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Perception of Growth From Changes in Body Proportions

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Three experiments examine the perception of age level from computer-generated line drawings of a human body, a Martian, a robot, and a flower that were mathematically transformed using a model of human growth developed by P. B. Medawar. The results suggest that observers' age level judgments are related by a power function to the size of the head relative to the rest of the body but that the exponents of these functions vary systematically across the different body forms. These results are discussed in relation to other research on biological event perception.

Many of the events observers encounter in a natural environment involve other biological organisms. Some of these events take place over relatively short intervals of time and are perceived as animate movements. Others take place over much longer intervals of time and are perceived as growth or development. In either case observers are able to segregate biological events into perceptually distinct categories. They can easily identify, for example, a variety of animate movements such as the walk of a human, the flight of a bird, or the slithering of a snake. They can also identify slow biological events such as the growth of a beard, the blossoming of a flower, or the development of a child from infancy to adulthood.

The visual information on which these identifications are based can be surprisingly subtle and abstract. For example, consider a demonstration reported almost 40 years ago by Heider and Simmel (1944). These authors created a 2½-minute cartoon in which a complex social interaction involving affection, aggression, fear, and frustration was visually specified by the movements of a few simple geometric forms (i.e., triangles, circles, and rectangles). Similar results have been obtained using the original Heider–Simmel film or related displays for a wide variety of subject populations including Japanese (Hashimoto, 1966), Australians (Marek, 1966), schizophrenic patients (Buck & Kates, 1963), the intellectually handicapped (Kassin & Gibbons, 1981), and young children (Kassin & Lowe, 1979; Kassin, Lowe, & Gibbons, 1980).

Another indication of the abstract nature of biological event perception comes from Johansson's classic demonstrations involving *point-light walker* displays. Johansson (1973) showed that the relative motions of 12 spots of light attached to the joints of an otherwise invisible human actor provide sufficient information to identify whether the actor is running, walking, jumping or doing push-ups (see also Johansson, 1975, 1976). Subsequent research has revealed that these point-light displays can specify the gender of an individual (Barclay, Cutting, & Kozlowski, 1978; Cutting, 1978a; Cutting, Proffitt, & Kozlowski, 1978; Kozlowski & Cutting, 1977), the identity of a friend (Cutting & Kozlowski, 1977), or the amount of force that is exerted when a person lifts a heavy weight (Runeson & Frykholm, 1981, Note 1). Similarly, if lights are attached to an individual's face, their relative motions will specify particular facial expressions such as frowning or smiling (Bassili, 1978).

Other researchers have shown that the visual perception of slow biological events such as growth or aging can also be based on abstract information. This was first demonstrated by Shaw, McIntyre, and Mace (1974) in an attempt to discover the perceptual information that distinguishes human craniofacial growth from other styles of change such as gaining

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weight or growing a beard. Working from the insights of the Scottish naturalist D'Arcy Wentworth Thompson (1917), Shaw et al. devised a geometric transformation called *cardioidal strain* that can simulate with perceptual accuracy how the shape of a human head changes from infancy to adulthood (see also Todd & Mark, 1981). The effects of this transformation are perceived as growth when applied to a wide variety of objects including three-dimensional representations of a human head (Mark & Todd, 1983), two-dimensional profiles presented in silhouette (Mark, Todd, & Shaw, 1981; Pittenger & Shaw, 1975; Todd, Mark, Shaw, & Pittenger, 1980), cartoon drawings of birds, dogs, and monkeys (Pittenger, Shaw, & Mark, 1979), or even drawings of inanimate objects such as Volkswagen Beetles (Pittenger et al., 1979).

Although these different lines of research on social interactions, human gait, and craniofacial growth have been pursued independently of one another, they all point to the same general conclusions: first, that human observers can identify biological events from unusual or sparsely structured stimulus displays, and second, that they will do spontaneously without special feedback or instruction. Unfortunately, however, it is often difficult to specify the particular display properties on which observers' judgments are based. Part of the problem is due to the tremendous complexity of biological events. Many typical examples such as human gait or the process of growth involve radical changes throughout the entire structure of an organism. Indeed, it is probably because of this complexity that such a tiny fraction of the biological events observed in nature has been investigated by perceptual psychologists.

The most commonly used technique for evaluating how specific stimulus parameters influence the perceived identify of an event involves the use of computer simulations (e.g., Bassili, 1976; Cutting, 1978a, 1978b; Hoenkamp, 1978; Mark & Todd, 1983; Pittenger & Shaw, 1975; Todd, 1983). The advantage of using a simulation rather than a natural event is that it gives a researcher complete control over the various components of change within a visual display. By manipulating these components independently of one another, it is possible to evaluate their individual and interactive effects on observers' perceptual judgments. A sufficiently precise description of an event for constructing a compelling simulation can sometimes be obtained by consulting the literature on animal behavior. Many biologists and naturalists have devoted their lives to studying the movement patterns of different animals (see Gray, 1968) and the morphological changes resulting from growth or evolution (see Huxley, 1932; Thompson, 1917). Some of these events have even been described mathematically so that they can easily be simulated on a computer.

Consider, for example, the geometric transformation developed by P. B. Medawar (1944, 1945) to describe how human body proportions change as a function of growth. Medawar's transformation was originally devised to fit Stratz's measurements of the mean vertical heights of several anatomical landmarks at a variety of ages.[1] He began with the measurements of a 5-month-old fetus (the youngest age in Stratz's sample) and attempted to derive a single mathematical equation that could continuously transform them into the measurements obtained at any given age within the period of maturation. To separate changes in body proportions from increases in the overall height of an individual, he normalized all bodies to an equal height of 4.85 in arbitrary units. The resulting transformation is expressed as a simple quadratic equation:

$$x' = f(t)x + \frac{(1 - f(t))}{4.85}x^2, \qquad (1)$$

where x is the height of a given landmark on a 5-month (.42 years)-old fetus, x' is the height of that landmark at some time t in years since conception, and $f(t)$ is a time-varying function given by

$$f(t) = 1.4176 + .4127 \log(t - .406) + .147/t. \qquad (2)$$

When applied to a line drawing of a human form, the effect of this transformation is to stretch the entire body in a graded fashion toward the head. Thus, we refer to it as a *tapered stretch*.

[1] Stratz's data are reproduced by Medawar (1944, 1945).

It is important to recognize that Medawar's tapered stretch transformation is derived from standard curve-fitting techniques and provides few insights about the biological mechanisms that control human growth. Nevertheless, because it is an abstract description of the morphological effects of growth and is easily simulated on a computer, it offers a good opportunity to extend the number of biological events that have been investigated by perceptual psychologists. The research reported in the present article attempts to demonstrate that the changes in human body proportions described by Medawar's transformation are perceived as growth in much the same way as other biological events are perceived. We present evidence that the transformation is perceptually compelling—that it is spontaneously identified as growth by naive observers and that it can be generalized to unfamiliar objects. We also demonstrate, however, that the perception of growth can be affected by the particular body form to which the transformation is applied, and that certain aspects of the transformation are more perceptually salient than others.

Experiment 1

Experiment 1 employed a free response task using naive observers to evaluate the perceptual salience of changes in body proportions as a potential source of information for identifying growth events.

Method

Stimuli were generated from the hand-drawn bodies of a human infant and a Martian (see Figures 1 and 2), which were both transformed on a NOVA minicomputer using Medawar's tapered stretch transformation. Because the transformation affects only the vertical proportions of the body, it results in a flattening of the head if applied in isolation. To prevent this from occurring, the horizontal dimension of the head was subjected to the same change as the vertical so that its overall shape remained unaltered. The values of t used in the transformations were .42, .55 and 3.00. Thus, there were three variations of each body that were output on an electrostatic printer/plotter and arranged in a horizontal sequence. These are depicted in Figures 1 and 2. One other sequence used as a control is depicted in Figure 3. This was constructed by compressing the human body along the horizontal dimension. The three body forms depicted in the figure from left to right represent compressions of 50%, 25%, and 0%, respectively.

Observers were given the following instructions:

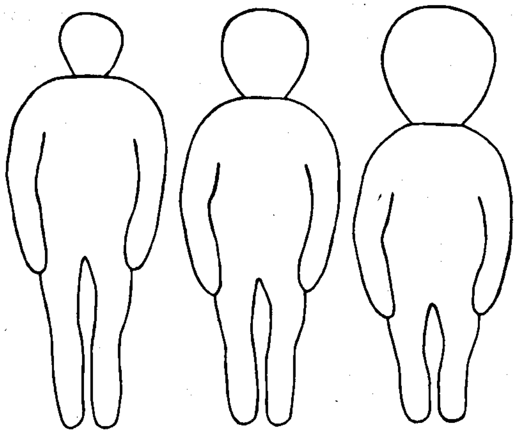

Figure 1. A sequence of human body forms related by Medawar's tapered stretch transformation. (The figures from left to right were generated with t values of 3.00, .55 and .42.)

Today's experiment is part of a series of studies about visual perception. I'll be showing you a series of slides, each of which shows three pictures of the same scene or object. Your task is to identify the process that produced the changes shown in the pictures. Please do not describe the changes in the appearance of the object but rather the process or event that produced the changes. [A slide depicting a rolling wheel is presented as an example.] Here is a sample slide to show you what I mean. The process that produced the change is that the wheel rolled down the hill. That is the type of answer I'd like you to give. Please do not describe the changes themselves. For example, for this scene you should not have said, "the wheel is moving to the right," "the wheel is getting lower in the picture," or "the wheel moved to different places." The process of rolling down the hill produced these changes in appearance, but it is the process itself that I would like you to describe. [A slide depicting a piece of pie at various stages of consumption is presented.] Here is another example. Appearance changes like "the slice of pie is getting smaller" or "the shape is changing" are not the sort of answer I am looking for. Here a good answer would be "the pie is being eaten." This is the process that produced the changes.

After receiving these instructions, the observers were shown one of the three possible stimulus sequences and asked to record their responses. A total of 102 undergraduates at the University of Arkansas at Little Rock participated in the experiment, with 34 observers judging each sequence.

Results

The responses were scored according to a strict set of criteria: A subject's description was counted as a growth response only if it contained the words *growth, aging* or *matur-*

ing. Other descriptions, such as "got taller" or "head got smaller," were counted as nongrowth responses. Of the 34 observers who viewed each event, 21 gave growth responses when the tapered stretch transformation was applied to the human body, 7 gave growth responses when the tapered stretch transformation was applied to the Martian body, and only 1 gave a growth response when the horizontal compression transformation was applied to the human body.

A Fisher exact probability test was used to determine if the number of growth responses for the tapered stretch transformations was significantly greater than for the horizontal compression transformation. The analysis revealed that a difference as large as the one observed between the human tapered stretch sequence and the human horizontal compression sequence would have occurred under the null hypothesis with a probability of only 3.76×10^{-11}. Similarly, the observed difference between the Martian tapered stretch sequence and the human horizontal compression sequence would have occurred under the null hypothesis with a probability of only .027. Given the low demand characteristics of this experiment and the crudeness of the drawings, these results provide strong evidence that the effects of Medawar's tapered stretch transformation are a perceptually salient source of information about growth events. However, because the perceptual salience of the transformation is considerably greater for the human bodies than for the Martian bodies, the results also suggest that the perception of growth may be strongly dependent on the particular body form being transformed.

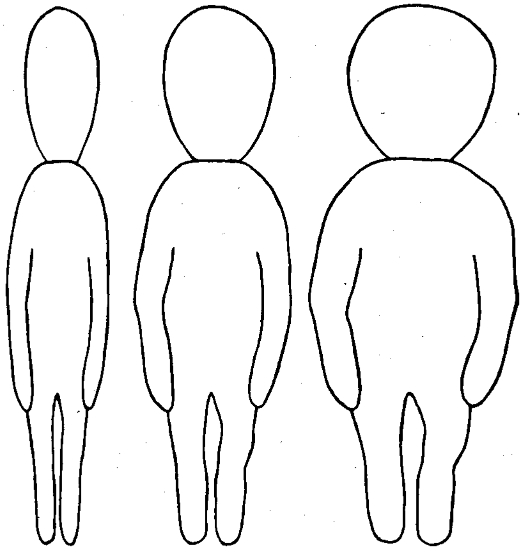

Figure 3. A sequence of human body forms related by a horizonal compression transformation. (The figures from left to right were generated with compressions of 50%, 25%, and 0%).

Experiment 2

Experiment 2 employed a more powerful response measure to systematically investigate the effect of body form on the perception of growth.

Method

Stimuli were generated from the hand-drawn bodies of the human infant and Martian used in Experiment 1, together with two new figures—the robot and flower person depicted in Figures 4 and 5, respectively. Thirty-one variations of each body were constructed using Medawar's tapered stretch transformation. The values of *t* used in the transformations were .4198, .4225, .4258, .4299, .435,

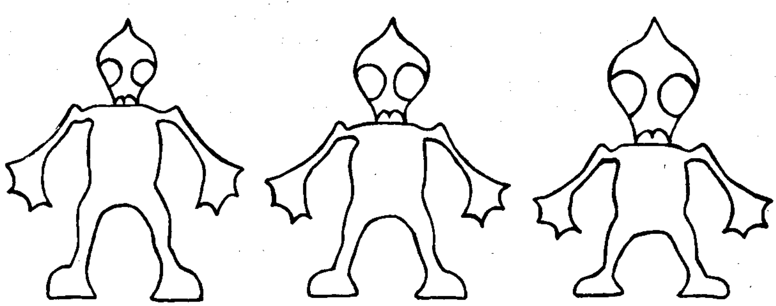

Figure 2. A sequence of Martian figures related by Medawar's tapered stretch transformation. (The figures from left to right were generated with *t* values of 3.00, .55 and .42.)

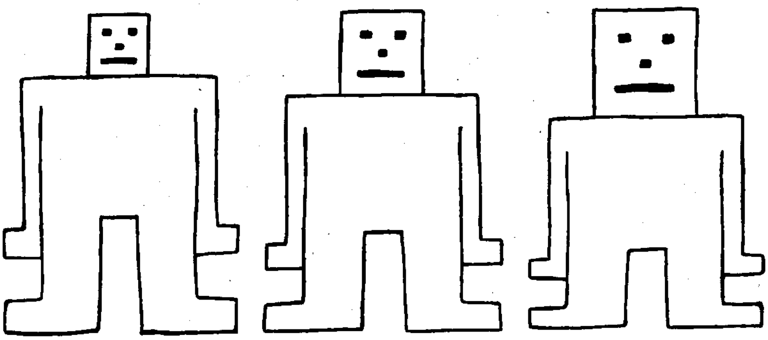

Figure 4. A sequence of robot figures related by Medawar's tapered stretch transformation. (The figures from left to right were generated with *t* values of 3.00, .55 and .42.)

.441, .449, .459, .475, .490, .513, .545, .591, .661, .76, .901, 1.1, 1.35, 1.65, 2.03, 2.47, 3.0, 3.63, 4.38, 5.25, 6.3, 7.55, 9.0, 10.75, 12.8, 15.3; these were selected to produce equal intervals in the size of the head. The resulting stimuli were output on an electrostatic printer/plotter and photographed individually as slides projecting white lines on a black background.

A total of 120 undergraduates at the University of Arkansas at Little Rock participated in the experiment. The observers were instructed to estimate the absolute ages (in years) depicted in the individual stimuli. In general, they had no difficulty understanding these instructions, and most reported that the task seemed quite natural. The human, Martian, robot, and flower figures were presented separately to different groups of observers so that the judgments for one body form could not be influenced by the others. Each observer viewed all 31 variations of a single body form presented in a randomly ordered sequence. Each body form had three different random orders, and each order was presented to 10 observers. The individual stimulus slides were displayed for approximately 8 sec each.

Results

It is important to recognize that there is no single set of correct responses for the absolute age judgment task employed in this experiment. There are, after all, significant individual differences in the body proportions of human beings at any given age level, and there are obviously no correct proportions for Martians, robots, or flower people. Nevertheless, it is reasonable to assume that if changes in body proportions are perceived as growth, then the application of Medawar's tapered stretch transformation should significantly affect the absolute age estimates for a particular body form.

The results of the experiment confirmed that the observers' judgments were indeed in-

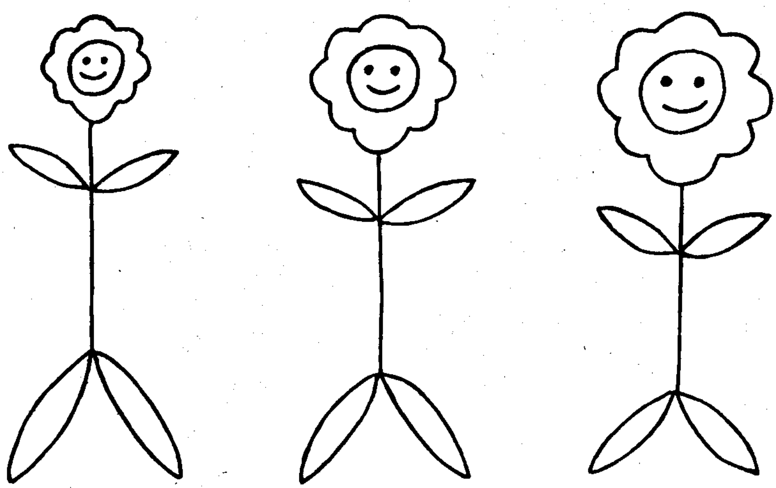

Figure 5. A sequence of flower figures related by Medawar's tapered stretch transformation. (The figures from left to right were generated with *t* values of 3.00, .55 and .42.)

fluenced by the effects of the transformation. The specific pattern of responses indicated, moreover, that the age estimates were related by a power function to the size of the head relative to the rest of the body. This is clearly demonstrated in Figure 6, which shows the mean absolute age judgments for the different body forms plotted against the head-to-body ratio on a log–log scale. With the exception of the flower data, there is a clear linear trend in all of these curves. The correlation coefficients for the humans, Martians, robots, and flowers are .98, .98, .96, and .30, respectively.

It should also be noted, however, that there are systematic differences in the slopes of these functions. The changes in body proportions had an especially strong effect on the perceived ages of the human bodies, producing a slope of −2.55; they had a moderate effect on the perceived ages of the Martians and robots, producing slopes of −1.89 and −1.21, respectively; and they had almost no effect whatsoever on the perceived ages of the flower people, producing a slope of only −.17. These findings provide additional support for the conclusion of Experiment 1 that the perception of growth can be influenced by the particular body form to which a transformation is applied.

One other aspect of the results that deserves to be mentioned is that the range of ages in the observers' estimates was surprisingly large. The mean estimates of the human bodies, for example, ranged from 1.79 to 44.37 years, despite the fact that human beings generally stop growing by the age of 20. One possible explanation for this phenomenon that was suggested during the debriefing sessions is that the observers were essentially trapped by their initial estimates. Several observers indicated that they were forced to use estimates in the 30s and 40s in order to remain consistent with their earlier judgments.

Experiment 3

Although the results of Experiment 2 suggest that the observers' absolute age judgments were based primarily on the size of the head relative to the rest of the body, it is important to keep in mind that there were many other relationships among different anatomical landmarks that systematically covaried with the head-to-body ratio. Experiment 3 was designed, therefore, to vary these alternative sources of information independently of one another in order to determine their relative perceptual salience.

Method

Thirty-six variations of the human body depicted in Figure 1 were constructed using Medawar's tapered stretch

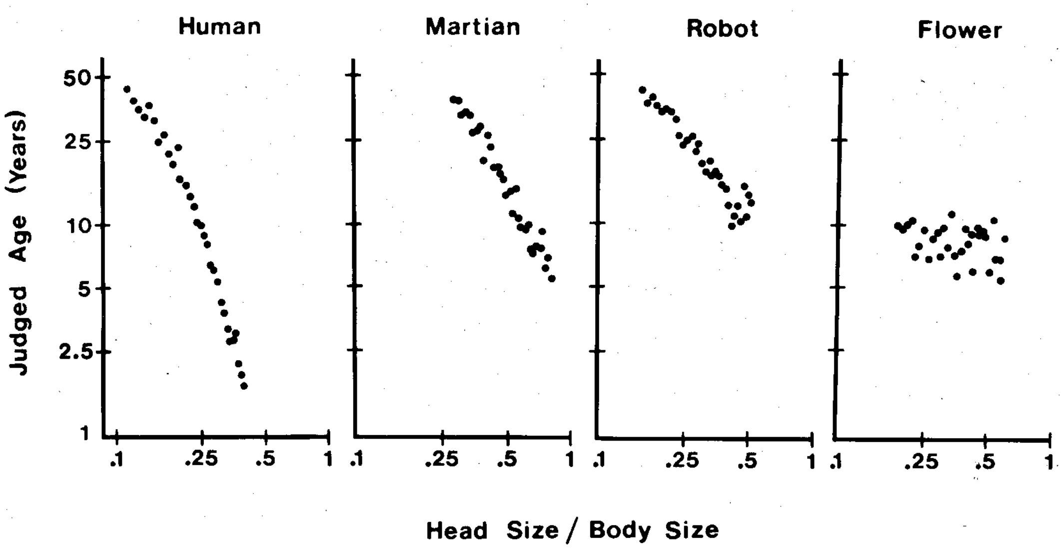

Figure 6. Mean absolue age judgments as a function of the head-to-body ratio for drawings of humans, Martians, robots, and flowers.

transformation. Unlike the previous experiments, however, one value of t was used to determine the internal body proportions of the arms, legs and trunk, whereas another value of t was used to determine the relative size of the head. The 36 stimuli were generated with t values of .42, .449, .591, 1.65, 5.25, and 15.3 applied to both the head and body in all possible combinations. Because this procedure could result in figures of varying heights, a scaling transformation was also applied to insure that the heights of all stimuli were equated.

Thirty undergraduates at the University of Arkansas at Little Rock participated in the experiment, each observing one of three randomly ordered sequences of the 36 stimuli. The procedure was identical to the one used in Experiment 2.

Results

The results are presented in Table 1. An analysis of variance revealed that there was a significant effect of head size, $F(5, 145) = 108.06$, $p < .001$, which accounted for over 98% of the between-display sum of squares. Indeed, at each level of internal body proportions the observers' age estimates increased monotonically with the parameter values used to generate the size of the head relative to the rest of the body. There was also a significant effect of internal body proportions, $F(5, 145) = 3.09$, $p < .05$, but this effect was quite small, accounting for less than 1% of the sum of squares. It was also in an inappropriate direction. It appears, therefore, that the observers were insensitive to internal body proportions as a potential source of information for the perception of growth and that they relied almost exclusively on the head-to-body ratio in determining their age estimates.

General Discussion

The research reported in the present article was designed to examine the ability of human observers to identify growth events from changes in body proportions. Using a coordinate transformation developed by P. B. Medawar to simulate the effects of growth on a variety of objects, three experiments were performed to isolate some of the relevant stimulus dimensions by which growth events are perceptually defined.

Experiment 1 examined the perceptual salience of changes in body proportions as a potential source of information for the identification of growth. Naive observers were presented with sequences of mathematically transformed line drawings (see Figures 1, 2, and 3) and asked to identify the physical process by which the drawings were related. When the outline drawing of a human body devoid of any internal details was subjected to Medawar's tapered stretch transformation, the resulting deformations were identified as growth by 21 out of 31 observers. When the same figure was subjected to a horizontal compression transformation, in contrast, it was identified as growth by only 1 of 31 observers. Given the low demand characteristics of this experiment and the crudeness of the drawings, these findings indicate that the changes in body proportions described by Medawar's transformation are a perceptually salient source of information about the process of growth.

Experiment 2 examined the ability of naive observers to estimate the absolute age of an individual from the relative sizes of different body parts. The results indicated that the effects of the tapered stretch transformation had a strong effect on perceived age, and, more specifically, that the observers' judgments were related by a power function to the size of the head relative to the rest of the body. The results

Table 1
Mean Age Estimates for Experiment 3

Age parameter for body proportions	Age parameter for head size						
	.4198	.4490	.5910	1.650	5.250	15.30	*M*
.4198	3.730	6.480	10.47	20.20	33.20	42.67	19.45
.4490	3.980	7.720	7.77	19.90	27.70	41.27	18.04
.5910	3.300	5.920	10.13	17.30	29.03	42.53	18.04
1.650	4.130	5.240	10.62	16.27	29.20	38.60	17.34
5.250	4.890	6.430	10.73	20.63	25.37	39.37	17.90
15.30	4.920	7.520	11.63	16.50	23.23	38.30	17.02
M	4.150	6.550	10.23	18.47	27.96	40.45	17.97

also indicated that the effect of body proportions was significantly influenced by the particular body form depicted in each display. Although the judgments obtained for the human, Martian, robot, and flower figures could each be fit by a power function, the exponents of these functions varied systematically across the different body forms.

Experiment 3 was designed to confirm our hypothesis from Experiment 2 that the observers' age level judgments were primarily determined by the size of the head relative to the rest of the body. Since Medawar's tapered stretch transformation alters the relative sizes of a variety of structures throughout the body, there are many other relations among different body parts that ordinarily covary with the proportional size of the head. In Experiment 3 these different sources of information were manipulated independently of one another in order to compare their relative perceptual salience. The results showed clearly that the proportional size of the head was responsible for most of the variance in the observers' age level judgments. Although the relative sizes of the arms, legs, and torso had a marginally significant effect, it was in an inappropriate direction.

It is important to keep in mind when evaluating the theoretical significance of these results that our perception of events has two components: a structural component and a transformational component. The structural components are the nouns of perception. They are the objects that participate in events, such as people, dogs, triangles, or points of light. The transformational components, in contrast, are the verbs of perception. They are the styles of change by which objects are transformed such as walking, growing, rolling, or bouncing.

Much of the research on biological event perception during the past few years has attempted to demonstrate that the transformational component of an event can be reliably identified even when it is applied to seemingly inappropriate objects that could never undergo such a change in a natural environment. Some of the more spectacular examples of this phenomenon include Heider and Simmel's (1944) demonstration of simple geometric forms that appear to participate in a complex social interaction, Johansson's (1973, 1975, 1976) demonstrations involving point-light walkers, and the experiments by Pittenger et al. (1979) on the perceived growth of a Volkswagen. It is tempting to conclude on the basis of this evidence that the structural and transformational components of events may be analyzed independently of one another. The results of the present experiments suggest, however, that this is not always the case. For some events such as growth, our ability to identify a specific style of change is apparently constrained to a limited class of objects. This is particularly evident in the results of Experiment 2. Although the changes in body proportions produced by Medawar's tapered stretch transformation were readily perceived as growth when applied to drawings of humans, Martians, or robots, they were interpreted quite differently when applied to the drawing of a flower person (see Figure 5).

These large variations in the perceptual effects of Medawar's transformation for different body forms are difficult to explain on the basis of existing theory. Indeed, by most geometric criteria the four body forms used in these experiments are quite similar: They all consist of a central region (the trunk) and five appendages (two arms, two legs, and a head) arranged in a pentagonal pattern. The details of these constituent elements vary significantly across the different body forms, but there is no obvious figural property that could account for the systematic differences in the observers' perceptual judgments.

Why, then, should some of the objects be more easily seen as growing than others? One possible hypothesis to consider is that the effect of the transformation on any given object is based on the object's resemblance to a human form. Thus, we might expect that the transformation should be perceived as growth for objects with human characteristics but not for objects that lack those characteristics. Although at first glance this hypothesis seems perfectly reasonable, a closer examination reveals that it does not really explain the phenomenon. It merely shifts the focus from why an object is seen as growing to why an object is seen as human. One need only consider some of the distorted representations created by modern artists such as Picasso to realize that the issue of what constitutes a perceptually identifiable human form is far from straightforward. It should also be kept in mind that all of the objects used in the present experiments—including the flower figures—had basically the same human characteristics (e.g., arms, legs, head, and facial features). It appears, therefore, that the figural properties by which these objects are distinguished in the perception of growth are surprisingly subtle and abstract.

Another closely related issue addressed by these experiments concerns the redundancy of information within a single body form. Just as some objects can be more informative than others for the perception of biological change, there may also be large variations in the perceptual salience of different parts of an object. The results of Experiment 3 provide an excellent case in point. The observers in this experiment seemed totally oblivious to the potential information provided by the relative sizes of the arms, legs, and torso, yet they were extremely sensitive to the size of the head relative to the rest of the body in making their judgments. In other words, they attended to one aspect of the available information while apparently ignoring all others. There is some evidence to suggest that a similar process of selective attention may also be employed for identifying other types of biological events. Consider, for example, the ability of observers to distinguish between running and walking in the perception of human gait. When the gait of an individual switches from running to walking (or vice versa), there are measurable changes in the movement patterns of every limb segment. Todd (1983) has recently demonstrated, however, that observers do not attend to most of these changes and that the perceptual distinction between running and walking is determined primarily by the movements of the lower leg (i.e., the tibia).

It should not be surprising that there are strong similarities in the perceptual analyses by which different biological events are identified. Given the enormous variety of these events that are observed in nature, it is difficult to imagine that our perceptual systems could have developed a separate process for dealing with each one. In an effort to describe a possible general mechanism for addressing this problem, Mark et al. (1981) have recently speculated that the different styles of change involved in biological events may be distinguished from one another by the properties of objects they leave invariant (see also Todd et al., 1980). Although this approach has proven extremely useful for classifying transformations in the field of mathematics, there are several difficulties that will have to be overcome before it can be considered as an adequate theory of human perception. It remains to be demonstrated, for example, how this type of analysis could account for the complex interaction between structure and change observed in the present experiments or how it could be applied to those biological events, such as social interactions or human gait, that cannot yet be described as coordinate transformations. An adequate explanation of these phenomena will have to await future research.

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