Perception, 1994, volume 23, pages 5-13

The perception of spatial structure with oblique viewing: an explanation for Byzantine perspective?

Jan B Deręgowski, Denis M Parker
Department of Psychology, King's College, University of Aberdeen, Old Aberdeen AB9 2UB, Scotland, UK
Manfredo Massironi
Instituto di Psicologia, Faculta di Magistero, Universita Degli Studi di Verona, Verona, Italy
Received 14 May 1993, in revised form 21 October 1993

Abstract. Earlier work has confirmed that (i) observers can judge divergent receding lines, placed directly in front of them, to be parallel, and (ii) converging lines which are displaced laterally, so that they are viewed obliquely, can also be judged to be parallel. The former observation is in accord with traditional views of perspective while the latter, which is in accord with the depictions of objects found in Byzantine painting, is not in accord with perspective but is predicted by the relative magnitude of the visual angles subtended by the near and far ends of the pair of lines. To investigate whether these effects occurred when the stimulus was clearly three-dimensional, experiments were conducted with a novel apparatus, consisting of a framework of computer-controlled motor-driven luminous rods. This could be remotely adjusted so that all visible sides appeared to be parallel, ie to resemble a cube. Results showed that observers set the sides of this trapezohedron framework as diverging when it was viewed immediately in front of them, a result which is concordant with linear perspective, ie they see the normal projection of a cube as having converging edges. When the framework was displaced from the median plane so that it was viewed obliquely, the sides were set as converging and the magnitude of this effect was significantly related to angle of view, ie observers see the normal projection of a cube as having diverging sides. These results confirm the suggestion that 'Byzantine perspective' is a legitimate reflection of perceptual experience, but they do not provide an explanation why the perception of laterally viewed objects was adopted as a model for centrally depicted patterns.

1 Introduction

Deręgowski and Parker (1992) showed that when observers are required to set out four points of light on a horizontal plane so as to form a rectangle, they arrange them differently depending on whether the points are presented immediately in front of them or are laterally displaced. When the four points are presented immediately in front of the observers the arrangement of lights forms a trapezium with its shorter parallel side close to the observer. When the four points are laterally displaced relative to the observer, so that the lights are viewed obliquely, the arrangement forms a trapezium with its longer parallel side close to the observer (see figure 1). These observations confirm and extend findings reported by Bartel (1960) and ten Doesschate and Kylstra (1955) and indicate that observers will judge *divergent* receding lines that are placed directly in front of them as parallel and *convergent* lines that are laterally displaced, and hence viewed obliquely, also as parallel.

The former observation is in accordance with traditional views of linear perspective but the latter observation is not. Instead it suggests the presence of divergent perspective in the perception of obliquely viewed objects. There is a ready explanation of this apparently eccentric phenomenon. When subjects view rectangular patterns placed immediately before them, the nearer edge subtends a larger visual angle than the further edge (the lateral edges of the pattern appear to recede) and it appears that constancy scaling is unable to compensate accurately for the difference in angular subtense when they make their matching judgments: they overcompensate.

With laterally placed rectangular patterns, the oblique angle of view results in the more distant of these same edges subtending a larger visual angle than the nearer and, in attempting to reproduce a perceptually rectangular arrangement, they in fact set the lateral edges converging. A simple geometrical account of the angles subtended by the different parts of the pattern under two different viewing conditions predicts either convergent or divergent perspective. Deręgowski and Parker argued that these data demonstrate why elements of divergent perspective found in certain artistic styles can be as legitimate a representation of visual experience as convergent perspective; the two distinct modes of representation may derive from a difference in the notional position relative to the artists which the depicted object occupies. Frontally viewed horizontal rectangles which are drawn as converging and laterally displaced rectangles which are drawn as diverging are both legitimate reflections of visual experience.

Divergent perspective is often found in icons done in traditional Byzantine style and has attracted the attention of several semioticians (Florenskii 1967; Szolc 1973; Uspensky 1971, 1976), whose views are most comprehensively expressed in Uspensky's (1976) monograph. Uspensky thinks of divergent perspective in icons as having a special, almost mystical, significance. Pictures incorporating divergent perspective are said to represent a summary of the perceptual experiences which an artist had when viewing the depicted object from a variety of stances, in contradistinction to a view of an object as seen from only one particular stance. It is argued that the painter notionally places both himself and the viewer within the representation of space that he has experienced. Thus the sides and the top of the footstool may be represented as seen from different stances. This would be indicated by discrepancies in the points of convergence of appropriate edges in the drawing, and this is shown diagrammatically in figure 2.

This explanation of divergent perspective is, it must be noted, essentially paradoxical since it claims that what appears, to a viewer unfamiliar with the 'divergent style', to be a drawing in divergent perspective is really drawn in convergent perspective, but from one or more stances which are different from those assumed by the uninitiated.

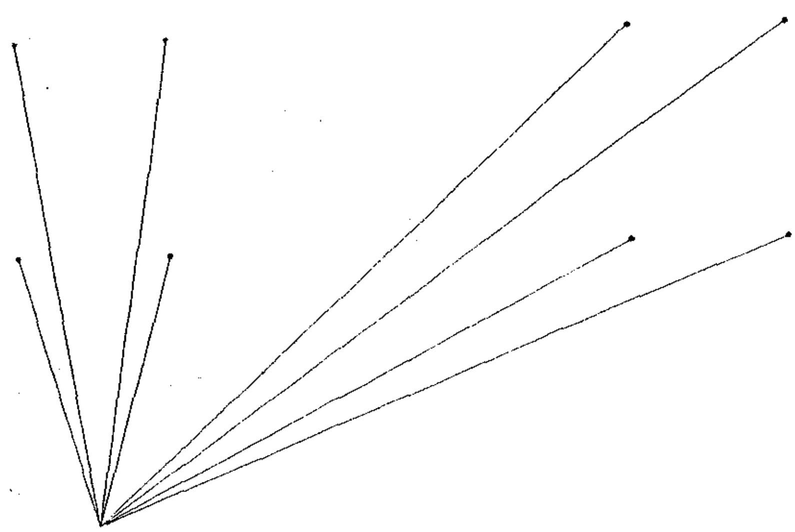

Figure 1. Angles subtended at the eye, the point of confluence of the visual directions of two sets of points. When a constellation is viewed frontally (the four points on the left of the diagram) the most distant pair of points subtend a smaller visual angle than the closest pair. This relationship is reversed when the constellation is viewed laterally (four points on the right of the diagram).

There are several objections to an *unquestioning* acceptance of this explanation. There are occasional, yet reliable, observations of Western draughtsmen and of students of art and architecture, who have had no or negligible exposure to this style, yet produce drawings in 'divergent' perspective (Parker and Deręgowski 1990). There are empirical studies of convergent perspective conducted in 'real-life' situations which indicate significant departures from the assumptions of linear perspective. The most important of these studies are those of Bartel (1960), who conducted several experiments on the perception of real space as well as of depicted space. In one of these, observers were presented with two staves hung on a laterally displaced wall, receding from the observer and they instructed an assistant where to interpose four further identical staves so as to construct a row of six equispaced staves. The results showed that observers systematically, and contrary to the rules of perspective, increased interstave intervals so that the distance between the pair of staves furthest from the observer was largest and that nearest to the observer smallest. A much later experiment by ten Doesschate (1964, pages 133–138), in which subjects were required to judge the orientation of luminous parallel horizontal rods, confirms this lack of concordance between the perception of real space and the rules of perspective, particularly when contours are laterally displaced from the observers' viewing stance.

There are two points which arise from this discussion. First, the experiments mentioned above were concerned with the perception of coplanar elements and therefore it is uncertain whether their findings are pertinent to depictions of solid objects. Second, and because of this same consideration, the results of these studies do not cause us to question directly the notions which according to Uspensky (1976) have inspired artists to draw in divergent perspective. If it could be demonstrated that divergent perspective is experienced when viewing laterally displaced rectangular solids then the case against more-involved theories of its origins will be much strengthened.

The findings of Deręgowski and Parker (1992), and indeed of others, have suggested that there is a readily available perceptual explanation for the Byzantine style. These observations are, however, like those of ten Doesschate (1964) and Bartel (1960), limited to the perception of stimuli either in the horizontal (Deręgowski and Parker 1992; ten Doesschate 1964) or in the vertical (Bartel 1960) plane (the top or the side of a footstool, as it were). Furthermore, data from only a very restricted range of observation stances has been gathered. In contrast to Deręgowski and Parker's subjects, the artists responsible for pictures in divergent perspective observed their models from a variety of stances and saw them not as an arrangement of coplanar elements but as clearly three-dimensional objects. It is necessary therefore to extend earlier work by using a clearly three-dimensional model and gathering information on observers' percepts when they occupy a larger range of stances than previously employed.

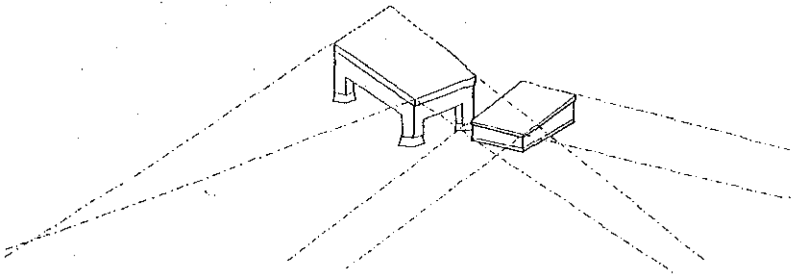

Figure 2. Outlines of two footstools depicted in a Russian 15th century icon of the Novogrod School, 'St John the theologian'.

One of the objects often depicted by Byzantine artists is a footstool. This piece of furniture, essentially a parallelepiped, is usually drawn so that its 'further' vertical and horizontal edges are longer than the 'nearer' edges, ie it is usually seen by those accustomed to linear perspective as a depiction of a trapezohedron. The apparatus used in the present experiment, which is intended to obtain data on perception of convergence of lines in mutually orthogonal planes, was inspired by the frequency with which footstools are depicted in icons. It was designed to provide the observer with the projection of the visible edges of a solid trapezohedron in which two of its visible trapezia could be directly varied and could if desired be arranged to form a parallelepiped.

The purpose in the experiments reported below was to gather data on the perception of a three-dimensional object from a number of viewing stances. Because of the basic observation that an obliquely viewed rectangle is perceived as a divergent trapezium, and hence the subject will adjust its sides so that it becomes a convergent trapezium, the formal hypotheses in the present study were (i) that subjects adjusting a framework so that its horizontal face appears to them to be rectangular will set it as convergent (in terms of distance from the observer) when the object is displaced laterally and hence viewed at an oblique angle; (ii) that an analogous effect will pertain to the vertical face when the elevation of observers' stance changes; (iii) an increase in displacement (obliqueness of view) will result in an increase in the degree of convergence of the settings.

Evaluation of these hypotheses is, as shown above, immediately relevant to divergent perspective in depictions.

2 Method

2.1 *Subjects*

Twenty-two adult subjects—men and women—were drawn from the research panel of the Department. None of them had any known uncorrected ocular defects. The subjects were paid for participation in the experiment. Twelve subjects participated in the first experiment, ten in the second.

2.2 *Apparatus and procedure*

An apparatus consisting of interconnected luminous rods (46 cm long) was constructed. The rods were arranged to form three abutting quadrilaterals (see figure 3). Two of these quadrilaterals formed the frontal square (ABCD) and the lateral trapezium (BEGC) and lay in mutually orthogonal vertical planes. The third face (ABEF) which formed the top surface of the construction was also a trapezium and lay approximately in the horizontal plane. The rods were connected to stepping electric motors so that (i) the inclination of the entire 'top' trapezium could be changed so altering angle b' and hence the shape of the lateral trapezium, and (ii) by altering the direction of member AF, so changing angle a', the shape of the top trapezium could be changed. Subjects could make these changes by operating handheld joysticks which were connected to a BBC computer, which in turn controlled the stepping motors.

The apparatus, when presented in a darkened room with 'black light' illumination, was perceived as a solid trapezohedron whose visible edges were formed by the luminous rods. Other features of the room were dimly discernible. It was necessary to present the apparatus under these conditions in order to conceal the support plates for the luminous rods.

The position of the apparatus and of various stances at which subjects stood in the course of the experiment is shown in figure 4. Stances J, L, M, N, and P were used in the first experiment and all these stances were at floor level. The subjects responded from all of them in turn, each subject doing the series of readings in a different, quasi-randomised order. Two further stances were used in the second experiment. Both were 1.80 m above the floor level and subjects stood on a scaffolding platform. One of these (L′) was immediately above stance L and the other (K) was above a point half way between stances J and L (see figure 4).

Subjects were first instructed how to use the joysticks to adjust the apparatus, and were then directed to the first stance, from which they were required to make five responses, by adjusting the model till it seemed to be a 'proper rectangular box'. They were free to operate either one or both joysticks in any manner they wished in order to achieve the desired effect. The subjects' binocular vision and head movements were entirely unrestrained throughout the experiment, but they were not

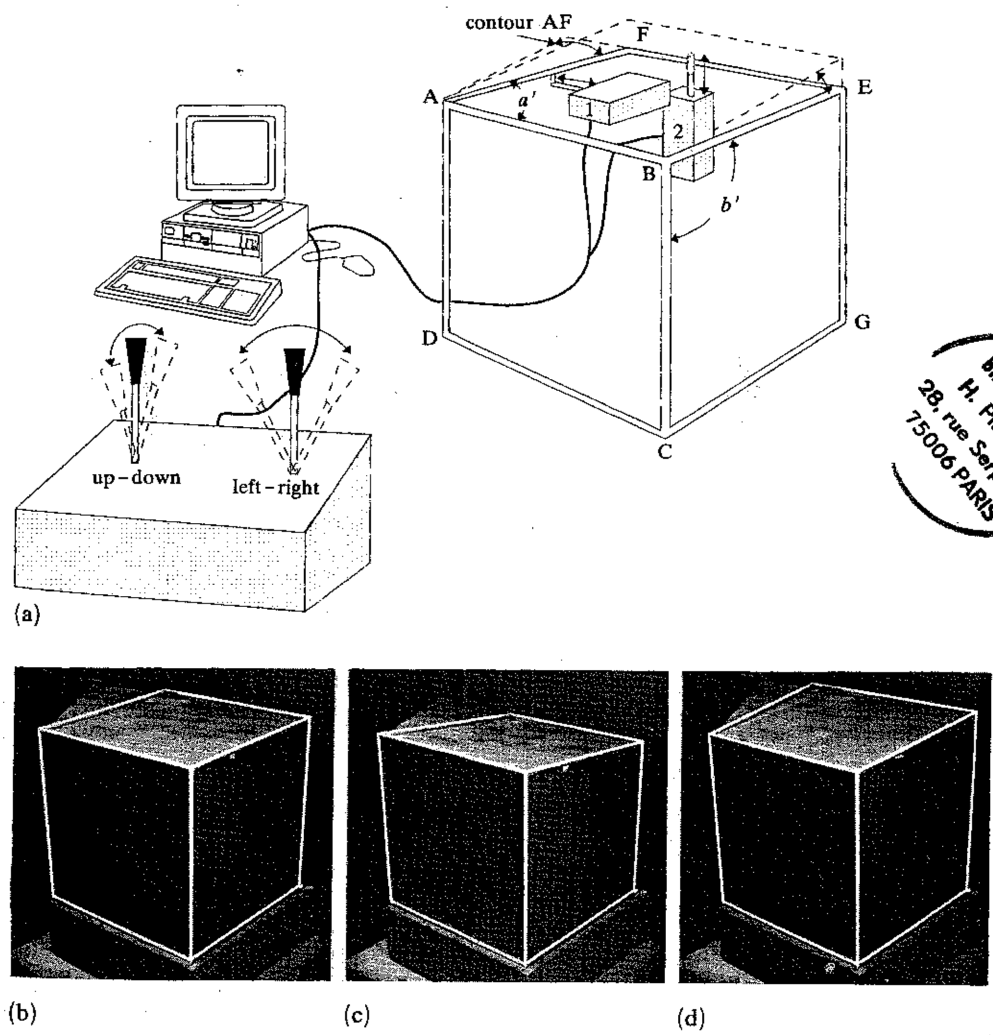

Figure 3. (a) Diagram of the apparatus used in the experiments. The arrangements of luminous rods supported the three visible faces of a cube. Motor 1 allowed movement of contour AF, so altering the top face, while motor 2 allowed the whole of the top face to move up and down, so altering angle b' and hence the lateral face of the cube. Bottom: photographs of the apparatus (b) as a regular cube; (c) with angle b' reduced, so altering the lateral face; (d) with angle a' expanded, so altering the top face. Note that the matt black surfaces, which are designed to conceal reflective internal parts of the apparatus, were not visible under the 'black light' viewing conditions.

allowed to move away from the designated stances. Angles at which subjects set the adjustable members were recorded and the settings were then randomly changed by the experimenter so that succeeding adjustments were made from arbitrary starting points. On completion of the set of five adjustments the subject moved to the next stance indicated by the experimenter. This procedure was used in both experiments.

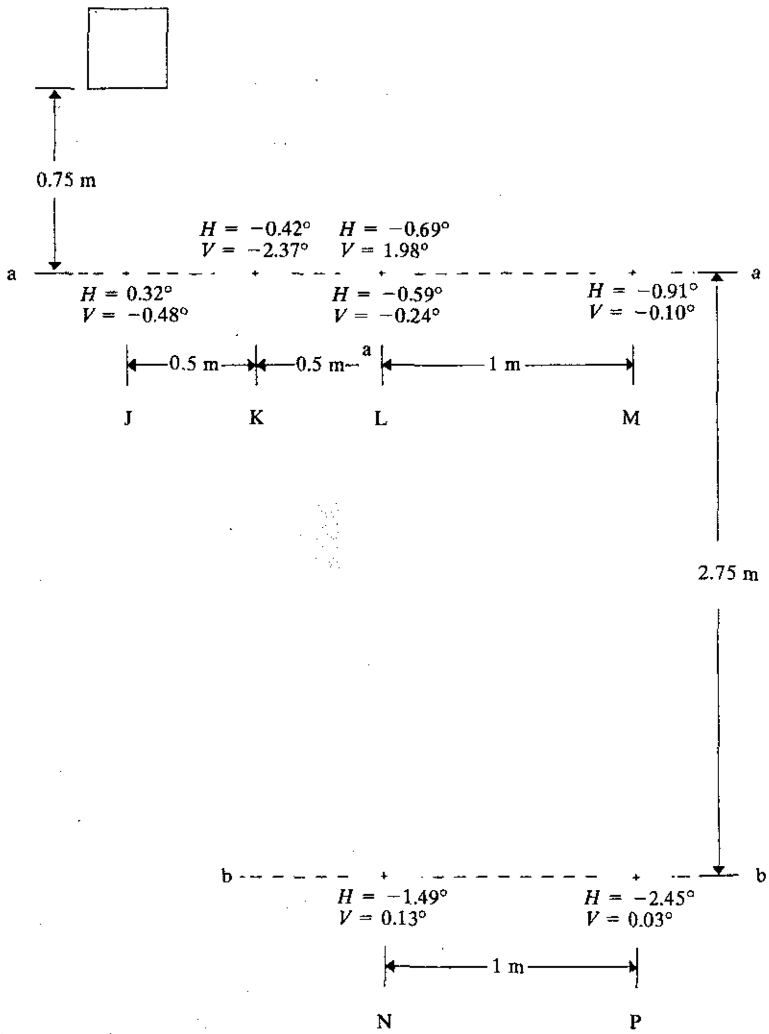

Figure 4. The viewing positions adopted in the two experiments. The positions J, L, and M on *traverse* aa (0.75 *m from the apparatus*) together with positions N and P on traverse bb (3.5 m from the apparatus) were used in the first experiment. Positions K and L', 1.80 m above the floor, on traverse aa were used in the second experiment. The mean values for the settings obtained for angle *a'* (see figure 3) are indicated as *H* (horizontal) values and those for angle *b'* as *V* (vertical) values, since they refer to distortion of the visible horizontal and vertical faces of the apparatus. Results from the first experiment are shown below the lines indicating traverses aa and bb while values above traverse aa indicates the values obtained in the second experiment where observers viewed from elevated stances. Note that negative values of the angles indicate divergent perception while positive values indicate convergent perception.

3 Results

For each subject the means of the angular settings made at each stance were calculated. The 'horizontal' mean was that derived from settings of member AF and its associated angle a' (figure 3a) and the 'vertical' mean was derived from the setting of the four coplanar members of the top of the model (angle b' in figure 3a). The 'vertical' and 'horizontal' angles were analysed separately.

Results from the first experiment, which was concerned only with the set of data gathered at ground level, are considered first. Analysis of variance of the obtained values of angle b', which gives an indication of the subject's perception of the vertical face of the cube, yields a nonsignificant between-stance effect ($F_{4,44} = 1.37$, $p = 0.26$), indicating that obliqueness of view has a negligible effect. These data will not therefore be analysed further.

Analysis of variance of the obtained values of the 'horizontal' angle a' of this experiment, which gives an indication of the subject's perception of the top face of the cube, yields a highly significant stance effect ($F_{4,44} = 14.73$, $p = 0.001$). The mean values (expressed in degrees) obtained at the various observation stances are shown in figure 4. The values on the two parallel ground-level traverses change in the hypothesised manner, indicating that subjects see the lateral pair of contours bounding the top face of the cube as diverging when viewed obliquely; in order to compensate for this, they set the arm AF to produce convergence. A paired comparison between values by means of Fisher's PLSD test shows that within each of the two traverses the adjacent values differ significantly. Between the two traverses the direction of change is also as expected. Although responses obtained at stances L and M fail to reach significance, they do, however, differ significantly from responses gained at stance J and their direction of change is that hypothesised. The pattern of evidence therefore supports two of the hypotheses proposed in the introduction [(i) and (iii)] that oblique viewing will yield evidence of divergent perspective, and that the magnitude of this effect will be monotonically related to the angle of view; increasing lateral displacement of the model leads to a decrease of the setting of angle a'.

The second experiment was concerned with the obliqueness of vertical views of the 'cube'. It will be recalled that there was no stance effect for the vertical face in the first experiment. Of course, if a significant stance effect did not occur for the viewing position closest to the apparatus, then it would be unlikely to occur at any other stance since these would result in a reduction in the obliqueness of the subjects' view of the vertical face. Accordingly, arrangements were made to have subjects view from positions where the obliqueness of the view of the lateral face of the cube could be increased relative to ground level. Subjects made their adjustments from two positions (K and L′) on a platform 1.80 m above the floor. Comparison of settings of angle a' at these two stances yielded no significant effect ($t_{20} = 0.23$, $p = 0.8$). Comparison of the settings of angle b' (the measure that is related to perception of the vertical face of the 'cube') measured at stance L with those measured at stance L′ (1.80 m above stance L) yielded a significant effect ($t_{20} = 1.96$, $p = 0.03$). Similar comparisons were carried out between the responses obtained at stance K and the values interpolated from stances J and K which would have presumably been obtained for a position on the floor immediately below stance K. The 'vertical' angles were found to differ significantly ($t_{20} = 4.65$, $p < 0.01$) in the hypothesised direction whilst the 'horizontal' angles were not found to differ ($t_{20} = 0.93$, $p > 0.1$). Thus the hypothesis that the relative angular subtense of the top and bottom edges of the lateral surface of the 'cube' will lead to divergent perspective with increasing viewing height is also supported; as the subjects' stance is displaced vertically their settings of the angle b' decrease so that the model is set as increasingly convergent. However this manipulation does not produce a significant effect on perception of the top face of the 'cube'.

4 Discussion

The data from the two experiments reported above show that the larger the observers' displacement and hence the more oblique the angle of view, the more convergent the setting of the edges of the model which they accept as rectangular. It therefore follows that a truly rectangular model is seen as increasingly divergent as the peripherality of its position relative to the observer increases. Furthermore, the data indicate that while one face of a three-dimensional object may maintain its relative perceptual stability as the observer moves away from it, either laterally or vertically, this is not sufficient to prevent the apparent divergent trend in its other face. Overall, the findings from these experiments are in agreement with that of the seminal experiment by Deręgowski and Parker (1992) and with the implication of ten Doesschate's (1964) observations. It confirms divergent perspective to be a legitimate manner of representing rectangular objects clearly seen in three-dimensional conditions, just as legitimate under appropriate conditions as convergent perspective. Both effects are indeed supported by the present data which show that in central viewing (stance J) the setting of the model is divergent, whereas settings made in all displaced settings are convergent (thus they indicate 'perceptual divergence'). It seems unnecessary, therefore, to invoke a complex cultural vector derived from higher levels of cognition to explain the phenomenon of divergent perspective in the Byzantine and other schools of art where it is found. Divergent perspective is clearly a result of direct perceptual experience. However, as always, artists have a choice from a range of perceptual experiences when constructing their work. An explanation is clearly wanting as to the reasons which cause certain schools of artists to choose visually peripheral experiences while others choose visually central experiences. The present data cannot provide this explanation.

Ten Doesschate (1964), and after him Deręgowski and Parker (1992) in their study of two-dimensional arrays, examined the relationships between the position of their planar stimuli and the angles which they sustain at the observer's eye. The assumption was made that whenever the visual angle sustained by a more distant contour is larger than the angle sustained by the nearer contour, when in fact the two contours are equal, 'inverse perspective' will result. It is of interest, therefore, to examine the present findings, which derive from a three-dimensional array, and examine the extent to which this assumption is supported. To this end, ratios of angles supported by edges EF and AB of a cube (46 cm long), assumed to occupy the same position in space relative to the observer as the apparatus used in the present experiments, were calculated. An analogous calculation was carried out for the edges of the cube corresponding to the edges EG and BC (see figure 3a for the labelling convention). These ratios are given in table 1, together with indications (cf figure 4) whether the subjects set the apparatus as to indicate convergence (c) or divergence (d). Angle ratios greater than 1 suggest divergent perspective, those less than 1 convergent perspective.

The data obtained do not match those suggested by the ratios. Responses indicative of perceived divergence were obtained in all cases in which they were predicted, although in one of the cases (vertical face seen from stance J) the mean magnitude of the angle set does not differ significantly from zero (one-tailed t-test, $p = 0.10$). In addition, as shown in the table, such responses were also obtained in four other stances for the 'horizontal' face. The results clearly cannot be adequately explained by reference to angles supported by the edges of the faces of the datum solid considered in isolation. They suggest that such an explanation may be inappropriate as it fails to take account of the relationships which prevail between elements of the array. For example, it takes no account of the fact that angles sustained by the horizontal and vertical edges of the face nearest to the observer, which are used as the datum angles above, change as the observer moves about. In consequence the face in question changes not only in shape but also in size relative to other faces, and hence the extent to which its edges influence the percept is affected further. The complexity of the problem is further illustrated by the fact that, when the ratio of the diagonals, FG and AC, is considered as an index of expected divergence, then it is found that divergent (Byzantine) perspective should occur when a cube is viewed from any of the laterally displaced stances used in the present experiment, as in all of them this ratio is greater than 1.

Table 1. Ratios of angles calculated on the assumption that subjects view a regular cube. A ratio greater than 1 indicates that the cube should be seen as divergent. Subjects' mean responses (cf figure 4) are classified as those indicative of perceived convergence (c) or divergence (d). * indicates that the obtained mean setting differs significantly ($p < 0.05$) from zero as indicated by a one-tailed t-test. K and L' are the two elevated stances.

Stance	Horizontal face		Vertical face	
	ratio	response	ratio	response
J	0.80	c*	1.10	d
K	0.96	d*	1.43	d*
L	0.93	d	0.99	d
L'	0.96	d*	1.23	d*
M	1.08	d*	0.95	d
N	0.93	d*	0.91	c
P	0.94	d*	0.92	c

The present data were not, however, obtained with the view of investigating the more general hypothesis which these considerations imply, but merely to determine whether there is any perceptual justification for the Byzantine type of divergent perspective in depictions of pronouncedly three-dimensional objects. They clearly demonstrate that such justification exists. However, they also demonstrate that the 'planar' models considered by ten Doesschate and after him by Deręgowski and Parker do not offer adequate descriptions of the phenomenon in question.

Acknowledgement. We are indebted to Dr S Dagger (Department of Mathematics) for his advice.

References

Bartel K, 1960 *Perspektywa Malarska* Volume 2 (Warsaw: PWN)

Deręgowski J B, Parker D M, 1992 "Convergent and divergent perspective" *Perception* **21** 441-447

Doesschate G ten, 1964 *Perspective, Fundamentals, Controversials, History* (Niewkoop: B De Graaf)

Doesschate G ten, Kylstra J, 1955 "The perception of parallels" *Aeromedica* 4 115-119

Florenskii P A, 1967 "Obratnaya perspektiva" *Trudy po Znakovym Sistemam* 3 381-416

Parker D M, Deręgowski J B, 1990 *Perception and Artistic Style* (Amsterdam: North Holland)

Szolc P, 1973 "Znaczenie i symbolika ikony" *Studia z Historii Semiotyki* 2 91-115

Uspensky (Uspenskii) B A, 1971 "O semiotike ikony" *Trudy po Znakovym Sistemam* 5 178-222

Uspensky (Uspenskii) B A, 1976 *The Semiotics of the Russian Icon* (Lisse: The Peter de Ridder Press)