Notes and Comment

Perceiving the geometry of age in a human face

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The human head exhibits typical changes in shape from infancy through adulthood and into old age. Without overt knowledge of the geometry of such change, we, as observers, can still recognize the process. Perception of an aging head, as seen in sagittal profiles, closely follows the mathematical specifications of two factors (Pittenger & Shaw, 1975; Shaw & McIntyre, 1974): (1) a factor of constant change, called a cardioid transformational invariant, and (2) a factor of constant morphology, or structural invariant, represented by a fixed, functional point in anatomical space. Concentrating on the latter, I have found that the best point for this geometric transformation to occur around is near the foramen magnum (the point where the skull meets the spinal column) and brainstem. As the place of attachment, this point provides a structural ground around which growth can occur: It is growth's frame of reference for the head (Enlow, 1975, p. 105). Therefore, viewers can judge the relative goodness of various transformations of growth and aging, and their best-judged stimuli match those that are anatomically most plausible.

At the beginning of this century, D'Arcy Thompson (1917) suggested that one could compare the anatomies of different species through topological transformation. More recently, Enlow (1968, 1975) suggested that the process of aging in human faces followed a simple rule: The proportional enlargement of the cranium in the child is gradually overcome by mid-puberty, after which the lower portion of the face becomes larger. Putting the views of Thompson and Enlow together, Shaw and Pittenger (1977) found that a cardioid (or heart-like) transformation provided a good fit for describing age change in sagittal profiles of human heads. That is, if the outline of

a face is specified in Cartesian coordinates, the deformation of the head follows the equations:

$$x' = (1 - k \cos \theta) x,$$

and

$$y' = (1 - k \cos \theta) y,$$

where x and y are the coordinates for a particular point along the profile before transformation, x' and y' are those values after transformation, k is a cardioid constant, and θ is the angle deviation from polar "north" formed by the line connecting point x,y with the point of origin (where x,y is 0,0) that generates the transformation.¹ Starting with a profile of an early teenager, increasingly negative values of k (.00 to $-.25$) yield more childlike profiles, whereas increasingly positive values (.00 to about $+.30$) yield older profiles. Shaw and Pittenger used as a functional generating center a locus near the ear canal, with the Frankfort plane (the plane intersecting the ear canal and the bottom of the eye socket) as the x axis. It occurred to me, however, that since the head is three-dimensional, the best point of reference would be internal, perhaps near the ear canal in sagittal projection.² The thrust of this study was to determine if this were true, and if so, to speculate why.

METHOD

Nine points of origin, in a 3 by 3 geometrically square matrix, were chosen such that the central point fit most closely to the center of the profiled head. I assumed that this point would yield the best-transformed stimuli. These nine points are shown in Figure 1a, placed within the sagittal profile chosen for study. Eighteen Stanford University undergraduates were paid or given course credit to view and judge the goodness of one younger and one older version generated from each of the nine points. These stimuli are shown in Figures 1c and 1d. They were presented with 18 randomly ordered trials, 2 for each of the nine points of origin. Each trial consisted of four presentations of profiles: (1) standard, (2) younger, (3) standard again, and (4) older. The cardioid constant k was $-.20$ and $+.25$ for younger and older profiles, respectively. Viewers gave two ratings per trial, one each for younger and older versions, using a 7-point unipolar scale, with 7 indicating good renditions and 1 poor. In this manner, they determined how much each profile looked like a younger or older version of the *same* individual shown as the standard. Stimuli were drawn on a Tektronix 604 oscilloscope face, generated on-line by a FORTRAN program written for a Data General Nova computer. Each profile appeared for 3 sec and was drawn over the previous profile within that trial. Profile sizes were normalized so that visual angles were the same, about 3° for all stimuli. Viewers participated in groups of one to four.

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Figure 1. The schematic profile used as a standard for generating older and younger faces is shown in (a), with the nine different points for generating cardioid transformations. Another profile suggesting the internal anatomy of the head is shown in (b), with emphasis on the foramen magnum, the place where the skull meets the spinal column. Below these are shown (c) the nine younger and (d) nine older profiles transformed from the standard, arranged in the same 3 by 3 matrix shown in (a). Below these are relief maps of judgment scores for the (e) younger and (f) older profiles. The mean of the 7-point judgment scale is 4, with the darkened areas corresponding to values nearest the middle of the scale. Contours were chosen so that they were roughly two-thirds of the mean standard error for judgments at all points. In this manner, any points separated by more than two contour lines are significantly different from one another, while those separated by two or less are not. The black square in each map is the point of maximum judgments as determined by fitting an elliptic paraboloid to the data. These two points match closely that of the foramen magnum, indicated in (a).

RESULTS AND DISCUSSION

Mean judgment values are shown as relief maps in Figures 1e and 1f. These, of course, could be drawn in many ways; here I assumed that all slopes between adjacent points were linear. Systematic differences occur in judgments of both younger and older profiles [$F(8,136) = 4.27$, $p < .01$, and $F(8,136) = 6.42$, $p < .01$, respectively]. That is, both maps are statistically different from flat terrains, which would denote equal judgments throughout. Moreover, trend tests of the central points as against the other eight points in each matrix were also reliable [$F(1,135)$

$= 7.78$, $p < .01$, and $F(1,135) = 5.42$, $p < .05$, respectively]. Thus, both maps are reliably pyramidal in terrain. Then, assuming the data generally fit elliptic paraboloid functions,³ I derived a maximum value in sagittal space from both younger and older sets of judgments. I assumed these points corresponded to the loci of best-judged transformations. Both are shown as squares in Figures 1e and 1f, and are very near the generating points chosen by Shaw and Pittenger. Note the striking correspondence between their relative locations. Comparing these points with the sagittal sketch in Figure 1b, one can see that both match rather closely the locations of the foramen magnum and brainstem. If we consider an aging face to be a viscoelastic event (Pittenger & Shaw, 1975), the growth changes in the shape of the head can be interpreted as a topological deformation about a stable, functional point, and this point matches a plausible anatomical locus. The relative growth downward and outward could be due, in part, to the forces of gravity acting over a lifespan, yanking tissues around their point of support.

These results suggest that viewers tacitly know the mathematical transformations involved in growth and aging.⁴ Not only can they use those transformations generally, as Shaw and Pittenger suggested, but, more particularly, they know the point around which those transformations ought to occur. This finding is important for two reasons. First, it is another example of perception following production (Liberman, Cooper, Shankweiler, & Studdert-Kennedy, 1967; Cutting, 1977, 1978b). In this case, the best-judged stimuli follow "production" rules of growth and aging. Second, it supports a theory being developed by my colleagues and me (Cutting, 1978a; Cutting, Proffitt, & Kozlowski, 1978; Proffitt, Cutting, & Stier, in press): The perception of dynamic forms is guided by an abstraction—an unseen point in the anatomical space of that form. This rule is supported by our analysis of relatively rapid changing forms, such as a human being walking or a wheel rolling, and now by this analysis of change over an extended span, as in the aging of faces.

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NOTES

1. Equations given by Shaw and Pittenger (1977) specify sine rather than cosine functions, with polar "east" as 0°. My formulation is equivalent to theirs.

2. For convenience, I assumed that the cardioidal transformation would affect equally all sagittal slices through the head. This assumption is ultimately incorrect, because the midsagittal slice would be affected least, with increasing strain on all slices as one moved away from it.

3. The matrix of mean judgments was converted into four parabolic functions. These cut through the two diagonals and the horizontal and vertical axes around the central point. The maximum of each parabola was then determined and given a weight that represented how much it exceeded the value of the mid-matrix point. The x,y coordinates were then averaged according to the weights given each. An alternative solution is to find the geometric mean of all pairs of points (36 per matrix), weighted by their judgment scores, then compute the mean of those means. This technique and others yield essentially the same solution as the first.

4. Like Shaw and Pittenger, I make no assumption that a cardioidal transformation is the true transformation for growth and aging, only that it is a good approximation to whatever that transformation may be and, most importantly, that it is useful for psychological study.

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