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journal or publication title	Tohoku psychologica folia
volume	47
page range	16-20
year	1989-03-31
URL	http://hdl.handle.net/10097/62566

Tohoku Psychologica Folia
1988, 47 (1-4), 16-20

PERCEPTION OF RIGID/NONRIGID 3-D ROTATION[1]

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Based on Johansson's 'vector analysis' and Todd's 'trajectory-based analysis', it was examined whether the perception of nonrigid 3-D rotation from 2-D transformation can be explained only by the 'magnitude' of a residual motion vector. In this experiment, 20 subjects were asked to report what nonrigid motions they perceived from non-perspective patterns generated on a CRT display and the results did not support the above possibility ; two distinct nonrigid motions (2D (stretching, contracting) or 3-D (folding, bending)) were perceived according to variables manipulated to elicit the perception of nonrigid motions.

The candidates for the information about these percepts are (1) moving elements' locations in a 2-D transformation pattern at the minimal contraction, and (2) the 'direction' of a residual motion vector.

Key words: rigidity/nonrigidity, vector analysis, trajectory-based analysis, residual motion vector.

INTRODUCTION

In the first half of this century, many studies had reported the phenomena that three-dimensional (3-D) motions (translation and rotation) were perceived from a two-dimensional (2-D) transformation pattern (Braunstein, 1976).

Since Wallach & O'Connell (1953)'s research of 'Kinetic depth effect', many experimental studies have been conducted to test what factors might affect such phenomena. But most of them have dealt with bistable percepts of either 2-D plastic deformation or 3-D rigid motion, not the simultaneous percept of both motions.

The first and most famous research about the latter percept has been carried out by Johansson (1964) ; he has examined percepts from non-perspective patterns and proposed a 'vector analysis'. The fundamental idea of this analysis is that the perception of rigidity/nonrigidity of 3-D motion is determined by the existence of a residual motion vector as a result of subtraction of a motion vector corresponding to

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3. Börjesson & von Hofsten (1975) named the vector corresponding to 3-D rigid translation "concurrent motion vector", and the one corresponding to 3-D rigid rotation "parallel motion vector".

3-D rigid motion.[3]

On the other hand, Todd (1982) has proposed a 'trajectory-based analysis'. This analysis is based on a projective geometrical fact that the rigidity of 3-D rotation constrains the variables specifying trajactories of moving elements in its projective chart (eccentricity, orientation, intercept, and frequency), and assumes that the specific geometric relations established among these variables of the projective trajectories determine rigidity/nonrigidity of the perceived motion.

It seems to deal with the bistable percepts mentioned above. But, if a 'vector analysis' is applied to the 2-D transformation pattern supposed to correspond to nonrigid motion in a 'trajectory-based analysis', there necessarily remains a residual motion vector. In this respect we can recognize the commonness between both analyses.

Thus a question to be examined arises ; Can we predict rigidity/nonrigidity of the perceived 3-D rotation only by the 'magnitude' of a residual motion vector, regardless of variables manipulated to elicit nonrigid motions ?

The purpose of this experimental research is to examine this problem.

METHOD

Subjects : Twenty naive observers, aged 21-28 years, participated in this experiment as *S*s. All of them have normal or correct-to-normal vision.

Apparatus : Stimuli were presented on a CRT display (NEC, PC/8853n), controlled by a computer (NEC, PC/9801).

Each frame duration was 67 msec. The CRT display (13×21 cm) was viewed monocularly at distance of 57 cm, lest observers should perceive the 'flatness' of it by cue of binocular disparity.

Head movements were restricted by a chin rest.

Stimuli : A stimulus was a square made of four connected line segments whose endpoints (vertices of a square : P1, P2, P3, and P4) moved on elliptical or linear trajectories according to the previously computed function of translation.

17 kinds of stimuli (transformation patterns) were used in this experiment (one control stimulus and 16 experimental stimuli).

Control stimulus

A control stimulus was an orthogonal projective chart of a square ($4.8 \times 4.8°$, visual angle) rotating in depth rigidly about a horizontal line. It rotated at frequency of 0.375 Hz.

Experimental stimuli

An experimental stimulus was the same as a control stimulus except that trajectories of P1 were different between both stimuli. This difference was generated by manipulating one of four variables which specify P1's trajectory on space and time (eccentricity, intercept, orientation, and frequency).

The 'magnitude' of a residual motion vector was set at four rates (0.6°, 1.2°, 1.8°, and 2.4°) for each variable, so that 16 (4 variables ×4 'magnitude' of a residual motion vector) transformation patterns were used.

Procedure : In a pilot study, some observers reported that they could distinguish two kinds of perceived nonrigid motion accompanied with 3-D rotation ; 2-D nonrigid motion (strectching, contracting, etc.) and 3-D nonrigid motion (bending, folding, etc).

Thus, in the actual experiment, subjects were asked to report whether they perceived nonrigid 3-D rotation and which nonrigid motion they perceived.

After instructed the task and the concepts of rigid and two kinds of nonrigid motion, subjects were presented 17 practice trials, and then 85 experimental trials in randomized order- 5 trials for 17 stimuli. An experimental session was divided into 5 blocks of 17 trials each and conducted in a darkroom.

Results

Figure 1. shows the perception rate for three types of motions (rigid rotation in depth, 2-D nonrigid rotation in depth, 3-D nonrigid rotation in depth). A three-way analysis of variance (variables of P1's trajectory (eccentricity, intercept, orientation, frequency)×'magnitude' of a residual motion vector (0.6°, 1.2°, 1.8°, 2.4°)×subjects) revealed that the effects of both factors on the quantity (rate) of the perceived nonrigid motions were significant (variables of P1's trajectory ; $F(3,48)=3.840$, $p<0.05$: 'magnitude' of a residual motion vector ; $F(3,48)=11.798$, $p<0.01$), and that the interac-

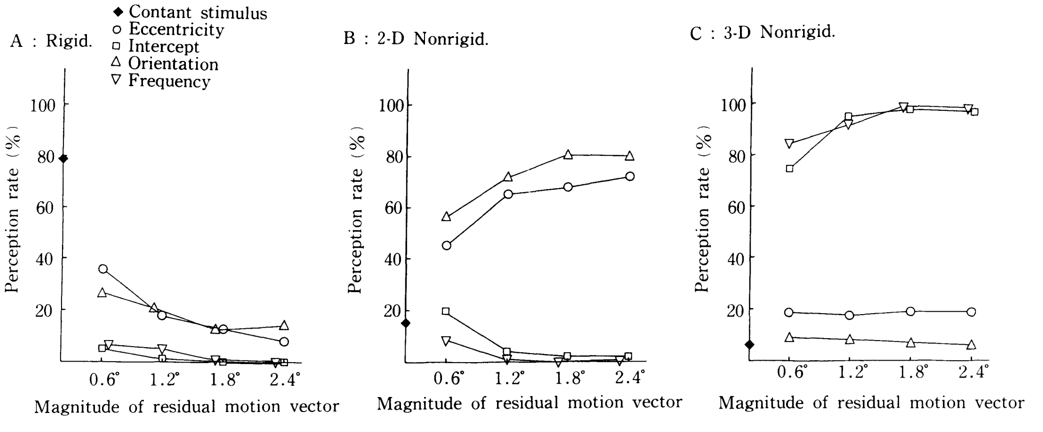

Fig. 1. Perception rate for 3 types of motion (A : rigid rotation in depth, B : 2-D nonrigid rotation in depth, C : 3-D nonrigid rotation in depth) plotted as a function of 'magnitude' of a residual motion vector.

tion of them was significant ($F(9,144)=2.542$, $p<0.01$)[4].

Further analysis was performed on each experimental condition with a pairwise signed-ranks test to examine the quality (2-D or 3-D) of the nonrigid motion. Significant differences were shown at 14 experimental conditions out of 16($p<0.05$ except 0.6° -eccentricity condition and 0.6° -intercept condition), which confirmed that 2-D nonrigid motions were predominantly perceived in eccentricity/orientation conditions and 3-D nonrigid motions in intercept/frequency conditions.

Discussion

The results of this experiment are summarized as follows; (A) observers perceived predominantly 2-D nonrigid motions in eccentricity/orientation conditions and 3-D nonrigid motions in intercept/frequency conditions, and (B) nonrigid motions were more frequently perceived in intercept/frequency conditions than in eccentricity/orientation conditions, particularly when the 'magnitude' of a residual motion vector was small.

Therefore, the quality (2-D or 3-D) and quantity (rate) of the perceived nonrigid motions concurrent with 3-D rotation could not be explained only by the 'magnitude' of a residual motion vector as a result of a 'vector analysis'.

At present, I cannot give a satisfactory explanation of the result (B), so I will examine here what information brought up such a difference as shown in result (A). The candidates for the information are (1) locations of moving elements in a 2-D transformation pattern at its minimal contraction and (2) the 'direction' of a residual motion vector:

(1) If a planar object rotates in depth rigidly or accompanying 2-D nonrigid motion, its projective pattern necessarily becomes a line at the minimal contraction ('alignment'). In addition, if 'alignment' occurs in an orthogonal projective pattern of a planar object doing 3-D nonrigid motion concurrent with 3-D rotation, the simulated object is perpendicular to a frontparallel plane in a rigid state, which constrains the location of each moving element.

The contrapositives of these statements are also true, and, in this experiment, the antecedents of them were satisfied; in intercept/frequency conditions, 'alignment' did not ocur, and in eccentricity/orientation conditions, each element was not at the constrained location when 'alignment' ocurred.

This might lead to the perception of two distinct nonrigid motions.

(2) The 'direction' of a residual motion vector was parallel to that of 3-D rotation in intercept/frequency conditions, but perpendicular to it in eccentricity/orientation conditions.

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4. The data of 3 subjects, who did not perceive rigid 3-D rotation in all trials, were excluded from the ANOVA.

Such a difference might be the information for the distinction of the quality of the perceived nonrigid motions.

Information (2), however, was hinted from only comparing between both conditions, and, unlike information (1), it did not have a projective geometrical validity in this experiment.

Further researches are necessary to examine the efficiency of information (1) and (2) for the perception of two distinct nonrigid motions.

Acknowledgement

I express my appreciation to Professor Kinya Maruyama of Tohoku University for his comments and criticisms of earlier drafts, and to Mr. Eiichi Jodo for his valuable technical advice.

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(Received December 15, 1988)