Visual apparent movement: transformations of size and orientation

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Abstract. Sequential alternation between same-shaped stimuli differing in size (size ratio s) and orientation (angular difference θ) produced a visual illusion of translation in depth and concurrent rotation. The minimum stimulus-onset asynchrony required for the appearance of a rigidly moving object was approximately a linearly increasing function of (s−1)/(s+1) for simple translation in depth and a linearly increasing function of θ for simple rotation. The extrapolated zero intercept was lower for translation than for rotation, but estimated transformation times were additive in combined transformations. The results suggest that (a) the processes of apparent translation in depth and apparent rotation are individually sequential-additive in structure, and (b) apparent translations and rotations are combined by fine-grained alternation of steps of apparent translation and steps of apparent rotation. Similar principles account for recent data on imagined spatial transformations of visual size and orientation.

1 Introduction
Apparent movement can be generated by successively flashing a visual stimulus in two spatial locations. Following Korte (1915), a number of workers have investigated the spatiotemporal conditions for this illusion (see references and data in Larsen et al 1983). The results show that, when other parameters are kept constant, the minimum stimulus-onset asynchrony (SOA) required for optimal apparent movement (beta or apparent continuous movement of an object) is an increasing function of the visual angle separating the stimulus presentations. For long-range apparent movement (cf Anstis 1978, 1980; Braddick 1974, 1980; Pantle and Petersik 1980; Pantle and Picciano 1976; Petersik and Pantle 1979) the function is approximately linear. The slope constant increases with viewing distance, suggesting that the threshold for apparent movement depends upon the apparent separation between the stimulus presentations in three-dimensional space (cf Attneave and Block 1973; Corbin 1942).

Parametric studies of apparent rotational movement have yielded comparable results. By presenting a pair of perspective views of a three-dimensional object in continuous sequential alternation, Shepard and Judd (1976) created a perceptual illusion of a single object rotating back and forth. The minimum SOA required for apparent rigid rotation was a linearly increasing function of the angular difference in orientation between the two views, and the function was essentially the same for perceived rotations in depth and in the picture plane. In a similar experiment by Farrell et al (1982), variation in the size of the object affected the zero intercept of the SOA function, but the slope of the function was virtually constant.

Consider the meaning of linear relations between the minimum SOA required for perception of apparent translation or rigid rotation and the extent of those transformations. In one theoretical interpretation (Shepard 1981; Shepard and Judd 1976), the slope constants of the SOA functions are measures of the maximum speed of visually impleting (Beck et al 1977; Farrell and Shepard 1981) or ‘filling in’ a

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path connecting the two stimulus presentations. The impletion is regarded as an internal transformation that passes through a sequence of representations similar to those that would be generated if the stimulus were presented in intermediate locations or orientations (see Robins and Shepard 1977). The transformation presupposes that the visual system has established a correspondence between the two stimulus presentations and selected the path to be impled (see, e.g., Ullman 1979). The zero intercepts of the SOA functions may reflect the time taken by these computations\(^{(1)}\).

Shepard and Judd's (1976) data on apparent rotational movement parallel the results from the classical experiment on mental rotation by Shepard and Metzler (1971), and the impletion interpretation for apparent movement is akin to the assumption that imagined spatial transformations be sequential-additive processes in the sense that, for example, a mental rotation over a large sector of the circle be a sequence of mental rotations over smaller subsectors, the durations of these steps being additive (cf. Cooper and Shepard 1973, 1978). These results and interpretations fit in with growing evidence of functional resemblance between spatial imagery and perceptual processes (cf. Finke 1980; Shepard and Podgorny 1978). Building on a recent investigation of imagined spatial transformations of size and orientation (Bundesen et al. 1981), the current study of apparent movement was designed to explore further the extent of functional similarity between mental and apparent visual transformations.

In the previous study of mental transformations (Bundesen et al. 1981) subjects were required to decide as quickly as possible whether two versions of the same alphanumeric character were identical except for change in size and rotation in the frontoparallel plane. The mean decision times increased approximately linearly with both the linear size ratio and the angular difference in orientation between the two stimuli (cf. Bundesen and Larsen 1975; Cooper 1975; Larsen and Bundesen 1978; Metzler and Shepard 1974), and the effects of angular and size disparities were approximately additive (cf. Sekuler and Nash 1972). The results suggested that the task was performed by mentally transforming one of the stimuli into the visual size and orientation of the other one and then testing for a match.

The additivity of the effects of size and angular orientation suggested that mental transformations corresponding to combinations of external size transformations and rotations are composed from mental transformations corresponding to simple size transformations and simple rotations. Subjects reported that mental changes in visual size and orientation were gradual and concurrent in the sense that, in intermediate states of mental transformation, imagined visual size and orientation were both intermediate between those of the initial state and those of the final state. From the combination of temporal additivity and apparent concurrence we conjectured that mental transformations corresponding to simple size transformations and simple rotations are individually sequential-additive in structure. The combination of temporal additivity and apparent concurrence could then be explained by the hypothesis that mental transformations of size and orientation were performed by sequential alternation of smaller steps of mental size transformation and smaller steps

\(^{(1)}\) Burt and Sperling (1981) recently suggested that strength of correspondence is a separable function of spatial and temporal separation between stimuli, implying that the contributions of space and time to processes selecting among competing paths of movement should be independent. This suggestion on the nature of the path-selection process makes an interesting contrast with the maximum-velocity constraint suggested for the hypothesized impletion process. However, Burt and Sperling's data were obtained with many-view stimuli and small spatial separations (below 0.5 deg) and apparent movement in such conditions may possibly be based on other processes than those subserving apparent movement with two-view stimuli and large spatial separations [cf. Bradrick's (1974) interpretation of the data of Kolvers (1972) on many-view stimuli].
of mental rotation. Further, from the assumption that mental size transformation is sequential-additive in structure and the finding that mean decision times increased linearly with the size ratio of stimuli, we showed that the mental transformation of size could not correspond to a simple geometric multiplication about the center of the stimulus. However, the linear size functions could be explained on the dual hypothesis that (a) disparities of size were visually resolved as differences in depth, and (b) mental transformation times were directly proportional to these differences in depth.

We paralleled the Bundesen et al (1981) study of mental transformations by the present investigation of the joint effects of disparities of size and angular orientation on apparent movement.

1.1 Initial observations
Our subjects were presented with two sequentially alternating views of the same character differing in size and angular orientation. When the rate of alternation was sufficiently slow, the subjects unanimously reported a perceptual illusion of a single object moving in three-dimensional space while preserving its shape. If stimulus size was kept constant, the character appeared to be rotating back and forth in a frontoparallel plane. When stimulus size was changing, the character appeared to be moving in depth rather than changing in distal size. Apparent changes in distance and orientation seemed to be gradual and concurrent in the sense that, when the character appeared at intermediate distances, its apparent angular orientation was intermediate between those of the two stimuli. One observer described his experience as a perception of a "helical or screwlike rigid motion in depth" (Shepard 1981, page 314). In general, the subjective evidence on the nature of the investigated transformations was stronger in this (nonspeeded) experiment on perceptual processes than in the previous (speeded) experiment (Bundesen et al 1981) on imagery processes.

1.2 Depth interpretation
The subjective reports suggested that changes in stimulus size were visually resolved as changes in apparent distance such that, within trials, the apparent distal size of the moving object was approximately constant. Let x and y be alternating stimulus patterns presented in a frontoparallel plane at a distance D from the subject (see figure 1). Let \( L_x \) and \( L_y \), where \( L_x \leq L_y \), be the linear sizes (say, the greatest linear extents) of x and y, and let s be the size ratio \( L_y / L_x \). If it is assumed that the visual system acts as "a projective decoder of the optical message" (Johansson 1978), complete visual resolution of the size disparity between x and y as a difference in depth should correspond to central projection of the patterns onto frontoparallel planes at distances \( d_x \) and \( d_y \), respectively, such that apparent distal sizes \( l_x \) and \( l_y \) are equalized. It is easy to prove that, if \( l_x = l_y \), then

\[
d = d_y (s - 1),
\]

(1)

where \( d \) stands for \( |d_x - d_y| \), the difference in depth between the images of x and y.

Proceeding from equation (1), the linear temporal effect of s obtained in the previous experiment on mental transformations (Bundesen et al 1981) was explained by the assumption that \( d_y \), the represented distance of the larger pattern in a pair, was a constant, regardless of \( L_x \) and \( L_y \). The same constraint might conceivably be satisfied in the present study of apparent movement. However, given the resulting visual impression of a single object in movement, another constraint on the visual resolution of the disparity of size as a difference in depth seems favored by simplicity, namely, that the

(2) The sequential model could be mimicked by a parallel one, constrained ad hoc. Our argument appeals to parsimony.
average apparent distance of that object, \( \frac{1}{2}(d_x + d_y) \), be some constant \( a \), regardless of \( L_x \) and \( L_y \). The constant average apparent distance \( a \) should be determined by the constant indications of distance from accommodation, convergence, and binocular disparity, and from the texture and borders of the screen; the deviation from \( a \) represented by \( b \) should be a function of the sole cue to such a difference in depth, the disparity of size between \( x \) and \( y \).\(^{(3)}\)

As \( d = d_x - d_y \), the hypothesis that \( \frac{1}{2}(d_x + d_y) = a \) implies that \( d_y = a - \frac{1}{2}d \). By substitution of \( a - \frac{1}{2}d \) for \( d_y \) in equation (1), one finds that

\[
d = 2a \frac{s - 1}{s + 1}.
\]

Equation (2) was used in the analysis of the results.

**Figure 1.** Resolving a disparity of size as a difference in depth. Objects \( x \) (smaller solid arrow) and \( y \) (larger open arrow) with linear sizes \( L_x \) and \( L_y \) are shown at a distance \( D \) from a subject. By geometric multiplications with respect to the subject’s point of view (the origin of the coordinate system), the disparity of size between \( x \) and \( y \) is resolved as a difference in depth between the images of \( x \) (larger solid arrow) and \( y \) (smaller open arrow). The sizes and distances of the images are designated by \( l_{x}, l_{y} \) and \( d_{x}, d_{y} \).

**2 Method**

**2.1 Subjects**

Twelve subjects with normal or corrected-to-normal vision participated, including two of the authors (AL and JEF) and ten students or members of the staff at Stanford University.

**2.2 Stimuli**

The stimuli were normal or right–left reversed versions of the six characters employed in the experiment of Bundesen et al. (1981); 3, 4, 7, J, P, and R. The characters appeared in any of three fixed size formats with linear size ratios of 1:2:8 and in any of six orientations differing from the standard upright by 0°, 60°, 120°, 180°, 240°, or 300° of clockwise rotation in the frontoparallel plane.

For each of the two versions (normal versus reversed) of each of the six characters, 270 stimulus pairs were constructed by combining different transforms of the given pattern. Let the angular difference in orientation and the linear size ratio within a

\(^{(3)}\) The nature of the cue conflict may be elaborated as follows. The size disparity between \( x \) and \( y \) indicates that \( d_x/d_y = s \), where \( s = L_y/L_x \). Other cues to depth indicate that both \( d_x \) and \( d_y \) have a certain value \( a \). If \( s = 1 \), all indications are satisfied by setting \( d_x = d_y = a \). If \( s \neq 1 \), the indications are in conflict. However, if \( d_x \) and \( d_y \) are unequal, letting \( \frac{1}{2}(d_x + d_y) \) equal \( a \) is a simple way of finding a compromise between \( d_x = a \) and \( d_y = a \). Moreover, it is easy to show that this way of solving the conflict is optimal in the sense that, given the constraint that \( d_x/d_y = s \), the solution minimizes \( \max (|d_x - a|, |d_y - a|) \), the greatest discrepancy between assigned distance and indicated distance.
stimulus pair be $v$ and $s$, respectively. $v$ could be $0^\circ$, $60^\circ$, $120^\circ$, or $180^\circ$; $s$ could be 1, 2, 4, or 8. Each of the four values of $v$ was represented by six ordered combinations of orientations, corresponding to $(u, u+v)$, for $u = 0^\circ$, $60^\circ$, $120^\circ$, ..., $300^\circ$. For each value of $v$, each of the six orientation combinations was used three times with each of the four values of $s$, except that $v = 0^\circ$ was not used with $s = 1$. For $s = 1$ and $v \neq 0^\circ$, the three replications consisted of one use of format combination 1:1, one of 2:2, and one of 8:8.

Each of the twelve sets of 270 stimulus pairs was presented in a random order to one subject such that each of the twelve subjects worked with a single pattern (one version of one of the characters) throughout the experiment.

2.3 Apparatus and procedure
The subject was seated in front of a computer-driven cathode ray tube (Tektronix 604 Monitor equipped with a P-31 phosphor) at a viewing distance of 60 cm in a dimly illuminated room. All stimulus characters were centered on the face of the tube where the largest format covered about $7.9 \times 5.3$ cm and the smallest format about $1 \times 0.67$ cm. The stimuli were displayed by periodic intensifications at a rate of 40 Hz, each with a luminous directional energy of approximately 0.6 cd $\mu$cd cm$^{-1}$ (cf Sperling 1971); the background luminance of the screen was about 0.5 cd m$^{-2}$. Viewing was binocular and fixation was free.

On each trial, the two stimuli in a pair were presented in continuous sequential alternation with zero interstimulus interval and zero interpulse interval. The SOA was initialized at 1 s. At this rate of alternation the pair of stimuli created a visual impression of a single object moving back and forth while preserving its shape. If the subject tapped a right-hand key, the SOA was decreased by one eleventh. The subject was instructed to tap this key repeatedly until a limit was reached at which the visual impression of form-preserving movement disappeared (to be replaced by impressions of plastic deformation, partial movement, and/or flicker). The limiting value of SOA, SOA$_1$, was registered by pressing a center key. By then pressing a left-hand key, the SOA was increased by one tenth, which the subject had to do repeatedly until the visual impression of form-preserving movement reappeared. The limiting value of SOA, SOA$_2$, was again registered by pressing the center key, which also terminated the trial. After a series of about twenty-five practice trials, the 270 experimental trials were run in the course of four to six sessions, depending on the subject.

3 Results and discussion
3.1 Simple transformations
3.1.1 SOA thresholds. Effects of disparities of either size or angular orientation, but not both, are summarized by group means of the critical SOAs, SOA$_1$ and SOA$_2$, in figure 2. For same-sized stimuli, both SOA$_1$ and SOA$_2$ increased approximately linearly with the angular difference in orientation within stimulus pairs. Deviations from linearity were not significant: for the depicted means across size format combinations 1:1, 2:2, and 8:8, $\chi^2(1) = 0.71, p = 0.40$, for values of SOA$_1$, and $\chi^2(1) = 0.30, p = 0.58$, for values of SOA$_2$.

Effects of the absolute orientations of the stimulus characters were small and inconsistent, but some systematic effect of the absolute size format was observed for pairs of same-sized stimuli. For format combinations 1:1, 2:2, and 8:8, group means were 252, 266, and 273 ms, respectively, for SOA$_1$, and 353, 374, and 383 ms for SOA$_2$. Both variations were notable: for SOA$_1$, $\chi^2(2) = 9.75, p = 0.008$; for SOA$_2$, $\chi^2(2) = 7.92, p = 0.02$. To a good approximation, however, both SOA$_1$ and SOA$_2$ were linear functions of angular difference in orientation for each of the three format combinations, and effects of angular difference in orientation and
absolute size format were additive: for values of SOA₁, χ²(5) = 3.49, p = 0.63; for values of SOA₂, χ²(5) = 5.87, p = 0.32.

For pairs of stimuli in the same orientation with linear size ratio s, both SOA₁ and SOA₂ increased approximately linearly with the value of (s−1)/(s+1), as expected from equation (2). The fit was excellent (see figure 2): for values of SOA₁, χ²(1) = 0.02, p = 0.89; for values of SOA₂, χ²(1) = 0.16, p = 0.69. The hypotheses that SOA₁ and SOA₂, respectively, were linear functions of the linear size ratio s were tested for comparison: for SOA₁, χ²(1) = 38.5, p < 0.001; for SOA₂, χ²(1) = 40.4, p < 0.001.

For same-sized stimuli, the mean threshold SOA, defined as the average of SOA₁ and SOA₂, was a linear function of angular difference in orientation with a slope constant of about 0.95 ms deg⁻¹ and a zero intercept at about 203 ms. Between subjects, the slope constants ranged from 0.12 to 1.96 ms deg⁻¹, but product-moment correlations within subjects between SOA and angular difference in orientation reached an average of 0.93. For pairs of stimuli in the same orientation, the mean threshold SOA was a linear function of (s−1)/(s+1) with a slope constant of about 330 ms and a zero intercept at about 104 ms. Again, the individual variation was substantial with slope constants ranging between 108 and 804 ms, but the within-subject correlations between SOA and (s−1)/(s+1) were high, reaching an average of 0.98. For eleven of the twelve subjects the extrapolated zero intercept was lower for the size transformation function than for the rotation function, p = 0.006.

![Figure 2](image)

Figure 2. Group means of SOA₁ and SOA₂ for pairs of stimuli of the same size as functions of their angular difference in orientation, and group means of SOA₁ and SOA₂ for pairs of stimuli in the same orientation as functions of their linear size ratio. Theoretical fits are indicated by solid curves.

3.1.2 Theoretical interpretation. The subjective reports accorded with the description in section 1.1. In conjunction with the subjective data, the reported pattern of SOA thresholds supports the following theoretical interpretation. First, for pairs of stimuli
differing in angular orientation, but not in size, a slow rate of sequential alternation created a visual impression of a single object rigidly rotating back and forth in a frontoparallel plane. The process of apparent rigid rotation was sequential-additive in structure; when speeded as much as possible, the duration of the process was directly proportional to the angular extent of the transformation (cf. Farrell et al. 1982; Shepard and Judd 1976).

Second, for pairs of stimuli differing in size, but not in angular orientation, a slow rate of sequential alternation created a visual impression of a single object moving back and forth in depth. As previously assumed in the derivation of equation (2) (see section 1.2), differences in size were visually resolved as differences in apparent distance such that (a) the apparent distal size of the moving object was constant within trials, and (b) the average apparent distance of the object was constant over trials. The extent of the apparent translation in depth, then, was proportional to \((s - 1)/(s + 1)\).

The process of apparent translation in depth was sequential-additive in structure; when speeded to the limit, the duration of the process was directly proportional to the length of the path apparently traversed and, accordingly, to \((s - 1)/(s + 1)\).

Finally, the minimum delay between successive transformations, measured by the zero intercepts of the SOA functions, was less for apparent translations in depth than for apparent rotations. The difference in delay suggests that visual computations of relative size and distance were faster than visual computations of relative orientation.

### 3.2 Combined transformations

The effects of disparities of both size and angular orientation are summarized by group means of critical SOAs in figures 3 and 4. Figure 3 displays the mean threshold SOA as a function of the value of \((s - 1)/(s + 1)\) with angular difference in orientation \(\nu\) as the parameter. The underlying patterns of values of SOA\(_1\) and SOA\(_2\) were similar. As shown in figure 4, SOA\(_2\) was approximately a linear function of

\[
\frac{s - 1}{s + 1} \approx \frac{s-1}{3+1} = 3.3, 50, 78
\]

\[
\text{Figure 3. Group mean of critical SOAs as a function of } \frac{(s-1)}{(s+1)}, \text{where } s \text{ is the linear size ratio between stimuli, with angular difference in orientation of stimuli as the parameter. A theoretical fit is indicated by solid curves.}
\]

\[
\text{Figure 4. Correlation between group means of SOA}_1 \text{ and SOA}_2. \text{ Data are fitted by a solid regression line; a dotted reference line indicates where SOA}_2 \text{ equals SOA}_1.
\]

\[
\text{SOA}_1 = 211.05 \text{ ms}; \text{ SOA}_2 = 116.28 \text{ ms}; \beta = 86.175 \text{ ms/}^\circ; \delta = 310.75 \text{ ms}
\]
SOA₁ with a slope constant of about 1.6 such that, by extrapolation, SOA₂ = SOA₁ for SOA₁ = 63 ms; the linear correlation was 0.996.

Theoretical fits to the data in figure 3 were made on the following assumptions. First, for pairs of same-sized stimuli with a difference \( v \) in angular orientation, the expectation, \( E \), of SOA was a linear function of \( v \): 

\[ E(\text{SOA}) = \alpha + \beta v, \]

where \( \beta \) is a measure of the rate of apparent rotation and \( \alpha \) is the minimum delay required between successive rotations.

Second, for pairs of stimuli in the same orientation with a linear size ratio \( s \), 

\[ E(\text{SOA}) = \gamma + \delta(s-1)/(s+1), \]

where \( \delta \) is a measure of the rate of apparent translation in depth and \( \gamma \) is the minimum delay required between successive translations\(^{4}\).

Third, measured from the completion (with respect to both apparent distance and apparent orientation) of a transformation in one direction, say, from stimulus x to stimulus y, apparent translation from the apparent depth plane of y back to that of x was released with a shorter latency than was apparent rotation from the orientation of y back to the orientation of x. The release latencies equalled the constants \( \gamma \) and \( \alpha \), respectively, such that \( \gamma < \alpha \).

Fourth, apparent translations in depth and apparent rotations were combined by sequential alternation of steps of apparent translation and steps of apparent rotation. Thus, in case the translation time \( \delta(s-1)/(s+1) \) was shorter than \( (\alpha - \gamma) \), the expected SOA for a combined transformation should equal the time taken to release and complete the rotational component, \( \alpha + \beta v \). But in case the translation time was longer than \( (\alpha - \gamma) \), \( E(\text{SOA}) \) should be extended by the difference between \( \delta(s-1)/(s+1) \) and \( (\alpha - \gamma) \).

In general, then,

\[ E(\text{SOA}) = \alpha' + \beta v + \max \{0, \gamma + \delta(s-1)/(s+1)\} - \alpha', \]

where \( \alpha' = 0 \) ms or \( \alpha' = \alpha \) according as \( v = 0^\circ \) or \( v \neq 0^\circ \). The minimum chi-square fit by equation (3), shown in figure 3, accounted for 99.2% of the variance. Estimates for the parameters were 211 ms for \( \alpha \), 0.86 ms deg\(^{-1}\) for \( \beta \), 116 ms for \( \gamma \), and 311 ms for \( \delta \). The deviations from the predicted pattern did not reach significance, \( \chi^2(11) = 19.1, p = 0.06 \).

4 General discussion

Thresholds depend upon criteria. A number of previous studies have shown little effect of figural similarity for perception of "smooth continuous movement" between stimuli (cf Berbaum et al 1981; Hochberg and Brooks 1974; Kolers 1972; Kolers and Pomerantz 1971; Navon 1976). Kolers and Pomerantz (1971) reported that "under proper stimulus conditions, any simple shape will change smoothly into any other" (page 104), and they found that the influence of figural similarity on the likelihood of seeing smooth continuous movement between stimuli was very small. Kolers and Pomerantz also measured the frequency of seeing a "smooth continuous change of any kind" between same-shaped stimuli in different sizes and orientations, separated by different interstimulus intervals with exposure durations kept constant. For combined changes in size and orientation, the frequency of seeing a smooth continuous change was generally at least as high as the corresponding frequency for the change in size alone. In the present experiment, however, subjects were instructed to record when form-preserving movement was perceived, and this procedure produced strong and systematic effects of extent of transformation on temporal thresholds. Moreover, in accordance with the notion that the visual system is biased toward perception of rigid

\[ \sigma_x + \sigma_y \]
objects moving in space (cf Farrell and Shepard 1981; Johansson 1978; Ullman 1979), the data suggested that as long as apparent form was preserved, so was apparent distal size.

The present results on form-preserving apparent movement fit in with our previous analysis (Bundesen et al 1981) of imagined spatial transformations of visual size and orientation. In both studies the results suggested that (a) internal transformations corresponding to compositions of external size transformations and rotations were composed from internal transformations corresponding to simple size transformations and simple rotations; (b) the component transformations themselves were sequential-additive in structure; and (c) disparities of size were visually resolved as differences in depth and internal transformation times were directly proportional to these differences in depth. In these respects, then, mental and apparent visual transformations seemed to obey the same principles.

We offer the following speculations on the nature and function of internal transformations in motion perception. Representing objects viewed in apparent movement (ie, with discrete presentations) in the same format as objects viewed in real movement is presumably adaptive (see, eg, Gregory 1973). Following, say, normalization of long-range discrete input to real-movement format, the scene analysis and recognition routines used in analyzing representations of objects viewed in real movement may be directly applied to representations of objects seen in apparent movement. Viewing an object in real movement over a long path normally implies, we propose, that the object is successively represented in a number of intermediate states along the path. To simulate the internal response to an object viewed in real movement, the system subserving long-range apparent movement should generate a similar sequence of representations of the apparently moving object, and this may be the function of impletion processes in apparent movement.

The finding that estimated transformation times for translation and rotation were additive in combined transformations suggests that there are independent routines for impleting translation and rotation, jointly forming a procedure for impleting any sort of change that preserves the rigid structure of an object in visual apparent movement.

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