and few days prior to their discharge. The average time between assessments is three months and does not include the effects of outpatient treatment. As part of the ongoing clinical validation process, the self-ideal discrepancy score is calculated for each of the subjects. The subjects are requested to choose an image on the continuous scale in response to the requests: “show me how would you *like* to look like” (representing the ideal body shape) and “show me how do you *feel* your body looks like now” (representing the perceptual body shape). The anorexic patients differ significantly from the healthy subjects when measuring the self ideal

discrepancy. In view of the encouraging preliminary results, we plan to further develop and study the suggested method, towards application in the research, diagnosis, evaluation and treatment of eating disorders.

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