THE VISUAL HORIZON AND EYE-LEVEL JUDGEMENTS; A PSYCHOPHYSICAL APPROACH TO SPATIAL ORIENTATION PERCEPTION

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ABSTRACT

The effect of systematic changes to the visual field, upon judgements of eye-level, was investigated. The psychophysical concepts of gradients of texture density and perspective were used to describe physical changes in the three-dimensional visual field of an observer; changes which were postulated to account for specific errors in eye-level judgements. A stimulus surface composed of a grid pattern of lights was presented to the subjects at various slopes to the ground. It was predicted that the S's apparent eye-level position, in the case of a level surface, would be above that for a downward sloping surface, and below that for an upward sloping surface. All predictions were confirmed by the results. Similar results were obtained when the stimulus surface was replaced by a stimulus field consisting of four parallel rows of lights, arranged such that one pair was vertically above the other pair. The results supported a postulated mechanism accounting for errors in eye-level judgements, based on the position in an observer's visual field, of the point at which the gradients of texture density and perspective reach a limit.

CHAPTER 1

GENERAL INTRODUCTION

I HISTORY

For a long time now, the psychologist interested in the problems of space and movement perception has examined the general nature of the factors which enter into the orientation of the main axes of our bodies. A considerable amount of experimental data exists demonstrating the importance of the visual field upon orientation perception, and an integral part of this, the notion of visual frames of reference, is particularly well established.

The belief that certain features of our visual environment play an important part in our spatial orientation, goes back to the earliest work on space perception. For instance, Jastrow (1893[1]), found that the individual can make very precise judgements of the visual vertical and horizontal, and believed this to be due to the fact that in his common experience, the observer is surrounded by verticals and horizontals. Consideration of the structure of the environment in which orientation takes place, only really reached prominence however, with Koffka's (1935) proposal of a visual spatial framework constituted by the main coordinates of the visual field. According to Koffka (1935), it was the directions of the main lines of the field of view which determined the directions of the apparent vertical and horizontal.

Koffka was one of the few investigators to emphasize the importance of studying the total organization of the visual field. He wrote, 'Our phenomenal space is filled with tri-dimensional objects and surfaces. Lines, under normal conditions, are not lines by themselves, but lines belonging to, or bounding the surfaces of these things or those that confine our space.' (Koffka, 1935, p. 215). Visual space, he said, can only be understood as the product of field-organization.

Koffka's emphasis on the importance of the structure of the visual field in spatial orientation perception was overshadowed by the greater issue of 'visual versus postural' factors, i.e. whether visual or postural factors are dominant in the determination of the apparent vertical. Koffka (1935) had stressed that even the position of the body - the 'ego' - was dependent on his 'visual framework'. The ego, being only one of the objects in visual space, was assumed to be orientated in the same way as any other object, i.e. by reference to the main lines of visual organization.

Evidence against such a theory of complete visual dominance comes from Neal (1926), Gibson and Mowrer (1938) and Boring (1952). In general these researchers attempted to show that visual factors alone could not account for the visual vertical. Support for Koffka's viewpoint came mainly from an extensive series of experiments carried out by Asch and Witkin (1948), who concluded that the visual frame is more important than postural factors in judgements of verticality. With an upright visual frame, tilting the subject does not disturb judgements whereas even an upright observer is greatly influenced by a tilted frame.

In reviewing the long theoretical dispute centered on this visual-postural question, Howard and Templeton (1966) conclude that it seems that the 'visual versus postural' problem has not been, and perhaps cannot be, solved. Rather, they say, there is a tendency towards the opinion that a manipulation of circumstances could result in the dominance of either the visual or postural modalities in spatial judgements. In practical terms, this 'over-simplified theoretical dichotomy' as Howard and Templeton refer to it, has meant that the problem became one of 'visual field present' versus 'no visual field present', rather than a specific enquiry as to what features of the visual field play a part in the judgement of our own position relative to the world around us. What made up the visual field was a minor issue.

Studies of the perception of other spatial directions besides the vertical, have also been made, although to a far less extent. These include studies of the perception of direction in a horizontal plane centered around the ego-centric straight-ahead, (Dietzel, 1924[2], Loemker, 1930[3], Roelofs, 1935[4], Comalli, 1963[5], Akishige, 1951[6], Wapner, Werner et al., 1953, Bruell and Albee, 1955, Kleinhans, 1970), and studies of the perception of direction in a vertical plane centered around eye-level, (MacDougall, 1903, Sharp, 1934, Wapner, Werner et al., 1953, Comalli, 1963[5], Kleinhans, 1970). Of interest is the fact that this work often specifically studied the systematic effects of variations of the surrounding visual field upon perceived radial direction. Surprisingly, only a very small minority of these studies used a three-dimensional visual field of some sort for the external stimulus conditions.

MacDougall (1903) carried out the first, and one of the most extensive studies of this type. He measured the position of phenomenal eye-level under a variety of experimental conditions, several of which included specific changes to the structure of the visual field. When judgements were made in a lighted room, the constant error was small, which MacDougall took as an indication of a highly refined sense of bodily orientation in space, for judgements of this type. In a dark room however, the average and constant errors were greatly increased. This latter finding was also apparent in Sharp's (1934) results, and in the more recent work by Kleinhans (1970).

MacDougall considered that the increased average error in the dark was due to the absence of a stabilizing visual frame. Anticipating Koffka (1935), MacDougall often emphasized the importance of the main lines of the visual field in our bodily orientation in space, with particular emphasis being placed on the perspective planes produced by convergence to the horizon, of natural and artificial arrangements of the lines in our visual environment. In this sense, MacDougall (1903) was one of the very few experimenters to regard the use of a three-dimensional stimulus situation, as being essential for the study of spatial orientation perception.

Dietzel (1924[2]), found that if the left-hand edge of a luminous figure, seen in the dark, is placed so that it is on the objective median plane, it is judged to be displaced to the left. Roelofs (1935[4]) discovered this phenomenon independently, and so apparently did Akishige (1951[6]), who found that the apparent straight-ahead position of a spot of light shifts in the direction of a second light. This effect has been confirmed by several investigators, (Wapner, Werner, Bruell and Goldstein, 1953, Bruell and Albee, 1955) and basically there exists an abundance of evidence showing that asymmetrical visual stimulation does affect the position of the apparent straight ahead. The nature of the visual stimulation adopted in these studies has, with the exception of a recent study by Kleinhans (1970), consisted of simple two-dimensional stimulus patterns such as luminous solid squares or rectangles. Theories accounting for the Roelofs effect have, in the main, ignored the properties of the stimulus and concentrated instead on explanations associated with organic properties of the body. (e.g. Bruell and Albee's motor theory of ego-centric localisation, Werner and Wapner's sensory-tonic field theory of perception.).

Kleinhans (1970) used a visual field in his experiments, which was three-dimensional. His subjects viewed the interior of a large box which provided a simple, cube-shaped visual field. By presenting this field at varying horizontal angles relative to the subject (slant) and at varying vertical angles (slope), Kleinhans was able to show that sloped fields interfere with the perception and judgement of eye-level and slanted fields interfere with the perception and judgement of straight ahead, in the same way that a tilted visual framework is able to interfere with the perception of the vertical.

Although Kleinhans (1970) limited himself to a very basic box-like stimulus field, both his study and the experiments carried out by MacDougall (1903) qualify as the only work as yet, in which three-dimensional visual fields have been used to demonstrate visual field effects in the perception of other spatial directions besides the vertical. Even in the studies involving the perceived vertical, the use of three-dimensional visual fields has been minimal. Miniature tilted rooms have been used in several studies. (Asch and Witkin, 1948, Austin, Singer and Day, 1969), but any attempts to analyze why such an arrangement should differ from the two-dimensional frames also used in this work, appears to be lacking.

Closely associated with the work on perceived radial direction, is the study of the stability of judgements of visual direction, or auto-kinesis. To a certain degree, attention to aspects of the visual field has also been a feature of this work. Perhaps the most widely accepted explanation of autokinesis is that the observer has no anchor for his observations of the spot of light in his visual field. He has no frame of reference, and therefore, the autokinetic light is free to wander. The work on the autokinetic effect had for a long time been qualitative, but there exist several studies in which different visual field configurations have been systematically used. These have generally involved multiple light patterns, in an attempt to specifically study the reduction-effect upon the autokinetic movement, but they do provide a quantitative appraisal of a certain variety of visual stimuli which are acting as a visual framework.

An experiment by Luchins (1954) provides some of the most interesting findings from the point of view of visual field effects. He studied the autokinetic effect under variations in illumination of the visual field. The autokinetic light (the A-light) source was embedded in a box 18 inches long and 20 inches wide, of which the illumination could be varied by two bulbs placed within it. Luchins found that when the illumination inside the box was gradually increased, the A-light was reported as stable or "bobbing" slightly about a fixed point. Luchins attributed the reduction of movement as being due to the increase of light intensity in the visual field. However, Luchins' apparatus differed from that customarily used in the study of autokinetic phenomena in two ways, both of which Luchins himself stated; the A-light was on continuously rather than presented intermittently, and, (of greater importance), the A-light was embedded in a box, the illumination of which could be varied. It can be seen that not only having variable illumination separates his experiment from those carried out previously, but also the fact that the A-light was surrounded by a three-dimensional field in the form of a box. We note with interest therefore, how Luchins reports that as the illumination was increased, some of the subjects remarked that they were aware that the dot of light was inside a box. Prior to this they had observed a two-dimensional surface or haze; but as the light inside the box increased, they became aware of tri-dimensionality. This latter realization coincided with the occurrence of the reduction in autokinetic movement. It could be said therefore, that the Luchins experiment, whether intentionally or not, represents one of the first studies examining the effects of a three-dimensional visual field upon the autokinetic effect, and, in this regard could be more closely associated with the work on visual direction perception, than the paradigm of autokinesis studies.

Royce, Stayton and Kinkade (1962) represent the first attempt at a truly quantitative study of the role of the visual frame in autokinesis. However, their study was limited to the use of two-dimensional frames, in particular, a quarter inch concentric circular band of light. They found that the use of a physical frame of reference resulted in a reduction or freezing of autokinetic movement. The extent of perceived movement decreased as the number of lights in a multiple light configuration increased; in the presence of a quarter inch wide concentric band of light, regardless of radius, and as the light intensity of the concentric circle increased. Now even though certain properties of the stimulus have been considered in this study, the findings are limited in their generality. A circle is neutral in relation to the vertical and horizontal directions, both of which have been shown to be important in our spatial environment, and the omission of the third dimension in the visual frames used, limits their generality even further. This criticism can be levelled at most of the other studies examining the role of a visual frame in autokinesis, from the point of view that we are concerned with trying to discover which factors in our visual fields influence our spatial perception.

So far we have summarized a small sample of the work on, or related to, spatial orientation perception, in which the physical properties of the visual field have been considered to some degree or other. We know that certain specific changes to the visual information available to the perceiver can result in the erroneous perception of his own spatial orientation. Tilted frameworks can appear less tilted than they really are, or a framework displaced to the right or left may appear closer to the medial plane than it really is. All in all, it appears that a considerable amount of experimental data exists, demonstrating the importance of the visual field upon our orientation in space. A variety of visual stimuli have been utilized in these experiments for the construction of a visual field, in which various spatial judgements are made, but the large majority of these studies have been limited to the use of two-dimensional frameworks, with only a small minority considering the more real life situation of three-dimensional frameworks. There is a surprising absence in this field of an analysis of the visual environment in which orientation takes place.

II. A PSYCHOPHYSICAL APPROACH TO SPATIAL ORIENTATION PERCEPTION

We perceive and orientate ourselves in a space which is structured and organized. The nature of the physical world we live in has just as important a part in our spatial behaviour as the internal contraints of our bodies. The fact that vision is an important determinant in the perception of our body position in space, is well supported by the experiments quoted in the first part of this introduction. However, to limit oneself to the satisfaction of knowing that *something* we perceive enables us to maintain spatially coordinated behaviour, is a denial of the vast amount of information available to the perceiver. To fully understand the role of the visual field upon our spatial orientation perception, attention must also be paid to the physical properties of the field, just as the physical constraints of the body have been extensively studied in the determination of the role of postural factors in orientation.

The previously cited work on orientation has, in general, left several important questions unanswered; which features of our visual environment provide the fixed reference axes, shown by countless studies to be vital in the orientation of our bodies? Of the vast amount of information reaching our eyes, which particular features determine our spatial orientation perception? These are questions concerning the stimulus aspects of spatial orientation perception and, as such, are especially suited to a particular approach to perception research, namely the psychophysical approach which is based on the idea of isolation and control of modes of stimulation on which modes of perception might depend.

The problem of how we perceive space involves the puzzle that the physical environment has three dimensions, yet the projection of this physical space on the retina of the eye only has two dimensions. A visible scene has depth, distance and solidity, yet the retinal image is flat. We do know however, that the projection contains the information that the perceiver requires in order to perceive objects in space. The study of visual space perception basically becomes a study of how the perceiver acquires this information and one of the approaches to this problem is the psychophysical theory of space perception.

This approach developed from the nativism and relationism of Gestalt psychology and its principle proponent is James Gibson (1950, 1959[7], 1966). It starts with an analysis of perceptual experience and seeks stimulus correlates of visual space perception. It looks for correlates in the optical projection of light reaching the retina. One of the unique features of this psychophysical approach is that it considers the visual information at the eye in terms of surfaces with texture, rather than in terms of points and lines as is the usual case for an empiricist approach, (the other main viewpoint of space perception). The psychophysical viewpoint considers surface texture to play a major role in providing a scale for visual space. It regards space as objects on surfaces, and it gives special recognition to a particular surface - the ground. Gibson (1950) remarked on how the ground is not only a surface that extends away from the observer in the third dimension, but also provides support for motor activity and is involved in equilibrium, upright posture and locomotion in general. The notion of a visual world consisting of surfaces and edges, with a ground under it, is important to this psychophysical approach.

Gibson's principle innovation, as regards stimulus variables, was the theory that gradients of stimulation were, in many cases, sufficient to arouse directly a veridical experience of spatial orientation without the mediation either of learning or of special organizational processes in the brain as Gestalt psychology had suggested. Gibson (1950) concerned himself with vision in particular and gave attention to gradients of texture density of physical surfaces at various orientations. He argued that there is a univocal relation between a given texture density gradient and the corresponding perceived slant of a surface. For Gibson, slant perception became a crucial problem in the field of perception of orientation.

The adequacy of Gibson's theory has been criticised on several points (Epstein and Park, 1966), particularly the effectiveness of texture gradients as a cue to the slant of a surface. Gibson's (1950) original proposal that "slant at any point may be given by the rate of increase of density of texture at that point" (p. 371) was revised since "the gradient merely specifies a family of tri-dimensional arrangements rather than a particular distal stimulus situation" (Gibson, Purdy and Laurence, 1955). A gradient of increasing texture density may be produced either by a slanted surface having equal-sized elements at constant distances from one another or by a frontal-parallel surface having elements with progressively diminishing sizes and separations.

In the context of this paper, the importance of Gibson's work lies in his emphasis on particular features of the environment as important parts of the visual field. His concepts of gradients of perspective and texture density, form a useful analytical tool for describing physical changes to the visual environment. For Gibson, not only visual space, but also the location of oneself in that space, is determined by optical stimulation. It is on this basis that the investigations reported in this paper are centered. A consideration of visual field factors is being applied to one particular aspect of spatial orientation perception, namely judgements of eye-level.

It has long been known that under normal conditions an observer can, with considerable accuracy, locate a visual object as being in the same horizontal plane as his eyes (MacDougall, 1903), and it is the general belief that this ability is dependent to a large degree upon the use of environmental cues. Just what these 'environmental cues' may be however, remains unanswered. In general, the investigations in this field preferred to answer the question, that if these 'commonly used cues' are excluded from the observer's visual field (as in a dark room), then will he still exhibit the same ability to accurately judge a point as being at his eye-level? Sharp (1934) compared this situation to that in which an air pilot finds himself while flying through cloud or in night flying. An equally important question has been largely ignored; what are the 'environmental cues' being used, when a visual field of some sort is present? A pilot for instance, is dependent upon such cues during landings, and we normally orientate ourselves in a space which is full of visual environmental features, only rarely being confronted with a situation in which all visual cues are absent. Rather than removing all the visual cues from the observer's visual field, this investigation attempts to isolate the fundamental visual factors which may be determining the perception of eye-level. Examining the effect of specific visual field factors upon the estimation of subjective eye-level enables the importance of such factors upon our perceived ego-centric localisation to be evaluated. This is in accord with the common psychophysical method of showing that differences in experience, as evidenced by judgements, corresponds to differences in stimulation experimentally applied.

Gibson (1950) was the first to indicate a truly pervasive feature of our visual environment and not just talk about 'the many vertical and horizontal coordinates around us'. He described an out-of-doors world as one in which the lower portion of the visual field is invariably filled by a projection of the terrain and the upper portion of the visual field is usually filled with a projection of the sky. Between the upper and lower portions is the skyline (horizon), high or low as the observer looks down or up, but always cutting the normal visual field in a horizontal section. Gibson (1950, p. 60) goes on to indicate how in the typical indoors world of civilised man, the ceilings and walls take the place of the horizon and sky, but the floor is still the equivalent to the ground. This basic surface, he says, is the background for the objects to which we normally give attention and its horizontal axis is implicit in every visual field.

We have then, a feature of our visual environment which is present in almost every visual field, which dominates most visual reference frames, but which is seldom considered in the studies examining the role of visual factors in spatial orientation perception. Even though the ground and its associated horizon figured prominently in Gibson's psychophysical theory, their possible significance as factors affecting our spatial orientation perception has been ignored by workers in this field.

In the typical apparent eye-level experiment, an upright observer attempts to set a point to a position on the horizontal plane level with his eyes. Eye-level is that horizontal plane which passes through the centre of the pupil (Howard and Templeton, 1966, p. 183). This statement needs qualifying, because 'horizontal' is based on the existence of some external reference system, the nature of which is seldom specified. A horizontal plane is regarded in this paper, as one which is normal to the direction of gravity. The ground is such a plane.

The concept of horizontality would be meaningless in our environment, if some physical manifestation of normality to gravity was not present. It is often stressed how in a man made environment, there exists many visual indicators of verticality, but a visual analogue of the plane normal to gravity, is rarely considered. The ground provides a pervasive visual indication of horizontality - it is a plane normal to the direction of gravity, and, unlike the pull of gravity, it is a visible feature of our environment.

The ground provides a fixed reference plane for horizontality, and without such a reference plane, the concept of eye-level would be relatively meaningless. If a point is set to a position judged to be at eye-level by an observer, then the accuracy of such a judgement can be checked by comparing the height of the point above the ground, with the actual height of his eyes above the ground. If the heights are the same, then we say that the point is at the subject's eye-level, or that the subject's eyes are lying in the same horizontal plane as the point. Judgements of eye-level made in empty space are relatively meaningless. Eye-level judgements in the context of this paper, are considered to be what Howard and Templeton (1966) refer to as 'semi-egocentric' judgements, since they demand a reference point (the pupil) on the body, as well as a reference system outside the observer's body. Eye-level is not taken to be simply 'the felt neutral position of the eyes' as Kleinhans (1970) regarded it.

The importance of an objective plane of reference in eye-level judgements is suggested by the predominance of situations in which such judgements are in error, through the misinterpretation or lack of such an objective plane. Ross (1974) outlines the more common effects of this type. One such illusion involves the raised apparent height of surrounding mountains, viewed from the top of a summit. Peaks which are level with one's own summit appear considerably higher, and all points on the opposite mountains are raised correspondingly. Judging by Ross's account, theories explaining this effect appear to be inadequate. MacDougall (1903) and others since, have suggested that the descending slope of one's own mountain is taken to be more horizontal than it is, with the result that points at the same level as the eyes on the opposite mountain appear to be above eye-level. Ross (1974) dismisses this theory as a complete account of the illusion, because, she says, over-estimation of height occurs even when the slope of one's own mountain is hidden by a precipitous drop. This however is really a special case and one in which the other main theory for the effect may be applicable, i.e. that judgement of eye-level is normally too low, resulting in the over-estimation of points which are actually at eye-level. Ross (1974) questions the applicability of this latter theory on the grounds that only adult males are supposed to show this error, while women and children err in the opposite direction. However, the experiments quoted by Ross (1974[10]), as suggesting this sex difference, were carried out at very short distances, in which very little of the surrounding visual environment was visible to the subjects. It will be shown in a later chapter how such a situation is inherently different from that found in the wide open spaces of 'valleys and mountains'.

Ross (1974) doubts the relevance of laboratory experiments on eye-level to such illusions as the apparent height of mountains, yet MacDougall (1903) was able to show that sloping lines can indeed influence judgements of eye-level in the expected way, and more recently, Kleinhans (1970) has shown that sloped fields can affect eye-level judgements.

MacDougall (1903) also considered such illusions as the 'mountain road' illusion or slope misperception, to be the result of the same factors which determine the raised height of mountains effect. The mountain road illusion is the situation where roads appear flatter or steeper than they really are, or rivers may appear to flow uphill. MacDougall explains these effects as misinterpretation of the objective reference plane upon which, he said, judgements of eye-level are based. It is not obvious from MacDougall's theory, however, as to how such a 'misinterpretation' results in these cases. In the case of a single slope, there is no intervening valley to produce such an error. Ross (1974) tried to explain the slope misperception illusion by the fact that there are few cues which unambiguously indicate frontal slope, and hence she says, the observer is easily misled by surrounding slopes or other irrelevant contextual cues. This does not really explain what factors result in the observer's perception to be in error. There are also few cues which unambiguously indicate level ground, yet 'irrelevant contextual cues' need not result in misinterpretation of its true condition. Theories involving adaptation or normalization effects, could also be used to explain such illusions. For instance such illusions could be attributed to adaptation to the perceptual spatial norms so that as inspection progressed, a sloped road would appear more and more horizontal. However, such approaches do not emphasize the role of the observer's perceived ego-location, and so are of no immediate relevance to this discussion, which is concerned with the role of eye-level perception in such illusions.

MacDougall (1903), in his explanation for the illusions, was not specific as to the nature of the reference planes involved. Given that a fixed horizontal reference plane exists in an observer's visual field, it still remains to be shown how this plane is actually used by an observer in his judgement of eye-level. Saying that an observer knows (or presumes) that the ground beneath his feet is horizontal, does not explain how he then goes on to use this knowledge to aid him in his judgement of eye-level. It does not specify the factors actually influencing his perception. A proposal will now be presented, for a possible mechanism to account for errors in the judgement of eye-level brought about by changes to the visual field.

III THE VISUAL HORIZON

Judgements of eye-level, or perceived location in the vertical plane, can be influenced by certain changes to the visual field (MacDougall, 1903, Kleinhans, 1970). Such errors of judgement are said to account for such illusions as the raised height of mountains, but the actual physical features of the environment which result in spatial perception to be in error are obscure. An analysis of the changes to the visual field which may occur in such situations is required if we are to determine why a descending slope for instance, can produce a corresponding downward judgement of eye-level. It is here that Gibson's psychophysical formulations of gradients of texture density and perspective are useful, and the concept of a horizon is important. A special relationship exists between the eye-level plane and the position of the horizon in our visual fields.

The horizon is often described as the line at infinity to which all horizontal lines converge (e.g. Howard and Templeton, 1966), but the horizon is a phenomenal feature of our visual field, and it is determined by where horizontal lines *appear* to converge.

The horizon is best described in the context of Gibson's (1950) psychophysical theory of texture gradients, in which the horizon is described as the point at which the gradients of texture density and perspective approach a limit. The phenomenal horizon in his theory corresponds to the point in the gradient of the optical array where density becomes infinite.

The ground is a horizontal plane, and as such will create a phenomenal impression of a horizon in the visual field of an observer standing on that plane, by way of an increase in the texture density in the optical array of light reaching his retina, as the distance of the texture elements from the observer increases. Howard and Templeton (1966) wrote that the direction of any point at eye-level is always in the same optical direction as the horizon, that is, if a subject is asked to visually fixate a point on a wall at eye-level, he should perform in the same way as when asked to fixate the horizon. However they gave no reason as to why such a relationship should exist and it appears rather to be a consequence of the definitions they adopted for the horizon and eye-level. It is possible to explain why such a relationship between apparent eye-level and the horizon exists, however, using Gibson's psychophysical theory of gradients. Eye-level is a plane which is parallel to the ground's horizontal plane, but which runs through the pupils of the observer's eyes. Such a plane would have infinite texture density according to

Gibson's theory and its location should correspond to the position in the field of the phenomenal impression of the horizon. A point placed at eye-level by an observer should correspond to the position of the visual horizon in his visual field.

MacDougall (1903) was the only worker in this field to have really considered this relationship. He suggested that the point of convergence of the fundamental lines of perspective becomes assimilated with the idea of the visual horizon, as that concept has fused with the notion of a subjective horizon (MacDougall's term for apparent eye-level). The consequences and implications of this apparently simple and obvious relationship between apparent eye-level and the visual horizon, are considered by this present writer to be extensive. It provides a possible mechanism by which the plane of the ground may act as a fixed horizontal reference plane for judgements of eye-level, and it means that the visual features of our environment which define the visual horizon in our visual fields, are also determining the position we perceive as being level with the plane of our eyes. The phenomenal impression of a horizon in an observer's visual field is a function of certain specific stimulus properties such as gradients of texture density and perspective as well as more obvious general factors such as the slope of the ground that the observer is standing on. These are physical properties of the spatial environment we orientate ourselves in and, as such can be manipulated experimentally, in order to assess the importance of such factors in the perception of ego-centric localization in the vertical plane.

The term 'horizon' is being used here in a rather loose sense, and is only being used as a means of labelling a particular feature of the visual field, i.e. where texture density become infinite. The horizon referred to in the context of this paper, should not be confused with the more rigorously defined horizon associated with the geometric rules of perspective drawing, although some interesting parallels between the two concepts exist. Similarly, the sensory impressions being referred to under 'gradients of texture density and perspective', include the three different varieties of perspective outlined by Gibson (1950, p. 138): Texture perspective - the gradual increase in the density of the fine structure, the spots and gaps, or the extended pattern of either a part or the whole of the visual field. The increase in density may run in any direction, but very often it runs upward in the field. Size perspective - this is the apparent decrease in the size of the shapes or figures in the visual field. Linear perspective - this is size perspective when contours are rectilinear. It is the gradual decrease in the spacing between either outlines or inlines in the visual field. All of these perspectives can decrease to a zero limit of size or spacing (or to a maximum density of texture), creating the impression of a horizon in the visual field. A fixed eye position and a static field are being assumed, so gradations of motion and displacement are not being considered. This does not indicate a denial of their importance as factors in spatial orientation perception.

By using MacDougall's (1903) arguments as a basis and incorporating Gibson's psychophysical concepts of texture and perspective gradients, it is postulated that an attempt by an observer to judge the position of his eye-level in a particular three-dimensional visual field, can be regarded as an attempt on his part to locate the position of a 'horizon' in that field; the horizon being determined by such factors as gradients of texture and linear perspective. The usefulness of such a viewpoint comes from its ability to define the physical changes to the environment which accompany changes in the perception of eye-level.

CHAPTER 2

INTRODUCTION TO THE EXPERIMENTS

If the perception of our position in the vertical plane is determined by the position of the horizon in our visual fields, then the factors which determine the latter should also have some influence over judgements such as apparent eye-level. Gibson's (1950) psychophysical theory links the phenomenal impression of the horizon in our visual field with the point at which gradients of texture density and perspective approach a limit. Anything which changes the position in the visual field at which these gradients approach a limit (and consequently the apparent position of the horizon in the field), should, if the above statement is correct, also result in a change in the position of a point in the field set to apparent eye-level. This would include changes to the slope or slant of surfaces in the field.

The relationship between gradients of texture density of surfaces and the perception of slant has been extensively studied (Gibson, 1950, Gruber and Clark, 1956, Epstein and Mountford, 1963, Epstein and Park, 1964, Braunstein and Payne, 1969). The majority of these experiments concentrated on obtaining quantitative estimates from subjects, of the angle of slant indicated by a certain gradient. Typically the results have shown that an isolated gradient is actually quite ineffective at producing reliable and accurate judgements of slant.

The stimulus surfaces in these studies are often projected onto a circular screen or else viewed through a circular apperture, to ensure that the edges of the surfaces are not visible to the observer. Their presence would provide confounding information from convergence cues. The upper limit of the texture gradients is therefore omitted from these stimuli. The point where the density of texture units has reached its maximum would constitute an edge and, as such, cannot be included in these stimuli. This investigation considers this upper limit to be an important and unique feature of the visual field. If it is actually not visible in the field, then its implicit position, based upon the visible cues of texture density and perspective gradients, fulfils the same role. The importance of this unique feature of the visual environment is being examined in its role in the perception of ego-centric localisation in the vertical plane, as reflected by judgements of apparent eye-level.

Given a horizontal surface with a fixed unit size of texture elements, then an upright observer standing on this surface will perceive a particular gradient of texture, with the density of elements increasing towards the top of the visual field. A point placed at eye-level by the observer would be in the same optical direction as the point where the density of texture elements of the surface appears to have reached an upper limit if the surface is continuous, or if not continuous, at the point where it would reach a limit, given the particular gradient of texture density that is visible. Now if this same surface was sloped up slightly, i.e. it was no longer parallel to the gravitational horizontal, but lying closer to the fronto-parallel plane of the observer's body, then according to Gibson's theories on slant perception, the perceived gradient of texture density produced by the sloped surface, will be less steep than that produced by the level surface. The compression of texture elements towards the top of the field in the retinal projection of the surface, will be less in the case of the sloped surface than the level one. This means that the point at which the gradient of texture appears to reach a limit, will be higher up in the observer's field in the case of the upward sloping surface, than for the level surface.

If the postulated relationship between the apparent position of the horizon and eye-level applies, then an observer standing on this surface should judge his apparent eye-level in the case of the upward sloping surface, to be above that for the level surface. An analogous argument can be developed for the case of a downward sloping surface, with apparent eye-level being judged below that for a level surface.

Another way of expressing this is that if the ground is being used as an objective plane of reference, and the apparent position of its horizon is determining the apparent eye-level position for an observer, then a new objective plane of reference, one that is not horizontal, should alter the position of apparent eye-level for an observer according to where the 'horizon' of this new plane of reference appears in his visual field.

An interesting extension of this argument is to consider the case of a new objective plane of reference, that is still horizontal but above or below the original reference plane. Whereas in the above cases the gradient of texture density changes with the change in the slope of the surface, the gradients are the same for different *horizontal* planes of reference at varying heights above some arbitrary fixed plane. It is the *amount* of density which changes in this case, not the gradient of density. The gradient remains constant. This is an analogous argument to that used by Gibson (1950, p. 92), in his discussion of the difference between the perception of a corner and an edge. The rate at which the density changes, remains the same and so the density of texture elements will appear to reach an upper limit at the same point in the visual field for the different levels of horizontal planes. The apparent eye-level position for an observer using these planes as objective planes of reference, should not change.

By considering the physical changes that occur in the visual field of an observer, in terms of the apparent position of the 'horizon' in that field, a possible mechanism accounting for certain errors in perceived eye-level has been suggested. Though highly speculative, it provides a more general account of such illusions as slope misperception and provides greater insight into the possible important visual factors operating in such spatial perception.

Studies in which three-dimensional visual fields have been used to influence eye-level judgements are rare. MacDougall (1903) used a plane of wood, six inches wide, which extended from the observer to the vertical screen supporting the target disc. He found that the introduction of a descending plane lowers the apparent eye-level position and an ascending plane elevates it. Many other features of the room were visible to MacDougall's subjects however, and his results do not preclude other possible explanations for the effect. Though such findings are in accord with the mechanisms postulated regarding the position of the horizon in an observer's visual field, they do not provide a rigorous test for such a viewpoint. It needs to be shown that a change in the gradient of perspective and texture density of a plane surface in isolation, can affect judgements of eye-level made by an observer with only the surface visible to him. If there is any basis to the above proposed mechanism, then changes to the apparent position of the horizon in the observer's visual field produced for instance by changes to the gradient of texture density, should result in predictable errors in the resulting eye-level judgements.

The experiments reported in this paper are an attempt to show that errors in eye-level judgements can be accounted for by specific changes to the structure of the visual field. These changes can be described by Gibson's psychophysical concepts of gradients of perspective and texture density. The main question requiring an answer is whether a change in the gradient of texture density and perspective of a surface produced by a change in its slope, can actually result in a corresponding deflection of apparent eye-level from the objective eye-level plane?

Before the effects of specific changes to the visual field on eye-level judgements can be assessed, an indication is required of the type of errors to be expected in judgements made in the presence of any visual field. Part 1 of this investigation is therefore a pilot-study, seeking to determine the type and magnitude of constant errors common to eye-level judgements.

CHAPTER 3

THE EXPERIMENTS

I PART 1 - PILOT STUDY

Before certain visual field effects can be tested, some clarification is required as to what type of errors can be expected for judgements of eye-level made in the presence of a structured visual field.

MacDougall (1903), in the most extensive and comprehensive study of apparent eye-level so far, asked his subjects to position a small disc on a screen to a position judged to be level with the eyes. The disc was at a distance of 3.3 meters away from the subject. (Not 33 cm as reported by Howard and Templeton, (1966, p. 185).) All the other studies on apparent eye-level have generally been carried out at much closer distances than this, making cross comparisons of accuracy of judgement difficult. At a distance of 3.3 meters, a departure of 1 minute of arc from the plane of the objective eye-level position, corresponded to a displacement of 1 mm by the disc for MacDougall's subjects. This magnitude of displacement value, was quite readily obtainable from the vertical scale graduated in millimeters, that was attached to the apparatus. If however, a comparable reading of 1 minute of arc displacement was to be obtained at a distance of say 50 cm, the apparatus would need to be capable of measuring displacements from actual eye-level to an accuracy of approximately .1 of a millimeter, a figure well below that obtainable using the techniques adopted in the studies made over such small distances. For the most part, such accuracy is not required, but this factor should be considered if results from different studies are being compared.

MacDougall (1903) found that for judgements made in a lighted room, the average constant error was less than an eighth of a degree and the mean variation was also relatively small. When the judgements were made in a dark room, with only a circle of light visible to the subjects, the average and constant errors were greatly increased. The apparent eye-level was set below the real eye-level by all twelve subjects. MacDougall attributed this depression of the eyes to the process of binocular adjustment. In the general distribution of objects in the visual field, the nearer, for the human being, is characteristically the lower, the more distant, the higher, as one looks from the things at his feet to the horizon and vice versa. MacDougall said that because of this, we should expect to find, when the eyes are free to move in independence of a determinate visual field, that increased convergence is accompanied by a depression of the line of sight. Since the single illuminated spot of light causes continuous and effortful fixation, this sharp rise in the general sense of strain, in cooperation with the absence of a corrective field of objects results, according to MacDougall, in the large negative displacement of apparent eye-level in his experiments. MacDougall's (1903) findings for judgements made in the absence of external visual cues, were supported by Sharp's (1934) results, and the latter also found that subjects tend to drop the average perceived level progressively lower as they are removed in time from a view of the room surroundings.

Results from experiments carried out in the light, are not so conclusive, however. MacDougall used normal room surroundings to present his subjects with a diversified visual field. The average constant error in this case was less than an eighth of a degree. The average subjective eye-level did show a slight negative displacement, but MacDougall was unable to attribute this to any particular factors. There were large individual differences in his results, with some subjects exhibiting relatively large positive displacements of subjective eye-level. Observer variables were not considered by MacDougall, hence it is not possible to gauge whether such factors as sex or height differences, as postulated by Sandstrom (1959[9]), Howard and Templeton (1966) or Nair (1958[8]), were operating in MacDougall's condition. Sandstrom (1951[9]) found that when asked to set a point 50 cm away to eye-level, men set it about 0.8 of a degree lower than real eye-level and women set it higher than true eye-level by about the same amount. Nair (1958[8]) found that taller men set the apparent eye-level lower than short men, although no such difference could be found for women.

It is difficult to class such findings along with MacDougall's experiment carried out in a light room, for one important reason. MacDougall's subjects were at a distance of 3.3 meters away from the target disc, and hence many features of the environment were visible to them. The other studies of apparent eye-level have all been carried out at much closer distances than this. At a distance of 50 cm from a blank wall, a subject is basically faced with a uniform visual field. It could be said that the task of setting a point to eye-level in such a situation is similar to the experiments carried out in total darkness. (MacDougall, 1903, Sharp, 1934). Results from such experiments have shown, however, that a large negative displacement of apparent eye-level occurs, whereas Sandstrom's (1951[9]) results showed that there was a tendency for people to deflect their judgement in the direction of their most preferred direction of gaze. Eye-level judgements were above true eye-level for women and slightly below for men. These results for judgements made at short distances, are quite different from those obtained for judgements made in the dark. They can be explained, however, if we consider that in the case of eye-level judgements made at short distances, (e.g. Sandstrom, 1951[9]), the subject is no longer forced to fixate upon a single spot of light, as is the case for judgements made in the dark. The background may be plain and uniform, but it still reflects light and has some surface detail. Therefore, in this case, fixation should not occur and MacDougall's (1903) 'convergence mechanisms' cannot apply. In this way we can explain an important difference between the two types of eye-level judgements possible in the presence of some visual field. MacDougall used a distance of 3.3 meters and a full diversified visual field was visible to his subjects. The majority of other eye-level experiments carried out in a lighted room situation, have used much closer distances, resulting in only a uniform, featureless visual field being presented to the subjects. Although superficially similar to judgements made in the dark, the former situation sppears to result in specific types of errors. Whether or not such errors still occur in the presence of a full diversified visual field is unknown, since the only empirical evidence available for such judgements comes from MacDougall (1903), and he did not concern himself with such factors as sex or height differences.

Given these issues, a pilot study was conducted in which a distance of 3.3 meters was used between the subject and the target disc, and normal room surroundings were visible to subjects. This was basically an attempt to replicate MacDougall's first experiment, in which eye-level judgements were made in a lighted room. The sex and height of subjects were taken into consideration to determine the effects, if any, of such factors upon judgements made in the presence of a visual field. A condition was also introduced in which the ground was obscured from the subject's field of view, in an attempt to determine how much this feature was being used as a cue for the eye-level judgements.

1. METHOD

i. Subjects: The subjects were 10 students from the University of Canterbury, all volunteers. They consisted of 5 males and 5 females, ranging in age from 19 to 24 years. Their heights ranged from 158 cm to 180 cm.

ii. Apparatus: The main piece of equipment, used in this and the other two parts of the investigation, was a vertical wooden screen, 2 meters high, 2 cm thick, and 145 cm wide, mounted on a supportive base. The front surface of this screen was painted a matt black. A vertical slit, 10 mm wide, routed through the entire thickness of the screen, ran down the middle, beginning at a point 60 cm from the base of the screen and terminating 15 cm from its top, giving a total length of 140 cm. It was over the length of this central slit, that the target stimulus travelled. For the pilot study, this slit was narrowed down to 5 mm by the addition of two matt black 1/8" plywood panels, 10 cm wide and 140 cm long. The rear of the slit was also faced with black material so that the slit was not apparent to the subjects. Parts 2 and 3 were carried out in the dark and so these precautions were only necessary for the pilot study. For the pilot experiment, the target consisted of a white disc, 1 cm in diameter, which travelled flush to the front surface of the screen. For parts 2 and 3, the target was a red bezel type reflector, 1 cm in diameter and illuminated from behind. This ran vertically behind the screen, and was visible through the slit cut down the centre of the screen.

The equipment can be considered under three headings; drive, control and measurement. Its basic function was to provide a stimulus point which could be moved up or down to a particular position, by an observer sitting up to four meters away.

Drive: The stimulus was driven along the length of the 140 cm slit, by means of a Richard DC six-speed reversible motor with internal 60:1 reduction gearing. A 12 mm (19 teeth) Meccano gear, mounted on the motor axle, drove a 40 mm (57 teeth) gear on an axle running in a supportive bracket fixed to the rear of the wooden screen, 50 cm from the base. On this same axle was a knurled brass pulley, 35 mm in diameter, which when driven by the motor, rotated at a rate of 30 rev/minute. Directly in a vertical line with this drive pulley at the bottom of the screen, and mounted 10 cm from the top, was a free-running 40 mm pulley, with its central axis 5 cm from the rear of the screen. Passing over this top pulley was a single loop of nylon cord, the bottom end of which was looped around the knurled driver pulley. This loop ran in line with the vertical slit cut down the centre section of the screen, and it formed a 'continuous belt' which was driven by the bottom pulley coupled to the motor. A small sheet-metal box 65 mm x 50 mm x 40 mm, was attached to the nylon cord on the side nearest the screen, and a counterweight attached directly opposite it on the other section of the cord. Rotation of the driver pulley by the motor drove the cord around the two pulleys, resulting in a vertical displacement of the box, either up or down, depending on the direction of rotation of the motor. The box ran along two guide rails consisting of two parallel lengths of wire 8 cm apart and stretched between brass pillars projecting out from the top and bottom of the rear surface of the screen. One of these guide rails consisted of 22g copper wire and the other was 30g resistance wire. Each of these lengths of wire ran through a hole drilled down the centre of a tubular perspex guide mounted on each side of the box. For part 1, a short length of 18g wire fixed to the box and passing through the slit in the screen, served as a support for the stimulus disc, which then travelled vertically over the face of the screen in accord with the displacements of the metal box. The box was light tight and it housed a 6V bulb which rear illuminated a red bezel type reflector 1 cm in diameter. This provided the stimulus target for the experiments in Parts 2 and 3.

Control: (Refer to wiring diagram, Appendix 1) A DC regulated power supply provided 5 volts for driving the motor, which could be driven in either direction by pushing up or down, a spring return key-switch (double pole, double throw) mounted on the face of a sheet-aluminium control panel. One of these panels was operable by the subject, and a second one, wired in series with the first, was used by the experimenter. Pushing the switch in one direction moved the target disc vertically upward at a slow but regular pace until the switch was returned to the central position, at which time the stimulus stopped moving. Downward motion was achieved by simply moving the switch in the opposite direction. The experimenter's control panel also housed a single pole, single throw switch which activated the 6V bulb in the light box, used in Parts 2 and 3.

Measurement: (See diagram, Appendix 2). One of the perspex guides fixed to the side of the lightbox, was fitted with a spring contact which ran over the 30g 20 ohm/meter resistance wire running through the guide. This 180 cm length of resistance wire was stretched between two brass pillars, but insulated from them by a perspex block. This arrangement enabled the use of a Wheatstone Bridge resistance measurement technique, which gave readings in millivolts on a Marconi digital voltmeter, according to the movement of the contact along the resistance wire. The voltmeter was zeroed with the stimulus disc at the objective eye-level position using the variable resistor, (R1 in appendix 2).
Thereafter any displacements of the target stimulus registered on the voltmeter as either a positive or

negative voltage. A scale graduated in millimeters was fixed to the rear of the screen, over which a clear perspex cursor, attached to the light box, passed. This was used as a means of calibration for the voltmeter, and it was found that a reading of 1mV on the meter corresponded to a vertical displacement of 2 mm ± 1 mm. This amount of accuracy was found to be adequate. At a distance of 3.3 meters, the total vertical travel of the target disc was such that a radial displacement of 10° (≑ 400 mV) in either direction was possible.

The subject was seated in a bench arrangement at the observation position, with his head supported by adjustable head and chin rests, which, in conjunction with adjustments to the height of the chair through the use of cushions, enabled each subject's eyes to be vertically aligned with a fixed objective eye-level position. The alignment of the eyes with this position was by means of a sliding perspex cursor, which ran on a vertical scale to the side of the subject's head. The height of this fixed objective eye-level position above the floor corresponded to the height of the 'zero' position for the stimulus target. The control panel housing the subject's target disc control switch was mounted on a small extension platform extending out from the observation bench. (See fig. D, p.51).

For part 1, the vertical screen was placed up against the wall of a large room, and a curtain 2.5 meters high and 3 meters wide, was draped behind it to remove the possibility of alignment of the target disc by the subject, with any specific features immediately behind the screen. The subject was seated at the observation bench with the screen positioned on his objective median plane such that the distance from the eyes to the target disc, when placed at the zero position, was 3.3 meters. The experimenter was seated slightly behind and to the subject's left. A pinex board, 110 cm high and 130 cm wide supported by a base, was used for condition 2 of the pilot study as a means of preventing the subject from viewing the floor between himself and the screen.

iii. Procedure: The subjects were asked to move the disc up or down to a position judged to be level with their eyes. This task was carried out under two experimental conditions; a) ground in view, b) ground obscured by screen. Each subject was tested under both conditions, with one group of five beginning with condition a) and the remaining five beginning with condition b). Under each condition, five practice trials were given followed by twelve recorded trials. For each trial, the starting point of the disc was randomized, both in direction (above or below objective eye-level) and the amount of displacement. The subject was instructed to keep his eyes closed in between trials as the disc was being displaced by the experimenter. Random movements of the disc were also made during this period, by the experimenter, to prevent the subject from gauging the amount of displacement by the sound of the motor driving the disc. Both conditions were run in the same session with a five minute rest period between them. The apparent eye-level position was given as either a positive or negative displacement from true eye-level on the digital voltmeter, and the magnitude of the displacement given in millivolts, where 1mV corresponded to 1.65 minutes of arc deflection.

2. RESULTS

The results were analyzed as errors from accurate estimates of the eye level direction, and the mean constant error in minutes of arc was found for each subject. Because of the limited number of subjects used in this pilot study, a detailed statistical analysis will not be presented. Table 1 gives the means and standard deviations for each subject under the two conditions used.

TABLE 1

		GROUND	NO GROUND
MALE	S_1	- 3.85	- 20.35
	S_2	- 42.21	- 34.38
	S_3	- 68.61	- 12.78
	S_4	+ 19.8	+ 21.45
	S_5	- 35.61	- 84.97
	$\overline{X}$	- 26.1	- 26.2
	SD	30.8	34.7
FEMALE	S_6	+129.56	+ 83.6
	S_7	+108.62	+106.97
	S_8	- 23.23	+ 7.7
	S_9	-144.5	- 30.93
	S_{10}	+ 3.3	- 0.3
	$\overline{X}$	+ 14.5	+ 33.5
	SD	98.7	52.6
CONSTANT ERROR	$\overline{X}$	- 5.72	+ 3.6

These results are comparable with those obtained by MacDougall (1903) in his first experiment with the average constant error being less than an eighth of a degree. However, quite large individual differences are apparent, and a male-female difference in estimates is suggested by the results, though the difference is not statistically significant. They are in keeping with Sandstrom's (1951[9]) suggestion of a preferred most comfortable direction of gaze, which for men tends to be below eye-level. The height of the subjects had no obvious bearing on their resulting apparent eye-level position (product moment correlation $r = .055$). Howard and Templeton's (1966) explanation for the sex difference found by Sandstrom (1951[9]), in terms of the difference in average heights between men and women, is not applicable to these results. Removing the ground from the subject's field of view had no definite effect. With the large individual differences involved in eye-level judgements, a more sensitive procedure, with a greater number of subjects, would be required to adequately test for such an effect.

In general the pilot study shows a need to control for sex differences and the large individual differences indicate a need for a repeated measure design, when examining the effect of some factor upon judgements of eye-level.

II PART 2 - THE EFFECT OF SLOPED SURFACES ON EYE-LEVEL JUDGEMENTS

This experiment was designed to answer the main question raised in Chapter 1; i.e. can a change in the gradient of texture density and perspective of a surface, produced by a change in its slope relative to the objective eye-level plane of an observer, produce a corresponding deflection of apparent eye-level from the objective eye-level plane; i.e. are these visual field properties being used by the observer in his judgement of perceived eye-level?

In order to isolate these basic properties, the experiment was carried out in total darkness, with the only features visible in the subject's visual field being the target light, and the stimulus surface consisting of a grid pattern formed by points of light, covering a total area of 4.8 meters^2 (1.5 m wide x 3.25 m long). This surface lay at various slopes, close to the ground, between the subject and the target light. A typical configuration is shown in fig. A. A change in the slope of this surface produces a change in the gradients of texture density and perspective in the observer's retinal projection of the surface, and hence a change results in the position at which these gradients appear to reach a limit. If this position is determining the apparent eye-level position of the target light for the subject, then this change in the slope of the surface should result in a corresponding change in the subject's judgement of apparent eye-level. So as to ensure that any effect was not due solely to a change in the amount of asymmetrical stimulation in the visual field, i.e. the Roelofs effect, the end of the stimulus plane nearest the subject was raised and lowered, rather than the end nearest to the stimulus target.

Four conditions were used:

Condition 1A - The surface was level and actually lay on the floor of the experimental room.

Condition 1B - The end of the surface nearest the subject was 30 cm above the floor of the room, giving a downward sloping surface, inclined at 5.5° to the subject's objective eye-level plane.

Condition 2A - The surface was level, but each end was raised 30 cm from the floor of the room.

Condition 2B - The end of the surface nearest the subject was on the floor, 30 cm below the other end, producing an upward sloping surface inclined at 5.5° to the subject's objective eye-level plane.

It was predicted that the judged eye-level position for Condition 1B would be below that for 1A, and the judged eye-level position for 2B would be above that for 2A. No such differences should exist between conditions 1A and 2A, since the perceived gradients of texture density and perspective remain the same; only the amount of density changes, not the rate at which the density increases or decreases.

1 METHOD

(i) Apparatus

The vertical screen and observation bench used in part I, were also used in this experiment, but with some modification for use in the dark. The two plywood panels on the front of the screen were removed, leaving a 10 mm wide slit, through which the red bezel type reflector was visible. This provided the target stimulus for the subject in this experiment, and it was illuminated from behind by a 12 volt bulb housed in the light-box containing the reflector. The experimenter was able to activate this bulb from a switch mounted in his control panel. The screen and bench were located in a room which could be fully darkened, and the distance between them was 4.25 meters. The stimulus surface consisted of a grid pattern made up of 24 pinpoints of light. Each light consisted of a 12V bulb mounted in a miniature Eddson screw lamp holder and covered with a 2 cm length of surgical tubing, so that only the open end of the tubing was acting as a light source. The bulbs were wired in parallel and run from mains voltage fed into a Yamarbishi Volt-Slider set at 100V which was in turn fed into a 240:6 transformer. This provided a minimum of voltage to the bulbs which enabled the lights to be perceived as isolated circles of light (5 mm in diameter), without them giving off too much extraneous light. The lampholders were attached to a supportive frame made from 4 cm x 2 cm timber, which consisted of two 3.25 mm side pieces and

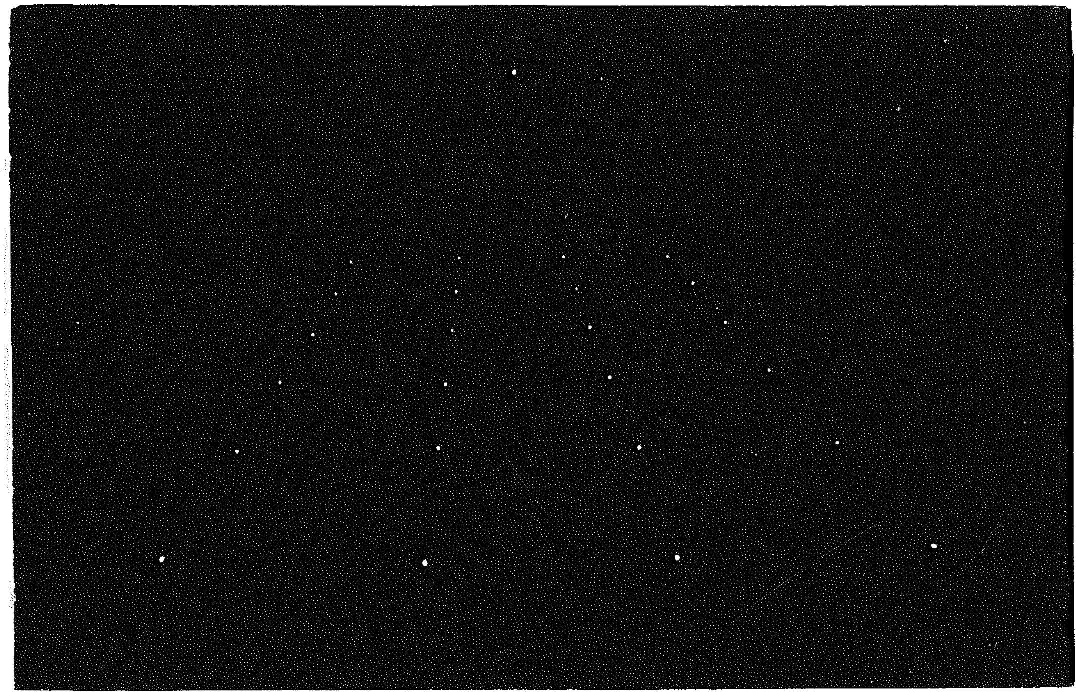

fig. A

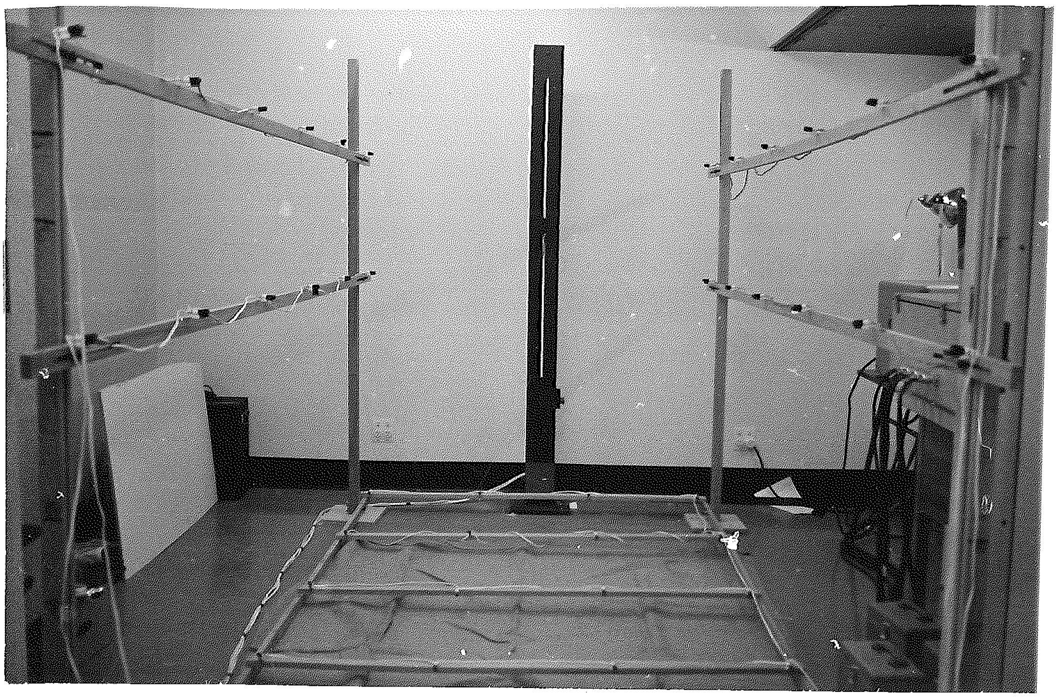

fig. B

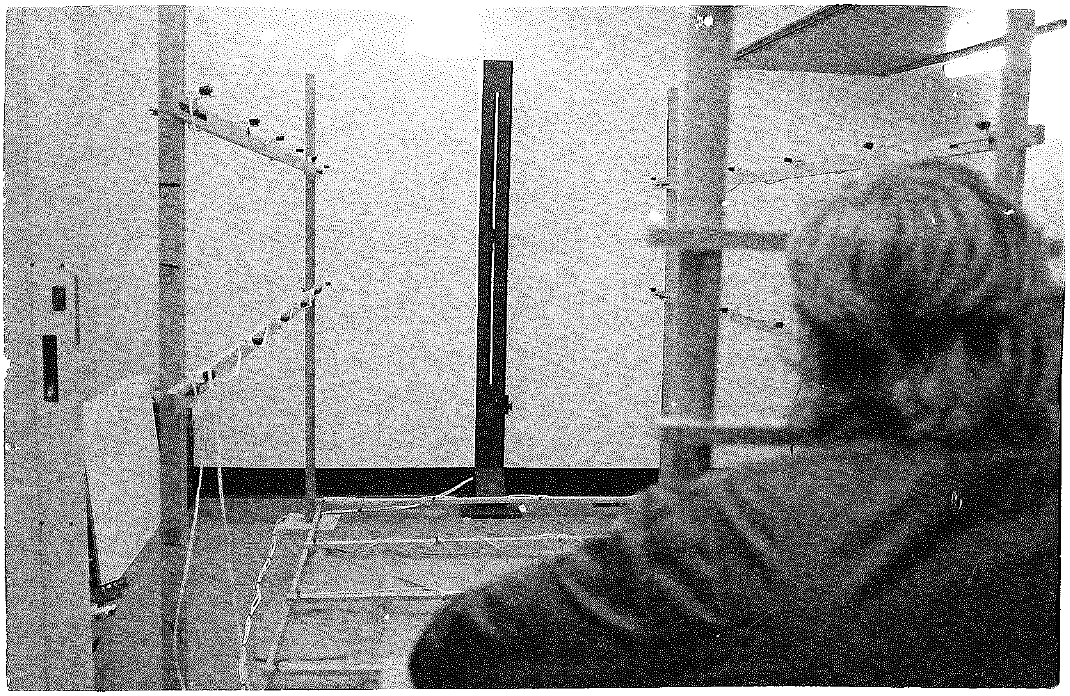

fig.C

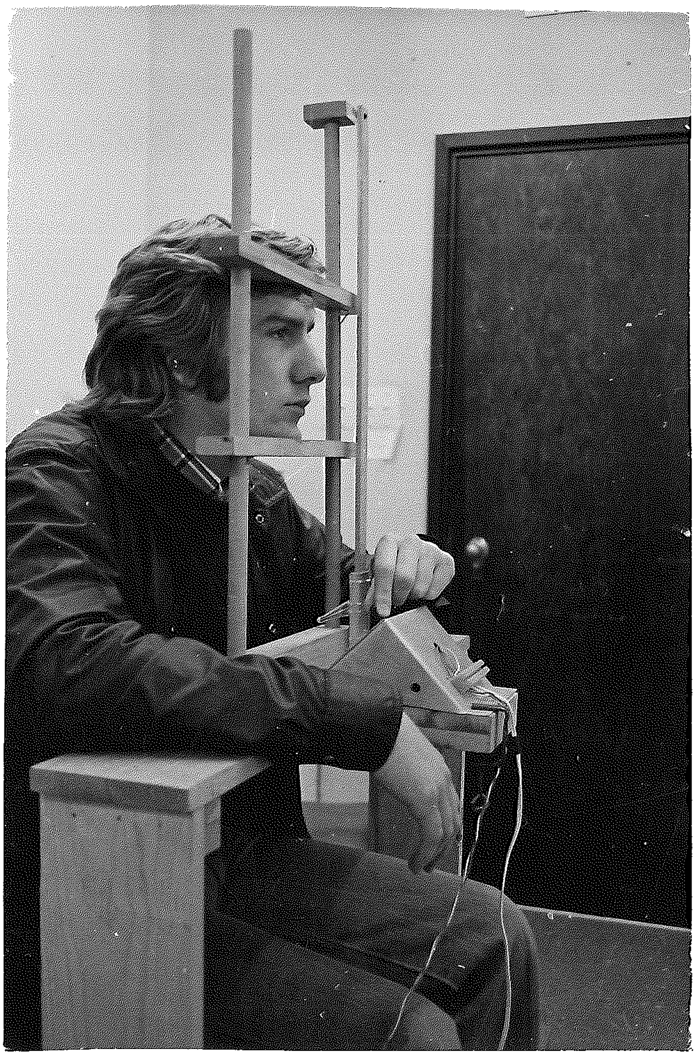

fig.D

six cross pieces, each 150 cm long and fixed to the sides at 65 cm intervals. Four lamps were fixed to each cross-piece at 50 cm intervals thus giving a grid of lights 6 deep and 4 wide. The spacing between each row of lights was 65 cm, and the spacing between each column of 6 lights was 50 cm. The four corners of this frame were slotted to accept bolts and wing nuts which suspended the frame between four slotted corner posts, 2 m high, each mounted on a supportive base. This arrangement enabled simple changes to the height and slope of the stimulus surface (See fig. B). The frame was arranged so that its longest central axis lay in line with the target screen and the subject's median plane. The distance between the last row of lights and the screen was 20 cm, and the nearest row was 80 cm away from the fronto-parallel plane of the subject's eyes. Fig. C shows the relationship between the subject, the screen containing the target light, and the stimulus surface. A black curtain suspended 50 cm in front of the observation bench, prevented the subject from viewing the layout of the room and apparatus while the room lights were on. This curtain was only removed when the room was in total darkness except for the stimulus surface and the target light.

(ii) Procedure

The subject was instructed to wear a pair of opaque 'welder's goggles' while the curtain was removed and the room lights switched off. The goggles were then removed and the subject was instructed to take up his observation position in the head rest. His task was to set the red light to a position judged to be on the same level as his eyes, given the particular stimulus conditions present. No information was given regarding the orientation of the stimulus surface. The subject was only told that the stimulus conditions would be changed in some way for the second part of the experiment.

Under each condition, fifteen settings were made by the subject in 5 trial blocks,(3 practice trials, 12 recorded trials). A three minute rest period occurred after every 5 trials, in which a plywood masking screen was placed directly in front of the subject's face, and the room lights were turned on. After one condition had been completed the curtain was replaced and the subject stepped outside the room, while the stimulus conditions were changed. After a six minute light adaptation period outside the room, the subject was again seated at the observation bench for 15 more trials under the new condition.

(iii) Subjects

The subjects were 24 volunteer students enrolled in various courses at the University of Canterbury. Twelve males and twelve females were used, randomly assigned to the different experimental conditions in the following way:

1A followed by 1B --- 3 males, 3 females.
1B followed by 1A --- 3 males, 3 females.
2A followed by 2B --- 3 males, 3 females.
2B followed by 2A --- 3 males, 3 females.

2 RESULTS

The results are presented and analyzed as errors from accurate estimates of the eye-level direction as a function of the slope of the stimulus surface. Judgements below true eye-level are arbitrarily assigned a negative value and those above are taken as positive. Table 2 gives the mean constant error in minutes of arc, for each subject under the various conditions.

TABLE 2

	CONDITION			CONDITION	
S	1A LEVEL(1)	2A SLOPED DOWN	S	1B LEVEL(2)	2B SLOPED UP
1	- 38.9	- 67.8	13	- 90.2	- 70.0
2	- 4.7	- 40.5	14	-128.3	- 53.8
3	- 25.6	- 69.2	15	-219.0	- 88.5
4	+ 3.8	- 64.1	16	+ 63.5	+ 81.0
5	+ 9.1	- 8.6	17	-160.0	- 23.1
6	- 62.3	-134.5	18	- 92.5	-147.7
7	- 57.9	-132.6	19	-287.6	-171.0
8	- 81.5	-159.5	20	+ 12.0	+102.3
9	+ 6.4	+ 57.5	21	-307.7	-304.0
10	- 40.3	-125.2	22	- 14.5	+ 20.5
11	-171.8	-263.1	23	-223.2	-187.4
12	-214.9	-271.3	24	-183.7	-184.2
$\bar{X}$	- 56.5	-106.6		-135.4	- 85.5
SD	67.7	92.1		111.1	114.8
	$\bar{d} = 50.04$ $s^2d = 1426$ t = 4.395 $p < .001$ (t-test repeated measures)			$\bar{d} = 50.02$ $s^2d = 3294$ t = 2.89 $p < .01$ (t-test repeated measures)	

A t-test (repeated measures) was carried out on the data for each of the two conditions.

Hypothesis H1 : $\overline{X}_{1A} > \overline{X}_{1B}$. t = 4.395,
significant at $p < .001$.

Hypothesis H2 : $\overline{X}_{2A} < \overline{X}_{2B}$. t = 2.89,
significant at $p < .01$

A t-test (unrelated measures) was also carried out comparing $\overline{X}_{1A}$ with $\overline{X}_{1B}$.

Hypothesis H3 : $\overline{X}_{1A} \neq \overline{X}_{1B}$. t (two tail) = 2.01, not significant. H3 rejected. There was no significant difference between the constant errors for the two level conditions.

All the predictions were confirmed by the results.

3 SUMMARY AND DISCUSSION

A stimulus surface composed of a grid pattern of lights was presented to the subjects at various slopes to the ground. This surface was the only visual information present in the subject's visual field. S's were required to set a point of light to a position judged to be at their eye-level. The principle findings are as follows:

(1) When the stimulus surface was level, estimates of eye-level were on average slightly low (-1.6°). They were less accurate than judgements made in the presence of a full diversified visual field, as in MacDougall's

experiment ($-.2^{\circ}$) or in the pilot study reported in this paper (-1°). However, they were on average more accurate than the experiments carried out in the total absence of a visual field, (MacDougall, 1903, Sharp, 1934). In keeping with the results of other experiments on eye-level, the individual differences were quite large. The average error for males was -105 minutes of arc, and for females -87.4, a non-significant difference, so sex differences were not apparent in the results.

(2) No significant difference was found between the estimates of eye-level for the two different levels of the stimulus surface. Estimates of eye-level were actually slightly lower on average, for the level surface which was raised 30 cm from the ground than for the level surface which actually lay on the ground. This finding is contrary to any theories dealing with the effect of asymmetrical stimulation on the position of apparent eye-level, (e.g. Wapner and Werner, 1955, Bruell and Albee, 1955). These would suggest that the surface which is lower in the S's field would deflect judgements of eye-level the most. The results from this experiment cannot be derived from the theories based on the distribution of stimulus energy in a two-dimensional field. They are in accordance, however, with the predictions made in the introduction.

(3) Quite large changes in eye-level judgement occurred in the predicted direction when the stimulus surface was sloped up or down in relation to the S's objective eye-level plane. This is the main finding and

it is in accord with the postulated mechanisms dealing with changes to the position of an apparent horizon in the observer's visual field. The evidence suggests that judgements of eye-level are being made on the basis of the particular gradient of perspective and texture density visible to the subject, and the stimulus surface was being used by the subjects in their perception of eye-level. Subjects' verbal reports suggest that in most cases, the stimulus surface was perceived as being level, even when it was in fact sloping up or down. The suggestion is that the horizontal position is acting as the norm for this particular spatial dimension. Normalization is the process where stimuli which are off the norm, come to be reported as being more like the norm as they continue to be inspected. Most of the work on this effect has been carried out with lines tilted from the vertical, and is reviewed by Howard and Templeton (1966, p. 221). When a tilted line gradually comes to appear less tilted, it is said to normalize to the vertical.
It has been pointed out that normalization is difficult to measure directly (Howard and Templeton, 1966, p. 215), and just what magnitude of inspection times would apply in the case of a sloping plane, is difficult to infer from the studies using vertical lines. However, the data from this experiment reveals that errors in eye-level judgement occurred from the very first trials, and there was no apparent tendency for the errors to increase or decrease over the 15 trials. For this reason, the role of normal-

ization tendencies, as applied to the apparent tilt of vertical lines, will not be stressed as an account for the effects noted in this experiment. As argued previously, it is not sufficient to show that the observer knows or presumes that an objective plane of reference in his field of view, is horizontal; further mechanisms are needed to account for his resulting perception of eye-level. There is obviously some special significance in the horizontal position of the stimulus surface, but there is little to be gained from simply applying the label 'normalization' to the effects noted in this experiment. The results do, however, indicate a need for adaptation and normalization effects to be studied in the third dimension as well as just tilt effects, and for such investigations to be extended to planes and surfaces.

(4) The changes in eye-level judgements produced by a downward sloping surface were on average equal to those produced by an upward sloping surface, ($\bar{d}_1 = 50.04$, $\bar{d}_2 = 50.02$). This opposes the findings of MacDougall's (1903) experiment using a plank of wood as a new objective plane of reference. MacDougall found that the general disturbance of eye-level judgements, was distinctly greater in the case of a downward incline than that of an upward incline. Since the compression or expansion of texture elements in the retinal projection should be the same for a given change of slope in either direction, the postulated theory would predict the

amount of error for the two types of condition to be the same, as was found in the experiment reported in this paper. A possible explanation for MacDougall's results may be that in the condition for the downward sloping plane of wood, the new objective plane fills a larger part of the visual field than it does in the upward incline. It begins just below the eyes of the observer, where it obscures the ground, whereas in the upward sloping condition, with the six inch wide plane of wood beginning at the feet of the observer, most of the ground is still visible. The two situations are not identical in the amount of new objective plane or reference they introduce.

The experiment in Part 2 showed that changes to the gradient of texture density and perspective of a surface, produced by a change in its slope, can affect in a predictable way, the judgement of eye-level made by an observer having the surface as the only source of visual information in his visual field. This supports the postulated relationship between the apparent position of a horizon in an observer's visual field, and his resulting perceived ego-location in the vertical plane.

III PART 3 - PERSPECTIVE LINES AND EYE-LEVEL JUDGEMENTS

A single surface was used in part 2 of the experiment and it lay at various slopes, in a position which would normally be occupied by the ground in the observer's visual environment. In the normal visual environment many planes exist which are actually above an observer's eye-level plane. They form perspective lines, which, if they are parallel to the ground, appear to converge and meet at the horizon. MacDougall (1903) believed that the apparent point of convergence or point of focus of such lines, determined the position judged to be at eye-level. He carried out an experiment showing that eye-level judgements can be influenced by changes to this apparent point of convergence by changing the slope of the perspective lines in the observer's visual field. MacDougall had the subject and apparatus located between two walls of black fabric. The upper bounding lines of these inclosing walls were adjusted in different ways in their orientation relative to the plane of the ground. In one condition they were horizontal or parallel to the ground, in a second condition, the ends next to the observer were depressed five degrees and in a third, the ends were elevated five degrees. For the condition in which the lines were parallel to the ground, the target disc was placed in an intermediate position to that of the other two conditions. Upward sloping lines elevated the apparent eye-level, downward sloping lines depressed it. Here again it seems that the position in the visual field where the gradient of perspective had reached a limit, is related to the apparent eye-level position. How general is this effect? MacDougall's subjects were actually located between the main perspective lines in the visual field; the ground was visible and the upper walls were located above them. Is this a necessary condition for the effects noted in MacDougall's experiment, or will other perspective lines, not necessarily centred around the objective eye-level plane of the observer, still result in errors in eye-level perception when their apparent point of convergence is raised or lowered? Experiment 2 showed that errors in eye-level judgements could be accounted for by specific changes in the retinal projection of a physical surface present in the observer's visual field. This experiment extends this analysis to sets of lines. It attempts to isolate the effect found in MacDougall's experiment and to test the generality of his hypothesis regarding the apparent point of convergence of the lines of perspective in an observer's visual field.

The 'perspective lines' consisted of four rows of lights arranged such that two of the rows, spaced 140 cm apart and running parallel to the observer's median plane, lay parallel to and 50 cm above the other pair, thus forming a 'corridor' of lights 3.3 m long, 140 cm wide and 50 cm high. This formed the basic stimulus and the effect of changing the slope of this particular visual field, upon judgements of eye-level, was investigated under three different field configurations: the 'corridor' was centred around the subject's objective eye-level plane - a situation analogous to that used by MacDougall (1903) and Kleinhans (1970), the stimulus field was located above the subject's objective eye-level plane, and a third condition in which the stimulus field was located below the subject's objective eye-level plane.

Limitations in the apparatus meant that changes to the slope of the stimulus field were limited to the case of an upward slope only. However, as argued previously, the postulated mechanism governing the changes to the visual field, should be effective in either direction and so it is felt that no loss of generality results from limiting the changes to the field in this experiment, to upward slopes only.

Aim: The experiment is designed to see if changes to the slope of the perspective lines in the observer's visual field can produce consistent errors in his judgement of eye-level, even when he is not located between such lines. The perspective lines have an apparent point of convergence or point where the gradient of perspective reaches a limit. The experiment is an attempt to account for errors in eye-level judgements by changes in the position of this apparent point of convergence.

1 METHOD

(i) Apparatus

The only changes to the apparatus was the replacement of the stimulus surface by a stimulus field of lights made up of 4 rows of lights running parallel to the subject's median plane, with one pair vertically above the other pair. Each row consisted of 6 lights mounted at 60 cm intervals, along a 3.3 m length of

4 cm x 2 cm timber. This formed a 'corridor' of lights 50 cm high and 140 cm wide. The wooden supports were fixed to the 4 upright stands used in Part 2, and their height from the ground was adjustable. For condition 1, the stimulus field was centred around the subject's objective eye-level plane, with the top rows 25 cm above this plane and the bottom two rows 25 cm below it. For condition 2, both pairs of rows were below the S's objective eye-level plane, with the upper most pair 20 cm below the subject's actual eye-level. For condition 3, both pairs of rows were above the subject's eye-level, with the lowest of the pair 20 cm above it. For the sloped part of each condition, each of the 4 row ends nearest the subject was lowered 15 cm, creating an upward sloping field in relation to the horizontal plane of the ground.

(ii) Subjects

The subjects were another sample of 15 undergraduates from the University of Canterbury, naive with respect to the phenomenon under study, and divided at random into 3 groups of 5. A Split Plot Factorial design was used with two factors: Factor A - position of the stimulus field in relation to the objective eye-level plane of the subject. Three levels of this factor were used, A1 (middle) A2 (below), A3 (above). Factor B - orientation of the stimulus field, with two levels: B1 (field level), B2 (field sloped up).

Repeated measures were used on factor B. Five subjects were randomly assigned to each of the three levels of factor A, and each subject carried out judgements of eye-level under both the level (B1) and sloped (B2) conditions. Practice effects were controlled for by randomizing the order of conditions B1 and B2 over all subjects.

(iii) Procedure

The procedure was the same as that used in part 2, with 15 trials (3 practice and 12 recorded) made under each of the two conditions B1 and B2.

2 RESULTS

The results are presented and analyzed as errors from accurate estimates of the eye-level direction as a function of the slope of the stimulus field (factor B) and the location of the stimulus field (factor A). Table 3 gives the means and variances, in minutes of arc, for the apparent eye-level position under the different experimental conditions. Each of these means is based on the mean constant errors from five subjects.

TABLE 3

		B1 (level)	B2 (sloped up)
A1	$\overline{X}$	- 39.3	+ 26.9
Middle	s^2	11879	21807
A2	$\overline{X}$	-101.1	- 77.1
Below	s^2	57560	32856
A3	$\overline{X}$	- 3.21	+ 64.4
Above	s^2	9009	52903

Table 4 presents an analysis of variance performed on the data. The B main effect is significant at the .01 level and indicates that changes to the slope of the stimulus field produce a change in the apparent eye-level position. The A main effect is also significant at the 0.01 level and indicates that the general location of the stimulus field in relation to the objective eye-level plane of the observer, affects the apparent eye-level position. The AB interaction was found to be non-significant.

TABLE 4

ANOVA SUMMARY TABLE

Source	SS	df	MS	F
Between S's	136.762	14		
A	79409	2	397.049	8.307
S's within groups	57.352	12	4.779	
Within S's	37.144	15		
B	18.527	1	18.527	13.89
AB	2.606	2	1.303	0.976
B x S's within	16.010	12	1.334	
TOTAL	173.907	29		

$F_{AB}(2,12) = 0.976 < F_{.95}(2,12)$, $p > .05$ NS

$F_{A}\ (2,12) = 8.307 > F_{.99}(2,12) = 6.93$ $p < .01$

$F_{B}\ (1,29) = 13.89 > F_{.99}(1,28) = 7.64$ $p < .01$

TABLE 5

Means and T-tests of differences between sloped up (B1) and level (B2) conditions

	Location of field		
	BELOW	CENTRAL	ABOVE
Mean (B1-B2)	24.0	66.2	67.0
sd	30.0	41.1	52.2
t	1.603	3.226	2.575
p	> .05 NS	< .025	< .05

TABLE 6

T-test (unrelated groups) of differences between means for Central (A1) and Above (A3) conditions

	Orientation of field LEVEL	 SLOPED UP
t	1.404	0.746
p	> .05 NS	> .05 NS

TABLE 7

T-test of differences between means for Central (A1) and Below (A2) conditions

	Orientation of field LEVEL	 SLOPED UP
t	2.687	3.188
p	< .025	< .01

TABLE 8

T-test of difference between Above (A3) and Below (A2) conditions

	Orientation of field LEVEL	 SLOPED UP
t	3.53	3.367
p	< .005	< .005

Individual t-tests indicate that only in the central and above conditions can the effect of sloping the field upon apparent eye-level be regarded as statistically significant. Similarly the only significant difference between the apparent eye-level scores for the different levels of the visual field, is produced by the two extremes, i.e. between the Below condition and the Above condition.

3 SUMMARY AND DISCUSSION

A stimulus field was used, consisting of four parallel rows of lights so arranged to form perspective lines in the observer's visual field, with the rows appearing to converge to a point as the distance of the lights from the observer increased. The slope of this field was altered as well as its overall location in relation to the subject's objective eye-level. Subjects were again required to set a point of light to a position judged to be at their eye-level.

The principal findings are as follows:

(1) When the stimulus field was sloped upwards, relative to the plane of the ground, judgements of eye-level tended to be correspondingly elevated. For the case of the field located centrally around the observer's eye-level plane, this result is consistent with the findings of MacDougall (1903) and Kleinhans (1970). The results for the other two previously untried conditions

tend to support MacDougall's (1903) postulate regarding the apparent point of convergence of such perspective lines.

(2) The apparent eye-level position was influenced by the vertical position of the whole stimulus field in relation to the objective eye-level of the observer. When the field was above the observer's eye-level plane, judgements were on average higher, than when the field was located below the objective eye-level of the observer. If MacDougall's postulate was a complete account of perceived eye-level in such a situation, then these results should not have been obtained. The apparent point of convergence for the different levels of the field should be in the same position *for a particular observer*. Just how much this result is a consequence of not using repeated measures on this factor is uncertain. The suggestion made by Kleinhans (1970) that the eyes move to areas of the visual field which potentially maximize information input could account for the results, which appear to be a result of the asymmetrical stimulation produced by the field. In this regard they are similar to the findings of another experiment carried out by MacDougall (1903), in which he found that a light put below objective eye-level caused a lowering of apparent eye-level and one above had the opposite effect. The fact that slope also interfered with the perception of eye-level indicates that perhaps both effects were operating. A more sophisticated experimental design is

required to isolate the two types of effects. For instance if this information seeking tendency was not equal in strength over the three conditions used (e.g. the eyes may tend to be attracted more towards the bottom of the field than the top because of the way information is distributed in our environment), then one would expect this tendency to dominate more in the Below condition of the experiment than in the other two. Whether this is reflected in the fact that the effect of sloping the field upwards was least for the Below condition, is uncertain. A condition would need to be introduced in which the field was sloped down as well as up, in which case the greatest disturbance in eye-level judgements should occur in the Below condition, if information seeking is in fact a relevant factor.

(3) The apparent eye-level position was affected the most by the centrally located field. This may be related to the fact that in our normal environment we are usually located between the main perspective planes. Specific deductions concerning the importance of such a central configuration cannot be made, however, on the basis of this one experiment, as it was not designed to measure the strength of any of the effects. Rather the results point to a need for more specific investigations into the different types of field configurations possible and their effect, if any, on spatial orientation perception.

Generally the results of this experiment were not as conculsive as the experiment in Part 2, in which a stimulus surface was used. This may simply be a result of the particular stimulus field adopted and its physical properties. The use of isolated points of light arranged in a row, rather than a continuous line may have produced an insufficiently strong field for the particular effects under study. On the other hand, the results may suggest a certain functional difference between the stimulus surface and the perspective lines. The stimulus surface more closely approximates the reference plane of the ground, something which may be essential in the accurate perception of eye-level.

CHAPTER 4

CONCLUSIONS

1 GENERAL DISCUSSION

The general purpose of the preceding experiments was to show that certain errors in spatial orientation perception can be traced to specific systematic changes in the structure of the observer's visual field. The main parameter chosen to describe these structural changes, was the apparent position in the observer's visual field, of the upper limit in the gradients of perspective and texture density. Whereas the majority of previous studies on perceived radial direction have used simple two-dimensional stimulus fields to interfere with orientation perception, this investigation has shown that certain factors, only found in a three-dimensional field, can also influence such perception.

The speculative account of possible underlying mechanisms, presented in the introduction to this paper, served the purpose of generating testable expectations which were confirmed. However, the simplicity of the experimental situation in relation to the conditions found in our normal visual environment, is recognized. It is obvious that the perception of eye-level can be affected by many factors, ranging from purely visual effects (MacDougall, 1903, Kleinhans, 1970) to drug induced changes (Krus, Wapner and Freeman, 1958[11]) The experiments did show the usefulness of Gibson's psychophysical approach of systematically varying the geometrical and sequential properties of a textured optical array.

Changes to the slope of the surface resulted in the perception of radial direction in the vertical plane, to be in error. These judgement errors were such, that radial direction was consistently shifted towards parallelism with the stimulus field. A proper understanding of this tendency requires clarification of the underlying conditions present when the judgement is made. It is possible for the stimulus surface to be perceived as a number of equivalent configurations. Since it is the only visual information available to the subject, the surface need not specify any one unique configuration. It merely specified a family of tri-dimensional arrangements. For instance it could be an upward sloping surface, with the spacing between the rows decreasing as the distance from the observer increases, or, it could be a level surface with equal spacing between the rows.

The use of a simple isolated visual array, obviously introduces difficulties regarding the particular interpretation by the subject of the nature and orientation of the stimulus field. The postulated mechanism is based on many assumptions regarding this interpretation, and it becomes increasingly apparent that the problems and objections encountered in the theories of slant perception, would also produce difficulties in any account of eye-level perception based upon factors such as textural and perspective cues. A large theoretical leap is required, before specific deductions can be made as to why one particular stimulus configuration should be experienced in some form rather than another.

The postulated mechanism is dependent on the belief that the subject assumes equal spacing between the rows of the stimulus surface, or uniform texture density. It is on this assumption that the upper limit in the gradient of texture density of a level plane in his visual field, corresponds to his eye-level position. If he could not assume that the texture density of the surface was uniform, then he has no basis to believe that the point in the optic array where texture density appears to reach a limit, corresponds to a point level with his eyes. The principle of equivalent configurations poses some difficulty to the interpretation of the results from these experiments. It can be shown though, that if certain expectations regarding the orientation of the stimulus field are presumed in the observer, then the question of equivalent configurations is not entirely problematic.

For a given eye-position an upward sloping surface can be perceived as being level, by either assuming that the spacing between the rows is in fact increasing as the distance from the observer increases, or, by assuming equal spacing between the rows, but a higher apparent viewing position. Given the particular impingement produced by the upward sloping surface when the observer is located at height H, it is not possible for that impingement to also be experienced as an upward sloping surface, when viewed from a higher position H+h, without destroying the assumption of equal spacing between the rows. If, however, the sloped surface is perceived as being level, then an apparent eye position at H+h does not destroy the assumption of equal spacing between the rows. The surface can be perceived as _either_ a sloped surface viewed from a particular height H, _or_ a level surface viewed from a greater height H+h. Both percepts cannot hold while assuming equal spacing between the rows. The experiment in Part 2 showed that when the stimulus surface was sloped upwards, the judged position of the observer's eyes in the vertical plane was above his objective eye-level position. It is only by assuming some form of expectancy in the subject, that the surface is level and that the rows are equally spaced, can we attempt to explain why changes to ego-location were perceived rather than an apparent change in the physical configuration of the surface.

Such an account can only be hypothetical, as it ignores the many other cues available to the subject regarding the orientation of the surface, such as the binocular cues of convergence and disparity. Ittleson (1960) also points out how equivalent impingements cannot be produced in any simple way, and that impingements alone do not determine the perceived reality, which, he says, is a unique idiosyncratic experience into which a host of other factors enter.

The results suggest that the surface was perceived as if it was level, even when it was physically sloped, and the perception of eye-level adjusted accordingly. This implies a certain stability in the reference plane introduced by the stimulus surface. There is some 'ecological validity' in assuming that a surface which occupies a position in the visual field normally taken up by the ground, is horizontal, since, as Gibson (1966) pointed out, environmental space always has a floor or a ground, the horizontal axis of which is implicit in every visual field. The suggestion that the surface was assumed to be level and fixed, with the apparent eye-level position changing, has support from observations made by Loemker (1930^3) who showed that the subjective localization of an enclosing visual framework is more stable than that of a small enclosed visual stimulus. He found that not only was it more stable, but it is more stable in a particular direction of ego-centric space. In the case of the stimulus fields used in this investigation, the horizontal position becomes the norm, against which judgements of eye-level are made.

The idea that knowledge of the orientation of the reference plane is required before accurate perception of eye position is possible, suggest the possibility of a reverse relationship, i.e. that knowledge of eye position is required before accurate perception of the orientation of a surface is possible. A full discussion of this relationship is beyond the scope of this paper, but the importance of considering this aspect is reflected in an important distinction made by Epstein and Park (1966) between what they call optical slant and geographical slant. Many experiments on slant perception have failed to distinguish between these two. Optical slant is dependent only on the geometrical relation of the surface to the eye, whereas geographical slant is dependent on the relation of the surface to other parts of the world or gravity. Gibson and Cornsweet (1952) were able to show that the two kinds of slant can be perceived independently, and that optical slant corresponds to the gradients of density of texture at the fovea, while geographical slant does not. Kleinhans (1970) went as far as putting forward as a logically necessary truth, that optical patterns or gradients give ambiguous information regarding the egocentric orientation of surfaces, in the absence of knowledge of eye-position. In other words, an optical gradient plus knowledge of eye-position are necessary and sufficient for accurate judgement of the orientation of a surface.

II SUMMARY OF ARGUMENT

A psychophysical viewpoint was adopted to analyze the spatial information available to an observer attempting to set a point to the same level as his eyes. Haber and Hershenson (1973) summarize the properties of the environment that were considered. All surfaces in the physical world have texture. They possess a microstructure or a grain which can be thought of as units repeated over the entire surface. Thus the units are characteristic of the surface and must be represented in the information present in the retinal projection. If all elements of the surface are equidistant from the perceiver, then the retinal projection of each of the units, as determined by principles of geometry, will be the same size. However, in the real world we encounter surfaces which are almost invariably at a slant to our line of sight. Consequently, the units in surfaces are projected onto the retina according to the rules of perspective. When considering the projection of a textured surface, for example, one upon which the observer is standing and which stretches away from him, projected size will decrease with distance - the further away an element is, the smaller its projection will be.

For an observer standing on a level surface, the point in the observer's visual field at which the density of texture elements becomes infinite, corresponds to a point at the same level as his eyes. This point lies on a plane running parallel to the surface the observer is standing on, and which runs through the pupils of the observer's eyes. Any point on this plane can be regarded as being located at the observer's eye-level. In our normal visual environment, this same relationship exists. The ground provides the level surface and the apparent upper limit in the texture density is the horizon. Any surface parallel to the level surface the observer is standing on, will have an upper limit in its texture density, which is located in the same position as that of the level surface, and this point will also be at the observer's eye-level. A surface which is not parallel to the level surface, will also have an upper limit to its texture density, though such a point cannot correctly be referred to as a 'horizon', since the surface is not horizontal. However, a point set at the position of this upper limit, in an observer's visual field, will be located on a plane which is parallel to the sloped surface. This plane will not, however, be parallel to the surface the observer is standing on. These are the relationships that exist in our visual environment.

Based on the evidence from the experiments conducted in this paper, the following predictions can be made regarding an observer's performance in judging his eye-level position. Given a stimulus surface as the only source of visual information, an observer will apply the same principles that exist in the normal environment. With no other information regarding the true orientation of the surface, it will be assumed to be level and having uniform texture density or spacing between lines. The apparent eye-level position will be determined by where in the observer's visual field the upper limit in texture density would be located, given the particular gradient of density that is visible. If the surface is parallel to the ground, then judgements of eye-level made on this basis will essentially be correct. Certain constant errors will be evident as there appears to be some instability in the perception of radial angle in the vertical plane. If, however, the surface is objectively sloped in relation to the horizontal plane of the ground, then judgements made on this basis will be in error, deviating from the true eye-level direction according to the actual slope of the surface. Eye position will be judged as being 'level' with the sloped surface, but it will not correspond to his objective eye-level in relation to the level plane of the ground.

Gravity has long been regarded as the main factor in the perception of directions such as the vertical. The investigations reported in this paper point to a need for greater consideration to be given to the plane normal to the direction of gravity, namely the ground, as a frame of reference in spatial orientation perception, and as an important visual factor in such perception.

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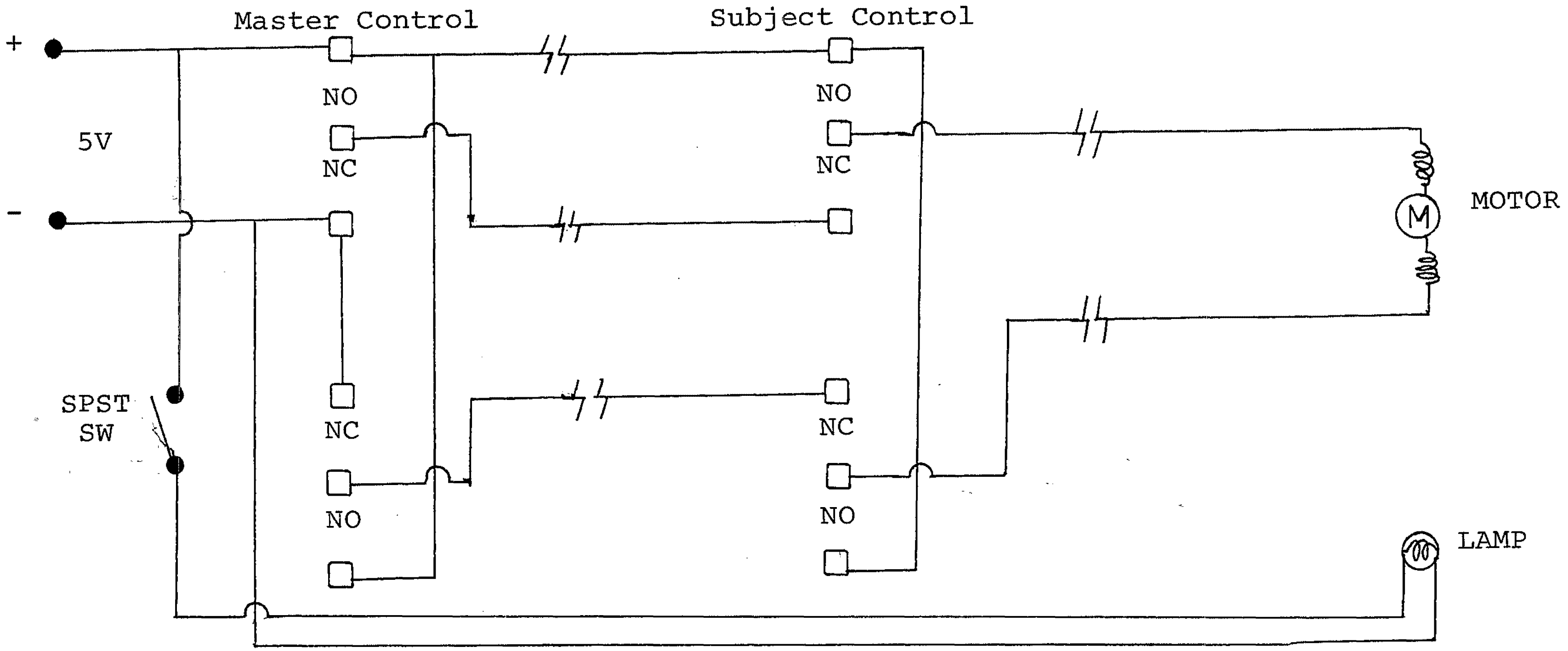
APPENDIX 1

MOTOR CONTROL SCHEMATIC



APPENDIX 2.

CIRCUIT FOR WEATSTONE BRIDGE READOUT