CALCULATION OF THE TRUE VALUE OF A HIGH JUMP USING A COMPUTER GRAPHICS MODEL

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INTRODUCTION

The true value of a high jump is the maximum height that the athlete would have been able to clear cleanly, and its value generally is not known. If the bar is knocked down, the jump is ruled a foul and the athlete receives no credit, although a hypothetical bar set at a lower height would have been cleared successfully. If the bar stays up, the athlete is credited with the height of the bar. This is also misleading: If the bar is cleared with room to spare, the height of the bar is an underestimate of the true value of the performance; if the bar is bent down during the bar clearance but does not fall, the height of the bar is an overestimate of the maximum height that would have been cleared cleanly. This is an important shortcoming for the evaluation of high jumping technique, because the researcher is left without the most important criterion measure for the value of the performance. A method involving three-dimensional (3D) film analysis, curvilinear interpolation and computer graphics was devised for the solution of the problem. A test showed that the method yielded reasonably close estimates.

DEVELOPMENT OF THE MODEL

General description
The upper arms, forearms and hands were modeled by pyramidal frusta; each thigh and each shank by two serially-linked pyramidal frusta; the neck by a prism; the feet by irregular polyhedrons; the head by three quarters of a sphere (cranium), with an irregular polyhedric surface (face and chin) replacing the fourth quarter; the trunk was modeled by six serially-linked pyramidal frusta connected to an irregular polyhedric pelvis and buttock; hemispheroid breasts were added to the trunk in the female version of the model.

The model required as input the mass, standing height and sex of the subject, and the 3D coordinates of 21 body landmarks (vertex, chin-neck intersect, suprasternale, and left and right shoulders, elbows, wrists, knuckles, hips, knees, ankles, heels and toes).

Anthropometry
The anthropometric parameters for the model were obtained from still photographs of 14 male and 11 female college varsity high jumpers. Most anatomical measurements were taken from a side view photograph; supplementary measurements were taken from frontal and diagonal views.

Scaling
Knowing the thickness t_{S1} of a segment in the average subject (mass m_1; standing height h_1), its thickness t_{S2} in a subject of different mass (m_2) and standing height (h_2) can be estimated using the following equation:

$$t_{S2} = t_{S1} \left[(m_2\, h_1) / (m_1\, h_2) \right]^{1/2}$$

Trunk arch
Between the hips and the suprasternale there is no intermediate landmark that can be

identified reliably in film analysis. Because of this, the trunk is kept straight in most computer graphics models. However, the trunk is known to arch markedly during the high jump bar clearance, and therefore it was decided to incorporate a flexible trunk into the model. Anecdotal evidence suggested that the trunk tends to arch backward when the thighs are hyperextended at the hip, and forward when the thighs are flexed at the hip. Sports magazines and books were searched for action photographs of sports activities showing a wide variety of hip flexion-extension angles. The main criteria for selection of a photograph were: a view as close as possible to the perpendicular to the sagittal plane of the trunk, tight-fitting clothes, and little or no obstruction of the view of the trunk by the arms or other objects. A total of 19 photographs were selected for analysis. This included 7 male and 12 female subjects (4 high jumpers, 1 triple jumper, 3 long jumpers, 2 hurdlers, 5 sprinters, 2 distance runners and 2 divers). The curved midline of the trunk and a straight line from the suprasternale to the hip joint were drawn on each photograph (see Fig. 1). The deviation of the trunk midline curve from the line was measured at five equally spaced cross-sections (d_1 through d_5). Positive deviations corresponded to a forward position of the trunk midline (hollow-back arch). For normalization purposes, each deviation was divided by the distance L between the suprasternale and the hip. The average flexion-extension angle of the two thighs with respect to the longitudinal axis of the trunk (θ) was also measured. This angle was measured in degrees, relative to the fully aligned neutral position; positive values corresponded to hip hyperextension. For each of the five intermediate cross-sections of the trunk, the normalized deviation values (d/L) obtained from the 19 photographs were plotted against the values of the hip angle θ. The statistical relationships were modeled using linear regression (Table 1).

Table 1.

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$d_1/L = 0.000914\,\theta + 0.030$
$d_2/L = 0.001564\,\theta + 0.059$
$d_3/L = 0.001957\,\theta + 0.078$
$d_4/L = 0.002052\,\theta + 0.081$
$d_5/L = 0.001526\,\theta + 0.054$

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Trunk twist
Due to axial rotations at the various intervertebral junctions, the upper trunk generally does not face the same direction as the lower trunk. This is reflected in the difference between the orientations of the shoulder and hip axes in the transverse plane. Table 2 shows the maximum amounts of accumulated axial rotation

Table 2.

	absolute	relative
$\Delta\phi_{0-1} =$	33°	37.9 %
$\Delta\phi_{1-2} =$	31°	35.6 %
$\Delta\phi_{2-3} =$	8°	9.2 %
$\Delta\phi_{3-4} =$	6°	6.9 %
$\Delta\phi_{4-5} =$	9°	10.3 %
$\Delta\phi_{5-6} =$	0°	0.0 %
Total =	87°	100.0 %

(twist) within each of the six equal-length serially-linked pyramidal frusta of the trunk ($\Delta\phi$), estimated from the maximum possible amount of twist at each intervertebral junction (White and Panjabi, 1978) and the number of intervertebral junctions included in each frustum (Hollinshead, 1974). For the model it was assumed that the amounts of twist within the six frusta are always
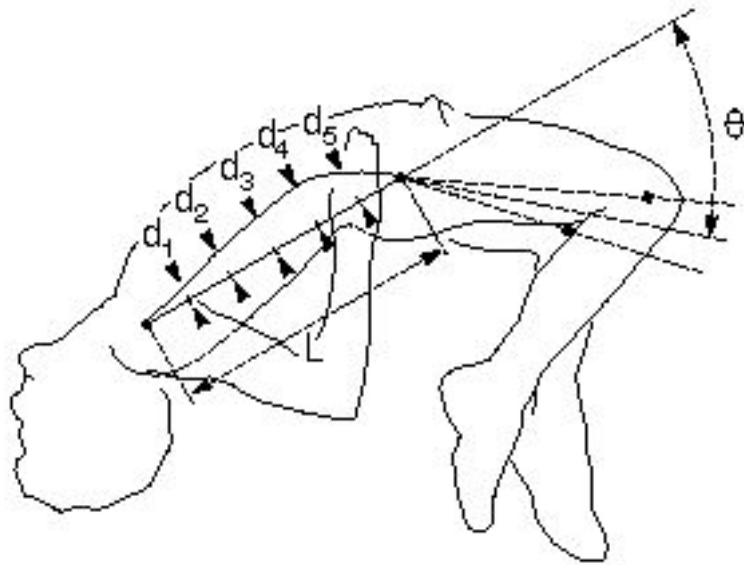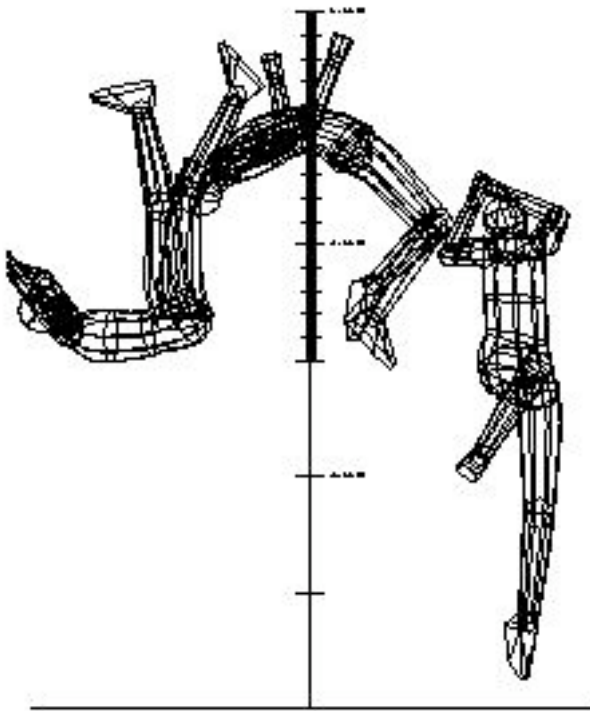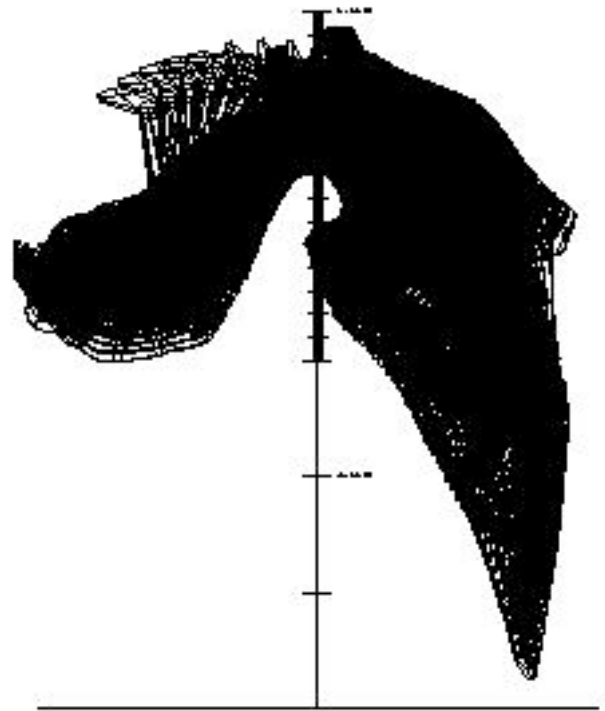
Figure 1

Figure 2

Figure 3

proportional to the maximum values given in Table 2.

TESTING THE MODEL

A set of 32 jumps (20 by males; 12 by females) was selected from a large pool of high jumps previously analyzed for other purposes at our laboratory. In the selected jumps, the bar was bent down during the bar clearance, but did not fall immediately. Film analysis provided the 3D coordinates of the standard 21 body landmarks at instants separated by 0.06-second intervals during the bar clearance. The coordinates of the body landmarks were input to a computer program that implemented the graphics model. Fig. 2 shows three selected images from one jump. Curvilinear interpolation with quintic spline (Wood & Jennings, 1979) was then used to generate landmark positions at 0.01-second intervals. With the addition of these interpolated positions, the computer graphics model produced a saturated plot (Fig. 3) which yielded an estimate (h_{cle}) of the maximum height that the athlete would have been able to clear cleanly. This value was compared with the true value of the jump (h_{cl}) as indicated by the minimum height of the bent bar, measured in the films.

RESULTS

The error in the predicted value of the maximum height cleared cleanly was
$\sum (h_{cle} - h_{cl}) / N = 0.010 \pm 0.032$ m (men); 0.024 ± 0.018 m (women). Considering absolute error values, the difference was
$\sum (\ h_{cle} - h_{cl}\ ) / N = 0.027 \pm 0.017$ m (men); 0.024 ± 0.018 m (women).

DISCUSSION

The results indicated that the proposed method yields a reasonably close prediction of the value of a high jump. The remaining errors are due to errors in the 3D coordinates of the body landmarks and in the shapes and thicknesses of the segments.

The method will be most useful in computer simulation analysis. In this approach, the researcher makes alterations in factors that control the motions of a high jumper; the resulting motions are predicted by a computer program. The method described here will provide estimates of the true values of any two simulated jumps. The method will be particularly accurate for the calculation of the *difference* between the values of the two simulated jumps, since the amount and direction of the error will be similar for both.

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