DETERMINANTS OF THE PERCEPTION OF ROTATION IN DEPTH OR TRANSLATION IN APPARENT MOTION

by

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A Ph.D. candidate is very much like a politician. He is trying to convince a sceptical public that he merits approval for something which he insists is all his own work. Like a politician, however, a Ph.D. candidate receives support and advice from a great throng of people and they have some share in the completed project. My Ph.D. was no different and I acknowledge the assistance I received with considerable gratitude.

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ABSTRACT

Depth ambiguous apparent motion may occur when two outline shapes with marked orientation differences are used in an apparent motion sequence, e.g. when two arrow-like shapes are presented pointing in opposite directions. In such cases two distinct percepts may be reported: the object may appear to undergo a two dimensional movement accompanied by a distortion of the contours (plastic deformation) or it may appear to rotate in depth (rigid rotation). The terms in brackets were coined by Kolers and Pomerantz (1971) to describe the phenomena reported by their subjects.

Orlansky (1940) and Kolers and Pomerantz (1971) reported that which percept occurs depends on the inter-stimulus interval (ISI). Kolers and Pomerantz (1971) found that plastic deformation occurred at short ISI's whereas at longer ISI's rigid rotation predominated. They offered an explanation for this result which was essentially a restatement of Korte's third law of apparent movement. The explanation was that rigid rotation predominated at long ISI's because it was only then that the visual system had the time to "construct" the longer path length required for rigid rotation. A corollary of this explanation is that the shapes themselves will have little effect on determining which type of movement will be seen: Kolers and Pomerantz found that there was no significant effect due to the shapes. However, White et al. (1979) demonstrated that shape factors can affect the resolution of the rigid rotation-plastic deformation ambiguity and that in some circumstances

ISI is not a major determinant of which percept occurs.

This thesis examines the relative effects of various spatial and temporal properties of the apparent motion display on the relative proportions of three dimensional and two dimensional motion.

The first series of experiments demonstrated that a number of different variables can affect the relative proportions of reports of the two types of movement. These variables include shape, spatial separation and ISI and an attempt was made to identify their relative importance. Generally it was found that shape is the major determinant, followed by spatial separation and then ISI. These factors were used in a model where the weight of each factor could vary and thus change its relative importance. The discrepancy between the results of Kolers and Pomerantz (1971) and White et al. (1979) may be explained by reference to this model.

The second series of experiments concentrated on investigating the shape variable. In particular, an attempt was made to determine which aspects of a shape are important for the phenomenon of depth ambiguous apparent movement. It was concluded that local features, such as line elements or angles, are relatively insignificant and are important only insofar as they determine global features of the shapes. The critical global feature seems to be the overall perceived "direction" or "pointedness" of the shapes.

The third series of experiments attempted to relate an independent measure of "direction" or "pointedness" to amount of observed rigid rotation. The attempt was not wholly successful and illustrates some of the extra-stimulus variables that can operate in studies of this phenomenon.

These experiments demonstrate that depth ambiguous apparent motion is not only a result of the temporal constraints on processing in the visual system but is also related to the ability of the visual system to extract pattern information from fleeting stimuli. It is suggested that if the degree of processing is such that the visual system is unable to recognise that the two shapes are the same shape then plastic, two dimensional motion may predominate. If the visual system identifies the two shapes as being the same shape then the perceived movement is likely to be a rotation in depth since this operation preserves the identity of a shape. It is possible that a careful examination of the phenomenon of depth ambiguous apparent motion may reveal important aspects of the pattern detection and recognition systems in human vision.

CHAPTER 1

INTRODUCTION

1.1 A Statement of the Problem

The term "apparent motion" is used to describe a variety of phenomena so some definition of the term is required. In this study it will refer to the perception of motion that arises from the presentation of at least two sensory events that are spatially and temporally distinct. This type of display is analogous to shining a strobe light onto an object in real motion and is also called "stroboscopic motion". The movement is characteristically brief in duration and rapid in apparent velocity. While it is relatively easy to specify the necessary conditions for "apparent movement", it is impossible to specify any one set of sufficient conditions. Apparent movement will occur within an extensive range of spatial and temporal parameters but it also depends to a certain extent on the individual observing the display. Experimenters can set different criteria for the reporting of motion which also partly determines the range of conditions in which apparent movement will occur. Phi motion, following Wertheimer (1912), refers to apparent movement that occurs relatively independently of the perception of any shapes or objects, i.e. it is "pure" motion. Optimal or "good" apparent movement produces movement that is smooth, continuous and compelling. It is comparable to a similar object undergoing similar real movement.

The apparent motion stimulus used in the experiments described below consists of two outline geometrical figures, each presented briefly with a short time interval between them. The shapes are presented on the face of a visual display unit and are similar, if not identical, in size, form, brightness, etc. In these circumstances it is reasonable to assume that the shapes define a fronto-parallel depth plane which is coincident with the screen. With particular combinations of shapes and temporal intervals, the apparent motion is said to be depth ambiguous. In other words, particular displays sometimes give rise to the percept of an object moving within the plane of the screen (two dimensional motion) but at other times the percept is of an object that moves behind or in front of that plane (three dimensional motion).

Because of the nature of the shapes used in these experiments, the three dimensional case most often looks like a rigid object rotating in depth about some axis as the first shape is rotated into the position of the second, like a door rotating on its hinges. For this reason this type of perceived motion will be referred to as "rotation in depth". This term is preferred to "rigid rotation" because it covers plastic three dimensional movements as well. The two dimensional motion is often accompanied by a sensation of the shape distorting or deforming as one shape "flows" into the other. The perception of either a rigid or plastic shape is not a necessary part of this phenomenon. Two dimensional motion can occur without any distortion of the shape, and it is possible to have some distortion during three dimensional motion.

Both these cases will be encountered in the following experiments.

The basic phenomenon under consideration is: that some apparent motion displays are ambiguous and will sometimes generate a three dimensional percept and at other times a two dimensional percept. The experiments below examine variables which resolve (or affect) this ambiguity.

The experiments will be restricted to one particular kind of depth ambiguous apparent motion, viz., where the three dimensional phase consists of rotation in depth. Another type of depth ambiguous display is illustrated by a square followed by a larger, concentric square. Such a display could either appear as a square expanding two dimensionally or as a distant square moving closer to the observer. This situation is distinguished from rotation in depth by the fact that the two shapes defining the endpoints of the motion are localised in different depth planes and that no apparent rotation is involved. The experiments are generally only concerned with the particular type of three dimensional motion that consists of a rotation in depth between two shapes that are perceived to be coplanar, i.e. a full 180 degree rotation.

1.2 A Brief Outline of the Literature

Initial research into the phenomenon of apparent movement was undertaken by people who were interested in its development as an entertainment. Serious research was begun in the 1830's and by the

1890's the art of projecting motion pictures had been perfected. All that was required from that point was to make the technology more sophisticated.

Investigations of the phenomenon of apparent motion by psychologists did not begin until the late 1880's. In 1912, Wertheimer used the results of his experiments on apparent motion to establish the school of Gestalt psychology. Until the late 1920's most research on the phenomenon was directed towards either proving or disproving the theories of this school.

By the 1930's Gestalt psychology had ceased to be a major force in the study of apparent motion and the field became fragmented with a great variety of different phenomena being included under the umbrella term "apparent motion". One of the new phenomena to receive attention was depth ambiguous apparent movement although only two or three researchers have looked at the phenomenon to the present day.

The following review sets out to give a brief history of the phenomenon of apparent movement, leading up to the investigations of depth ambiguous apparent motion. The study of depth ambiguous apparent motion will be related to the study of a variety of other, apparently related phenomena.

CHAPTER 2

THE APPARENT MOTION LITERATURE

2.1 A Brief History of The Cinema

Apparent movement is familiar to most people in the form of cinema or television, even if they are not aware of the mechanism used to produce the movement. These entertainments have arisen because of the long fascination man has had with the idea of producing moving pictures. This fascination was evident 25,000 years ago when a prehistoric artist in Altamir, Spain, added extra legs to a painting of a boar to suggest that it was running. Giacomo Ballo's painting called "Dynamism of a Dog on a Leash (Leash in Motion)" (1912) demonstrates that the same artistic device works as well for modern man as it did for ancient man. An examination of the history of the moving picture is informative in that it provides an historical and social background for the study of the phenomenon by psychologists.

Moving picture displays have a long history. Shadow puppet theatre was invented in China about 1 B.C. and is still popular in Asia. In Europe, the magic lantern was used to produce moving displays. Two notable types of "moving" pictures utilising magic lanterns were Robertson's "phantasmagoria" in 1795 and Child's "dissolving views" of the 1840's. However, the stroboscopic presentation of stimuli (the defining characteristic of apparent movement) was not considered until Roget (1825) described an illusion where a rolling wagon wheel seen through a picket fence seemed to move horizontally without rotation and the spokes appeared curved. He correctly deduced that this illusion was due to the intermittent exposure of the spokes by the fence and persistence of vision. In the same year Paris made commercial use of persistence of vision with his issue of a toy called the Thaumatrope. In 1831, Faraday published a paper which described a crude form of stroboscope where the intermittent exposure of an image was achieved by rotating a cardboard cog wheel in front of the eyes.

Meanwhile in Belgium, Plateau had patented his Phenakistiscope ("eye deceiver") in 1830 and released it to the public in 1833, just before Stampfer released his Stroboscope. Both the Phenakistiscope and Stroboscope were cardboard discs with a series of deep narrow slots cut into the edge. Between the slots were painted a series of images. The device was operated by holding the disc to a mirror and spinning it rapidly. When the eye was held to the back of the slots a moving image appeared in the mirror. This was a direct commercial application of the work of Roget, Faraday and Plateau. The principle of a rotating band of pictures exposed intermittently was quickly extended and refined. Horner's Daedelum (later known as a Zoetrope) was released to the public in 1867. The Daedelum was a horizontal drum with slots cut into the side. The observer looked through the slots at the successive images on the other side of the drum. In 1877 Reynaud eliminated the slots and placed mirrors at the centre of a Daedelum and marketed the resulting device as the Praxinoscope. Public demand for this sort of entertainment continued to stimulate research into the production of moving pictures.

The development of cinema required two technical innovations: a means of recording images and a means of allowing a large (paying) audience to view the moving images. Photography provided the means for recording images and by 1839 permanent photographic prints were being offered to the public. In 1877 Muybridge was slicing the movement of real objects into frozen photographic images by using a series of cameras along the motion path; each camera would take one picture of the moving object. Anschutz tried to solve the second problem in 1889 by passing these photographic images in front of an early form of strobe light in a device called an Electric Tachyscope. However, the solution finally adopted by the cinema industry was patented by Brown in 1869. He produced a Projecting Phenakistiscope which, although it used Phenakistiscope discs, incorporated a stepping mechanism and a shutter. These devices are necessary to produce a stationary image on the screen and a blank interval between images. Both these conditions are necessary for the production of smooth, realisitic movement. When it became possible to take photographs on celluloid strips all that remained was to combine photography and the technology of Brown to produce films as we know them. The birthday of modern cinema is generally taken to be December 28th, 1895 which is the day the Lumiere brothers presented a motion film to a paying public in Paris.

The story of the cinema is the story of a series of scientists, engineers and entrepreneurs refining a type of entertainment in response to public demand. In the process they developed a technology which approached apparent motion from a practical point of view. Their goal was to produce a lifelike display and they were not worried about the visual processes underlying the phenomenon. An investigation of why a rapidly presented sequence of stationary images should generate a percept of movmement was not undertaken until the advent of psychology. However, by the time psychologists began to study apparent motion it was well established as an entertainment of enormous popularity. The early psychologists must have been familiar with the phenomenon as an entertainment long before they began their experiments (for further detail of the history of the cinema see Boring, 1942; Wood, 1947; Cook, 1963; Ceram, 1965 and Pfragner, 1974).

2.2 Wertheimer (1912)

Psychologists did not investigate the phenomenon of apparent movement until after it had been established as an entertainment. This time lag is understandable in view of the fact that psychology did not really become established as a science until 1879 when Wundt established his laboratory at Leipzig (Boring, 1942).

In 1875 the physiologist Exner undertook a study of the perception of temporal order. He asked his subjects to view two spatially and temporally disparate electric sparks and to indicate their temporal ordering. When the spatial separation was relatively large, subjects could correctly indicate the ordering of the sparks when the time interval between them was 45 msec. or greater. At shorter time intervals subjects were not able to detect the temporal order of the flashes and they reported the flashes to be simultaneous. With small spatial separations subjects reported the correct ordering when the time interval was as low as 14 msec. In the latter case Exner discovered that subjects were able to use the additional cue of the apparent movement of the spark across the gap. As Kolers (1972) points out, Exner had demonstrated what was to become the three classic stages of apparent movement; succession, optimal motion and simultaneity. Exner pointed out the distinction between inferring movement from a perception of a change in position and perceiving the movement directly. He suggested that his results indicated that motion was in fact perceived directly, i.e. the sensation of movement was not based on a memory of position or perception of order.

Wertheimer was aware of the work of Exner and of other workers including Marbe, Ebbinghaus and Schumann. From this earlier literature he was able to identify five theories on the perception of motion. He mentioned the motion picture projector and conducted some preliminary observations with a "stroboscope": the description he gave was cryptic but his "stroboscope" appears to have been one of Plateau's Phenakistiscopes. It was against this background that Wertheimer began his experiments in 1910 at Frankfurt with Schumann's tachistoscope, using Kohler, Koffka and Koffka's wife as subjects. Wertheimer's study covered a wide range of apparent motion phenomena and his stimuli included parallel lines, lines at different angles to one another, curved lines, different coloured lines and displays where objects were placed in the path of the apparent movement. He also studied the effect of attention and "set" on the the phenomenon. From these experiments Wertheimer identified Exner's three stages of apparent motion and added to them the stages of partial and "pure" (phi) movement as well.

Wertheimer observed that if the conditions were just right, his subjects did not report the passage of an object but were nevertheless certain that they saw movement, i.e. they reported "objectless motion". Wertheimer regarded this finding of paramount importance and devoted more space to the discussion of the conditions for, and ramifications of, this phenomenon than of any other. He suggested that movement was the relation between two events and that the perception of movement does not necessarily depend on the perception of the events that give rise to it. He also suggested a physiological hypothesis which involves "short circuits" in the brain: an idea that anticipates the "isomorphism" of the Gestaltists.

It cannot be said that Wertheimer "discovered" apparent motion or even that he was the first to make a psychological examination of the phenomenon. The principal importance of Werthiemer's paper is not in terms of what it tells us about apparent motion, despite its prominence in the history of the phenomenon. Its importance is mainly historical in that it marks the beginning of Gestalt psychology. Later researchers were to use similar experimental conditions but to concentrate on different aspects of the perceptual experience, which were not discussed by Wertheimer. He did not, for instance, describe what happened to the phenomenal object when disparate shapes were used. Like many other researchers, Wertheimer wanted to use apparent motion to develop a particular theory.

2.3 Apparent Motion and Gestalt Theory

Wertheimer's paper stimulated a great deal of research in Germany. While the German literature is unavailable to this author, there are a few English translations and reviews (e.g. Helson, 1925 and Ellis, 1950) which indicate that this research effort was directed towards expanding and refining the principles suggested by Wertheimer, i.e. towards the development of the Gestalt school. The broad aim of the German school was to determine the relationship between the physical stimuli and Gestalten.

Korte (1915) was guided by this principle when he undertook the investigation of the relationship between stimulus duration, inter-stimulus interval and spatial separation and the phenomenon of apparent movement. From this work he formulated his so called "laws" although it fell to Neuhaus (1930) to extend and refine this particular aspect of Korte's work. Korte was also the first to describe delta or reverse movement which is apparent movement towards the first flash rather than the second. This occurs when the second flash is more "energetic" than the first, such as when the second flash is brighter or has a longer duration.

The work of Ternus (1926) illustrates another aspect of Gestaltist research. Ternus demonstrated "phenomenal identity" in apparent motion by arranging for a number of sources to appear in each flash. Ternus found that with this situation subjects most often reported that the multiple sources looked like a single object in motion, e.g. a "line of lights" or a "a triangle of lights" moving. The sources were arranged so that if each one in the first flash moved to its nearest spatial neighbour in the second flash then some would not have moved at all and the others would have moved in different directions through different distances. Ternus argued that the lights formed a pattern or Gestalt and it was this pattern that underwent the apparent movement, rather than the individual elements.

This sample of the German research is of neccessity meagre and only gives a tiny taste of that rich body of literature. However, the flavour was not to the liking of the Americans and from the outset American research sought to undermine the findings of the Gestalt school. Dimmick (1920) was the first American to investigate the phenomenon and he disputed Wertheimer's assertion that there was no "visual filling in of the field of movement" (Dimmick, 1920, p 332). Dimmick's subjects reported that they saw a "flickering grey film" between the endpoints of the motion. This, Dimmick suggested, was the psychological correlate of Wertheimer's physiological "short circuit" and as such obviated the need for Wertheimer's speculation. Dimmick supported the idea that there was no essential difference between the movement percept produced by an object in real movement and that produced by stroboscopic presentations (Dimmick and Scahill, 1925).

Higginson (1926b) suggested Dimmick's "flickering grey film" had an exaggerated significance and raised the possibility that it was an equipment artefact. Higginson had not found a "grey film" with coloured stimuli but rather that the phenomenal object took up the colour of one of the stimuli (Higginson 1926a). Higginson (1926a) argued strongly against the Gestalt theory explanation of apparent motion although he confirmed Wertheimer's finding of "pure" phi movement. He criticised Wertheimer and Dimmick for their preoccupation with stimulus properties, particularly temporal factors. Higginson emphasised non-visual factors including eye movements (Higginson, 1926c) and "a firmly entrenched set capable of producing, even when released under extremely diverse objective conditions, the same functional outcome" (Higginson, 1926b, p 112). Higginson claimed that there was no one-to-one correspondance between particular inter-stimulus intervals and reports of optimal movement. In effect his statements suggested that it was futile to attempt to determine the relationship between the stimulus and the Gestalt because there was no unique solution and any relationship found would have to take into account a variety of non-stimulus determinants.

Dimmick (1926) promptly entered into debate with Higginson. Dimmick claimed that Higginson had misreported his work and that Higginson had not appreciated the distinction between "apprehending" movement (e.g. noticing that the minute hand on a watch has moved) and directly perceiving movement. Dimmick was acutely aware of this problem and he was careful to distinguish between what he called "process" and "context" descriptions of apparent motion phenomena. This error on Higginson's part led to his claim that any inter-stimulus interval was as good as any other. Not only was this contrary to accepted opinion at the time but it was soon seen (Neff, 1936) to be disproved by McConnell. McConnell (1927) presented situations where the first and second flashes temporally overlapped by different amounts and found that reports of apparent movement did depend critically on the degree and type of overlap.

Higginson's assertion that eye movements were important fared no better. Wertheimer (1912) had already argued that eye movements were not important and his demonstration that apparent movement could occur in opposite directions simultaneously was extremely convincing. Langfeld (1927) found that apparent motion could be obtained by the successive stimulation of non-corresponding points on the two retinas and argued that while eye movements may occur, they could not be the fundamental cause of apparent motion. Guilford and Helson (1929) photographed eye movements and found that there was no relationship between eye movements and reports of apparent movement, within the limits of their technology. This settled the issue at the time (see also Hulin and Katz, 1934).

Higginson made a bitter reply to Dimmick (Higginson, 1926d) and his dismissal of Dimmick's "grey film" has been vindicated by history.

A positive result of the debate was the clarification of the distinction between "inferred" movement and "perceived" movement (Dimmick and Sanders, 1929) and it is probably true that many of the early researchers did not consider this distinction.

A common procedure in the early years was to examine a wide variety of different apparent motion phenomena and to try to derive a single, general explanation to account for all of them. DeSilva (1926, 1928, 1929) was the last American author to adopt this overall approach to the phenomenon. In 1926 DeSilva drew the distinction between stimulus and non-stimulus determinants. Non-stimulus determinants were things like attitude, preference for counterclockwise rotations (at least for right eyed subjects) and a tendency for motion not to cross the midline. Stimulus determinants included distractions introduced by the equipment or procedure, contrast (white figures on black backgrounds were best), position of fixation (peripheral fixations were best) and repetitions. DeSilva also included "meaningfulness" under the heading of stimulus determinants, e.g. a sequence showing a man saluting appeared to move more clearly than an abstract stimulus. DeSilva saw his work as broadly supporting Gestaltist ideas but he wished to emphasize that subjective determinants played a role in the phenomenon as well as objective, stimulus determinants. DeSilva's sympathy with the Gestaltist school is evidenced by his detailed study of Korte's laws with large stimuli (DeSilva, 1928). In 1929 he attempted to clarify some of Werthiemer's statements by introducing the terms "movingness" which denoted what Wertheimer meant by phi movement and "the vehicle of movement" which was the form that generated the movement which may or may not be perceived. He also undertook a more detailed study of the relationship between the perception of real and apparent movement. However, the era of Gestalt influence on the study of apparent motion was drawing to a close (at least in America) and DeSilva's ideas, couched as they were in Gestaltist terms, were to have little impact on the direction of research.

At about this time a number of reviews of the research on apparent motion were published. Three of the reviews were restricted to descriptions of previous experiments (Squires, 1928; Ewert, 1930 and Hovland, 1935) and as such did not concentrate on theoretical issues. However, it is clear that there was widespread disenchantment with Wertheimer's short circuit theory and interest in "pure" phi movement was beginning to wane. Some attempts were being made to explain apparent movement in terms of stimulation of local receptors on the retina (Ewert, 1928) and eye movements had been ruled out as an explanation of the phenomenon (Hovland, 1935).

Neff (1936) attempted a review of the theoretical issues in the study of apparent motion and in particular assessed the contribution of Wertheimer. Neff pointed out that Wertheimer did not distiguish between what constitutes movement and the phenomena that attend successive presentations of two stimuli but that Wertheimer did make a positive contribution in describing a whole range of new phenomena. The discovery of phi movement is a separate contribution in itself which served as a focal point for the idea that movement could be a sensation in itself rather than a complex percept inferred from other sense data. Wertheimer's physiological theory, while eventually shown to be inaccurate, did provide the stimulus that caused other workers to take up the problem of just how it is that apparent movement arises in the visual system. It is clear from Neff's review that by the mid 1930's the ability of Gestalt psychology to stimlulate research outside Germany had waned. There was a brief revival when Kohler and Wallach (1944) published a new field theory based on Gestalt ideas. Other researchers, however, began examining the phenomena that had been uncovered as interesting problems in their own right. The very real contribution of the Gestalt school was to provide the stimulus for the initial research.

The new direction of apparent motion research can be illustrated by considering the role of different coloured flashes in apparent movement. Nearly all the earlier papers included the condition where the two flashes were of different colours amongst a host of other conditions. Wertheimer simply mentions that movement is still seen under these conditions and does not seem to have any further interest in it. Higginson (1926a) noted that the main colour change of the phenomenal object was towards the second stimulus. There was general agreement that differently coloured flashes tended to reduce the number of reports of optimal movement but no-one had unertaken a systematic study of the effect of different colours. Vogt and Grant (1927) restricted themselves to flashes of different colours and found that reports of optimal motion were reduced. The moving object had a colour in which the colour of one of the stimuli predominated. The stimulus did not become grey if the colours were complementary, nor were the colours mixed to become a third colour. Their study was not particularly detailed and it was left to Squires (1931) to explore the matter further.

Squires found that there was little evidence for the "complementary grey" hypothesis, that the phenomenal object was the colour of the first stimulus for most of its journey but that it tended to abruptly change to the colour of the second stimulus after about 80% of its flight. The point is that research into apparent motion was moving away from the general study and becoming more particular. Instead of treating a variable like colour as just one variable among many, there was beginning to be a real interest in finding out the detailed effect of each particular variable. Squires' work is a good example because modern workers (Kolers and von Grunau, 1975, 1976) have not substantially added to his findings regarding colour.

Researchers in the field of apparent motion began to study new phenomena. Kelly (1935) was concerned with the role of instructions and previous experience on the perception of apparent movement. Miles (1933) used four lights arranged in a square and flashed the diagonal pairs alternately. He reported that his subjects sometimes saw a pair of lights move horizontally, sometimes vertically and sometimes they reported a "ferris wheel" effect. This study is of particular interest here because it is one of the earliest studies that addresses the problem of ambiguous apparent motion displays. This effect was also used by Brown and Voth (1937) to illustrate their theory that the visual field was a vector field of restraining and cohesive forces. Some of the phenomena that were under the umbrella term "apparent movement" at the time began to develop into new fields. Weber's work (1930) on Lissajous figures is an example of illusory rotation in depth and is very similar to the kinetic depth effect. Weber referred to his work as "apparent movement" but it would not be labelled as such now. Werner (1935) discusses the relationship between metacontrast and apparent movement although they are now often seen as separate problems.

The study of apparent movement began in the context of a new phenomenon which arises from the sequential presentation of two independant events. This has an obvious role to play in the development of Gestalt theory and was studied with this point of view in mind in Germany. American psychologists were more critical of Gestalt ideas and undertook the study of apparent motion as a means of criticising the German school. The early history of the study of apparent motion must be understood in the context of this struggle. The research was not conducted on a "look-see" basis but in terms of being used as support on one side or the other of a debate. By the mid 1930's most American psychologists seemed to have satisfied themselves that the phenomena of apparent movement did not support the arguments of the Gestaltists. In the meantime they had discovered that it was an interesting phenomenon in its own right and began to look at new apparent motion phenomena and to take a closer interest in their determinants.

2.4 Orlansky (1940)

In 1940 Orlansky published a paper called "The effect of similarity and difference in form on apparent visual movement". This paper is not usually considered a milestone in the history of apparent motion but it is of particular relevance here because it is the first study to examine systematically depth ambiguous apparent movement. The paper is also distinctive for its use of psychophysical techniques (principally the "method of limits"), rather than subjective verbal reports, for data collection.

The use of the "method of limits" in apparent motion research had been pioneered by Gilbert (1938). Gilbert slowly varied the rate of alternation of two flashing lights and had his subjects report when they saw simultaneity, apparent movement or succession. He did this as the alternation rate was increased and when it was decreased and was able to find a range of alternation rates for which apparent motion would occur. He found that the transitions from simultaneity to movement and from movement to succession were not smooth transitions but that there were wild fluctuations. This is implicit in many of the verbal report experiments although Gilbert was able to state the case with more rigour. Gilbert's experiment is a clear break from the tradition of verbal reports of Gestalten and is the first attempt to introduce a quantitative technique into the study of apparent movement. Orlansky adopted this same technique and also used Gilbert's experimental apparatus. Unfortunately the apparatus was not designed so that the inter-stimulus interval and stimulus durations could be manipulated separately: the stimulus duration was always twice the inter-stimulus interval. Orlansky was aware of this but did not seem to be aware of the consequences this might have on his conclusions.

Orlansky started with 5 rectangles of different heights and widths and presented subjects with the 25 different pairs that could be formed. He found that identical shapes exhibited movement over a greater range of alternation rates than any other combination. The next best combinations were those which consisted of identical shapes in different orientations. Combinations that consisted of two different rectangles exhibited movement over the smallest range of alternation rates. He noted that some subjects reported a three dimensional movement and that this type of movement tended to occur at relatively large alternation rates. This was not a new finding in that other researchers had found that some apparent motion displays would result in three dimensional motion (e.g. Neuhaus, 1930; Fernberger, 1934).

In his second experiment he used two arrows (a left pointing one and a right pointing one) and presented subjects with the four possible shape combinations. He repeated the procedure with a left facing curved line and a right facing curved line. He found that when the shapes were pointing in the same direction, simple translation of the shape within the plane of the display took place and that movement occurred over a greater range of alternation rates. When the shapes faced in opposite directions not only was there a reduction in the range of alternation rates for which movement was reported but there was a greater variety of types of movement. The most common report in this case was of the object performing a 180 degree rotation in depth. This report also predominated for large alternation rates.

In his third experiment Orlansky used shapes that were "very different in form" (Orlansky, 1940, p. 44), such as arrows paired with circles. He found that there were few movement responses and that they could not be easily categorised. The fourth experiment attempted to find a relationship between the Gestalt concept of "wholeness" and apparent movement between dissimilar shapes with negative results. Experiment Five found that there was no systematic relationship between suggestion and type of movement seen. In fact, movement of the contra-suggested type was reported more often than the suggestion favoured type. The final experiment found that increasing the physical separation of the shapes decreases the range of alternation rates for which movement is reported. He did not investigate how separation might effect the proportion of three dimensional motion responses.

Orlansky's study anticipates the findings of more recent workers (Kolers & Pomerantz, 1971; White et al., 1979) and seems to be relatively free of the theory-bound considerations of many of the earlier workers. It is an excellent example of the new type of research from the post-Gestalt era in that it is investigative and more rigorous in its use of experimental methods. However, Orlansky's use of the term "alternation rates" was misleading with respect to his conclusions about three dimensional motion. His conclusions might be thought to imply that three dimensional motion is more likely at longer inter-stimulus intervals since this would be a likely interpretation of "alternation rate". However, stimulus duration and inter-stimulus interval were hopelessly confounded and it is just as possible that longer stimulus durations result in more three dimensional motion responses. The role of the inter-stimulus interval in depth ambiguous apparent movement is still under debate.

Up to this point practically all the literature available (with the notable exception of the German literature) has been reviewed. This was possible not only because there were relatively few studies during this period but also because nearly all the work had Gestalt ideas as a focal point. During the 1930's this focal point became diffuse and research branched out into a number of different directions. It is beyond the scope of this work to attempt to review all the research of the post 1930's decades. Review articles (e.g. Aarons, 1964) and publication indexes tend to categorise a great variety of different phenomena under the heading "Apparent Movement". This discussion restricts the meaning of the term "apparent movement/motion" to include only the perception of movement generated by two successive exposures, i.e. movement produced by "stroboscopic" presentation.

There are very few studies that deal directly with depth ambiguous apparent motion but there are a number of areas that seem to be bear on the phenomenon. The following sections will attempt to identify some of these areas and to outline their development. Few of these studies are directly relevant to this study but it is instructive to consider why they are not.

2.5 Ambiguous Apparent Motion

Ambiguous apparent movement occurs when a particular stimulus configuration gives rise to two distinct motion percepts. One of the first ambiguous apparent motion displays was demonstrated by Miles (1933; Kelly & Miles, 1934) who arranged 4 lights in a square and then flashed the diagonal pairs alternately. Under these circumstances the perceptual outcome is multistable: subjects report two lights moving horizontally or vertically or rotating in a circle. Willey (1936) used this stimulus arrangement to investigate individual differences in the perception of apparent motion and more recently Attneave and Block (1974) used it to demonstrate a difference between real and apparent movement.

Von Schiller (1933) presented his subjects with a single object in the first flash and then two flanking objects in the second flash. Subjects often reported that the central object split and moved to both of the flanking flashes which von Schiller suggested was an example of "assimilation": the tendency for dynamic displays to "bind together" into a Gestalt "whole" (see also Jeeves & Brunner, 1956; and Brown, 1957). However, with some displays subjects reported that the movement appeared to be predominately in one direction for a time, and then change and move in the other direction, and so on. This ambiguity was used by a group of researchers to investigate the role of meaningfulness of stimuli (Toch & Ittelson, 1956), the role of directional information in the stimuli (Krampen & Toch, 1960) and the effect of training (Krampen, 1963a), handedness (Krampen, 1963b) and fixation (Toch, 1963) in apparent movement.

Of these studies the one by Krampen and Toch (1960) is of particular interest. They suggested that in a situation where a shape was free to move in either of two directions, an arrow should appear to move in the direction of its head. They also suggested that this tendency should increase as an arrow-like figure was made to look more like an arrow. Using a von Schiller arrangement, they found that generally the arrowheads did facilitate movement in the direction they specified. They also found that if the figures approximating arrowheads were shown in an orderly fashion (from least-like to most-like an arrow or vice versa), then sequential dependencies were introduced into the data. In other words, when the initial figures were arrows subjects tended to respond to later figures as if they were arrows, and similarly if the initial shapes were not like arrows. These findings suggest that directional information, such as the direction indicated by an arrow, may be an important variable in some apparent motion cases (it will be argued that it is crucial in depth ambiguous apparent motion) and that random presentation is a desirable strategy because subjects may show non-independence of successive responses if the presentations follow some orderly pattern.

Ratleff (1956) devised a display whereby if apparent movement was determined by the brightness (or colour) of the successive flashes then the movement would be in a particular direction (either up or down). On the other hand, if the movement was determined by the shape of the flashes, the movement would be in the opposite direction. He found that if the brightness differences were not too great, then the apparent movement would follow the shape but if the brightness differences were large then the apparent movement would follow the brightness. This early investigation of the relationship between form and brightness in apparent motion has been extended by more recent workers (Anstis, 1970; Braddick, 1974; Anstis & Rogers, 1975).

The main difficulty in relating these studies to the current one rests in the fact none of them look at depth ambiguities. Even though the apparent movement is ambiguous, the most probable kinds of movement are coplanar. None of these studies found that both three dimensional and two dimensional movements were reported.

2.6 Apparent Motion in Depth

Bartley and Miller point out that "Third dimensional apparent movement may be produced by (a) the successive presentation of stationary targets at different distances; (b) the successive presentation of targets of different size, but at the same distance; and (c) by manipulating the intensity of a stationary target" (Bartley and Miller, 1954, p 453). Corbin (1942) used method (a) to examine the relationship between the distance separating the flashes and the time interval required for optimal movement under these conditions. His data suggests that physical separation determines apparent movement, even when depth has to be considered: the retinally projected distances of the flashes are not important. Calvarezo (1934) used method (b) to investigate the relationship between perceived size and distance. Bartley and Miller (1954) also used method (b) and found that the phenomenon of metacontrast determines the degree to which apparent motion is perceived. Method (c) produces the phenomenon known as "gamma movement". It seems possible that all three methods could produce depth ambiguous movement with the two alternatives being a three dimensional movement or a two dimensional expansion or contraction. However, none of these studies discussed this possibility.

Most studies in this area of movement in depth have used continuous changes in size (rather than stroboscopic presentations) in order to be able to explore the relationship between perceived size and distance (e.g. Calvarezo, 1934; Hastorf, 1950; Smith, 1951; Smith, 1952; Smith 1955). Size constancy, which is the basic phenomenon under discussion here, is a field in its own right (see Vernon, 1937 for a summary of early work) and its links with depth ambiguous apparent motion are more or less fortuitous.

In general, this particular literature is of limited value to the current discussion because the studies usually use continuous rather than stroboscopic presentations. Thus, by the definition given above, they do not deal with apparent movement. In the few cases where stroboscopic presentations were used, depth ambiguous apparent motion may be possible although it does not seem to have been reported. However, even if these presentations did result in depth ambiguities they do not meet the condition that the two flashes should appear to be coplanar and as such are beyond the scope of this study.

2.7 Rotation in Depth

Weber (1930) reported that when subjects were presented with continuously moving Lissajous patterns they saw a variety of effects. Occasionally the patterns were reported to deform plastically in two dimensions, which is a veridical perception. More often they appeared to be a rigid object rotating in depth. The apparent rotation was found to be ambiguous in that the pattern spontaneously reversed its apparent direction of rotation. Interest centred on the reversal rates of these patterns and Philip and Fisichelli (1945) found that the reversal rate depended on the complexity of the pattern and the apparent speed. Fisichelli (1946) found that reversals were more common if the pattern has a horizontal axis of rotation rather than a vertical axis.

Lissajous patterns are two dimensional patterns that vary continously and systematically in a way that is not specifically related to real three dimensional objects rotating in space. However, there is an obvious connection between this type of pattern and the kinetic depth effect. Wallach and O'Connell (1953) used Miles' (1931) shadow projection technique and placed a series of objects between a point light source and a translucent screen and then rotated the objects about a vertical axis. They found that the static patterns were usually not reported to be representations of three dimensional objects. On the other hand, the moving patterns nearly always were, with frequent reversals of the apparent direction of rotation of the solid object.

The kinetic depth effect and related phenomena have been extensively studied and it appears that moving two dimensional patterns that exhibit changes in the length and orientation of projected contours will often give rise to the perception of depth (Braunstein, 1976). Of particular interest in this area is the finding by Green (1961) that the projection of a pattern undergoing a rigid transformation in three-dimensiónal space can be perceived as being non-rigid as well as moving three dimensionally. Plastic deformation of contours is not restricted to two dimensional percepts.

A similar phenomenon was reported by Ames (1951) who found that a trapezoidal figure rotating about a vertical axis appeared to oscillate in depth. It has been found that a great variety of objects will exhibit this ambiguity (e.g. Day and Power, 1963; Power and Day, 1973): it is not specific to Ames' window. It seems generally agreed that this illusion is due to a misperception of the slant of the moving figure although there is some question as to whether this misperception is due to misleading linear perspective cues (Graham, 1963), false shape constancy (Gibson & Gibson, 1957), dynamic changes in the projection (Braunstein, 1976) or some other factor.

The work on rotation in depth offers some intriguing parallels to depth ambiguous apparent motion but there are considerable differences. The rotation in depth phenomena occur with relatively slow verdicial movements of a solid object and are thus not apparent motion phenomena. More importantly, researchers in this area tend to assume that the object will be seen as three dimensional: the variable of interest is the direction of rotation. The possibility of two dimensional motion is not high in the Ames' window type of display but it is often likely in the kinetic depth effect type of display. An examination of why two dimensional motion might occur in the kinetic depth effect may have some bearing on the perception of depth ambiguous apparent motion.

2.8 Meaningfulness and Context

Many researchers have been interested to see if experiences in the real world would facilitate the perception of apparent movement (e.g. Kelly, 1935; Smith, 1951; Jones & Brunner, 1954). The assumption appears to have been made that apparent movement was at least partly inferred from the change in position of the flashes and if the flashes depicted familiar objects usually associated with movement then the apparent movement would be more compelling and more easily established. Jones and Brunner (1954) compared apparent motion sequences of nonsense figures and representations of real sitatuions (e.g. a man running or a car crossing a bridge). They reached the general conclusion that the meaningful stimuli will facilitate the perception of apparent motion.

However, their experiments were not very well controlled and were extensively criticised by Toch and Ittelson (1956). Toch and Ittelson used a von Schiller arrangement (described above) and changed the "information content" of the figures by using representations of bottles, aeroplanes and bombs. The figures were constructed so that their structure was not greatly different. They found that the "bottles" (which were presented horizontally whereas the "planes" and "bombs" were presented vertically) gave the usual ambiguous movement, that the "aeroplanes" tended to "fly" upwards and the "bombs" tended to "fall" downwards. They claimed that this indicated the influence of the meaninfulness of the stimuli. The experiment by Krampen and Toch (1960), which was similar in design except that the figures were a series of approximations to arrows, produced a similar result.

Despite the interest in the role of meaningfulness and context in the perception of apparent motion the results were generally disappointing. There is little concrete evidence that meaningful figures are any better at eliciting apparent movement than abstract figures. The studies by Toch and Ittelson (1956) and Krampen and Toch (1960) might suggest otherwise but it is possible to interpret their results in another way. In both cases it can be argued that the variable being manipulated was not meaningfulness but perceived direction. It could be that subjects assigned a direction to the figures they were viewing and the movement tended to flow in that direction. This agrees with the explanation that will be developed for depth ambiguous apparent motion.

2.9 Kolers and Pomerantz (1971)

An examination of the literature from 1940 to 1971 shows that there were no studies that examined depth ambiguous apparent motion. The preceding sections constitute a brief sketch of other areas of apparent movement research that may have a bearing on the phenomena The experimental data will be examined below in the light of these various phenomena. However, Kolers and Pomerantz (1971) did undertake an investigation of the phenomenon first described in detail by Orlansky (1940).

In Experiment 1, Kolers and Pomerantz used a square, a triangle, an arrow and a circle. They used four "same" pairs, and six "disparate" pairs randomly selected from the twelve possible such pairs. They found that with sufficient observations and identical pairs, significant differences were found between the ability of the shapes to elicit reports of "smooth continuous movement". However, these differences were very small and the effects due to ISI and individual differences were very much greater. With disparate shapes, all pairs could be seen in smooth continuous motion. The shapes changed their perceived contours to accommodate the disparity between the members. Like Orlansky (1940), they found that differences in shape between members of a pair does reduce the likelihood of reporting motion but that this effect is small. They conclude that any simple shape will change smoothly into any other.

In Experiment 2 they paired a trapezoid shape with its mirror relfection, inversion or planar rotation. Unfortunately, in their paper they do not illustrate these figures nor do they make clear whether the shapes were superimposed or spatially separate. However, other sources illustrate the shapes (Kolers, 1972) and indicate that they were superimposed (Kolers, Note 1). They found that both two dimensional plastic deformations and three dimensional rigid rotations in depth were reported. Plastic deformations tended to occur at short ISI's and rigid rotations occurred at longer ISI's. The likelihood of reporting motion differed between the pairs but this effect was again very small compared to the effects of stimulus duration, ISI and individual differences.

Their Experiment 3 was designed to test whether multiple transformations of the shapes would occur in parallel or in series. They used trapezoids that varied in orientation only, in size only and in both orientation and size. Since they were only interested in the likelihood of reporting motion, they did not address the question of how these conditions would affect the relative proportions of two and three dimensional motion. They found that perceived changes of size and orientation occurred just as easily as perceived changes of size alone; suggesting that the disparities are resolved in parallel. In this experiment they do spatially separate the shapes and remark "The major effect of superposition is to extend the range of ISI values at which smooth motion is seen" (Kolers and Pomerantz, 1971, p 106).

One explanation advanced for this phenomenon might be termed the Korte's third law explanation. Korte's third law states that all else being equal, as the phenomenal separation between the terminii of motion is increased, the ISI must also be increased for "good" motion to be reported. In the case of depth ambiguous apparent motion, the reason why rotation in depth occurs at longer ISI's than two dimensional plastic deformation is that the rotation in depth requires a longer path length. Since the path length is longer then it follows that a longer ISI is required: "... the visual system needs more time to construct a rigid change in depth than a coplanar change of shape." (Kolers and Pomerantz, 1971, p 107.)

The Korte's third law explanation receives some support from the work of Shepard and Metzler (1971) and Shepard and Judd (1971). Shepard and Metzler found that the time taken to recognise that two drawings of three dimensional objects were in fact drawings of the same object in different orientations increased with the angle of rotation between the two projections. In a similar study, Shepard and Judd used the same sort of drawings and presented them in an apparent motion display. They found that the ISI required for the objects to be seen in rigid rotation increased as the angle of rotation between the projections increased. This does suggest that the visual system takes longer to rotate an object through a large angle than it takes to rotate the object through a small angle.

There are some authors, however, who disagree with this explanation. Attneave (1974) points out that this explanation depends on apparent motion being a real time phenomenon. It requires that the motion be constructed during the presentation sequence, before the appearance of the second stimulus. Kolers (1972) does in fact subscribe to this view and argues that the repetitive nature of most apparent motion studies would enable the subject to anticipate the nature and location of the second stimulus. This anticipation, in Kolers view, could take the place of the presentation and this is in fact observed in some cases. Attneave takes the contrary view and is supported by the work of Beck, Elsner and Silverstein (1977). They found that it made very little difference if the subject could predict where the second stimulus would appear or not. In both cases the space-time relationships of Korte's third law were upheld. White (1975) confirmed this finding by showing that predictability had no effect on the relative proportions of two and three dimensional motion responses in a situation that was very similar to that used by Kolers and Pomerantz.

Attneave argues that the effect of ISI observed by Kolers and Pomerantz may have been to weaken the information concerning "where" the object is in space and thus leave it free to move along more exotic paths. However, White (1977) found that in his depth ambiguous apparent motion displays, ISI had a negligible effect on the relative proportions of two and three dimensional motion. He argued that the ISI may not be a very important determinant of depth ambiguous apparent motion at all. White suggested that the results found by Kolers and Pomerantz may have been an artefact of their stimulus presentation; that they may be peculiar to situations where the stimuli are spatially superimposed. The problem of superposition versus spatial separation is the subject of some of the experiments described below.

White et al. (1979) used an experimental arrangement that was similar to that used by Kolers and Pomerantz (1971) although there were a number of important differences. These include the use of naive rather than trained subjects, the use of a computer driven display rather than a tachistoscope and spatially separated shapes rather than superimposed shapes. In their main experiment, White et al. found that the Korte's 'third' law explanation could not predict the pattern of responses to a number of different shape pairs whereas an alternative hypothesis based on the properties of the shapes could.

White et al. advanced the hypothesis that the shapes and their spatial relationship would define an axis of rotation and the more salient this axis was, the more likely it was that rotation in depth would be reported. If the shapes were a long way apart this definition would be poor because it would be difficult to localise the position of the axis correctly. The "adjacent contour elements" of the shapes also played a role in determing the saliency of this axis of rotation. The adjacent contour elements were simply defined to be the contour elements of the two shapes that were facing each other. They were the contour elements that could be projected onto the axis of rotation without the projection line having to intersect any other contour element of the figure. They argued that the presence of parallel elements in particular would make it easier for the subject to identify an axis of rotation and would thus facilitate the perception of rotation in depth. White et al., however, restricted themselves to the same shapes as Kolers and Pomerantz had used and it was not clear whether either explanation would generalize to other shapes.

Kolers and Pomerantz suggested that depth ambiguous apparent motion might lead to the specification of the figural primitives of a perceptual grammar (Kolers, 1970). However, since they found that shapes had no effect it was not possible to pursue the matter. The results of White et al. (1979), showing that ISI is not a good predictor of subjects' responses and that shape is, suggest that there may be some profit in pursuing this idea. The experimental work described below continues on from White et al. (1979) and attempts to define the aspects of shapes that are important in the perception of depth ambiguous apparent motion. It is hoped that this information may be able to suggest new ways of looking at how the visual system analyzes patterns.

CHAPTER 3

THE OCTAGON EXPERIMENTS

Experimental Background

Casual observation of depth ambiguous apparent motion displays reveals that the three dimensional movement can either appear to be in front of the plane of the screen or behind it. There does not seem to be any pattern as to which type of movement is seen. While there is no doubt that this aspect of depth ambiguous apparent movement is worthy of study, it does not seem central to the question of what causes the depth ambiguity. There are considerable difficulties in obtaining reliable data relating to the depth ambiguity of these displays and at the present stage of development it would seem impossible to obtain worthwhile data about the direction of the perceived three dimensional motion. An examination of this aspect of rotation in depth probably requires a separate study in itself and certainly requires more sophisticated data gathering techniques than are currently available. For these reasons, no attempt will be made to distinguish rotation in depth behind the plane of the screen from rotation in depth in front of the plane of the screen.

The broad aim of this study is to establish what causes some apparent motion displays to be depth ambiguous, within the definitions and restrictions set out above. Throughout the series of experiments described below, a great many details are common to all experiments. The following section describes these common features.

Apparatus

A PDP-8 computer was programmed to control a visual display unit, to control the order of presentation of the stimuli and to collect and record the subjects' responses. The visual display unit was a Hewlett Packard 1317 which has a screen 360 mm wide by 265 mm high. Only a central portion of roughly 100 mm x 100 mm was actually used. The unit was supplied with a P4 phosphor which glows with a blue-white colour and has a nominal decay time to .1% of initial brightness of 470 microseconds. The actual decay time proved difficult to measure. A problem associated with the decay time was the possibility of having a faint permanent outline of the figures on the screen if the initial intensity was set too high. This problem was minimized by using a fairly low intensity. Given the problem of the phosphor decay time, it is difficult to ascribe an accuracy to the timing of the display. The effect of the decay time is to increase the effective stimulus duration and to decrease the inter-stimulus interval. In all the experiments reported below, the stimulus duration was constant for all conditions within an experiment and it seems likely that any errors that were introduced were constant. In situations where the stimulus duration was varied, however, the phosphor decay time could prove to be a more serious problem.

Subjects performed the experiments in a small sound attenuated room with a single overhead light. They viewed the stimuli from a distance of .5 m which was maintained by using a chin rest. In front of the subject, on a table, was a box with three switches mounted on it: they pushed one of these switches after every trial to indicate their response to that trial. Figure 3.0 is a schematic diagram of the experimental setup.

Stimuli

The figures appeared as bright, outline flashes in a dark field. The brightness of the contour lines was approximately 1.70 ft.l., while the background was approximately 0.16 ft.l. Measurements of brightness were taken with a Spectral Pritchard Photometer (Model 1970/PL) which was corrected for the spectral sensitivity of the average human eye. Contrast, defined as (Imax-Imin)/(Imax+Imin), was approximately 0.82. The contour lines were approximately .3 mm thick. The computer plotted the figures point by point which is a relatively slow process but there was no apparent flicker or variation in brightness in the contour lines.

The stimulus duration, defined to be the time a figure was displayed on the screen, was 200 msec for all experiments.

Subjects

All subjects were undergraduate students at Sydney University who participated in the experiment for some nominal course credit in

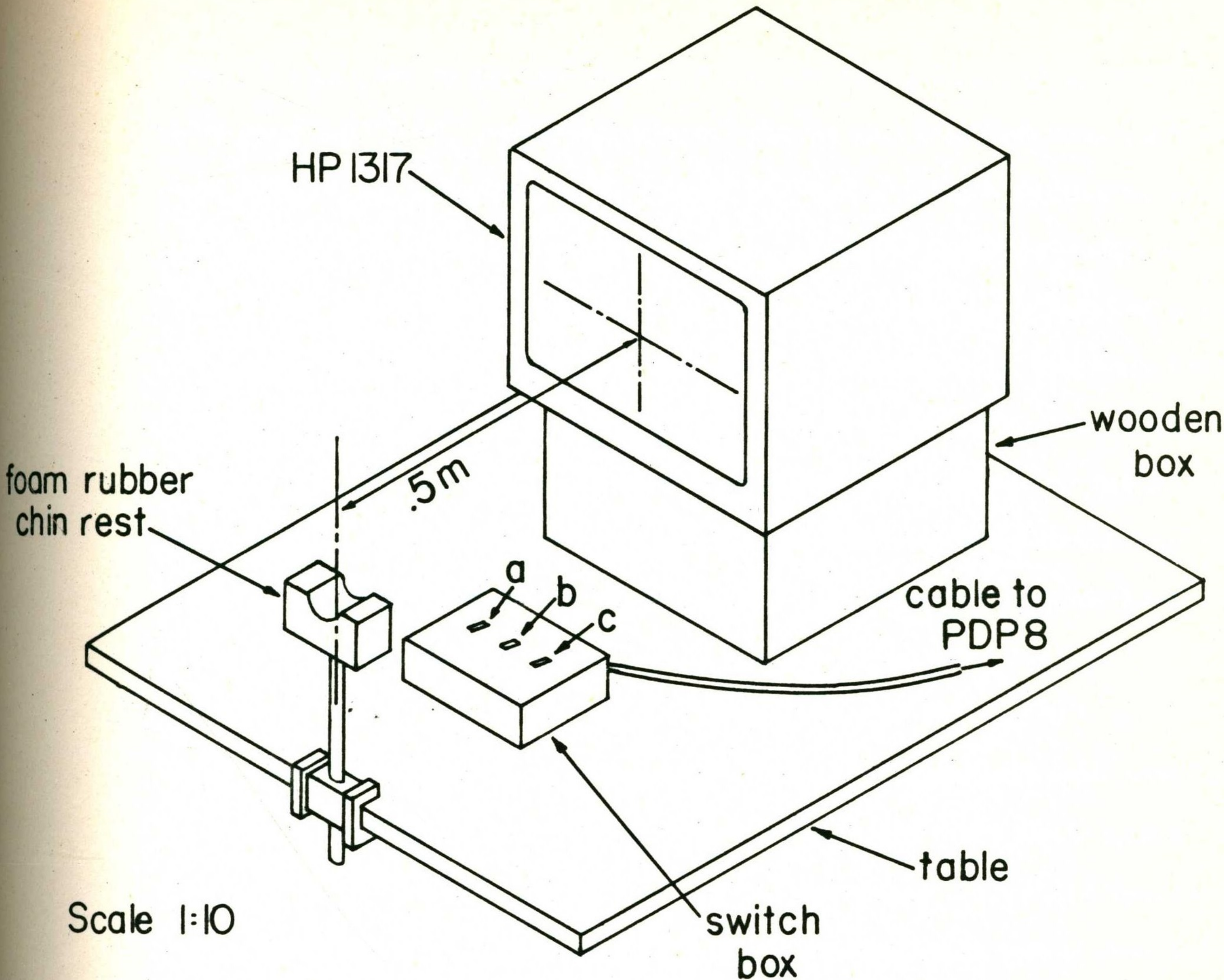


Figure 3.0 A schematic diagram of the experimental room. The switches on the switch box corresponded to the three response categories available to the subject. Switch a represented RID, switch b represented no motion and switch c represented 2D motion.

Psychology 1. The subjects had no prior knowledge of any aspect of these experiments.

Procedure

The instructions were delivered to the subjects as they sat in front of the screen (see Appendix A). In the experiments, subjects were presented with a single "cycle" of motion. One cycle was the first shape displayed for 200 msec followed by a blank inter-stimulus interval

(ISI), followed by the second shape for 200 msec, followed by a blank 2 second inter-cycle interval (ICI). During the 2 second ICI, subjects indicated their response by pressing one of the three switches in front of them. If a subject failed to make a response within 2 seconds, the fact was noted by the computer and the next trial was presented. The missed trial was presented again at some later point. For each trial the computer recorded which switch was pressed, which condition was presented and the latency of the response. The latency was defined to be the time (in milliseconds) elapsed between the termintation of the second shape and the pressing of any switch. The data were printed out on a teletype after every trial.

The response categories available to the subjects were labelled "rotation in depth" (RID), "two dimensional motion" (2D motion) and "no motion" (NM). These terms were used in preference to "rigid rotation" and "plastic deformation" (Kolers and Pomerantz, 1971) since they allow for the possibility of plastic rotations and rigid translations, respectively.

In all experiments an attempt was made to randomize presentations as much as possible. Typically there were 16 or 18 different possible combinations of the various treatment levels used in the experiment. On any given trial the computer would pseudo-randomly select one of those combinations to present to the subject. The effect of this procedure was to make it difficult, if not impossible, for subjects to predict which condition they would see next. This procedure was adopted because it was found White (1975) that when naive subjects were presented with a series of identical trials they tended to assume that they must make identical responses to each trial in that series.

Subjects were not given a fixed number of trials. For each of the conditions in the experiment, the computer kept a tally of the number of trials where motion of some kind was reported. Thus, "no motion" and missed trials, while they were recorded, were not added into this tally. When the tally for any condition reached 25, that condition was not used in the experiment any more. When the tally reached 25 for all conditions, the experiment was terminated. This ensured that for every treatment combination the subject saw 25 trials where apparent motion was successfully generated. In one experiment the required tally was 20 trials.

For most experiments the minimum number of trials needed to complete the experiment was 400 although nearly all subjects required more trials than this. Typically, the subject would take longer than two seconds to make a decision in the first few trials and fail to make a response. However, most subjects very quickly learned to make a response on every trial. Another consequence of this fixed tally procedure was that at the end of the experiment subjects sometimes saw the same treatment combination repeated a number of times since it was possible that one treatment combination might be well short of the required tally. There could be up to about 10 repetitions of the same condition which re-introduces the problem that this procedure was designed to minimise. However, subjects had received about 400 trials before these repetitions so it is unlikely that they were as naive as when they started. Furthermore, long series of repetitions were rare. On the whole it is not felt that this was a serious problem.

Interest in these experiments is centred on two different kinds of motion percepts. The effect that the stimulus conditions have on the probability of reporting apparent motion at all is of little concern. Data pertinent to questions about depth ambiguous apparent motion can only be gathered after some apparent movement has been established. The question being asked is: given that the subject does report motion, was it two dimensional or three dimensional motion? For this reason it is appropriate to restrict the discussion to trials where some sort of motion was reported. The fixed tally procedure was adopted to take into consideration the fact that different subjects may have different probabilities of reporting motion. A subject who had relative difficulty in seeing motion would have a relatively large number of "no motion" responses but his data relating to the relative proportions of two and three dimensional motion can be compared directly to the data from a subject who always reported motion.

In an earlier attempt to tackle this problem (White 1975,1979) a fixed number of trials was given and the ratio

$$\frac{\text{(Number of rotation in depth responses)}}{\left|\begin{array}{c}\text{Number of rotation}\\\text{in depth responses}\end{array}\right| + \left|\begin{array}{c}\text{Number of two dimensional}\\\text{motion responses}\end{array}\right|}$$

was calculated. This ratio also enables a comparison to be made between subjects with respect to the relative proportions of rotation in depth and two dimensional motion responses. However this ratio is complex and sometimes results in basing conclusions on a very small number of instances, such as when subjects do have a lot of "no motion" responses. By ensuring that the sum of RID and 2D motion responses is constant, only the rotation in depth responses need be considered for analysis (note that an analysis of the two dimensional responses would simply give the inverse results).

Analysis

Only one type of response needed to be analysed because of the fixed tally procedure that was adopted. The RID responses were chosen because it was felt that they were the better choice. The reasons for this choice are discussed below. However, it should be the case that an analysis of RID responses simply gives inverse results to an analysis of 2D motion responses.

In this study the subjects had available to them three different response categories but it is not possible to say with certainty how they used these categories. Post experimental questioning of the subjects indicated that they generally had a clear understanding of the rotation in depth case but they were unsure of the two dimensional case. The subjects offered good descriptions of what the shapes were doing when they were undergoing rotation in depth: they said things like "it appeared to flip over", "it appeared to flap like a door" and similar things which tended to indicate that they could recognise a rotation in depth. However, their descriptions of the two dimensional motion were usually vague and hesitant.

There were very few "no motion" responses reported in these experiments. This result was expected as the parameters of the apparent motion displays were deliberately chosen to miminise "no motion" responses. These parameters were derived from the study by Kolers and Pomerantz (1971). Kolers and Pomerantz used trained subject whereas all the subjects in these experiments were naive. Thus, one might expect there to be more "no motion" responses in these experiments than in the Kolers and Pomerantz study. Given that the subjects could describe rotation in depth well but were hesitant about two dimensional motion, the possibility arises that the subjects were reporting rotation in depth correctly but that they pressed the two dimensional motion button for any other case, effectively reducing the response categories to two. A consequence of this may be that the 2D motion and "no motion" responses may not be as reliable as the RID responses.

It should be the case that the conditions which give rise to two dimensional or three dimensional motion are inversely related. If a particular condition appears to rotate in depth frequently then it should appear to move two dimensionally infrequently. This appears to be true for this study but given that only one of the response categories is required for analysis, the better choice appears to be the RID responses. The discussion and statistical analysis will be restricted to the RID responses although it should be noted that it would probably be equally valid to restrict the discussion to the two dimensional responses.

The data from these experiments were examined using analysis of variance. Only three different designs were used: three treatments with repeated measures on two, two treatments with two repeated measures and three treatments with three repeated measures. The data were analysed by computer using algorithms found in Winer (1962, p 319ff) for the first two designs and Kirk (1968, p 237ff) for the third. Winer describes the algorithm for a three treatment design with two repeated measures. This was used for the two treatment case by setting the number of levels of the third treatment to 1. Kirk actually describes a two treatment design but this was extended to take into account the third treatment.

The data collected in these experiments were essentially frequency data but since the frequencies can vary from 0 to 25 they were considered to be fine grained enough to be used in an analysis of variance. However, problems may arise because the data have both upper and lower bounds. The variances are a function of the means to the extent that as the means approach a boundary value the variance goes to 0. This can lead to the data violating the assumption of homogeneity of variance. For this reason a preliminary test for homogeneity of variances was considered desirable. The test used was Hartley's Fmax (Winer, 1962, p93).

Occasionally a subject would not give any RID responses to any of the experimental conditions. When this occurred the subject's data were not included in the analysis of variance. This was done on the grounds that adding a string of zeros to the data affects the means but has no effect on the variances. This result was so rare as to suggest that the subjects concerned seriously misunderstood some aspect of what was required of them. Nevertheless, when it did occur some attempt was made to understand why it occurred.

At times a posteriori comparisons between means were performed. If the comparison was a pairwise comparison then Tukey's HSD test was applied. This test generates the statistic q. For more complex comparisons the statistic F was calculated using Scheffe's S method (see Kirk, 1968, pp 88-91).

When multifactorial designs are used a number of significant F ratios may be found. In such cases it may be useful to know the relative strengths of the statistical associations. Even though two variables may have significant effects on the responses, one variable may account for a much larger portion of the variance than the other. In this sense, one variable may be more important than the other. When this sort of information was required in the experiments below, an estimate of the population index "omega squared" was calculated (shown as E(w2) in the text). This index indicates how much of the variation found in the data can be accounted for by the treatment in question (see Hays, 1963, pp 381-385).

General Methodological Considerations

The discussion above about which type of response to use in the analysis highlights a common problem in perception. This is the problem of how the experimenter can be sure that a subject's response reflects his perceptual experience. In an attempt to circumvent this problem, the discussion throughout these experiments will be in terms of responses rather than percepts. It seems prudent not to commit oneself to saying that the subjects had a particular kind of perceptual experience but rather to say that they chose to make a particular response. In the worst possible case, these experiments will indicate the conditions which will cause subjects to respond in a certain way, irrespective of what they actually might have perceived. This pessimistic view is probably overcautious and it is probably true to say that there is in fact a direct relationship between the number of RID responses and the number of RID perceptual experiences. However, it is possible that it is not a one-to-one relationship.

A problem encountered in earlier studies (White, 1975; White et al, 1979) was that the absolute number of RID responses to a particular combination of stimulus conditions appeared to be partially dependant upon the other conditions in a given experimental session. A particular combination of shape, separation and ISI might give a large number of RID responses in one experiment but a relatively low number of such responses in a different experiment where the other conditions were not the same. This might be called a "context effect" because the responses depend to a certain extent on the experimental "context" in which a particular condition appears. No formal experimentation has been done on the "context effect" but it is suggested that it may account for situations where a variable has an effect within a subject but not across subjects, or where there is a marked difference in the level of RID responses for the same condition in two different experiments.

Introducing the "context effect" recognises that response biases can occur and that a subject's responses may not be completely independent. It takes into account the fact that the subject is likely to be influenced to a certain extent by the trials already seen. The danger lies in the fact that the "context effect" is so ill defined and broad in its scope that it is tempting to use it to explain any discrepanies in the data.

EXPERIMENT 3.1

In experiments on apparent motion that involve rotation in depth, the apparent motion display is often formed by reflecting a given shape through an axis to form a mirror image pair (Neuhaus, 1930; Orlansky, 1940; Kolers and Pomerantz, 1971; White et al., 1979). White et al. (1979) suggested that with this procedure the stimulus configuration is an important determinant of the amount of rotation in depth reported but were not able to identify which particular features of the stimulus configuration were important. One suggestion was that the adjacent contour elements may play an important role and this experiment was designed to explore this possibility. The adjacent contour elements are most simply thought of as the sides that face each other of the two shapes in the apparent motion display. This experiment attempted to examine the following three hypotheses concerning the role of adjacent contour elements in determining reports of rotation in depth. It also allowed some examination of the Korte's third law explanation of depth ambiguous apparent motion.

HYPOTHESIS 1. The amount of rotation in depth reported will increase as the length of any parallel adjacent contour elements is increased.

HYPOTHESIS 2. The amount of rotation in depth reported will increase as the total length of all adjacent contour elements is increased.

HYPOTHESIS 3. The amount of rotation in depth will increase as the length of all adjacent contour elements projected onto the axis of reflection is increased. In this case elements parallel to the axis will have a relatively greater effect than elements that are of the same length but at an angle to the axis.

METHOD

Stimuli. Four different mirror image pairs were used. These were formed by reflecting an octagonal figure through a vertical axis, rotating the figure through 90 degrees, reflecting it again and so on (see Figure 3.1). The octagonal figure fitted into an 40x40 mm square and was designed so that the length of parallel elements increased from pair to pair (they were in fact 5 mm, 10 mm, 15 mm and 20 mm), that the total length of adjacent contour elements decreased from pair to pair (the total lengths were 54.5 mm, 52.4 mm, 50.4 mm and 48.3 mm) and the projected length of all elements was the same for each pair (40 mm).

Procedure. A three treatment experiment was run with repeated measures on two treatments and four levels of each treatment. The first treatment was Shapes and the levels were the 4 mirror image pairs in Figure 3.1. The second treatment was ISI with levels of 25, 50, 100 and 200 msec. The third treatment was Separation, the distance between the parallel elements, with levels set at 0, 6.25, 12.5 and 25 mm. Four groups of 11 subjects were run: subjects were randomly assigned to the groups. Within

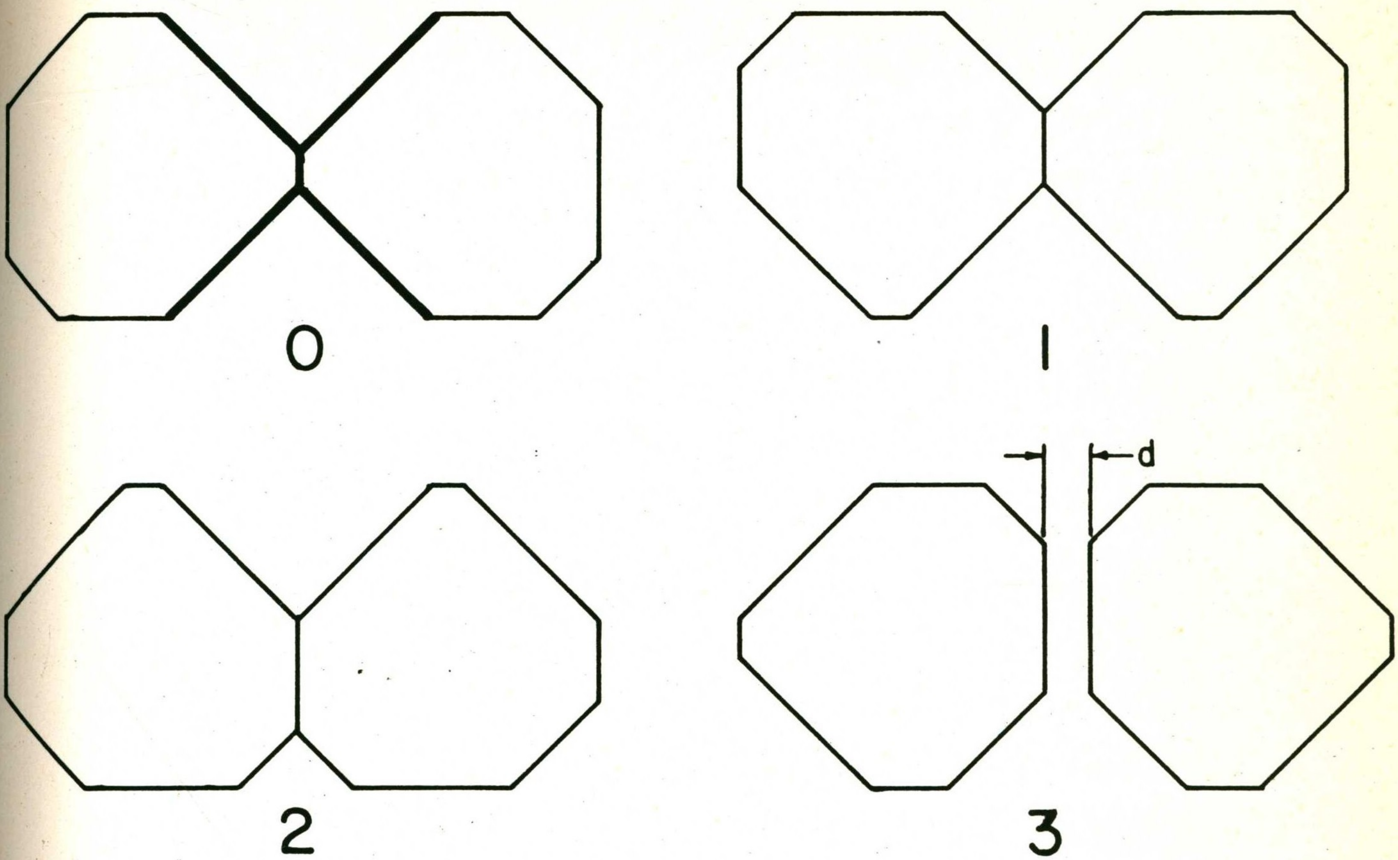


Figure 3.1 These stimulus configurations were used in Experiment 3.1, full size. The number beneath each pair is the shape pair code and is the number by which the stimulus configurations are identified in the text. The bold elements on Shape Pair 0 show what is meant by the "adjacent contour elements" for that condition. The distance marked "d" is the separation. In all presentations, the shape on the left was presented first.

each group Shapes was held constant while the ISI and Separation varied randomly. Thus each subject saw only one mirror image pair at each of the 16 possible ISI-Separation treatment level combinations.

RESULTS

Table 3.1 lists the means and standard deviations for all the treatment combinations in the experiment. The hypothesis of homogeneity of variance was supported (Fmax = 4.37, p>.05) so a 3 way analysis of variance with two repeated measures (ISI and Separation) was performed on the untransformed data. As can be seen from Table 3.2 the main effect of Separation was significant, the main effect of ISI was significant and the ISIxSeparation interaction was significant. Shapes had no significant effect on the data either as a main effect or in interactions with other variables.

The main effect of increasing the separation between the two shapes (Figure 3.2) was to decrease the number of RID responses. When the shapes share a common boundary (Separation=0) subjects reported rotation in depth on 64.5% of trials where motion was reported whereas when the separation is 25 mm this percentage dropped to 30.3%.

From an inspection of Figure 3.3, there appears to be little change in the number of RID responses as the ISI is increased from 25 to 100 msec but there is a decrease when the ISI is increased to 200 msec. A post hoc contrast of the means for 25 and 100 msec indicates that there is no significant difference between them (q=.60, p>.05). Thus there can be no difference between the means for 25, 50 and 100 msec but another post hoc constrast indicates that there is a significant difference between these three means and the mean for 200 msec (F=72.29,

TABLE 3.1

Means and S.D.'s of RID responses for Experiment 3.1

ISI (msec)	Separation (mm) 0	6.25	12.5	25
	SHAPE PAIR 0			
25	20.82	16.45	12.55	8.27
	4.00	6.43	8.04	7.78
50	19.73	17.36	13.91	6.73
	5.96	5.77	7.49	5.58
100	18.27	17.00	12.91	6.82
	5.03	5.88	7.56	6.51
200	16.45	13.18	10.73	5.64
	6.11	7.13	6.51	6.47
	SHAPE PAIR 1			
25	17.45	15.36	12.18	9.91
	4.94	6.06	4.86	4.60
50	15.82	13.09	12.18	9.82
	6.00	5.07	4.63	5.49
100	16.18	15.55	12.18	8.27
	4.55	5.00	4.37	4.65
200	14.36	9.09	9.91	10.00
	4.16	5.57	5.71	6.11
	SHAPE PAIR 2			
25	12.82	11.18	9.64	6.27
	6.23	3.86	5.28	3.96
50	14.64	11.82	8.45	7.00
	5.65	5.20	5.03	4.49
100	14.55	12.82	9.45	8.27
	6.10	4.45	4.29	5.22
200	12.00	9.73	7.91	5.82
	5.89	6.18	4.89	4.30
	SHAPE PAIR 3			
25	19.27	14.09	10.73	7.64
	5.01	5.11	5.21	4.92
50	16.82	14.18	11.55	8.09
	6.03	5.44	6.07	4.60
100	16.91	12.73	10.09	7.09
	4.29	5.94	3.99	5.18
200	12.09	8.18	6.27	5.55
	7.40	5.36	4.29	3.85

Note- For each ISI, the means are in the first row and the standard deviations are in the second row.

TABLE 3.2

Analysis of Variance Table for Experiment 3.1

SOURCE	SS	DF	MS	F
BETWEEN SUBJECTS	13064.8	43		
A (Shapes)	1157.4	3	385.8	1.30
Error A	11907.4	40	297.7	
WITHIN SUBJECTS	18912.3	660		
B (Separation)	7041.4	3	2347.2	50.00 *
AxB	587.1	9	65.2	1.39
Error B	5632.7	120	46.9	
C (ISI)	1040.2	3	346.7	24.30 *
AxC	234.4	9	26.0	1.83
Error C	1712.2	120	14.3	
BxC	202.2	9	22.5	3.62 *
AxBxC	226.8	27	8.4	1.35
Error BxC	2235.2	360	6.2	
TOTAL	31976.1	703		

* Significant at the .05 level

$p < .05$). The effect is not as marked as the effect due to separation: reports of rotation in depth ranged from 51.2% of motion responses at 25 msec to 39.3% for an ISI of 200 msec.

The nature of the ISI by Separation interaction (Figure 3.4) seems to be that the separation sets an overall level for the RID responses which can then be modified by ISI. Thus when the separation is small and the overall level of RID responses is high there is scope for the ISI to reduce that level but when the level is already low because of a relatively large separation then it is difficult to reduce these reports further by manipulating ISI. It might be argued that

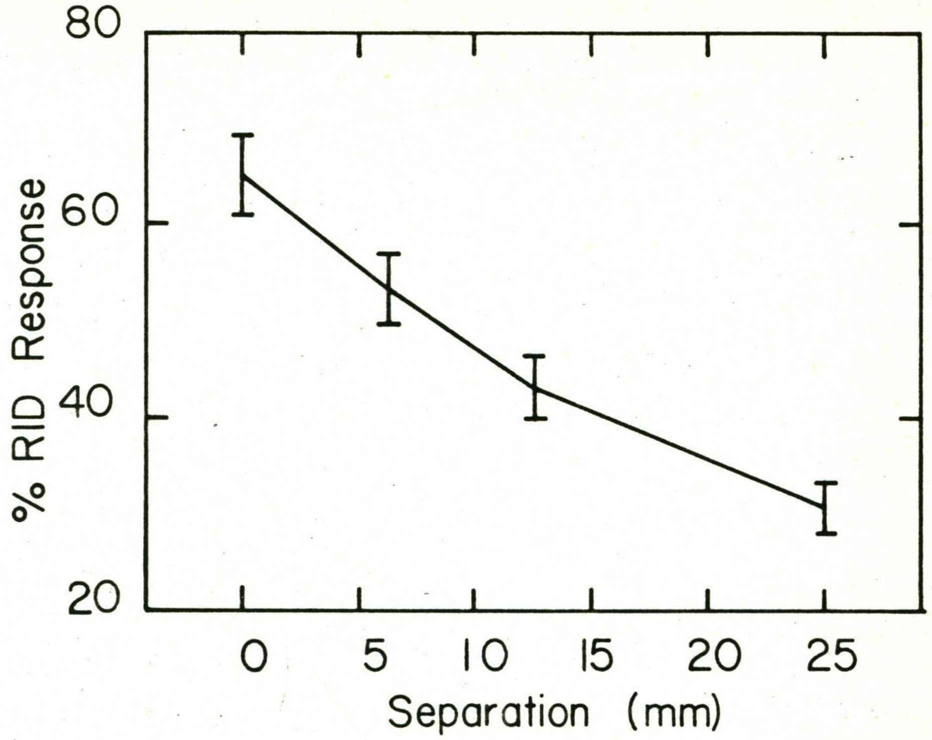


Figure 3.2 The main effect of Separation in Experiment 3.1. In this and in all subsequent graphs the error bars are + 1 S.E. of the mean.

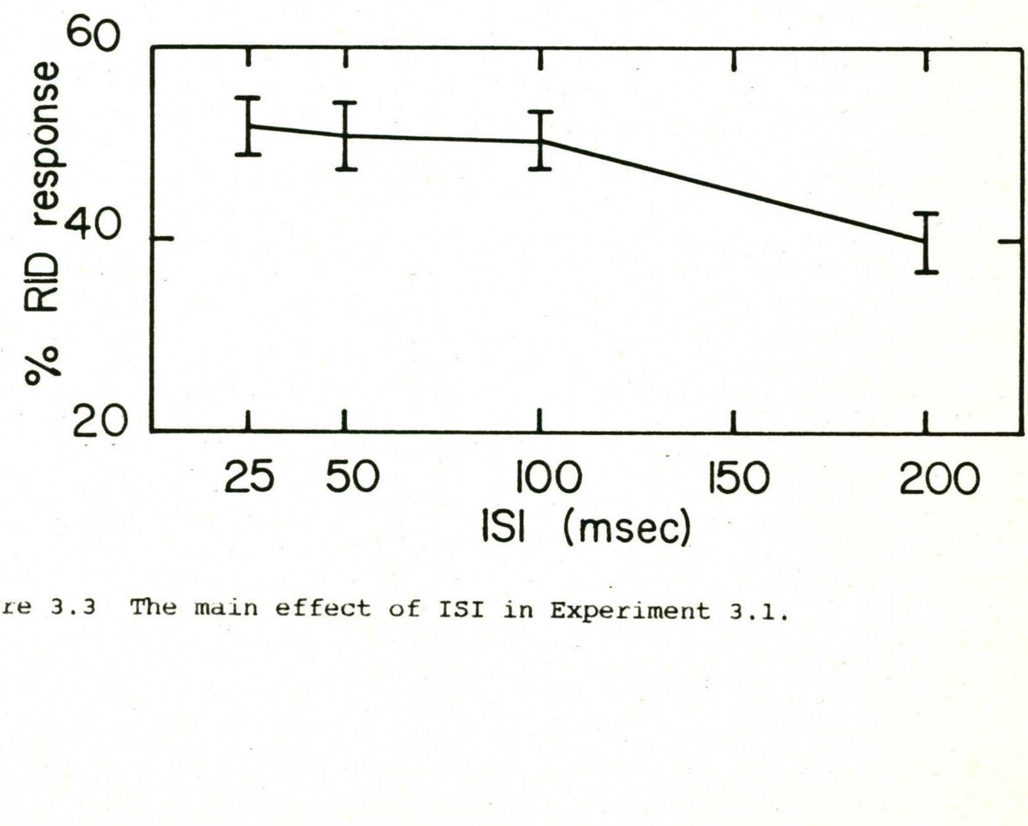


Figure 3.3 The main effect of ISI in Experiment 3.1.

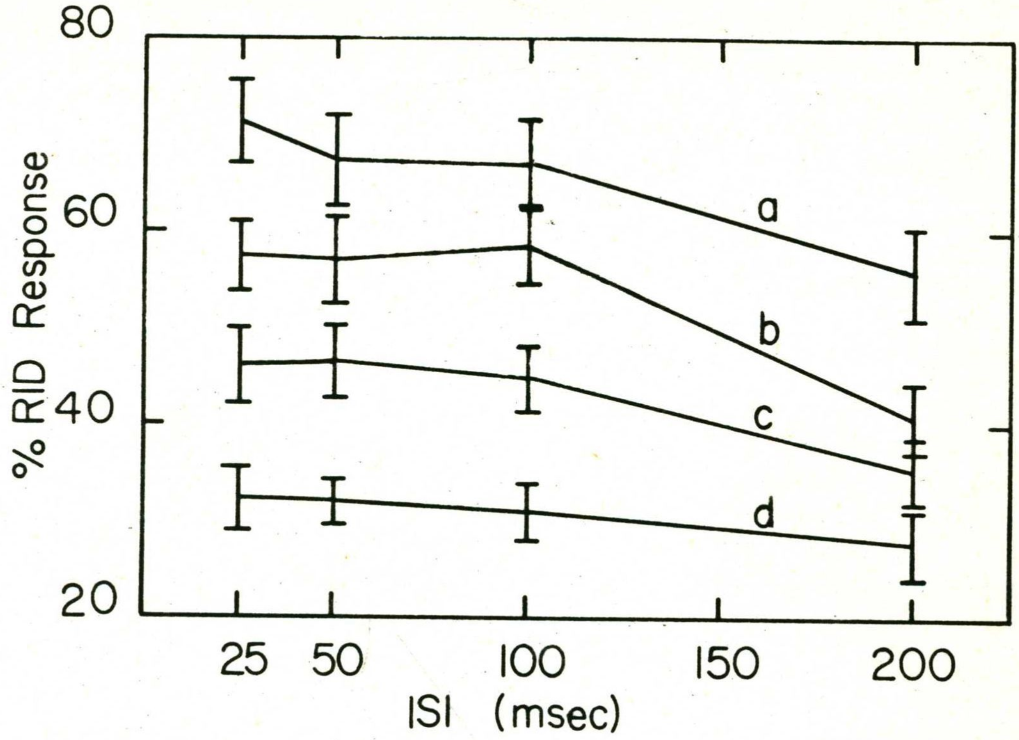


Figure 3.4 The Separation x ISI interaction in Experiment 3.1. The levels of Separation are indicated by the letters on the curves. These levels are 0 mm (a), 6.25 mm (b), 12.5 mm (c) and 25 mm (d).

exactly the reverse happens and that ISI dominates the responses. However, the Separation effect accounts for a large proportion of the variance (E(w2)=.364) whereas the ISI and the interaction only have weak, although statistically reliable, effects (E(w2)=.053 and E(w2)=.008, respectively).

DISCUSSION

The observed effects of Separation and ISI allow some conclusions to be drawn about the plausibility of the Korte's third law explanation of depth ambiguous apparent motion. In the first instance, the finding that shapes did not affect RID responses is consistent with this explanation. For a fixed ISI, the Korte's third law explanation would predict that increasing the separation will reduce the number of RID responses because this results in an increase in the phenomenal path length for the apparent movement. A reduction in the number of RID responses was found for increasing separation. However, the Korte's third law explanation was based on the result that RID responses increase wih increasing ISI, which is exactly the reverse of what was found in this experiment. Even though the separation data support the Korte's third law explanation, the ISI data do not.

Another problem for the Korte's third law explanation lies in the relative contributions of Separation and ISI to the observed number of RID responses. The main effect of Separation accounted for nearly 7 times as much of the variance as ISI, suggesting that in this sense Separation is the more important variable. The Korte's third law explanation assumes that the most important determinant of RID responses will be the ISI but these data suggest that it is not as important as separation. This experiment provides evidence both for and against the Korte's third law explanation. However, the ISI results are most at variance with previous findings and the corner stone of the Korte's third law explanation is the effect of ISI. Overall, the data from this experiment would seem to weaken the Korte's third law explanation.

Since there was no main effect of Shapes, no comment can be made on the three hypotheses put forward in the introduction to this experiment. The total lack of any effect due to the different mirror image pairs was most surprising considering the large consistent effect found in earlier work (White et al., 1979). Two observations can be made about this result. The first is that the variability across subjects was high so if there was any effect it has been masked by the noisy data. Secondly, in this experiment in contrast to White et al. (1979), any given subject saw only one of the four different mirror image pairs so subjects could not have used shape to differentiate their responses. It is possible that different mirror image pairs will give significantly different patterns of responses if a subject views a number of different pairs. In short, this result could be an example of a type of "context effect" in that the lack of an appropriate "shape" context led to the differences between the shapes being obscured.

EXPERIMENT 3.2

The aim of this experiment was to see if the different mirror image pairs used in Experiment 3.1 would have an effect on RID responses when every subject viewed all four pairs.

METHOD

Stimuli. The four mirror image pairs shown in Figure 3.1 were used.

Procedure. A two treatment design was run with two repeated measures and four levels of each treatment. The treatments were Separation and Shapes and the levels were the same as those used in Experiment 3.1. Ten subjects were used and they saw each of the 16 Shape-Separation treatment combinations at one fixed ISI of 25 msec.

RESULTS

Table 3.3 shows the means and standard deviations for all the treatment combinations used in this experiment. The hypothesis of homogeneity of variance was supported ($F_{max} = 2.99$, $p > .05$) so a two way analysis of variance with two repeated measures was performed on the untransformed data. As can be seen from Table 3.4, the main effect of both Shapes and Separation was significant but the interaction between them was not. The effect of Separation was similar to the previous experiment but the magnitude of the effect is smaller in this experiment. Referring to Figure 3.5, increasing separation causes the average RID response to decrease from 64.4% when the separation is zero

TABLE 3.3

Means and S.D.'s of RID responses for Experiment 3.2

	Shape Pair Code			
Separation (mm)	0	1	2	3
0	20.7	11.9	12.0	19.8
	3.77	7.03	5.35	6.24
6.25	19.4	10.5	10.4	20.5
	3.88	6.20	6.37	4.94
12.5	17.9	9.9	8.4	18.8
	3.88	5.65	5.54	6.01
25.0	15.7	7.1	5.3	16.4
	5.51	5.03	5.73	6.51

Note- For each Separation, the means are in the first row and the S.D.'s are in the second row.

TABLE 3.4

Analysis of Variance Table for Experiment 3.2

SOURCE	SS	DF	MS	F
BETWEEN SUBJECTS	2569.3	9		
WITHIN SUBJECTS	6395.4	150		
A (Separation)	566.8	3	188.9	10.36 *
Error A	492.4	27	18.2	
B (Shape)	3412.5	3	1137.5	20.04 *
Error B	1532.7	27	56.8	
AxB	39.7	9	4.4	1.02
Error AxB	351.4	81	4.3	
TOTAL	8964.7	159		

* Significant at the .05 level

to 44.5% when the separation is 25 mm (a drop of 19.9% as against 34.2% in the previous experiment). Unlike the previous experiment, Shapes did have a significant effect.

DISCUSSION

Since Shapes did have an effect on RID responses in this experiment, it is possible to see if the data are consistent with any of the three hypotheses put forward in the introduction to Experiment 3.1. These hypotheses concerned the role of adjacent contour elements in determining the number of RID responses.

The first hypothesis suggested that the total length of parallel elements determines the the number of RID responses. If this were the case one would predict that the curve in Figure 3.6 would be monotonic increasing from shape to shape since the length of the parallel elements was monotonic increasing. This is clearly not the case.

The second hypothesis was that the total length of the adjacent contour elements, including any parallel elements, determines the number of rotation in depth responses. In this case, the curve in Figure 3.6 should be monotonic decreasing since these lengths were monotonic decreasing. At best, one would predict that the curve would be flat given the very small differences in length. In neither case do the data confirm the hypothesis.

The third hypothesis was that the length of adjacent contour elements projected onto the axis of reflection determines the amount of rotation in depth responses. If this hypothesis were true then the curve in Figure 3.6 would be flat and this is also clearly not the case.

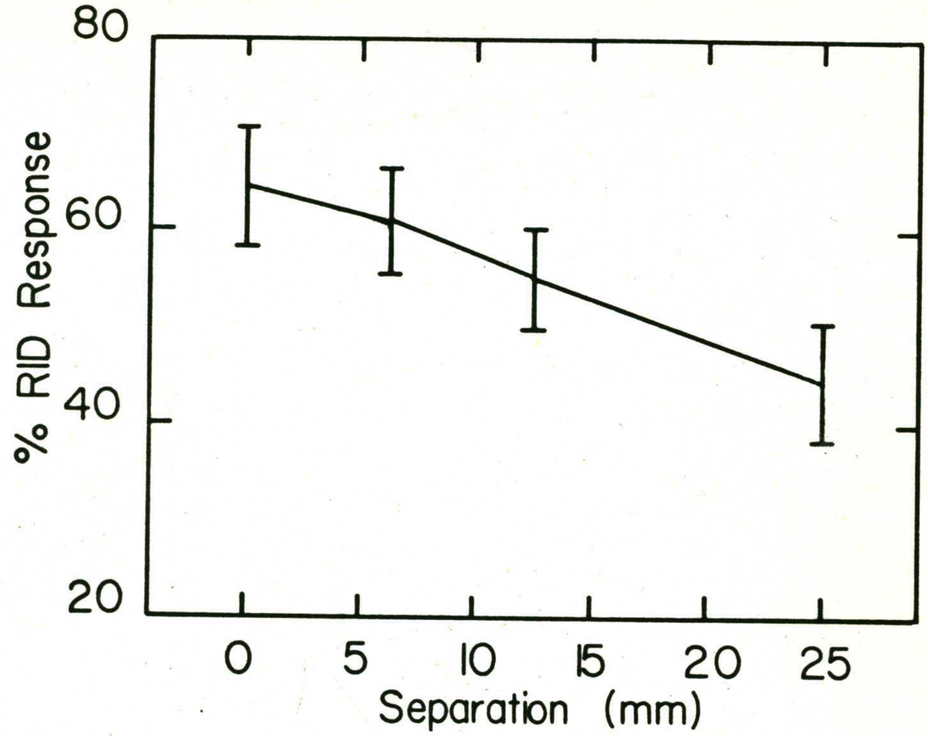


Figure 3.5 The main effect of Separation in Experiment 3.2.

There were differences between the mirror image pairs used in these two experiments, apart from the adjacent contour elements. One property that the particular octagon used in these experiments had was that it appeared to have a direction, insofar as it seemed to have a "pointed" end and a "blunt" end, a top and a bottom. Referring to Figure 3.1, the shapes in Pair 0 seemed to be pointing towards each other; their directions were opposed. The same was true for Pair 3. Although in this case the shapes were pointing away from each other. In Pair 1 both shapes were pointing up and in Pair 2 they were both pointing down; the directions of the shapes in these cases were

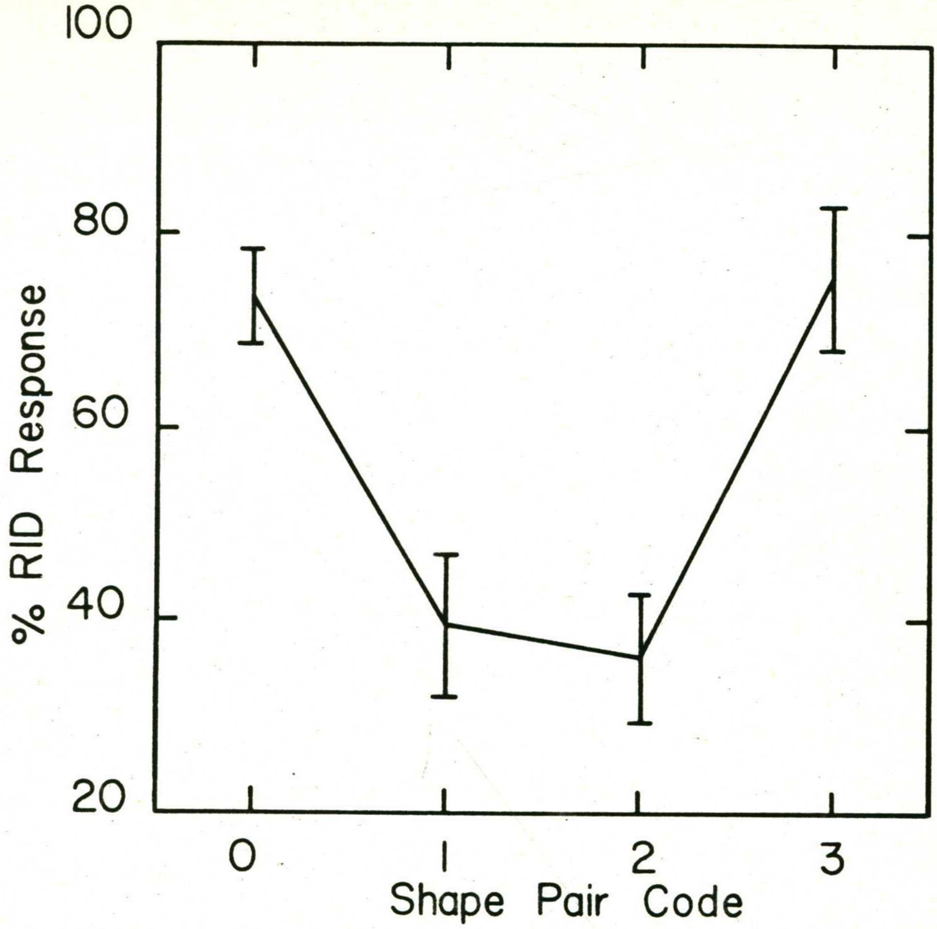


Figure 3.6 The main effect of Shape in Experiment 3.2. The shape pair codes refer to the codes in Figure 3.1.

parallel. The experimental data (Figure 3.6) suggest that Pairs 0 and 3 produced nearly equal numbers of RID responses as did Pairs 1 and 2 but that there were many more reports of rotation in depth for Pairs 0 and 3 than for Pairs 1 and 2. When the shapes were opposed in direction they predominately appeared to rotate in depth but when they were parallel they tended not to appear to rotate in depth. The data are therefore consistent with the idea that the "direction" of the shapes is an important factor in determining RID responses.

These octagonal shapes also have other properties such as area, perimeter length, number and size of angles and so on which could be important factors in determining RID responses. However, this experiment suggests that all of these factors must be of minimal importance because they were held constant between the experimental conditions. Within each pair the two shapes were mirror images so the area, perimeter, angles, etc. were unchanged. Furthermore, the only difference across the pairs was the orientation of the first shape used to form the mirror image pair. It seems that the obtained results must in some way be due to a global property of the shape and that this property is related to the perceived orientation of the shape.

Experiments 3.1 and 3.2 have shown that the separation between the two shapes is an important variable. This can be interpreted in the light of the above discussion of the direction of the shapes. It is suggested that the visual system compares the two shapes presented during the apparent motion sequence in an attempt to find the answer to two questions. The first question being: Are the two shapes the same shape in different orientations? The second being: Is the orienation change consistent with a rotation in depth? It seems plausible that such a comparison will be facilitated by the shapes being close together in space. As the separation is increased it may become more difficult to detect the features responsible for determining the direction of the shapes or to determine the relationship between such features which would reduce the number of RID responses.

The effect of ISI can be explained in similar terms. The visual system must store information about the first shape in order to be able to compare it to the second. It would follow that the longer the time interval between presentations then the more likely it is that the stored information will decay making the comparison more difficult and less accurate which would lead to a reduction in the number of RID responses.

It is known that the perception of apparent motion tends to "break down" as the separation between the end points of the motion is increased in time and space (see, for example, Korte, 1915; Neuhaus, 1930). In these experiments there were very few "no motion" responses which indicates that motion did not break down for these subjects. The stimulus duration and ISI's used in these experiments were found by Kolers and Pomerantz (1971) to produce about 2% "no motion" responses on average in their study. They were used in these experiments in order to try to maximise the probablity of reporting motion and this seems to have been successful.

However, with naive subjects one might well expect a higher proportion of NM responses than with trained subjects. Also, these subjects did not supply good descriptions of the appearance of the phenomenal object when it appeared to undergo 2D motion although they could describe rotation in depth quite well. Initially it seems plausible that these naive subjects may not have been clear about what

2D motion should look like and so categorised their responses as "rotation in depth" and "anything else". One could advance the hypothesis that the observed decrease in RID responses is due to a spurious increase in 2D motion responses caused by an increase in the breakdown of motion. The intial plausibility for this hypothesis comes from the fact that fewer motion responses are expected as the ISI and separation are increased. A statistical examination of the actual NM responses might settle the question but the observed frequencies are so low as to preclude any meaningful conclusions. The average "no motion" response within an experiment varies from a frequeny of about .5 to about 2.5, although the higher figure is rare.

However, work by Korte (1915) and Neuhaus (1930) on the relationship between ISI and spatial separation and the probability of reporting motion indicates that the ISI is the more important variable. In a careful examination of Korte's earlier work, Neuhaus found that increasing the ISI destroyed the apparent movement much more rapidly than increasing the separation. He found that a tripling of the spatial separation only requires a doubling of the ISI to maintain "good" motion. If the observed decrease in RID responses is in fact due to the motion breaking down, but being misreported as 2D motion, then the magnitude of the Separation effect in these experiments should be less than the magnitude of the ISI effect. If the 2D motion frequencies were spuriously inflated with no motion responses, then one would expect to see a large decrease in RID responses with increasing ISI and a relatively smaller decrease in RID responses with increasing separation. In fact, exactly the opposite is true.

In Experiment 3.1 Shape was found to have no effect on the number of RID responses whereas it did have a significant effect in Experiment 3.2. In Experiment 3.1 a given subject saw only one shape pair whereas in Experiment 3.2 all subjects saw 4 different shape pairs. In the latter experiment the subjects could see how the shapes fitted into a shape "context" and could differentiate their responses on the basis of shape. The data suggests that the "context" in which a particular condition is viewed will determine in part the proportion of times the subject will report rotation in depth.

If subjects consciously decided that a particular condition was the best (or worst) example of rotation in depth, one might expect that they would always say the same thing when that condition was presented to them. Thus, if the operation of the "context" effect was purely a conscious activity of the subject, response frequencies of 100% or 0% rotation in depth would be common. In practice, the average RID response rate tends to vary between 20% and 80% which suggests that subjects don't always say the same thing when a particular condition is shown to them which in turn suggests that the "context" effect is not the result of a purely conscious process on the part of the subject.

The existence of a "context effect" does not necessarily mean that differences between conditions will only be observed if all conditions are given to all subjects. The suggestion is that the experimental "context" will tend to enhance any differences that already exist between different conditions, provided that all those conditions are shown to the subject. Given the large individual differences that tend to occur in these experiments, differences between experimental groups that receive different conditions (as in Experiment 3.1) may be difficult to detect statistically. A corollary of this is that comparisons of results from different experiments should rely more on the rank ordering of conditions rather than the absolute level of RID responses.

EXPERIMENT 3.3

In the first experiment the data suggested that ISI has a relatively weak effect on the number of RID responses (see also White et al., 1979). This is in marked contrast to earlier findings (see in particular Kolers and Pomerantz, 1971). In order to explore this apparent discrepancy, an experiment similar to Experiment II of Kolers and Pomerantz (1971) was undertaken.

One of the notable features of their experiment was that the shapes were superimposed so in the present experiment the shapes were also spatially superimposed. It has been argued (White et al., 1979) that superimposition may enhance any effect ISI might have to the detriment of any effect that the shapes may have. Thus superimposing the shapes may produce the finding that ISI has a significant effect on the number of RID responses and that Shape does not.

METHOD

Stimuli. The stimuli are illustrated in Figure 3.7. The shapes are exactly the same as those used in Experiments 3.1 and 3.2 except that they have been spatially superimposed. It is the superimposition that makes the illustrated stimulus configurations difficult to interpret.

Procedure. A two way design was run with four levels of Shape (illustrated in Figure 3.7) and four levels of ISI (25, 50, 100 and 200 msec.). Ten subjects were run and each subject saw all of the 16 possible Shape-ISI combinations.

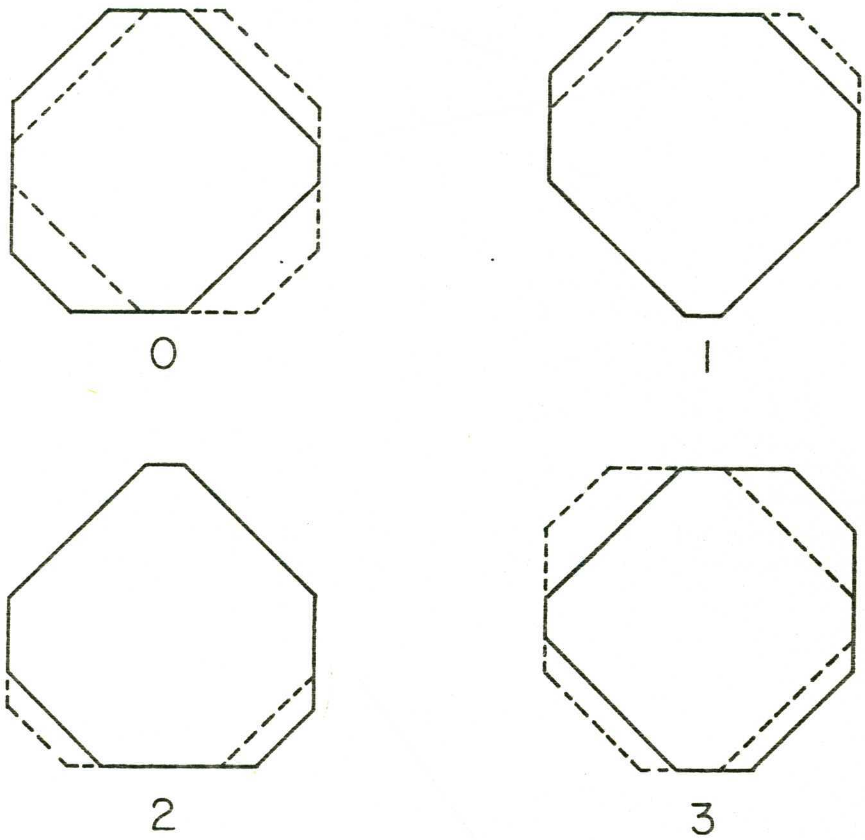


Figure 3.7 The stimulus configurations used in Experiment 3.3, full size. Note that they are the same as those used in Experiment 3.1 except that the two shapes are spatially superimposed. For each shape pair, the solid shape appeared first followed by the shape represented by dotted lines. The numbers beneath each stimulus configuration are the shape pair codes.

RESULTS

Table 3.5 is a table of the means and standard deviations of all the treatments used in this experiment. The data did not violate the assumption of homogeneity of variance (Fmax=2.17, p>.05) so a 2 way ANOVA with repeated measures was performed on the untransformed data. As

TABLE 3.5

Means and S.D.'s of RID responses for Experiment 3.3

	Shape Pair Code			
ISI (msec)	0	1	2	3
25	14.6	8.9	9.6	13.4
	7.31	7.09	6.80	8.52
50	14.5	8.5	8.4	15.9
	7.12	6.12	7.12	7.83
100	16.9	9.9	9.0	16.1
	8.14	6.64	6.74	7.20
200	16.3	10.3	7.6	16.4
	8.59	6.29	5.83	6.39

Note- For each ISI, the first row contains the means and the second row contains the standard deviations.

TABLE 3.6

Analysis of Variance Table for Experiment 3.3

SOURCE	SS	DF	MS	F
BETWEEN SUBJECTS	2751.6	9		
WITHIN SUBJECTS	7273.8	150		
A (ISI)	50.2	3	16.7	0.65
Error A	690.8	27	25.6	
B (Shapes)	1695.1	3	565.0	3.47 *
Error B	4390.5	27	162.6	
AxB	94.1	9	10.5	2.40 *
Error AxB	3531.3	81	4.36	
TOTAL	10025.4	159		

* Significant at the .05 level

can be seen from Table 3.6, the main effect of Shapes was significant and the ISI x Shapes interaction was significant.

In Figure 3.8 the main effect of Shapes has been plotted. This graph is very similar to Figure 3.6 from Experiment 3.2 and the stimulus configurations are formed from the same shapes. Shape pairs 0 and 3 are formed by superimposing octagons that appear to point in opposite directions whereas Shape pairs 1 and 2 are formed by superimposing octagons that appear to point in the same direction.

There was no significant variation of RID responses as the ISI was varied. However, there was a significant ISI x Shape interaction. An inspection of Figure 3.9 shows that it is not easy to interpret the nature of this interaction. It appears that for three of the stimulus configurations used (Pairs 0, 1 and 3) the effect of increasing ISI is to slightly increase the number of RID responses. For shape pair 2 there is a slight decrease in the number of RID responses with increasing ISI. This interaction only accounts for less than 1% of the variance (E(w2)=.008) so, even though the significant F ratio indicates that the interaction is reliable in this group of subjects, it is probably not an important effect.

DISCUSSION

When the octagons point in opposite directions there are more RID responses than when the octagons point in the same direction. The data from this experiment are thus consistent with the hypothesis that

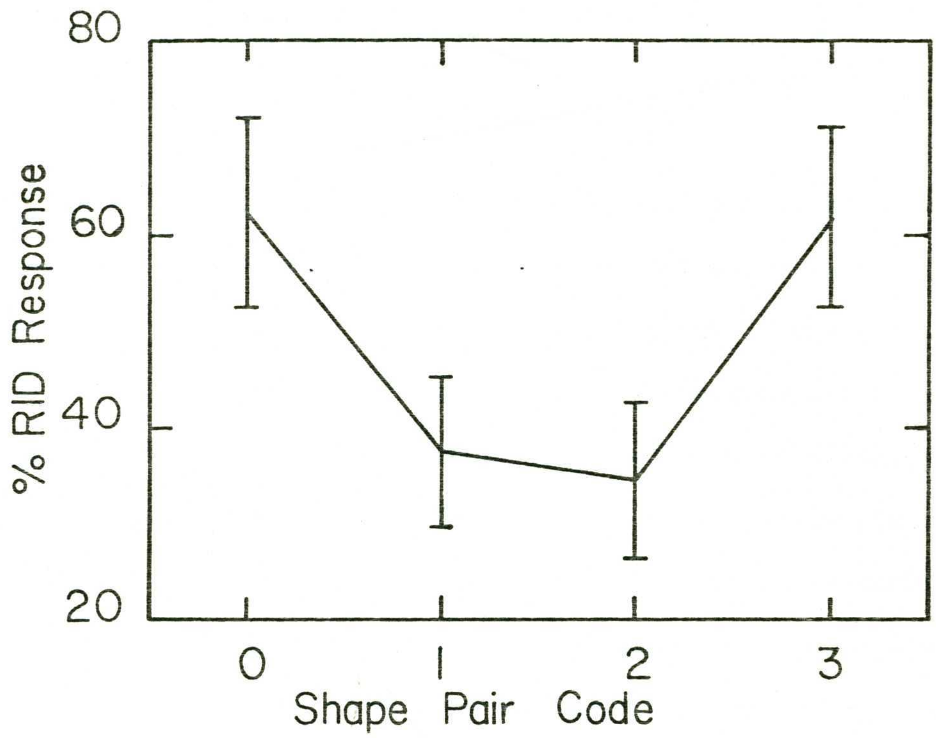


Figure 3.8 The main effect of shape in Experiment 3.3. The shape pair codes refer to the stimulus configurations in Figure 3.7.

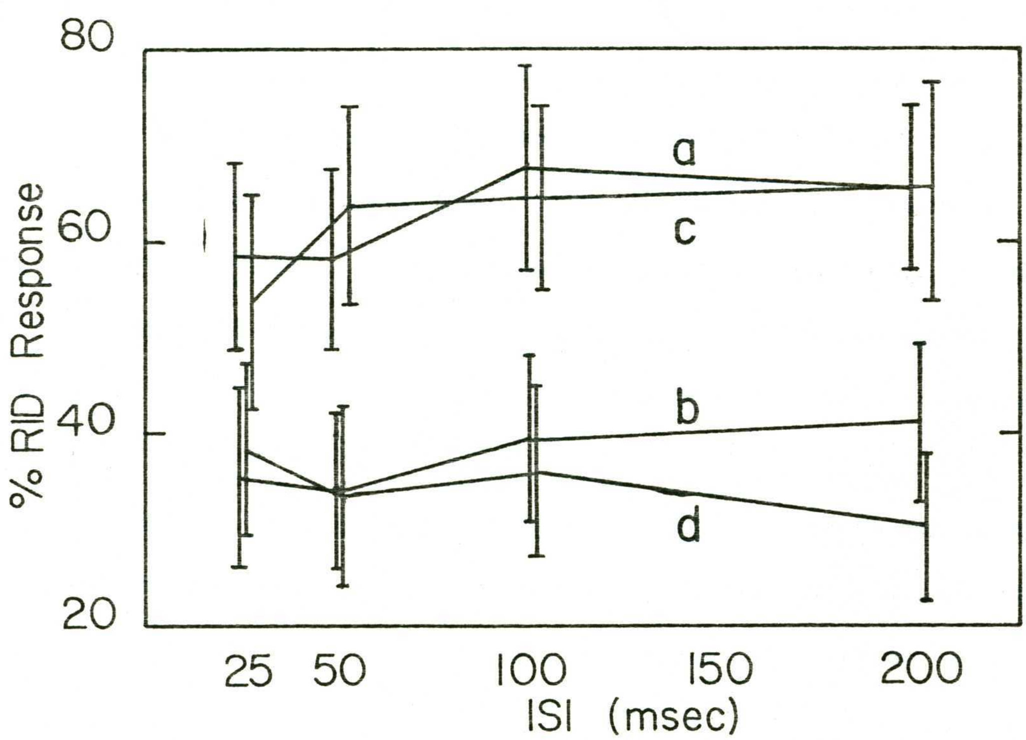


Figure 3.9 The ISI x Shape interaction in Experiment 3.3. The levels of Shape are indicated by the letters on the curves. These levels are Shape Pair 0 (a), Shape Pair 1 (b), Shape Pair 2 (c) and Shape Pair 3 (d).

rotation in depth depends on the visual system recognising that the two shapes are in fact the same shape in different orientations.

However, superimposing the shapes enables new interpretations to be placed on these stimulus configurations. Referring to Figure 3.7, one can see that a large portion of the figures in shape pairs 1 and 2 occupy the same spatial location whereas this is not true for shape pairs 0 and 3. It is plausible that there would be a tendency for pairs 1 and 2 to be perceived as an object, that it is mostly stationary, but which has a top (or bottom) that "wobbles". This presumably would be reported as 2D motion. Only small portions of the figures in shape pairs 0 and 3 occupy the same spatial location so most parts of the figure will appear to change spatial location. Thus shape pairs 0 and 3 are likely to produce the illusion of a whole object moving rather than a stationary object with a moving portion, as in shape pairs 1 and 2. When an ordinary object rotates in depth, all parts of that object appear to move with the possible exception of those parts that lie on the axis of rotation. Therefore, if shape pairs 1 and 2 are perceived to be largely stationary then it is impossible for them to be reported as rotating in depth. Since it is extremely unlikely that shape pairs 0 and 3 would be perceived as being largely stationary they are more likely to be reported as rotating in depth for this reason alone.

It appears likely that superimposing the shapes introduces a new factor into the experimental situation by suggesting new interpretations of the stimulus configuration, possibly by giving rise to new "gestalten". In this particular experiment this new factor tends to preserve the difference between shape pairs 0 and 3 and shape pairs 1 and 2 but it is conceivable that in other situations superimposition may tend to reduce differences between stimulus configurations.

EXPERIMENT 3.4

It was argued that the adjacent contour element hypothesis cannot account for the effects due to the shapes observed in the first three experiments. However, it could be argued that the adjacent contour elements do affect RID responses in a way that has not been considered. A critic might point out that the adjacent contour elements for the stimulus configurations used so far have all been different and that this accounts for the fact that differences were found between the stimulus configurations. It could be that the three hypotheses that were discarded were simply not the correct hypotheses to put forward.

To overcome this objection, a group of stimulus configurations were used where the adjacent contour elements were identical. The adjacent contour element hypothesis would predict that all these stimulus configurations should give similar results. Similarly another group of stimulus configurations were used where each of the stimulus configurations had different adjacent contour elements. The adjacent contour element hypothesis would predict that these stimulus configurations would give dissimilar results.

METHOD

Stimuli. The stimuli are illustrated in Figure 3.10. They were formed by taking the four different orientations of the basic octagon used in Experiments 3.1, 3.2 and 3.3 and converting the side most distant from the axis of rotation into a square. These four shapes fit into the same 40 x 40 mm square that inscribed the octagon used in Experiment 3.1.

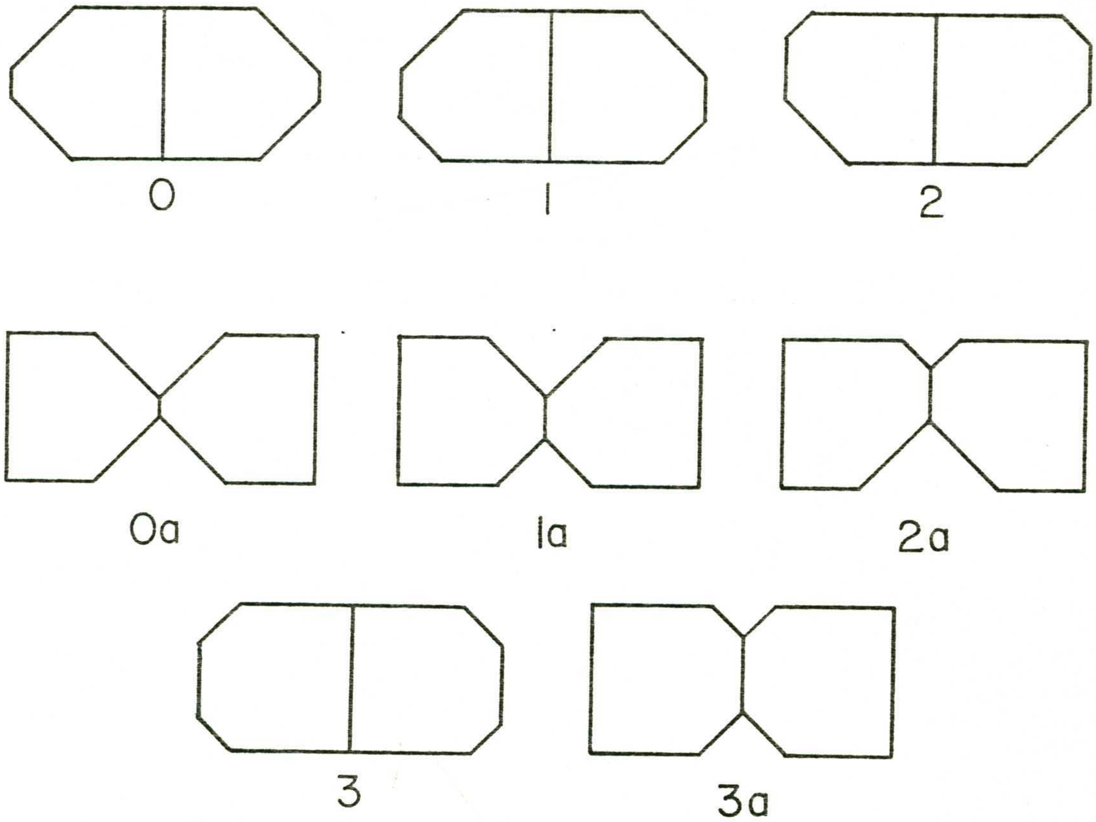


Figure 3.10 The stimulus configurations used in Experiment 3.4, half size. The Shape Pair codes are show beneath each stimulus configuration.

Procedure. A 2 way design was run with repeated measures on both treatments. The first treatment was separation and the levels were 0 and 12.5 mm. The second treatment was Shape and the 8 levels were the 8 different hexagon pairs shown in Figure 3.10. Ten subjects were run and all subjects saw all 16 of the possible Separation x Shape combinations at one fixed ISI of 25 msec.

RESULTS

The results are shown in Table 3.7 which is a table of the means and standard deviations for all the treatment combinations used in this experiment. The data did not violate the assumption of homogeneity of

TABLE 3.7

Means and S.D.'s of RID responses in Experiment 3.4

Shape Pair Code	Separation (mm) 0	12.5
1a	18.8	9.7
	5.93	6.89
2a	18.2	10.4
	5.49	7.02
3a	19.6	9.7
	5.94	6.03
4a	18.2	9.6
	6.34	7.34
1b	20.1	10.3
	4.16	8.76
2b	19.3	12.4
	6.18	7.67
3b	17.5	11.9
	7.09	8.04
4b	18.6	11.1
	4.52	7.85

Note- For each Shape Pair Code, the means are in the first row and the S.D.'s are in the second row.

TABLE 3.8

Analysis of Variance Table for Experiment 3.4

SOURCE	SS	DF	MS	F
BETWEEN SUBJECTS	3325.9	9		
WITHIN SUBJECTS	6618.9	150		
A (Separation)	2656.9	1	2656.9	11.50 *
Error A	2079.0	9	231.0	
B (Shape Pair)	52.0	7	7.4	.38
Error B	1238.9	63	19.7	
AxB	77.5	7	11.1	1.36
Error AxB	514.6	63	8.2	
TOTAL	9944.8	159		

* Significant at the .05 level

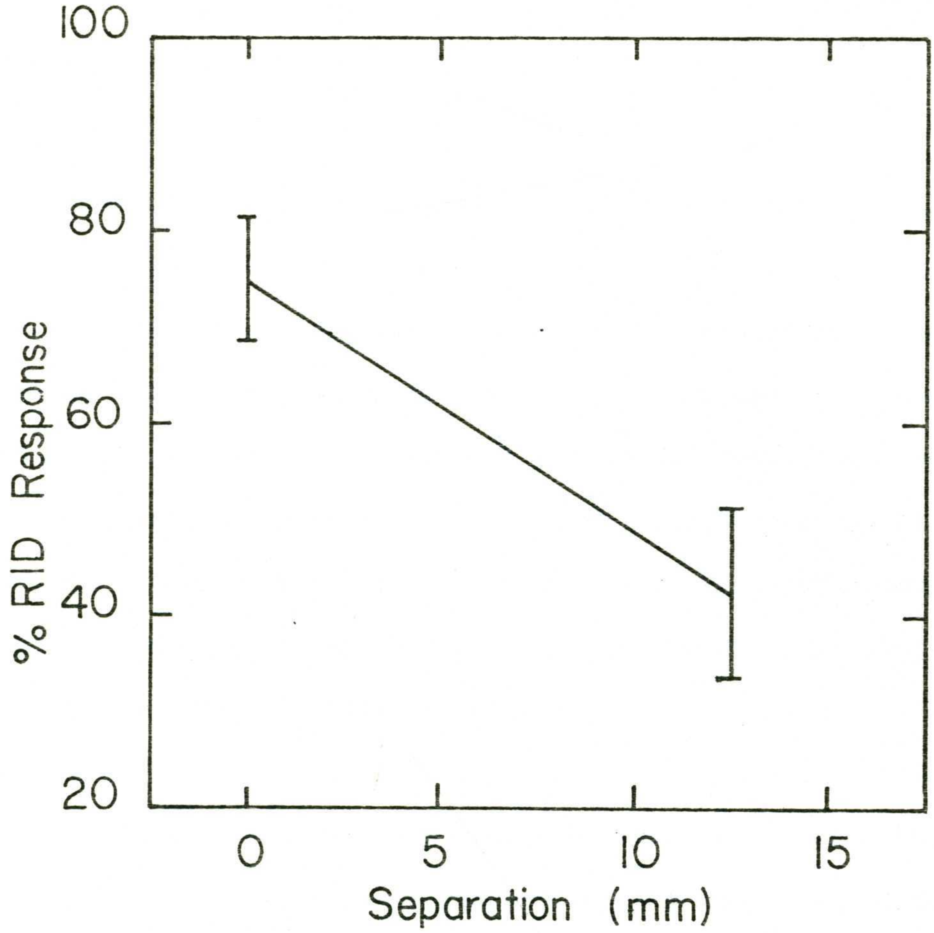


Figure 3.11 The main effect of Separation for Experiment 3.4.

variance (Fmax=4.44, p>.05) so a 2 way ANOVA with 2 repeated measures was performed on the untransformed data. The results have been tabulated in Table 3.8 where it can be seen that the only significant effect is the main effect of Separation. The effect of separation has been graphed in Figure 3.11 which shows that the effect of increasing the separation is to decrease the amount of rotation in depth reported. This result is consistent with the findings of Experiment 3.2 where a detailed discussion can be found.

DISCUSSION

There was no significant effect due to Shape. This means that there was no difference between the group of stimulus configurations that had identical adjacent contour elements and the group that had different adjacent contour elements. Furthermore, there were no differences within the group of stimulus configurations where the adjacent contour elements were all different. In the light of these results, it does not seem likely that the differences found between the stimulus configurations used in the first three experiments is are due to different adjacent contour elements.

The data from this experiment are consistent with the hypothesis that RID responses are determined by the perceived direction of the shapes. Insofar as direction can be ascribed to these shapes, the stimulus configurations are all made up of shapes that point towards each other or shapes that point away from each other. In other words, in this experiment the direction factor was constant for all stimulus configurations. In these circumstances, one would not expect to find a difference between the stimulus configurations. Some of these shapes are more "pointed" that others (cf. 1a, 1b and 4a, 4b) which might be expected to be an important consideration. However, it may be the case that once the perceived directions are opposed then differences in how well the shape specifies a particular direction are irrelevant.

EXPERIMENT 3.5

The main aim of this experiment was to see how increasing the size of the shapes affected reports of RID. Even though it is hypothesised that global properties of the shapes determine RID responses, these global properties must arise from local elements of the shapes. With very small shapes fine details may be lost and the global features of the shapes may not emerge. Very large shapes may not be able to be taken in at a single glance since each figure was only displayed for 200 msec. There may not be enough time available to do a visual search over the shape. Local features may be missed in very large shapes as well and this will also affect the emergence of global properties. Thus one might expect to find a reduction in RID responses for very small and very large shapes.

This experiment also manipulated Separation in order to answer the question of whether the observed separation effect is due to the absolute separation between shapes or the separation as a proportion of the overall size or width of the shapes. In the latter case, small shapes should be more affected by changes in separation than large shapes. In either case a main effect of separation was expected but if the separation as a proportion of the size or width of the shapes is important, then a Size x Separation interaction was expected, as well.

METHOD

Stimuli. The shapes used were shape pair 0 in Figure 3.1 (see Figure 3.12) but at different sizes. The different sizes can be specified by referring to the length of the sides of the inscribing square. These lengths were 20 mm, 40 mm, 60 mm and 80 mm, approximately equal to 2.3, 4.6, 6.8 and 9.1 degrees of visual angle, respectively. Figure 3.12 indicates the code numbers that were assigned to each of these sizes. Note that the octagon used in Experiment 3.1 could be inscribed in a 40 x 40 mm square.

Procedure. A 2 way design was run with two repeated measures: the two treatments were Size and Separation. The levels of Separation were 0, 6.25 mm, 12.5 mm and 25 mm. Ten subjects were tested and each subject saw all of the 16 possible Size x Separation treatment combinations at one fixed ISI of 25 msec.

RESULTS

Table 3.9 is a table of the means and standard deviations of all the treatment combinations used in this experiment. The data did not violate the assumption of homogeneity of variance ($F_{max}=3.79$, $p>.05$) so a 2 way analysis of variance with two repeated measures was performed on the untransformed data. The results are tabulated in Table 3.10 where it can be seen that the main effects of Size and Separation are significant.

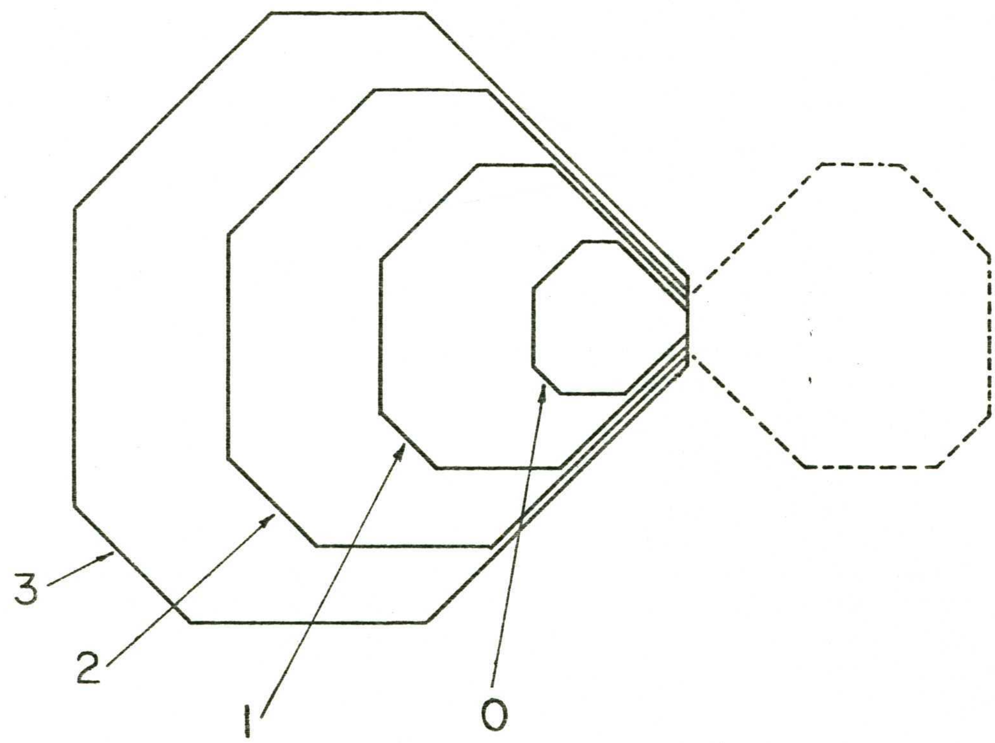


Figure 3.12 Illustration showing the relative sizes of the 4 different stimulus configurations used in Experiment 3.5, full size. The Size codes are also shown. The dotted figure illustrates the position of the second shape in the presentation sequence. The second shape was, of course, the appropriate size.

There was no significant difference between the means for Size codes 1 and 3 ($q=1.66$, $p>.05$) so there is no significant difference between the means for the Size codes 1, 2 and 3. However, there was a significant difference between these three means and the mean for Size code 0 ($F=22.98$, $p<.05$). This suggests that most of the variation in responses caused by changing the size of the shapes is due to the difference in responses to the smallest shape and the other three sizes.

TABLE 3.9

Means and S.D.'s of RID responses in Experiment 3.5

	Separation (mm)			
Size Code	0	6.25	12.5	25.0
0	11.3	8.6	8.0	6.2
	5.97	5.31	4.71	5.74
1	17.6	12.5	12.5	10.1
	3.35	4.52	5.94	5.11
2	17.6	13.6	13.2	10.9
	5.06	5.41	6.52	5.87
3	17.9	15.6	14.3	11.4
	4.25	5.08	5.46	6.05

Note- For each Size code, the means are in the first row and the S.D.'s are in the second row.

TABLE 3.10

Analysis of Variance Table for Experiment 3.5

SOURCE	SS	DF	MS	F	
BETWEEN SUBJECTS	1549.0	9			
WITHIN SUBJECTS	4811.9	150			
A (Size)	931.0	3	310.3	8.13	*
Error A	1031.2	27	38.2		
B (Separation)	852.5	3	284.2	6.44	*
Error B	1191.7	27	44.1		
AxB	34.0	9	3.8	.40	
Error AxB	771.6	81	9.5		
TOTAL	6361.0	159			

* Significant at the .05 level

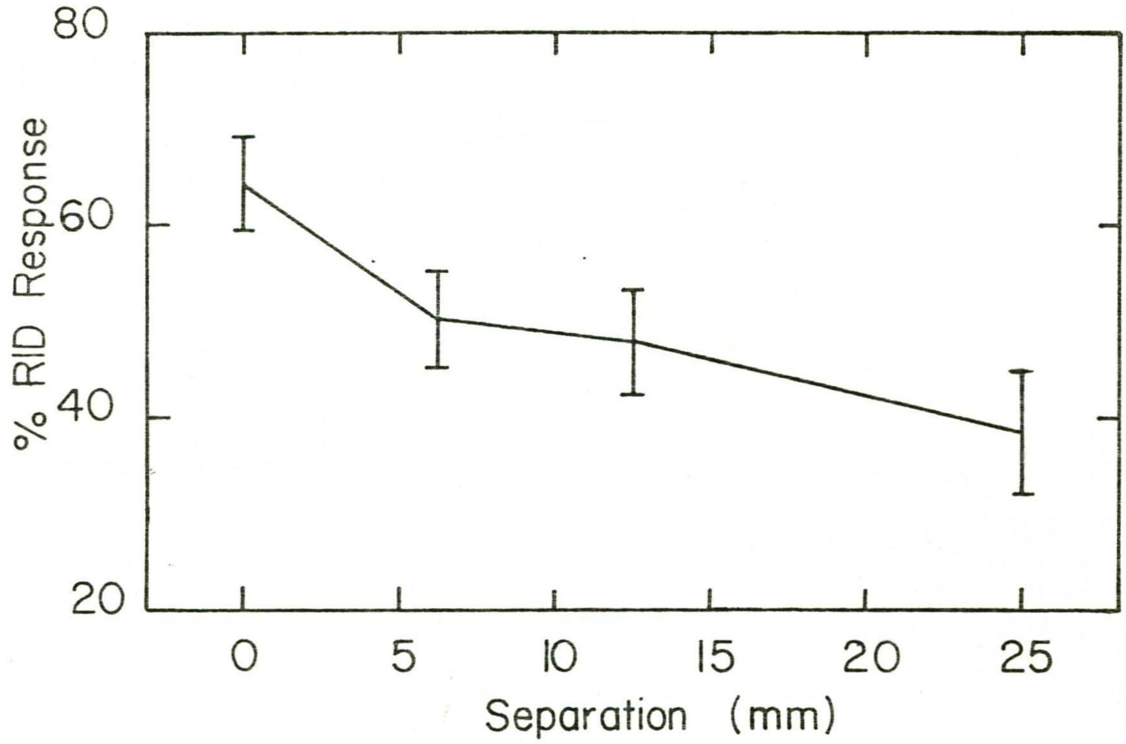


Figure 3.13 The main effect of separation from Experiment 3.5.

DISCUSSION

The effect of Separation is graphed in Figure 3.13 which shows that the effect of separation in this experiment is similar to the separation effect found in previous experiments. Increasing the separation reduces the number of RID responses.

The effect of increasing the size of the figures is to increase the number of reports of RID (see Figure 3.14) although most of the

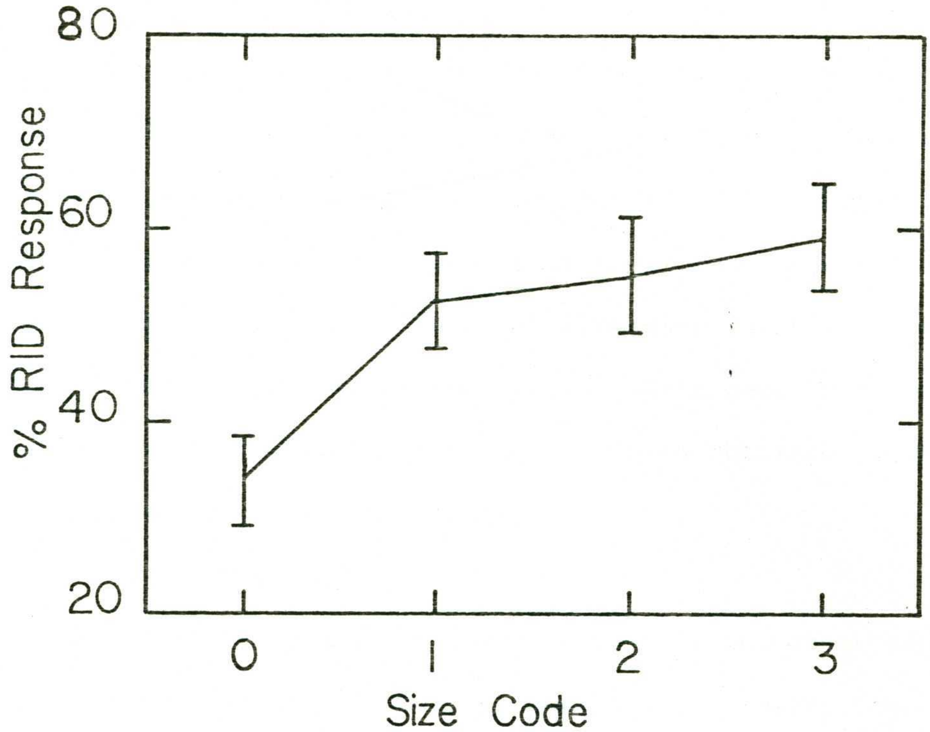


Figure 3.14 The main effect of size from Experiment 3.5.

effect occurs in the change from the smallest size to the next size. At the smallest size the octagon tends to look a bit like a circle, a shape which has no direction and would yield few, if any, RID responses. At larger sizes the various local features become more prominent and can contribute to the shape's direction. Further increases in size did not result in increasing numbers of RID responses. Presumably, once the features are obvious they cannot be made more obvious by increasing the size.

The question of what happens with extremely large shapes is still an open one. In this experiment there was no evidence of a decrease in RID responses at the largest size. However, this could be a consequence of a strategy that subjects may have adopted. Subjects would quickly learn where and in what orientation the shapes would be presented. They may have learned that they did not need to scan the whole shape to detect the local features necessary for the definition of the global property of direction and centred their gaze on the middle of the display. Different results might have been obtained if the shapes had pointed outwards rather than inwards.

The effect of separation observed in this and other experiments could be related to the absolute separation between the shapes, irrespective of their size. On the other hand, the effect of separation could depend on the ratio of the separation to the size of the figure. It is plausible that the rate of reduction in RID responses with increasing separation might be greater for small stimulus configurations than for large ones. In this latter case, one would expect to find a Size x Separation interaction in the data. No such interaction was found which suggests that the effect of separation is related to the absolute separation between the shapes, independent of their size. At least this is true for the particular shapes, sizes and separations used in this experiment but the picture may change if the range of sizes and separations were extended.

EXPERIMENT 3.6

So far in the present series of experiments the stimulus presentations have always been arranged so that the motion has appeared to go from right to left. In order to ensure that the conclusions reached generalise to other directions of motion, four different stimulus configurations were each presented so that they appeared to move in four different directions.

METHOD

Stimuli. Figure 3.15 illustrates how the 16 different stimulus configurations were derived. Mirror images were formed on all four sides of the central octagon, then the central octagon was rotated through 90 degrees and mirror images taken on all four sides again, and so on. There were four different stimulus configurations and they were specified by the length of the element common to both shapes of the pair. These lengths were 5 mm, 10 mm, 15 mm and 20 mm. The four possible different directions of the 5 mm pair are marked in Figure 3.15.

Procedure. A 2 way design with two repeated measures was run: the two treatments were Shape Pairs and Direction of Motion. There were 4 levels of Shape Pairs, designated 5 mm pair, 10 mm pair, 15 mm pair and 20 mm pair. There were four levels of direction of motion: up, down, left and right. All subjects saw all of the 16 possible Shape Pairs x Direction of Motion combinations at one fixed ISI of 25 msec.

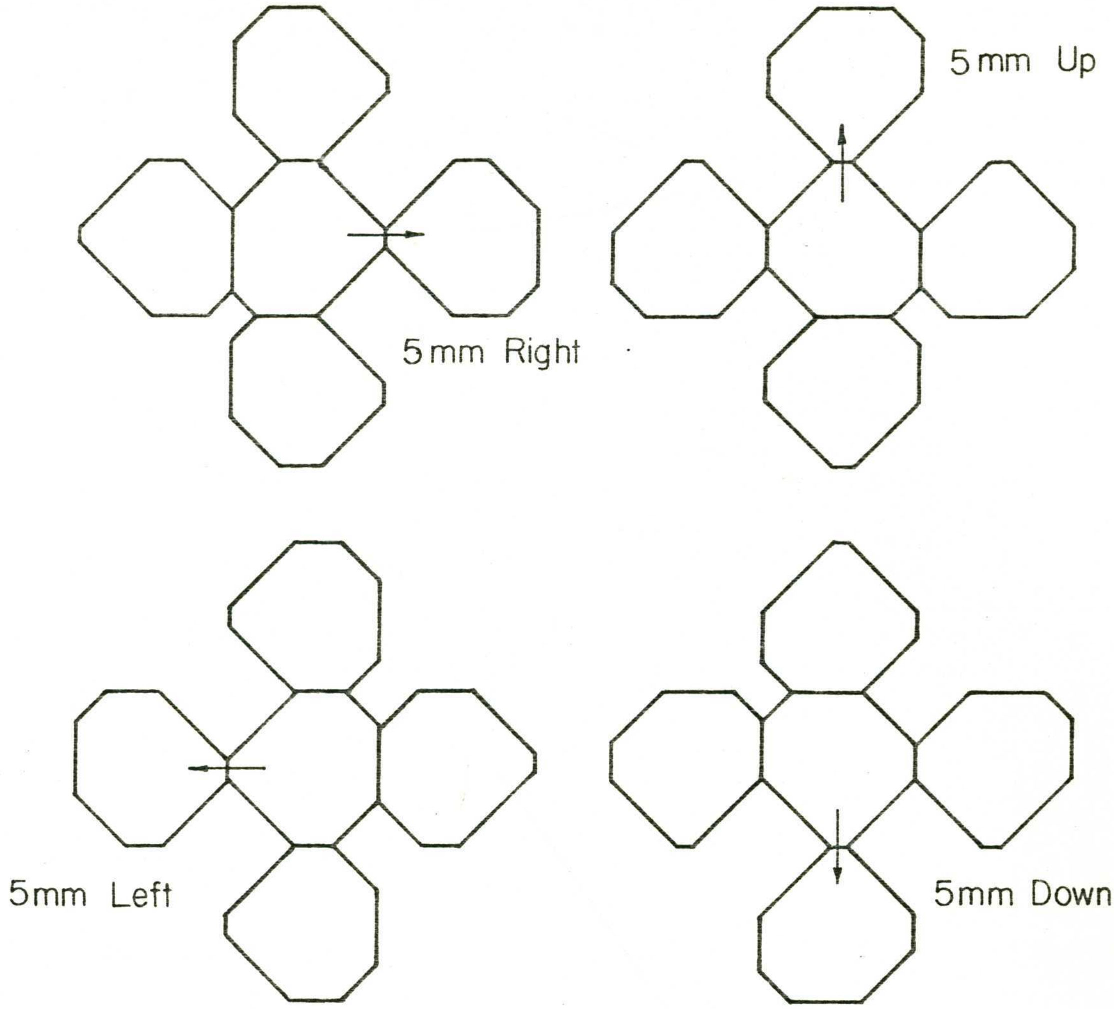


Figure 3.15 Illustration showing how the 16 different stimulus configurations (shown half size) used in Experiment 3.6 were formed. One of the four central figures was presented first, followed by one of the four flanking figures. The Up, Down, Left and Right stimulus configurations are shown for the 5mm Shape Pair. The different levels of Direction for the 10 mm, 15 mm and 20 mm Shape Pairs can be found in a similar manner.

RESULTS

The means and standard deviations of the RID responses of all the treatment combinations are shown in Table 3.11. The data did not violate the assumption of homogeneity of variance (Fmax=9.1, p>.05) so a 2 way analysis of variance with two repeated measures was performed on the untransformed data. The results are tabulated in Figure 3.12 where it can be seen that the main effect of Shape Pairs is significant.

TABLE 3.11

Means and S.D.'s of RID responses in Experiment 3.6

	Shape Pair Code			
Dir. of Motion	5 mm	10 mm	15 mm	20 mm
Up	19.8	14.1	22.4	13.6
	5.76	7.52	2.62	5.73
Down	19.7	13.6	18.4	14.3
	3.29	6.28	5.39	7.55
Left	17.6	15.2	20.3	12.4
	4.98	5.90	3.77	7.89
Right	20.9	16.4	19.0	15.1
	3.65	5.64	5.60	5.59

Note- For each Direction, the means are in the first row and the S.D.'s are in the second row.

TABLE 3.12

Analysis of Variance Table for Experiment 3.12

SOURCE	SS	DF	MS	F
BETWEEN SUBJECTS	2031.9	9		
WITHIN SUBJECTS	4501.8	150		
A (Dir. of Motion)	63.2	3	21.1	1.31
Error A	433.1	27	16.0	
B (Shape Pairs)	1201.8	3	400.6	10.74 *
Error B	1007.0	27	37.3	
AxB	173.7	9	19.3	.96
Error AxB	1623.1	81	20.0	
TOTAL	6533.6	159		

* Significant at the .05 level

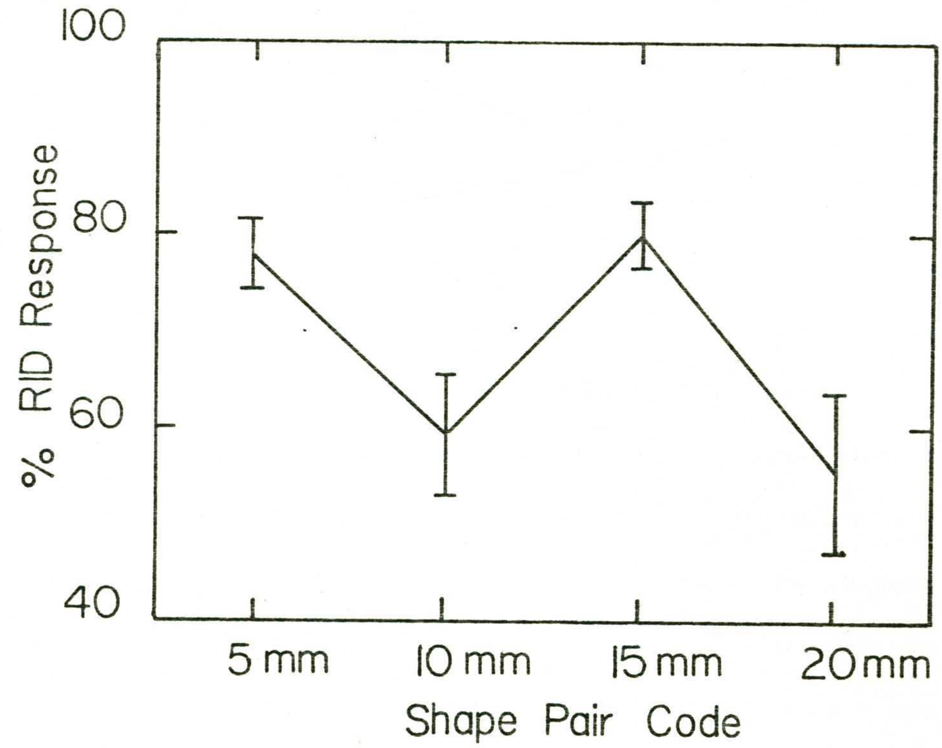


Figure 3.16 Main effect of Shape Pair from Experiment 3.6.

DISCUSSION

There did not seem to be any compelling a priori reasons to suppose that there should be a difference in the number of RID responses to a stimulus configuration when it is moving vertically, say, than when it is moving horizontally. The results of this experiment confirm this impression with the finding that Direction of Motion has no significant effect on the number of RID responses. It seems safe to say that the results found in the previous experiments are not peculiar to one particular direction of motion. This result is the same as an earlier result found by White et al. (1979), who also presented a number of different stimulus configurations at different directions of motion, although they used different shapes in their stimulus configurations.

The 5 mm and 20 mm stimulus configurations consist of shapes that appear to point in opposite directions, either towards or away from each other. The 10 mm and 15 mm stimulus configurations consist of shapes that point in the same direction. The former pair of stimulus configurations elicit about an equal number of RID responses, as do the latter pair. However, the 5 mm and 20 mm stimulus configurations elicited more RID responses than the 10 mm and 15 mm stimulus condigurations. Thus the observed effect due to Shape Pairs (Figure 3.16) in this experiment is consistent with the hypothesis, proposed in earlier experiments, that the "direction" of the shapes is a critical variable.

A MODEL FOR DEPTH AMBIGUOUS APPARENT MOTION

Previous researchers in the field of depth ambiguous apparent motion have tended to find that one kind of variable determines the relative proportions of RID and 2D motion responses. Kolers and Pomerantz (1971) found that temporal factors, such as stimulus duration and ISI, were the principal determinants of whether RID of 2D motion responses occurred. They also found that different shapes had negligible effects on the relative proportions of RID and 2D motion responses. White et al. (1979), on the other hand, reported exactly the opposite findings.

A common failing of these studies was that they did not study a wide range of variables but tended to concentrate on one particular type. Kolers and Pomerantz (1971) used a wide range of stimulus durations and ISI's but only three different stimulus configurations. White et al. (1979) used a relatively small number of ISI's and did not examine the role of stimulus duration.

The results of the experiments in this study suggest that both temporal and spatial factors affect the relative proportions of RID and 2D motion responses, although not all factors affect the relative proportions to the same degree. In particular, these experiments show that RID responses are affected by Shape, ISI and Separation. In the light of these results, any single factor explanation of depth ambiguous apparent motion is likely to be inadequate to some degree. This conclusion is supported by the fact that previous researchers have been unable to agree on which single factor should account for the results.

The problem with adopting a multifactorial approach lies in being able to describe the data in an easily understood manner. The solution adopted was to borrow the logic of multiple regression analysis. It should be clearly understood, however, that the model described below is not intended to be an exact, mathematical model. It is an ordinal model. The terminology of multiple regression has been used as a convenient means of expressing the relationship between the variables that have been studied. However, before a description of the model is attempted it is appropriate to discuss what happens when various factors are taken to the extreme.

The Boundary Conditions

The experiments in this study were principally concerned with the roles of Shape, Separation and ISI in determining RID responses. The model described below is not intended to cover every possible value that these variables can take, particularly at extreme values. The following discussion sets out the boundary conditions for the model.

As the separation between two shapes in an apparent motion sequence is increased, the probability that subjects will report that they have seen smooth, continuous motion decreases. This is referred to as "motion breakdown". It is not known, however, how the decrease in the probability of reporting motion will affect the proability of reporting a rotation in depth. In the experiments reported above, this problem did not arise since the range of separations used seemed to have no effect on the probability of reporting motion. If a wider range of separations were used, motion breakdown might become an important factor and some means of ascertaining how this affects the relative proportion of RID responses would need to be found. Since this model has been developed to explain the data at hand, one of the assumptions of the model is that the separation between the shapes does not affect the probability of reporting motion.

Like Separation, the variable ISI is complicated by the fact that at very short or very long ISI's the apparent movement will break down. As in the case of Separation, it is not known how motion breakdown induced by changing ISI will affect the relative proportion of RID responses. However, since in the experiments reported above ISI did not seem to affect NM responses, another assumption of the model is that the ISI does not affect the probability of reporting motion.

These two assumptions have the effect of constraining the model to situations where apparent motion is reported by the subject. This consequence is not restrictive in that the question that this study was designed to answer is: given that the subject does report movement, was it three dimensional or two dimensional movement? The assumptions made in developing the model are designed to cover just that situation.

The shapes used in the experiments reported in this thesis were entirely arbitrary. They were chosen from an infinite array of shapes because they exhibited certain features that were considered desirable at the time. If the model is successful in describing the results obtained with these arbitrary shapes, then it should be able to predict what will happen with any possible shape. The ultimate aim of this research is to be able to take any apparent motion sequence and to be able to predict the relative proportions of RID and 2D motion responses. The model described below is seen as the first step in achieving this goal.

The Model

In the equations that appear below, upper case letters represent various factors and lower case letters represent the coefficients of these factors. The coefficients reflect the degree to which a factor contributes to the observed number of RID responses. Multiplication, addition and subtraction signs are not used in a strict mathematical sense, but to suggest the nature of the relationship between two, or more, variables in an equation.

As a first approximation, consider the equation

$$RID = aD + bS + cI + E \qquad \text{Eq. 1}$$

where RID is the number of RID responses, D represents the shape factor, S represents the separation between the shapes, I represents the ISI and E is some constant that covers other variables that have not been considered (such as stimulus duration). The coefficients a, b, c are the relative weights of D, S and I in a particular experiment.

In the experiments reported in this study, the principal aspect of a shape that is important for depth ambiguous apparent movement appears to be its direction. The coefficient a is an index of how well a shape defines a particular direction, of how well it appears to point in a particular direction. The value of this coefficient is determined by the various local features of the shape in question. The value of a for a circle, for example, would approach 0 since this shape does not seem to have any directional properties, whereas for an arrow the value of a would be close to 1.

An apparent motion sequence consists of two shapes and in the case of depth ambiguous apparent motion, it is not sufficient to know that both shapes have well defined directions. In Experiment 3.2, for example, the same shapes were used for all stimulus configurations but there were marked differences in the number of RID responses to the different stimulus configurations. The critical factor appeared to be whether the directions of the shapes were opposed or parallel. This can be incorporated into the model by defining a variable o such that it has a value of 1 if the directions of the two shapes are opposed, and a value of 0 if they are not. Equation 1 then becomes

$$RID = (a \times o)D + bS + cI + E \qquad \text{Eq. 2}$$

This has the effect that if the directions of the shapes are not opposed, then there will be no contribution to the number of RID responses due to the shapes.

When the two shapes have a separation of 0, b (the coefficient of S) is defined to have a value of 1. Increasing the separation between the shapes will decrease this value. This reflects the finding that the number of RID responses decreases with increasing separation. It is assumed that b will go to 0 when the separation is sufficiently large but the experiments reported above do not provide any information about very large separations.

A special case of Separation that needs to be considered is superimposition of the shapes. It does not seem reasonable to talk about the separation between the shapes when they are superimposed, so b will be defined to be 0 when the shapes are superimposed. The experimental data also suggested that superimposition might affect the contribution the shape factor makes to the number of RID responses. It is impossible to guess, however, how superimposition may affect the coefficient of D because it may be different for every combination of shapes. The problem of how superimposition affects the value of the coefficient of D will be set aside for the time being.

The value of c (the coefficient representing the weight of ISI) will vary with ISI, reaching a maximum at some optimal ISI and falling away at other values of ISI. The shape of the function of c with respect to ISI is a matter of some controversy. According to Kolers and Pomerantz (1971) it is an inverted U-shaped function. The data of White et al. (1979) suggest that the number of RID responses do not vary with ISI until a certain point. Beyond that point, increasing the ISI decreases the number of RID responses. For the purposes of the model, it is not important to know the shape of the function. All that is important is that ISI does affect RID responses.

The context effect can add to, or subtract from, the coefficient of any of D, S and I. The context of a particular experiment may affect different factors in different ways, enhancing the effect of some and reducing the effect of others. A superimposition experiment, for example, might reduce the effect of Shape and increase the effect of ISI. The context effect can be incorporated into Eq. 2 in the following way:

$$RID = o(a + a1)D + (b + b1)S + (c + c1)I + E \qquad \text{Eq. 3}$$

The variables a1, b1, c1 can be positive or negative, depending on whether the particular experimental context tends to enhance or reduce the effect of the particular variable affected.

The data relating to size as a variable from Experiment 3.5 can be incorporated into this model. These data suggested that the size of the shapes affected the ability on the part of the subject to perceive the direction of the shapes. The variable l (for "largeness") can be defined such that it is 1 when the shapes are sufficiently large for all their features to be readily detected. As the shapes become smaller, it will tend to 0. Equation 3 can now be written as

$$RID = (l \times o)(a+a1)D + (b+b1)S + (c+c1)I + E \qquad \text{Eq. 4}$$

If the effect of Separation was related to the size of the shapes then the coefficient of S would also have required some modification. The lack of any Size x Separation effect in Experiment 3.5 suggests that this modification can be avoided for the moment. However, since it is not known what happens with very large shapes it is possible that Equation 4 will require some modification when experiments with wider ranges of shapes, separations and sizes are performed.

Applications of the Model

Equation 4 is not necessarily only valid for one particular combination of Shape, Separation and ISI. It can be used to indicate the relative standings of these three variables within a series of experiments. This can be demonstrated using the data from Experiments 3.1 to 3.3. These three experiments all used similar levels of Shape, Separation and ISI and are thus roughly comparable. It has been assumed that conclusions derived from one experiment can be used in conjunction with conclusions derived from the others.

In Experiment 3.1, Separation and ISI were both found to have a significant effect on the number of RID responses. However, Separation accounted for about 35% of the variance in that experiment whereas ISI only accounted for about 5%. One could argue that the ratio of the coefficients of S and I are thus 7:1. In Experiment 3.2 Shape and Separation were found to have significant effects but Shape accounted for about 6 times as much of the variance as Separation ($E(w2)=.502$ and $E(w2)=.080$, respectively). Thus, the ratio of the coefficients of D and S might be 6:1. These ratios have been combined in Equation 5.

$$D : S : I = 42 : 7 : 1 \qquad \text{Eq. 5}$$

Assuming that these variables account for half the variance (which is consistent with the data), Equation 4 could be re-written as

$$RID = 0.42D + 0.07S + .01I + 0.50E \qquad \text{Eq. 6}$$

It is not suggested that this equation is mathematically exact nor that the process which led to its derivation is free from problems. However, this equation does reflect the findings of Experiments 3.1 to 3.3, which suggest that Shape is a more important variable than Separation which, in turn, is a more important variable than ISI.

In the discussion of Experiment 3.1 it was argued that the fact that any given subject only saw one of the four different shape conditions would have tended to obscure the effect of Shape. This is equivalent to saying that a1 , the coefficient reflecting the operation of the context effect for shapes, takes a large negative value. Thus, the results of Experiment 3.1 can be explained by the model.

In Experiment 3.3 Shape and the Shape x ISI interaction were found to have significant effects on the number of RID responses. Shape was found to account for about 16% of the variance (E(w2)=.162) while the Shape x ISI interaction accounted for less than 1% (E(w2)=.008). This suggests that when Shape and ISI are the only variables operating in an experiment, ISI has such a weak effect that it can only perturb levels of Shape differentially and cannot exercise an independent effect. This is consistent with the suggestion, as shown in the model, that Shape is a much more important determinant of RID responses than ISI.

The model can also be used to explain the differences between the results of Kolers and Pomerantz (1971) and White et al. (1979). Consider the design of the experiment performed by Kolers and Pomerantz (1971). They used superimposed shapes which, according to the assumptions of the model, sets the coefficient of S to 0. Superimposition causes the resultant stimulus configurations to look very similar. This reduces the effect of having different stimulus configurations. This is represented in the model by having a1 assume a negative value. Kolers and Pomerantz (1971) used a wide range of ISI's which could result in c1 assuming a large positive value, which is equivalent to saying that the ISI "context" enhances the effect of ISI. They also used a wide range of stimulus durations, a variable that has not been incorporated into the model but would take up some of the effect bound up in the variable E. An application of the model tends to suggest that the conditions chosen by them tended to emphasize the temporal factors used in their experiments, at the expense of spatial factors such as separation and shape. In the experiment by White et al. (1979) the emphases were reversed.

The model suggests that there is a single underlying principle that ties together the apparently discrepant results of Kolers and Pomerantz (1971) and White et al. (1979). However, there are a number of possible reasons as to this discrepancy has arisen: the use of trained vs naive subjects, tachistoscopic vs computer driven displays, peripheral vs central vision, etc. Even the suggestion that the model can accommodate both sets of data is not without some problems. One problem is the possibility that "context" effects would be smaller for trained subjects than for naive subjects. Another problem arises from the finding of Kolers and Pomerantz (1971) that the effect of ISI had an inverted U-shaped function. White et al. (1979) found that it was a generally decreasing function.

Corollaries of the Model

The above discussion suggests that separating the shapes may be a better strategy than superimposing them. Superimposing the shapes is not only a special case of Separation but it seems to have an effect on the Shape variable which is very difficult to define. Separating the shapes certainly does affect RID responses but it is possible to statistically isolate this effect and examine the effects of other variables relatively independently of Separation.

One of the predictions made by this model is that as the effect of one variable is increased, the effect of other variables will be decreased. In the following experiments, the directional properties of shapes will be manipulated, which will affect the coefficient of D. The model predicts that this will alter the relative effect of other variables such as ISI and Separation.

SUMMARY OF OCTAGON EXPERIMENTS

These experiments investigated the role of shape, spatial separation, ISI, size and direction of movement in determining the RID responses. The data from these experiments suggest that the explanation for depth ambiguous apparent motion cannot be couched in terms of a single variable. The Korte's third law explanation cannot account for the role of shape in depth ambiguous apparent motion and the adjacent contour element hypothesis does not consider the role of temporal factors. A model has been proposed which assumes that many factors can influence the production of RID responses and that these factors will have different weights in different experimental situations. The main factors, in order of importance, were found to be Shape, Separation and ISI.

The model is somewhat tentative because it has been developed as a post hoc explanation. There are also gaps in the experimental evidence. Nonetheless, even in its present form it seems to be able to account for most of the data gathered in these expriments. Furthermore, the model is able to incorporate the findings of Kolers and Pomerantz (1971) by changing the weights of the relevant factors to reflect the fact that their experimental conditions tended to favour temporal factors at the expense of spatial factors.

The main aim of this study was to determine how Shape affects RID responses. This first series of experiments has established that

Shape is the single most important factor in determining RID responses in the type of apparent motion display used in these experiments. In the next series of experiments a closer examination will be made of the stimulus configurations in an attempt to define the minimum requirements that must exist before a shape will appear to rotate in depth. Most of the experiments used simple quadrilateral figures to which various features were added. The quadrilaterals on their own give no indication that one might be the mirror image partner of the other so simple translational movement is expected to occur more often than a rotation in depth.

CHAPTER 4

THE QUADRILATERAL EXPERIMENTS

EXPERIMENT 4.1

A great number of apparent motion displays will rarely, if ever, appear to rotate in depth. A good example of this occurs when the shapes are identical and laterally displaced. The basic stimulus configuration in this experiment was a pair of shapes which were not expected to rotate in depth, viz. a pair of upright rectangles. The aim of this experiment was to see how adding features to these rectangles changed the number of RID responses.

METHOD

Stimuli. The stimuli are illustrated in Figure 4.1. The plain rectangles are 30 mm x 7.5 mm and the shapes with triangles on them have approximately the same area of 225 sq. mm. The triangular portion of shape pair 2 occupied 2.5% of the total area of the shape and the triangular portion of shape pair 3 occupied 5% of the total area. The spike on the rectangles in shape pair 1 was nominally .5 mm long.

Procedure. There were 3 treatments in this experiment: Shape, ISI and Separation. There were 4 levels of Shape (see Figure 4.1), 2 levels of ISI (50 and 100 msec) and 2 levels of Separation (0 and 11.7 mm). Ten

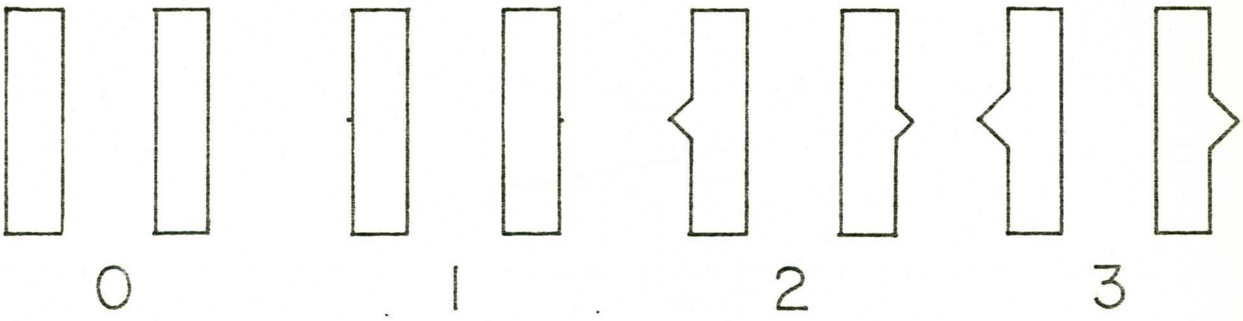


Figure 4.1 The stimulus configurations used in Experiment 4.1, full size. The shape pair code numbers are shown beneath each stimulus configuration.

subjects were used and each subject recevied all 16 possible treatment combinations.

RESULTS

Table 4.1 is a table of the means and standard deviations of RID responses for all the treatment combinations used in this experiment. The data did not violate the assumption of homogeneity of variance (Fmax-2.88, p>.05) so a 3 way ANOVA with 3 repeated measures was performed on the untransformed data. The results are tabulated in Table 4.1 where it can be seen that the effects of Shape and Separation were significant. ISI had no significant effect.

DISCUSSION

Figure 4.2 shows that the effect of separation in this experiment follows a familiar pattern. As the separation is increased the number of RID responses is decreased.

TABLE 4.1

Means and S.D.'s of RID responses for Experiment 4.1

	Shape Pair Code			
Separation (mm)	0	1	2	3
		ISI=50 msec		
0	8.9	8.3	17.5	17.6
	5.17	5.31	5.87	6.00
11.7	6.4	5.1	13.2	13.5
	5.78	5.09	6.06	5.55
		ISI=100 msec		
0	7.2	7.2	16.3	16.3
	4.09	4.51	6.37	6.66
11.7	4.6	4.4	12.5	14.2
	3.92	4.59	5.85	5.34

Note- For each Separation, the means are in the first row and the S.D.'s are in the second row.

TABLE 4.2

Analysis of Variance Table for Experiment 4.1

SOURCE	SS	DF	MS	F	
BETWEEN SUBJECTS	2162.7	9			
WITHIN SUBJECTS	6036.4	150			
A (Shape)	2986.7	3	995.6	24.55	*
Error A	1094.7	27	40.5		
B (ISI)	38.0	1	38.0	3.91	
Error B	87.6	9	9.7		
C (Separation)	403.2	1	403.2	5.89	*
Error C	616.2	9	68.5		
AxB	10.6	3	3.5	.55	
Error AxB	173.8	27	6.4		
AxC	11.9	3	4.0	.34	
Error AxC	315.7	27	11.7		
BxC	4.9	1	4.9	.53	
Error BxC	83.5	9	9.3		
AxBxC	6.2	3	2.1	.27	
Error AxBxC	203.5	27	7.5		
TOTAL	8199.1	159			

*- significant at the .05 level

Figure 4.3 graphs the effect of Shape. There was no significant difference between the means for shape pairs 0 and 1 ($q=.52$, $p>.05$) nor between the means for shape pairs 2 and 3 ($q=.52$, $p>.05$) but there was a significant difference between these two sets of means ($F=73.39$, $p<.05$). In this experiment adding a small spike to the side of the rectangle had no effect but adding a small triangle did. Further more, the size of the triangle had no effect which is consistent with the idea that once the shape has a direction determined by some feature, simply adding to that feature may not have any further effect.

A post experimental check of the stimulus display revealed that the very small spike on shape pair 1 was difficult to detect. This stimulus configuration often looked exactly like two plain rectangles. This happened was because the spike was just two dots long and the line itself was, of course, one dot wide ("dots" are co-ordinate positions on the screen). At the viewing distance used, it turns out that the spike was about 14' of arc long. Thus the feature which was designed to give the shape direction was barely discriminable and may have been overlooked on many occasions.

The model developed in the previous chapter suggested that for rotation in depth to occur the two shapes must be perceived to be pointing in opposite directions. So the subjects would have to perceive both barely discriminable markers (one on each shape) before rotation in depth was likely to be reported. The perception of a shape with no

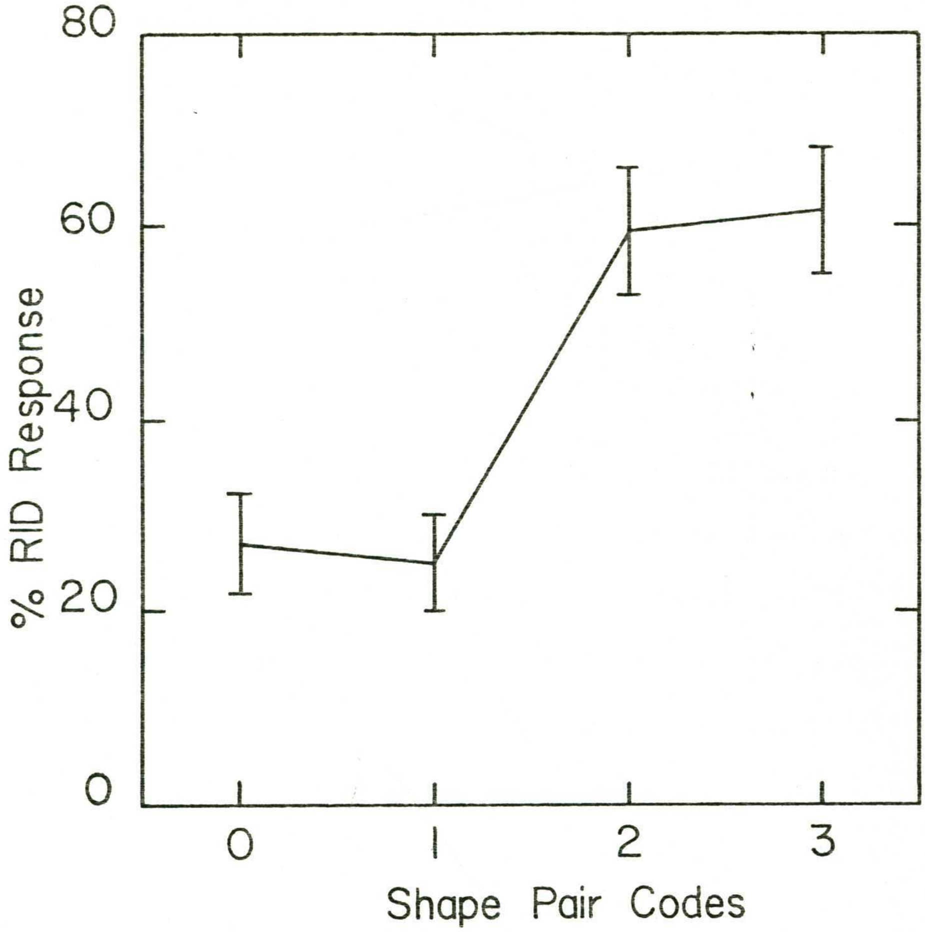


Figure 4.3 Shape effect from Experiment 4.1.

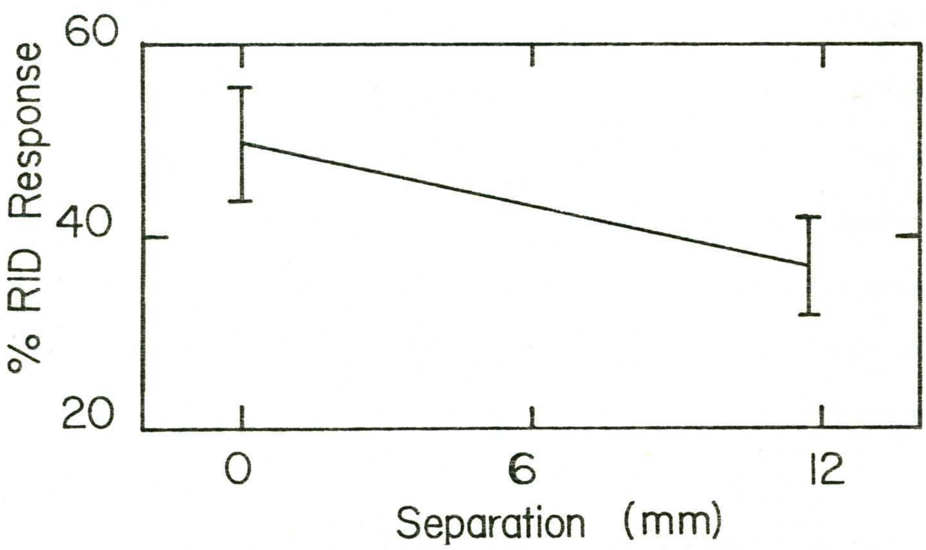


Figure 4.2 Separation effect from Experiment 4.1.

direction turning into a shape with some direction, or vice versa, should not necessarily facilitate RID resonses. This experiment again demonstrated that features that are to be used to determine the direction of the shape must be discriminable. This argument was advanced in Experiment 3.5 which dealt with the effect of size.

It might be argued that a rectangle already has some sort of direction in that it could be said to be pointing in the direction of its long axis, or possibly its short axis. However, in the figures used in the present experiment this direction is ambiguous because it indicates both up and down, or left and right. Any contribution that the long axis makes to the perceived direction of a shape would not have been detected in this experiment because the long axes of the shapes were parallel.

The data from this experiment are consistent with the model proposed in the previous chapter. In this experiment only two different ISI's were used and they were fairly similar in value (50 and 100 msec). This might tend to reduce the coefficient of I (the ISI factor) and thus account for the failure to find an effect of ISI in this experiment. The same considerations apply to S (the separation factor) although since it had a stronger effect than ISI in the previous experiments it might still be expected to play a role even when the effect of ISI is no longer noticeable. On the other hand, the stimulus configurations clearly did or did not have opposed directions (leaving aside the problem of the small spike) and there were a number of different shape pairs (4 in all) which should enhance the differences between the stimulus configurations.

The model predicts that Shape should have the most effect on RID responses, followed by Separation and then ISI. That prediction has been confirmed in detail in this experiment: it was found that Shape accounted for nearly half the variance (E(w2)=.471) whereas Separation accounted for about 5% (E(w2)=.055) and ISI did not have a significant effect on RID responses.

EXPERIMENT 4.2

It seems likely that the single, small spike on Shape pair 1 in the previous experiment had no effect simply because it was too small. This experiment used larger spikes and examined the proposition that the more spikes a rectangle has (which may improve the definition of its direction) the better it will appear to rotate.

METHOD

Stimuli. Figure 4.4 illustrates the eight different stimulus configurations used in this experiment. Seven of these consist of rectangles to which various numbers of spikes have been added and the eigth is a pair of right isoceles triangles. The pair of triangles back to back (Neuhaus triangles) were expected to appear to rotate in depth nearly all the time and were used as a comparison condition. The figures were all 30 mm high and the rectangles were 7.5 mm wide. The spikes were all .9 mm long and, at the viewing distance used, easily resolvable.

Procedure. A two treatment experiment was run with two repeated measures. The treatment Shape had 8 levels (illustrated in Figure 4.4) and there were 2 levels of Separation (0 and 11.7 mm). Ten subjects were run and each subject received all 16 possible treatment combinations at a fixed ISI of 25 msec.

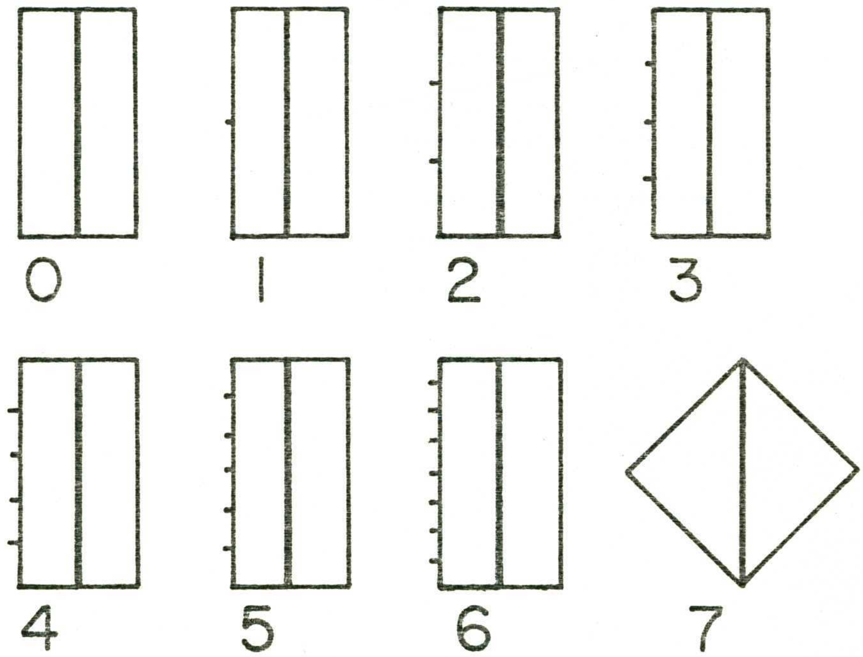


Figure 4.4 The stimulus configurations used in Experiment 4.2, full size. The shape pair code number appears beneath each stimulus configuration.

RESULTS

Table 4.3 is a table of the means and standard deviations of the RID responses for all the treatment combinations used in this experiment. The data did not support the assumption of homogeneity of variance (Fmax=217.20, p<.05). Inspection of the data revealed that the variances for the rectangles without spikes and the triangles (shape pairs 0 and 7) were very small. The variances were small because the means for both these conditions were very close to the extreme values. The mean for Shape pair 0 was close to 0, while the mean for Shape pair 7 was close to 25. The problem of inhomogeneity of variance was overcome by dropping Shape pairs 0 and 7 from the analysis. This was

TABLE 4.3

Means and S.D.'s of RID responses in Experiment 4.2

Shape Pair Code	Separation (mm) 0	11.7
0	1.5	2.1
	1.50	3.62
1	15.7	12.0
	5.88	6.99
2	19.6	14.7
	3.10	5.39
3	19.8	17.2
	3.79	4.31
4	21.2	18.3
	4.02	4.94
5	20.5	16.8
	3.96	5.90
6	20.6	17.9
	5.40	4.57
7	24.8	24.7
	0.40	0.64

Note- For each Shape pair, the means are in the first row, the S.D.'s in the second.

TABLE 4.4

Analysis of Variance Table for Experiment 4.2

SOURCE	SS	DF	MS	F	
BETWEEN SUBJECTS	1348.0	9			
WITHIN SUBJECTS	2444.6	110			
A (Separation)	350.2	1	350.2	6.29	*
Error A	501.2	9	55.7		
B (Shape)	462.4	5	92.5	5.90	*
Error B	705.6	45	15.7		
AxB	19.0	5	3.8	.42	
Error AxB	406.0	45	9.0		
TOTAL	3792.6	119			

* Significant at the .05 level

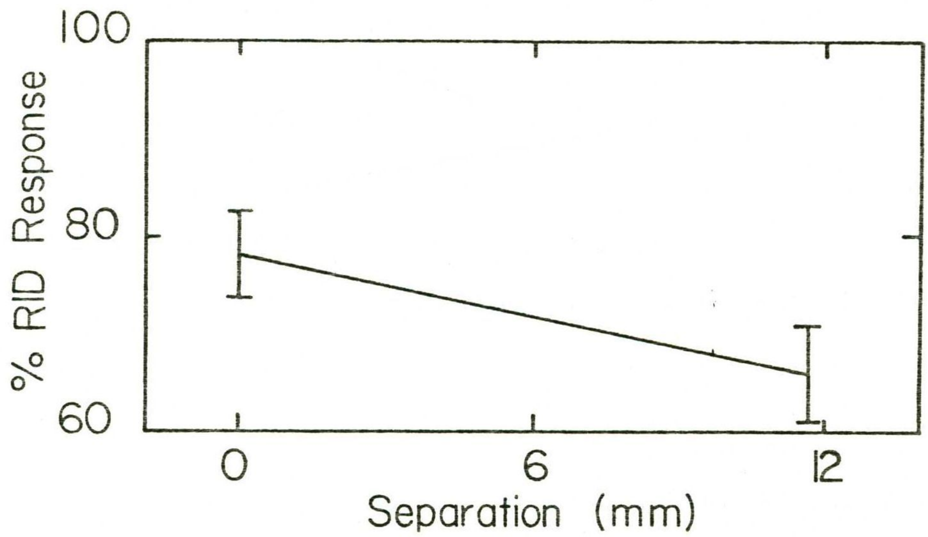


Figure 4.5 Separation effect from Experiment 4.2. These data do not include the data for shape pairs 0 and 7.

justified on the grounds that that both means were about 15 standard errors removed from the other means.

The reduced set of data did support the assumption of homogeneity of variance ($F_{max}=3.61$, $p>.05$) so a 2 way ANOVA with 2 repeated measures was performed on this data. The results are tabulated in Table 4.2 where it can be seen that Separation had a significant effect as did Shape.

There was no significant difference between the means for Shape pair 4 and Shape pair 2 ($q=2.54$, $p>.05$). These were the largest and second smallest means, respectively, of the means for Shape pairs 1 to 6. Thus, there was no significant difference between the means for shape pairs 2 to 6 inclusive. There was a significant difference between the mean for shape pair 1 and the pooled means of shape pairs 2 to 6 ($F=24.59$, $p<.05$). This indicates that there was an increase in the number of RID responses as the number of spikes on the rectangles was increased from 1 to 2 but that there was no further significant increase in RID responses.

The ANOVA table suggests that Shape and Separation accounted for about eqaul amounts of the variance (E(w2)=.162 and E(w2)=.140 respectively). This result is misleading because of the conditions that were dropped. If the data for Shape pairs 0 and 7 were included in the data then Shape would probably have a larger effect than Separation.

DISCUSSION

The effect of Separation is graphed in Figure 4.5 which shows that the effect of increasing separation follows the familiar pattern of reducing RID responses.

Figure 4.6 graphs the effect of Shape and includes conditions 0 and 7 (they are not connected to the other points on the graph because they were not included in the analysis of variance). The data suggest that once a direction marker is easily discriminable there is no further increase in RID responses to be had by repeating that marker. The difference between one spike and more than one spike can be explained by suggesting that subjects might occasionally miss one spike on the rectangles which would make the stimulus configuration look like the

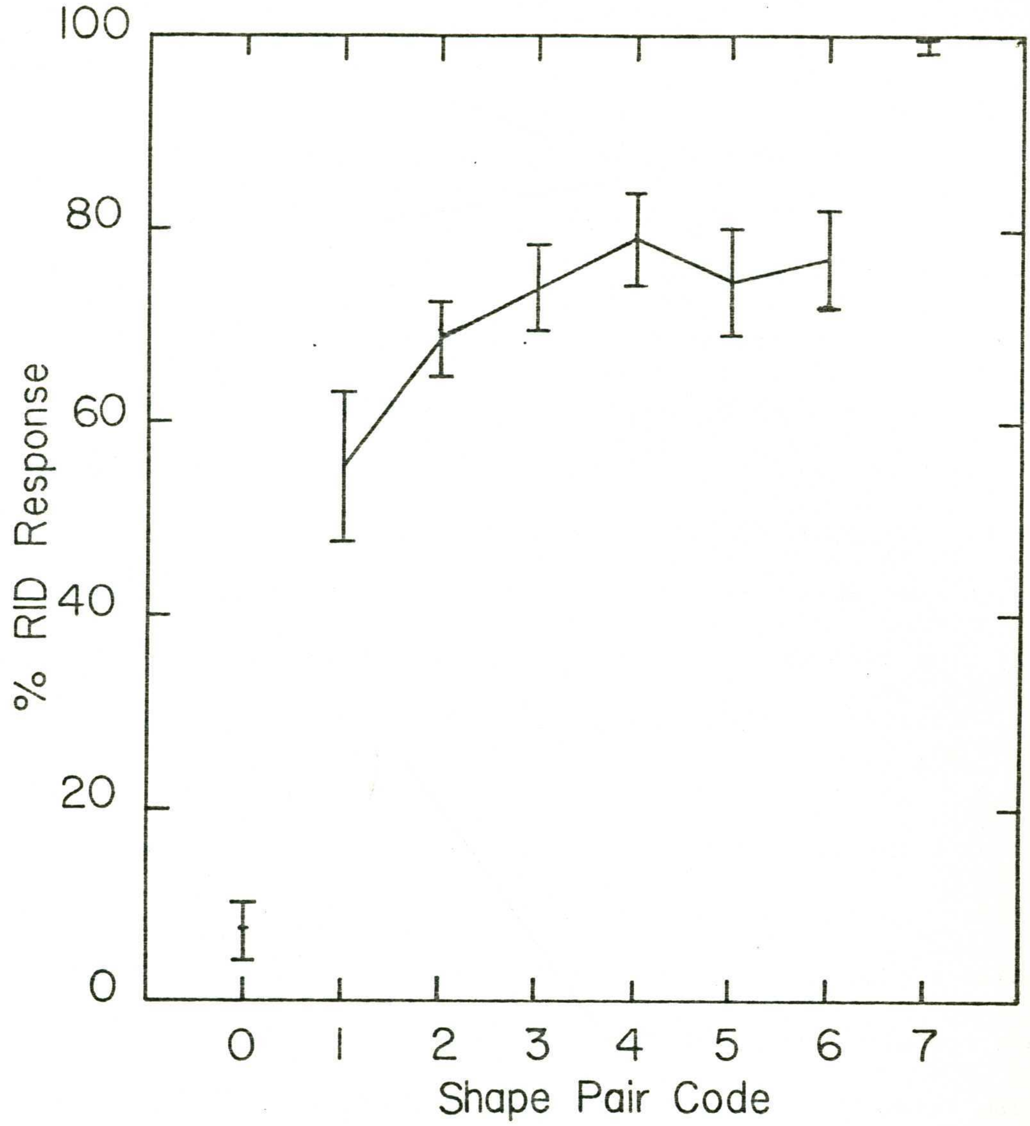


Figure 4.6 Shape effect for Experiment 4.2. Shape pairs 0 and 7 are shown but the curve does not include them because they were not included in the analysis of variance.

rectangles with no spikes. With more than 1 spike on the rectangles this mistake rarely occurs and the shapes reach their maximum level of RID responses. If this mistake occurs then it is fairly rare, given the very large difference between the means for the condition with no spikes and the one with 1 spike.

Even though it was expected that rectangles with no direction marker on them would not rotate in depth very often and that the Neuhaus triangles would rotate very well, the magnitude of the difference between the shapes obtained in this experiment was surprising. The effect of these two extreme stimulus configurations may have been enhanced by a context effect in that one clearly had no direction marker and the other indicated direction very well. The comparison with the other figures, which had some direction, may have made them appear to rotate even less (in the case of the rectangles) or even more (in the case of the Neuhaus triangles) than would normally be expected.

A reason why the rectangles with spikes never appeared to rotate in depth as often as the Neuhaus triangles might be that the rectangles have conflicting direction information. The spikes indicate a direction orthogonal to the axis about which the two shapes were reflected whereas the long axis of the rectangles indicate a direction which is parallel to that axis. Also, the spikes, which were the features responsible for defining the direction of the rectangles were not a prominent part of the whole figure. The spikes may not, therefore, have been as effective as the broad point on the Neuhaus triangles.

EXPERIMENT 4.3

The previous experiment showed that the addition of a relatively minor addition (a spike) to an otherwise directionally neutral figure will increase the probability of reports of RID. Without the spikes, the two rectangles side by side can be thought of as either two shapes that are mirror images of one another or as the same shape translated in space. There are no features on the shapes that suggest that they are mirror images and therefore, no evidence to suggest that the two shapes are in different orientations. If RID reports depend on the visual system recognising that the two shapes are the same shape in a different orientation, then it is unlikely that two plain rectangles side by side will elicit reports of RID.

Adding an appropriate spike to these rectangles means that there is now a feature that indicates that the shapes are mirror images and that one is not a simply translation of the first. The possibility arises that the visual system will recognise the two shapes as being the same shape in different orientations and reports of RID may occur. The question now arises of whether or not the mirror image nature of the display is important. It could be that the only important feature is the difference in perceived orientation due to the direction markers. In an attempt to find the answer to this question this experiment asked whether rotation in depth will occur between two similar shapes that are not perfect mirror images.

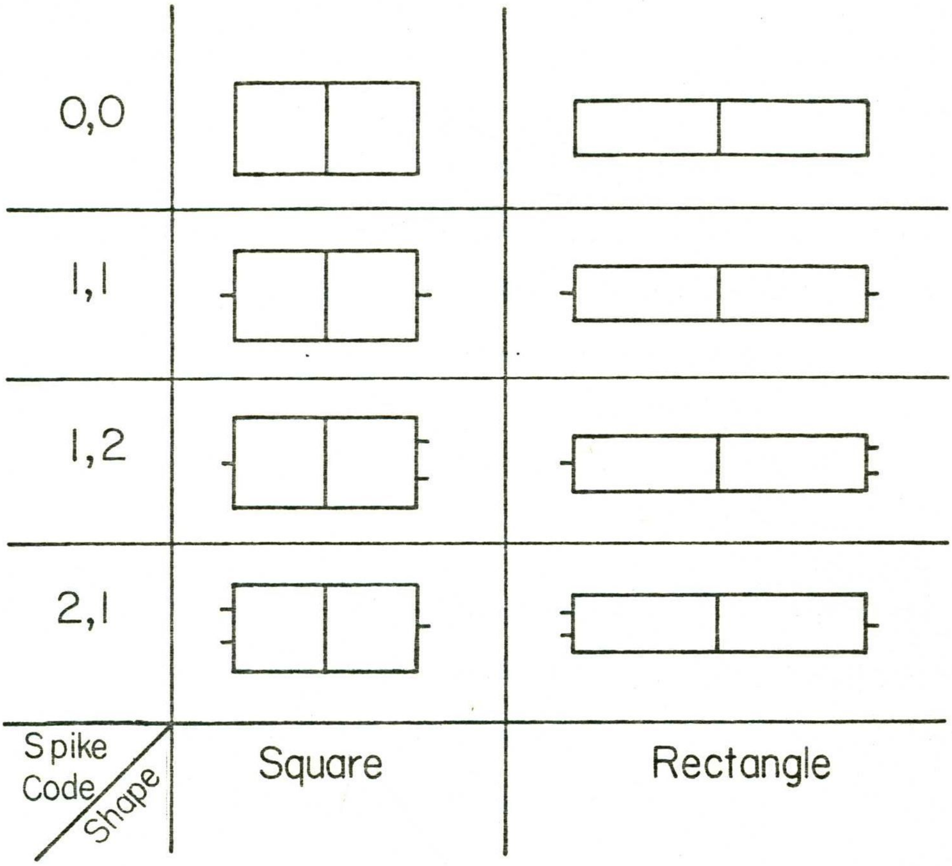


Figure 4.7 The stimulus configurations used in Experiment 4.3, full size. The four levels of Shape and the four levels of Spikes are shown along with the code numbers for Spikes.

METHOD

Stimuli. Figure 4.7 illustrates the figures used in this experiment. The squares were 11.9 mm x 11.9 mm and the rectangles were 7.5 mm x 18.75 mm. The squares and rectangles were of approximately equal area. The spikes were 1.4 mm long and easily resolvable.

Procedure. Three different treatments were applied in this experiment: Shape (square and rectangle), Spikes (no spikes, one spike each, one spike followed by two spikes, two spikes followed by one spike) and Separation (0 and 11.7 mm). Fifteen subjects were used. All subjects saw all of the 16 possible treatment combinations at a fixed ISI of 25 msec.

RESULTS

Three subjects had no RID responses at all and their data were not included in the analyses. Table 4.5 is a table of means and S.D.'s of RID responses for all the treatment combinations used in this experiment. Note that this table does not include the data for the three subjects who reported no rotation in depth. The data did not violate the assumption of the homogeneity of variance ($F_{max}=5.42$, $p>.05$) so a 3 way analysis of variance with 3 repeated measures was performed on the untransformed data. Only the effect of Spikes and the Separation x Shape interaction were significant (see Table 4.6).

The effect of Spikes is graphed in Figure 4.8. There was no significant difference between the mean for the first spike configuration (one-one spikes) and the third spike configuration (two-one spikes) ($q=1.71$, $p>.05$). Therefore, there was no difference between any of the spike configurations. There was a significant difference between these configurations and the no spike configuration ($Fs=52.53$, $p<.05$).

TABLE 4.5

Means and S.D.'s of RID responses for Experiment 4.3

Shape	Spike code 0,0	1,1	1,2	2,1
Separation = 0 mm				
Square	4.0	13.0	12.42	15.42
	4.62	5.60	4.70	6.51
Rectangle	4.0	11.5	10.75	11.67
	4.10	5.87	5.37	4.90
Separation = 11.7 mm				
Square	2.08	9.83	11.12	13.12
	2.87	5.54	5.52	6.19
Rectangle	3.0	10.67	10.67	11.75
	3.08	5.20	6.46	6.48

Note- For each shape, the means are in the first row and the S.D.'s are in the second row.

TABLE 4.6

Analysis of Variance Table for Experiment 4.3

SOURCE	SS	DF	MS	F	
BETWEEN SUBJECTS	2575.9	11			
WITHIN SUBJECTS	5814.9	180			
A (Separation)	81.4	1	81.4	3.36	
Error A	266.7	11	24.2		
B (Shape)	37.6	1	37.6	2.90	
Error B	142.7	11	13.0		
C (Spikes)	2737.4	3	912.5	18.16	*
Error C	1658.3	33	50.3		
AxB	34.2	1	34.2	15.90	*
Error AxB	23.6	11	2.1		
AxC	11.6	3	3.9	.62	
Error AxC	207.1	33	6.3		
BxC	60.4	3	20.1	1.66	
Error BxC	401.0	33	12.2		
AxBxC	5.1	3	1.7	.38	
Error AxBxC	147.8	33	4.5		
TOTAL	8390.9	191			

* Significant at the .05 level

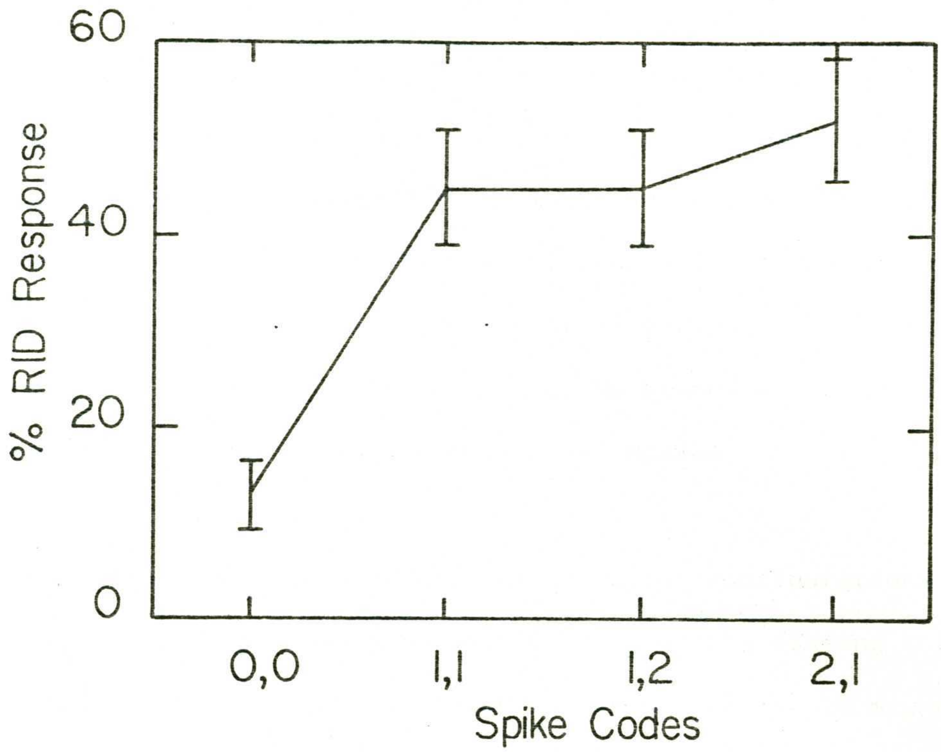


Figure 4.8 The Spike effect from Experiment 4.3.

DISCUSSION

These data suggest that the two shapes do not need to be perfect mirror images of one another in order to produce the perception of rotation in depth. The differences between the two shapes in the non-mirror images were not great but they were easily noticeable. Subjects' verbal reports and the experimenter's observations indicated that the extra spike blinked off or blinked on, depending on whether the shape with two spikes was the first or second in the presentation sequence. The situation was one of rotation in depth coupled with a sort of deformation of the shape. In keeping with the idea that the primary variable of interest in these experiments is the apparent depth of the motion, it was emphasised to the subjects that the distingishing characteristic they were to base their responses on was the depth. It seems that for most subjects the appearance of an object rotating in depth was not affected by that shape appearing to change during the movement. It seems safe to argue that, in general, the effect of the spikes was to indicate the direction of the shapes and that it did not matter whether this was done with one or two spikes.

However, the fact that half the stimulus configurations did not consist of mirror images may have some bearing on the finding that three subjects did not report any rotation in depth at all. It might be the case that these subjects had some preconceived ideas that rotations in depth result in perfect mirror image pairs. When they saw that some of the shape pairs were not mirror images, they may have assumed that none of the displays would rotate in depth and stopped trying to assess which type of movement was present. This bias could have been reinforced by the fact that one stimulus configuration (0,0 spikes) would not have appeared to rotate in depth very much in any case. The result is nonetheleess puzzling and it is assumed that its explanation lies in the peculiarities of the individuals concerned.

Figure 4.9 graphs the nature of the significant Separation x Shape interaction. It can be seen that Separation had very little effect on the number of RID responses for the rectangles but that increasing the separation decreased the number of rotation in depth responses for the squares. The difference could be due to the long axis

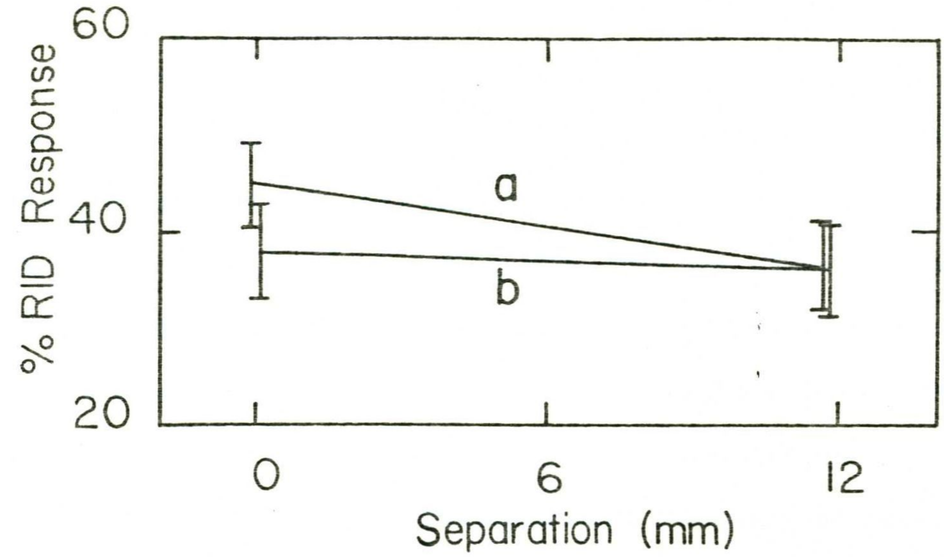


Figure 4.9 The Shape x Separation interaction effect from Experiment 4.3. The letters on the curves indicate the different levels of shape. These levels were: square (a) and rectangle (b).

of the rectangles adding to the direction information supplied by the spikes. The long axis should be readily apparent even when the shapes are separated in space so the rectangles were not affected to the same extent by increasing the separation. The only cue for the direction of the squares was the spikes and since the detection of the spikes depends on inspecting the outside edges of the shapes, increasing the separation would be expected to have an effect. The nature of this interaction suggests that the long axis of a shape may contribute some directional information that is useful for the formation of rotation in depth. However, it should be noted that the Shape x Separation effect is very small, accounting for less than 1% of the variance (E(w2)=.006).

The data from this experiment are consistent with the model developed in Chapter 3. In the model, the only aspect of the shapes that was assumed to be important was their direction. These data support that assumption in that they show that the shapes do not need to be mirror images for RID responses to occur. They also show that RID responses occur more frequently with shapes that have opposed directions than with shapes that have no direction. The small effect of Separation in this experiment is also consistent with the proposed model. In this experiment, Separation only exercises an effect by interacting with a feature of the shapes.

EXPERIMENT 4.4

Experiment 4.3 demonstrated that the shapes in a stimulus configuration do not have to be mirror images for that configuration to produce rotation in depth. The results also suggested that the long axis of an otherwise neutral shape, such as a rectangle, may contribute to the perceived direction of the shape. In this experiment the shapes in the stimulus configurations were rectangles and arrows. The configurations were designed to further explore the idea that the stimulus configurations do not need to be mirror image pairs in order to generate rotation in depth.

The particular stimulus configurations used also allowed an examination of the hypothesis that the long axis of the shapes may contribute to their perceived direction and thus, to the number of RID responses. The long axis of a shape is an ambiguous indicator of direction in that it indicates two opposite directions. The stimulus configurations were designed to find out what happens when a shape with ambiguous direction (a rectangle) is combined with a shape with well defined direction (an arrow).

METHOD

Stimuli. Figure 4.10 illustrates the nine different stimulus configurations used in this experiment. The rectangles were 24 mm x 12 mm and the "arrows" were 24 mm x 12 mm with a triangle of base 12 mm and height 6 mm added.

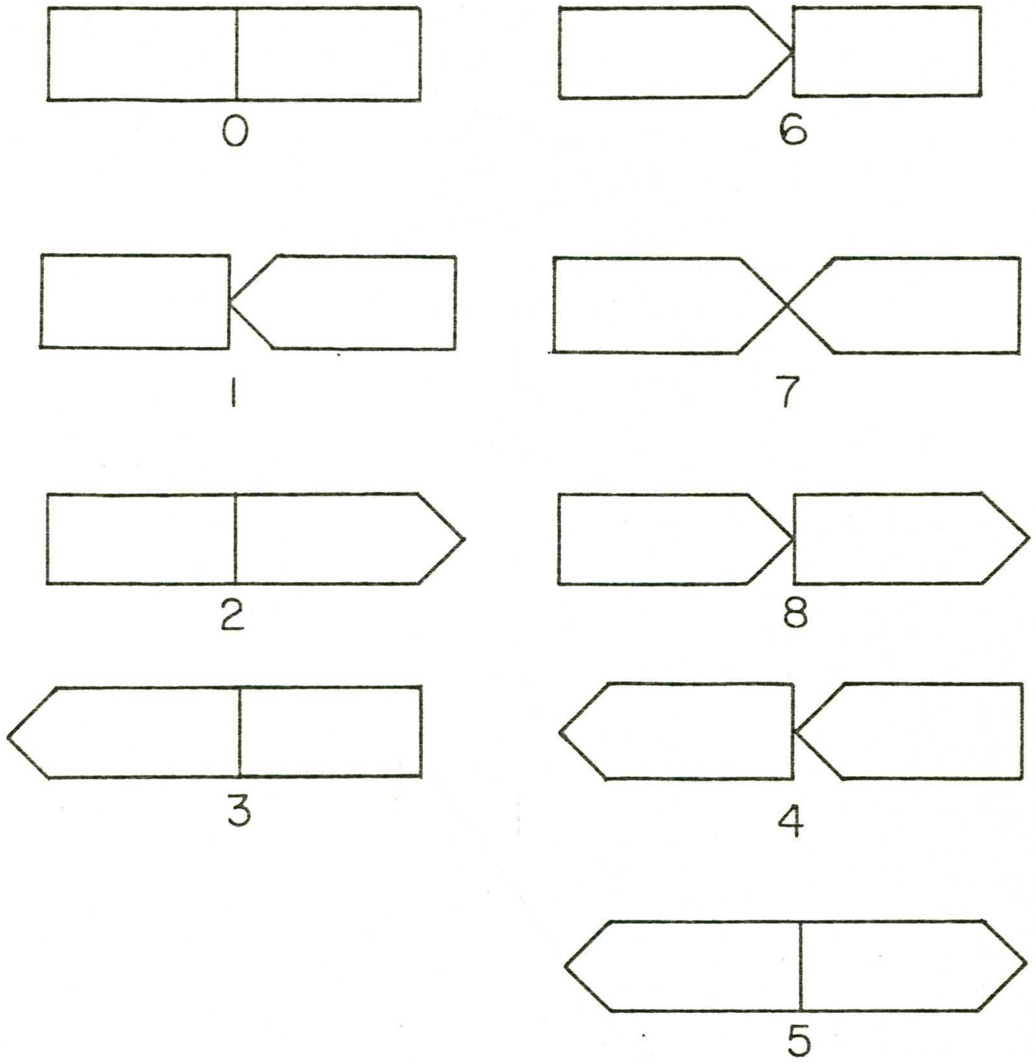


Figure 4.10 The stimulus configuratios used in Experiment 4.4, full size. The shape pair code numbers are shown beneath each stimulus configuration.

Procedure. A two treatment experiment was run with 2 repeated measures. The first treatment was Shape with 9 levels (illustrated in Figure 4.10) and the second treatment was Separation where the levels were 0 and 10 mm. Ten subjects were run and each subject saw all of the 18 possible Shape-Separation treatment combinations at a fixed ISI of 25 msec.

RESULTS

The means and standard deviations of the RID responses to all treatment combinations used in this experiment are shown in Table 4.7.

TABLE 4.7

Means and S.D.'s of RID responses for Experiment 4.4

	Separation (mm)	
Shape Pair Code	0	11.7
0	4.7	2.5
	4.56	1.96
1	10.0	7.7
	7.43	6.66
2	7.8	7.0
	5.93	5.62
3	10.4	11.1
	7.61	5.61
4	4.9	4.1
	4.3	4.3
5	16.1	16.3
	7.41	7.67
6	6.3	5.5
	5.85	5.94
7	14.2	14.9
	8.44	7.92
8	2.3	2.3
	2.97	3.44

Note- For each shape pair, the means are in the first row, the S.D.'s are in the second.

TABLE 4.8

Analysis of Variance Table for Experiment 4.4

SOURCE	SS	DF	M	F
BETWEEN SUBJECTS	2895.3	9		
WITHIN SUBJECTS	6705.7	150		
A (Shape)	3254.7	7	465.0	9.70 *
Error A	3022.4	63	48.0	
B (Separation)	6.0	1	6.0	.48
Error B	113.3	9	12.6	
AxB	35.1	7	5.0	1.15
Error AxB	274.0	63	4.3	
TOTAL	9601.0	159		

* Significant at the .05 level

The data did violate the assumption of homogeneity of variance ($Fmax=18.48$, $p<.05$). Inspection revealed that there was a very small variance associated with the stimulus configuration that consisted of two rectangles 10 mm apart. This small variance was in part a reflection of the mean, which was close to 0 and thus near the lower bound. The data for the two rectangles (at both separations) were removed. This reduced set of data did not violate the assumption of homogeneity of variance ($Fmax=8.08$, $p>.05$) so a two way analysis of variance with two repeated measures was performed on this data. The results are tabulated in Table 4.8 where it can be seen that the only significant effect is due to Shape.

The effect of Shape has been graphed in Figure 4.11: the data point for the rectangles has not been connected to the rest of the graph because these data were not included in the ANOVA. The data indicate that most RID responses occur with arrows pointing in opposite directions, either both in or both out. These stimulus configurations were called "opposite direction" configurations. There was no significant difference between arrows pointing out and arrows pointing in (Shape Pairs 5 & 7 respectively; $q=1.07$, $p>.05$). Few RID responses were recorded when both arrows pointed in the same direction. These configurations were called "same direction" configurations. There was no significant difference between both arrows pointing left and both arrows pointing right (Shape Pairs 4 & 8 respectively; $q=1.42$, $p>.05$).

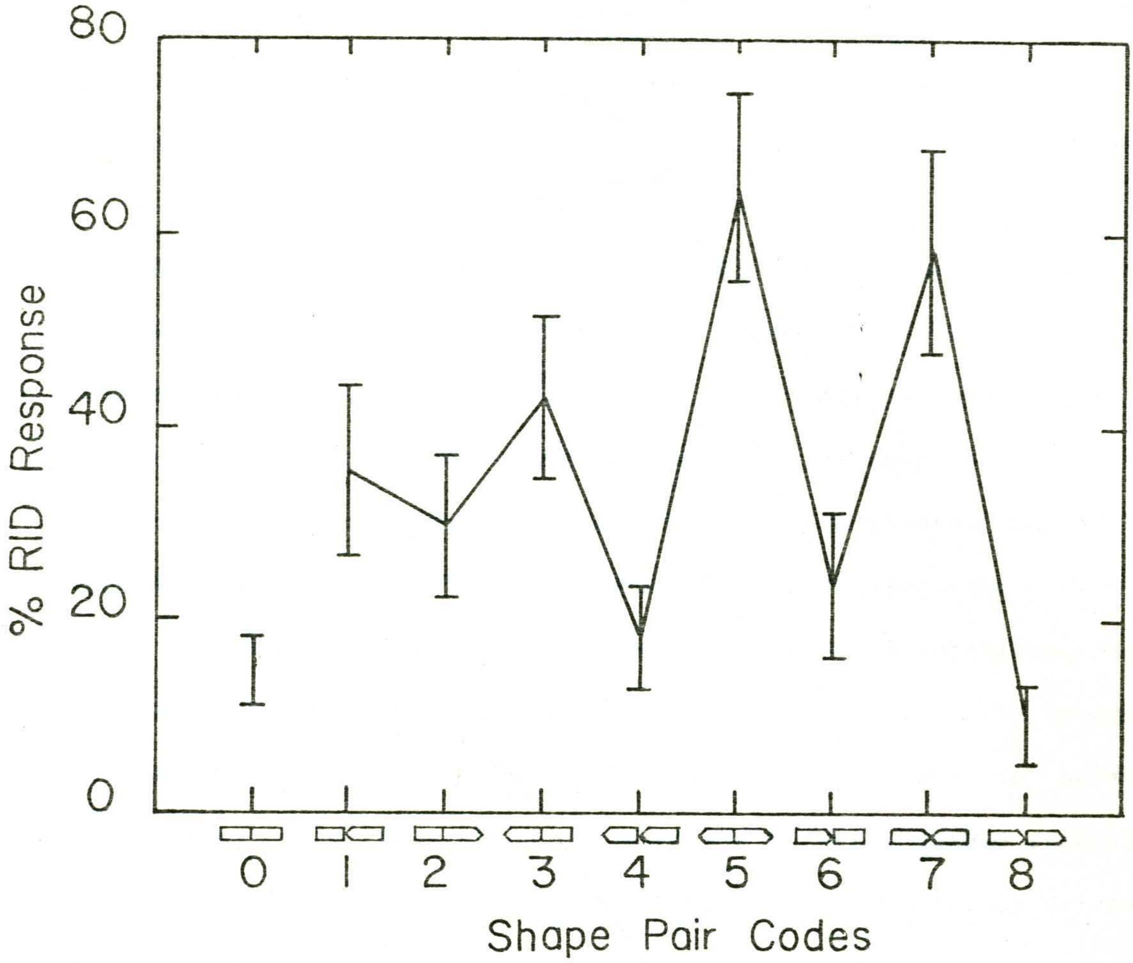


Figure 4.11 The shape effect for Experiment 4.4. The point for Shape pair 0 is not connected to the curve because these data were not included in the ANOVA.

The remaining configurations were called "mixed" configurations because they consisted of one arrow and one rectangle. There was no significant difference between the largest and smallest of the four means of the "mixed" configurations (Shape Pairs 3 & 6 respectively; $q=3.13$, $p>.05$). Therefore, there was no significant difference between any of these means. There was a significant difference between the pooled means of the "mixed" configurations and the "opposite direction" stimulus configurations ($F=28.42$, $p<.05$; shape pairs 1, 2, 3 & 6 vs. 5 & 7). There was no significant difference between the pooled means of the "mixed" configurations and the pooled means of "same direction" stimulus configurations. ($F=12.94$, $p>.05$; shape pairs 1, 2, 3, & 6 vs. 4 & 8).

In summary, the data suggest that RID responses occur most frequently for two arrows pointing in opposite directions. Mixed configurations did not elicit significantly more RID responses than "same direction" stimulus configurations. It was noted, however, that all four means for the "mixed" configurations were greater than the two means of "same direction" configurations. This suggests that there may be some increase in RID responses for stimulus configurations where a shape with well defined direction is paired with a shape with ambiguous direction (i.e. arrows and rectangles) as opposed to stimulus configurations that consist of two shapes with well defined directions both pointing in the same direction. There is no statistical evidence, however, in this experiment for such a conclusion. Few RID responses are expected when both shapes clearly point in the same direction whereas the "mixed" configurations allow for the possibility of a rotation in depth accompanied by some deformation.

DISCUSSION

From the above data one can conclude that the types of stimulus configurations which will appear to rotate in depth frequently are those in which the two shapes are very similar and have well defined directions. Those directions must be opposed to one another and perpendicular to the axis of rotation. If the shapes are too dissimilar or do not have a well defined direction or if those directions are not in the correct relationship, the number of rotation in depth responses will be reduced. Shape pairs 5 and 7 consist of similar shapes with well defined directions that are opposed and perpendicular to the axis of rotation and, as expected, they are reported as rotating in depth most frequently. The "mixed" configurations might be expected to rotate in depth better than the identical configurations because the rectangle can be said to be "opposing" the direction of its arrow partner. They should not rotate as well as the opposed arrows because the direction of the rectangle is not well defined and is ambiguous.

The results suggest that a rectangle does contain enough direction information (presumably information derived from its long axis) to form the percept of an object rotating in depth. As in the previous experiment this percept also involves some deformation of the shape as it moves. In many cases this deformation involved the sudden disappearance or appearance of the point, depending on whether the arrow was first or second in the presentation sequence.

Whenever the left pointing arrow was first in the sequence there were more rotation in depth responses than in a similar sequence where the right pointing arrow was first (compare conditions 1 & 2, 3 & 6, 5 & 7 and 4 & 8). Despite the fact that these differences were not significant, their consistency suggests that there is something different happening when the arrows point away from the axis of rotation than when they point into the axis of rotation. It may be that the stimulus configuration is scanned as though the subject were reading, from left to right, and that features on the left hand side are picked up first and retained better than features that occur later. Another possibility is that direction markers on the periphery of stimulus configurations may be more salient than those near the middle and thus contribute more to the process of defining the direction of a shape.

It is likely that Separation had no effect in this experiment because the shapes had features that were very easy to distinguish. In this case it is not expected that increasing the spatial separation should make the comparison between the shapes any more difficult. In terms of the model described previously, the presence of well defined shape information should increase the coefficient of that factor at the expense of the separation factor, the only other factor operating in this experiment.

EXPERIMENT 4.5

The previous experiments have demonstrated that it is possible to elicit RID responses using stimulus configurations that do not consist of mirror images. This experiment extends the use of non-mirror image pairs.

METHOD

Stimuli. The basic stimulus configuration consisted of a square followed by a rectangle. On half the trails this basic configuration had a spike added to both figures. The square and rectangle were presented in 4 different spatial relationships. The rectangles were 16 x 32 mm and the squares were 16 x 16 mm. The spikes, when present, were 2 mm long. Figure 4.12 illustrates the 4 basic stimulus configurations (with spikes added).

Procedure. Three different treatments were used: ISI (25 and 100 msec), Spikes (present or absent) and Stimulus Configuration. Ten subjects were run. They saw all of the 16 possible treatment combinations.

RESULTS

Table 4.9 is a table of the means and standard deviations of RID responses for all the treatment combinations used in this experiment. The data did not violate the assumption of homogeneity of variance ($F_{max}=8.43$, $p>.05$) so a three way analysis of variance with three

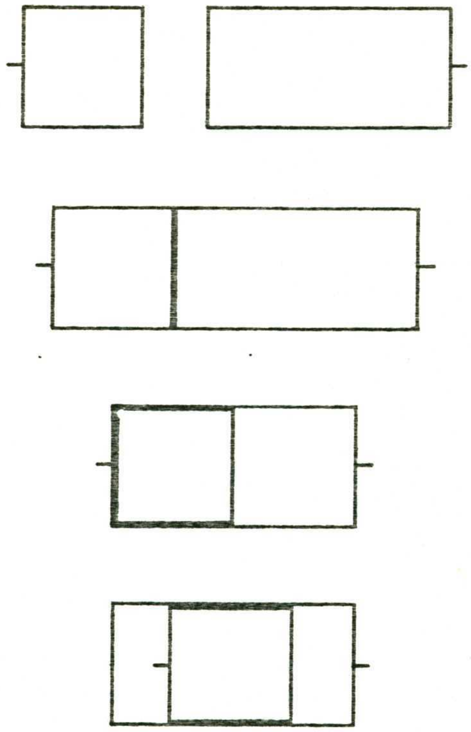


Figure 4.12 The stimulus configurations used in Experiment 4.5, full size. The stimulus configurations are shown with added spikes. The bold contours are common to both shapes.

respeated measures was performed on the untransformed data. The results are tabulated in Table 4.10, where it can be seen that the two effects of Stimulus Configuration and Spikes were significant. Neither ISI nor any of the interactions had a significant effect on the number of RID responses.

DISCUSSION

Figure 4.13 indicates that there was an increase in RID responses to Stimulus Configuration 2 relative to Stimulus Configuration 1. This may be due to the reduced separation in 2 as opposed to 1. In this case this would be an example of the Separation effect observed in

TABLE 4.9

Means and S.D.'s of RID responses for Experiment 4.5

	Stimulus Configuration Code			
ISI (msec)	0	1	2	3
		Spike Absent		
25	4.0	3.9	11.6	15.5
	2.83	3.88	5.44	8.21
100	3.0	5.2	12.5	14.9
	3.26	5.15	6.68	7.73
		Spike Present		
25	7.5	8.5	15.0	18.1
	7.53	7.88	6.03	4.30
100	8.0	9.4	16.1	17.7
	7.56	7.38	6.56	5.55

Note- For each ISI, the means are in the top row and the standard deviations are in the second row.

TABLE 4.10

Analysis of Variance Table for Experiment 4.5

SOURCE	SS	DF	MS	F
BETWEEN SUBJECTS	926.6	9		
WITHIN SUBJECTS	9381.4	150		
A (Stim. Con.)	3330.6	1	3330.6	12.26 *
Error A	2445.8	9	271.8	
B (Spikes)	768.7	3	256.2	3.36 *
Error B	2057.7	27	76.2	
C (ISI)	1.6	1	1.6	0.16
Error C	92.8	9	10.3	
AxB	41.1	3	13.7	1.04
Error AxB	354.5	27	13.1	
AxC	.1	1	.1	.04
Error AxC	26.0	9	2.9	
BxC	10.3	3	3.4	1.58
Error BxC	58.4	27	2.2	
AxBxC	36.5	3	12.2	2.09
Error AxBxC	157.3	27	5.8	
TOTAL	10308.0	159		

* Significant at the .05 level

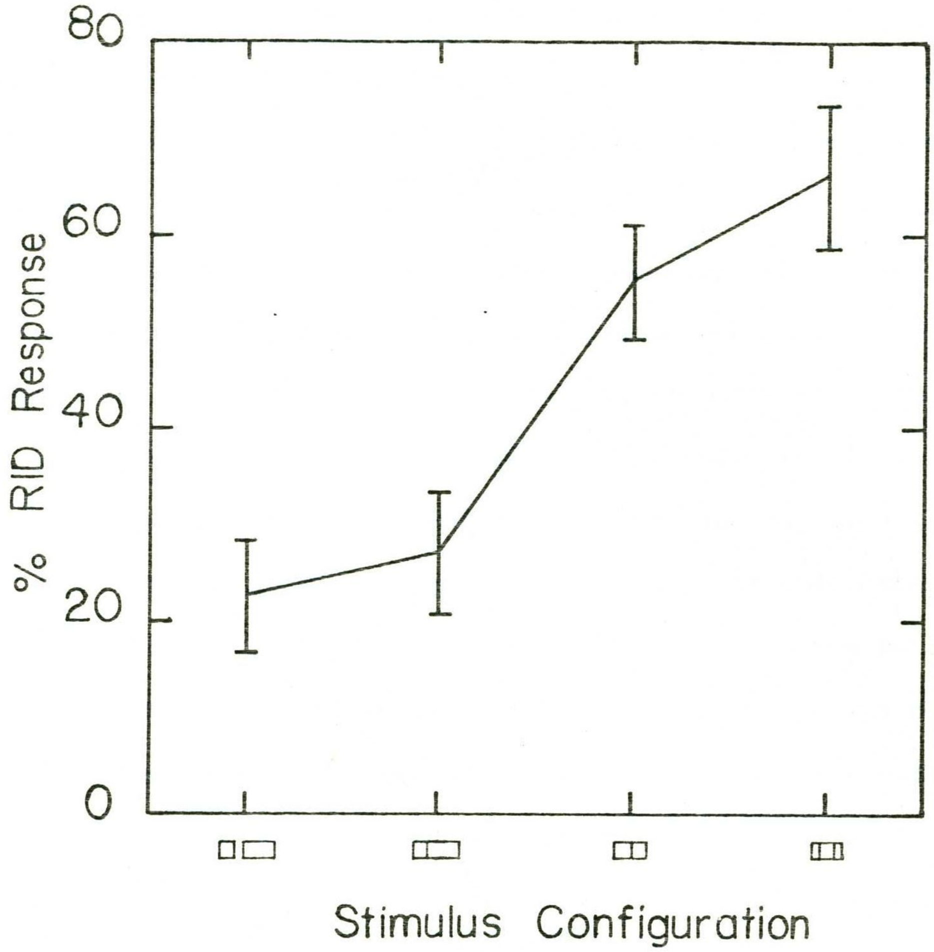


Figure 4.13 The stimulus configuration effect from Experiment 4.5.

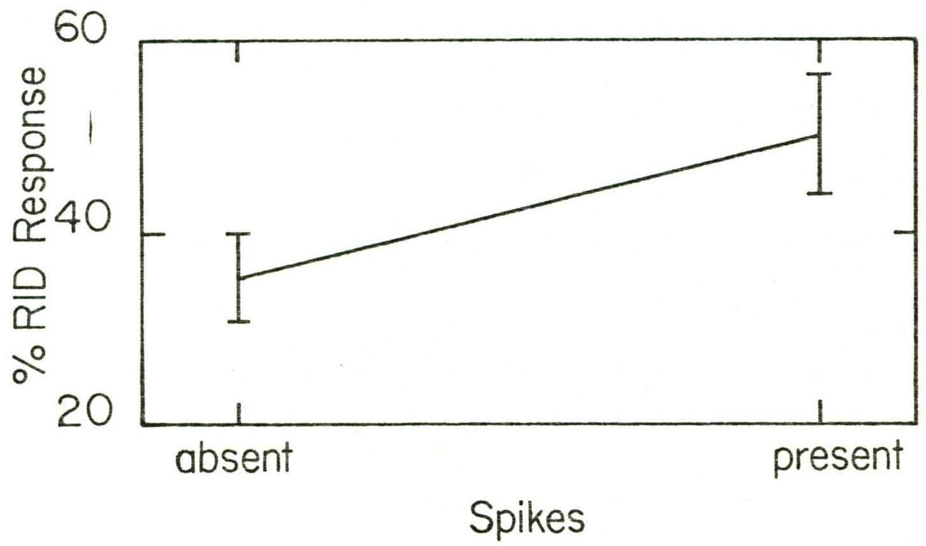


Figure 4.14 The spike effect from Experiment 4.5

earlier experiments. However, the number of RID responses continues to increase for Stimulus Configurations 3 and 4. This cannot readily be explained by the separation effect used in the development of the model described above because in that model the coefficient for Separation was defined as 0 when the shapes were superimposed. One possible explanation could be that with these particular stimulus configurations the important distance was the distance between the sides bearing the spikes, rather than the distance between the shapes. On the other hand, a previous experiment suggested that superimposition may introduce a new factor into the display by suggesting new ways in which the stimulus material can be organised. It is plausible that this may be operating here and that the superimposition of the shapes induces a way of looking at the display that encourages RID responses. Neither explanation is very satisfactory and this result remains puzzling.

The spikes were expected to play a very large role in this experiment. The effect of the spikes was in the expected direction (see Figure 4.14). Stimulus configurations without spikes appeared to rotate in depth significantly fewer times than those with spikes. It is most surprising, however, that the stimulus configurations without spikes rotated as well as they did. In other words, the stimulus conditions without spikes (and therefore without good specifiers for direction) were expected to elicit very few RID responses yet the average RID response for the conditions without spikes was actually 35.3%. The data suggest that a stimulus configuration consisting of a shape with practically no direction information (the square) and a shape with limited, ambiguous direction information (the rectangle) can still appear to rotate in depth quite frequently. This is at odds with previous results and is taken as further evidence that superimposition may overturn relationships discovered with separated shapes.

The relatively small effect of spikes might be explained by arguing that a particularly strong context effect was operating in this experiment. Since the only difference between these stimulus configurations was the single spike and since these are difficult displays to interpret, the configurations without spikes may have been strongly identified with the configurations that did have spikes. It might be argued that stimulus configurations without direction markers were used in other experiments and they did not elicit nearly as many RID responses as similar conditions with direction markers (see Experiment 4.3 and 4.4). However, the stimulus configurations in the other experiments consisted of shapes that seemed more similar than the square and rectangle used in this experiment.

If a strong context effect was operating in this experiment, then if stimulus configurations without spikes are shown on their own, then the pattern of responses to these configurations should be reduced. On the other hand, if the observed pattern of responses in Figure 4.14 is related to the stimulus configurations themselves, without any reference to the spikes, then showing only the configurations without spikes should make little difference. The following experiment examines this question.

EXPERIMENT 4.6

The stimulus configurations used in this experiment were the same as those used in the previous experiment except that the conditions with spikes were not used. In this experiment, there is no possibility that configurations with spikes will induce similar configurations, without spikes, to appear to rotate in depth.

METHOD

Stimuli. The stimulus configurations appear in Figure 4.15; they were a subset of the configurations used in the preceding experiment.

Procedure. Two treatments were applied in this experiment: Stimulus Configuration and Order. The two levels of Order were square followed by rectangle, and rectangle followed by square. The two shapes appeared in the same spatial location for both orders so in the first case the movement was generally left to right and in the second case it was generally right to left. Ten subjects were used and they saw all 8 possible treatment combinations at a single fixed ISI of 25 msec.

RESULTS

The means and standard deviations of RID responses for all treatment combinations used in this experiment are shown in Table 4.11. The data did not violate the assumption of homogeneity of variance ($F_{max}=5.03$, $p>.05$) so a two way analysis of variance with two repeated measures was performed on the untransformed data. Table 4.12 indicates that the effects of Stimulus Configuration and Order were significant but the interaction between them was not.

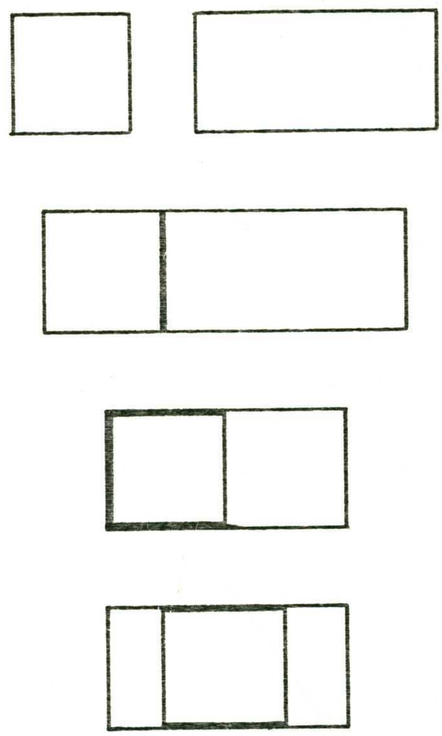


Figure 4.15 The stimulus configurations used in Experiment 4.6, full size. On half the trials the square appeared first and on the other half the rectangle appeared first. Note that these stimulus configurations are a subset of those used in Experiment 4.5.

TABLE 4.11

Means and S.D.'s of RID responses for Experiment 4.6

	Stimulus Configuration Code			
Order	0	1	2	3
Square 1st	4.1	5.7	6.1	12.6
	4.66	6.12	7.44	7.89
Rectangle 1st	6.6	7.6	11.6	16.1
	5.50	3.93	7.94	8.81

Note- For each order, the means are in the first row and the standard deviations are in the second row.

TABLE 4.12

Analysis of Variance Table for Experiment 4.6

SOURCE	SS	DF	MS	F
BETWEEN SUBJECTS	1120.3	9		
WITHIN SUBJECTS	3718.5	70		
A (Order)	224.5	1	224.5	10.63 *
Error A	190.1	9	21.1	
B (Stim. Con.)	946.6	3	315.5	4.09 *
Error B	2084.9	27	77.2	
AxB	37.4	3	12.5	1.43
Error AxB	235.2	27	8.7	
TOTAL	4838.8	79		

* Significant at the .05 level

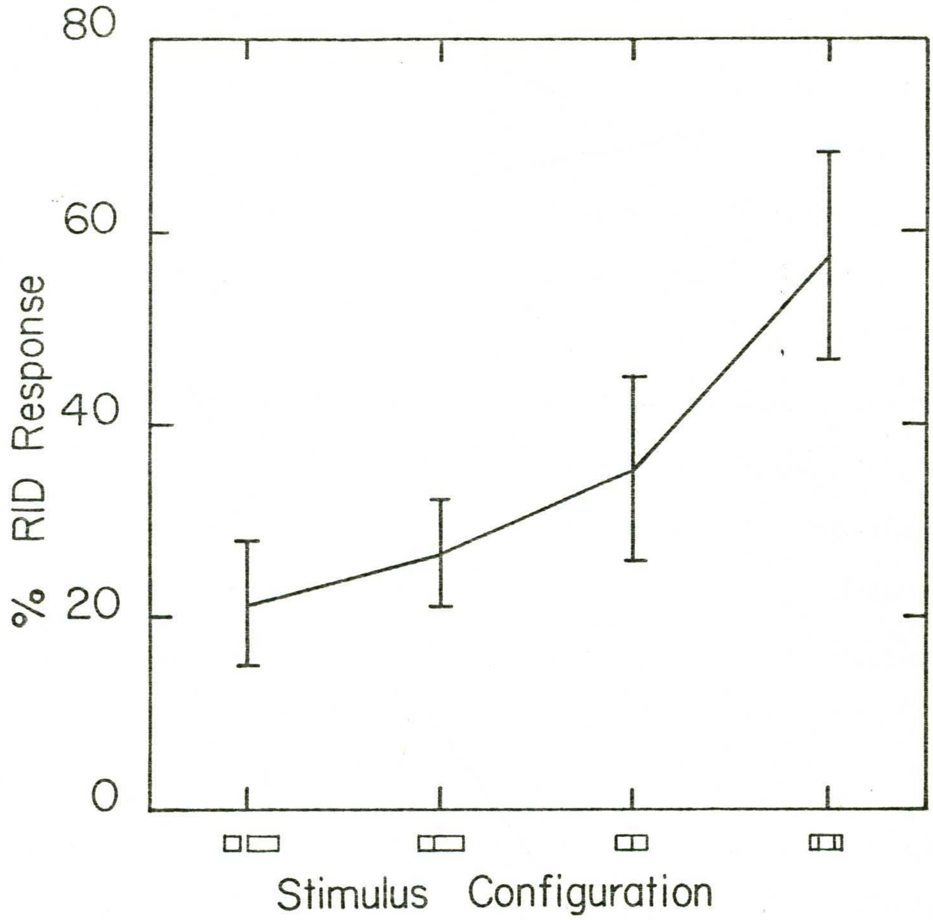


Figure 4.16 The stimulus configurations effect from Experiment 4.6.

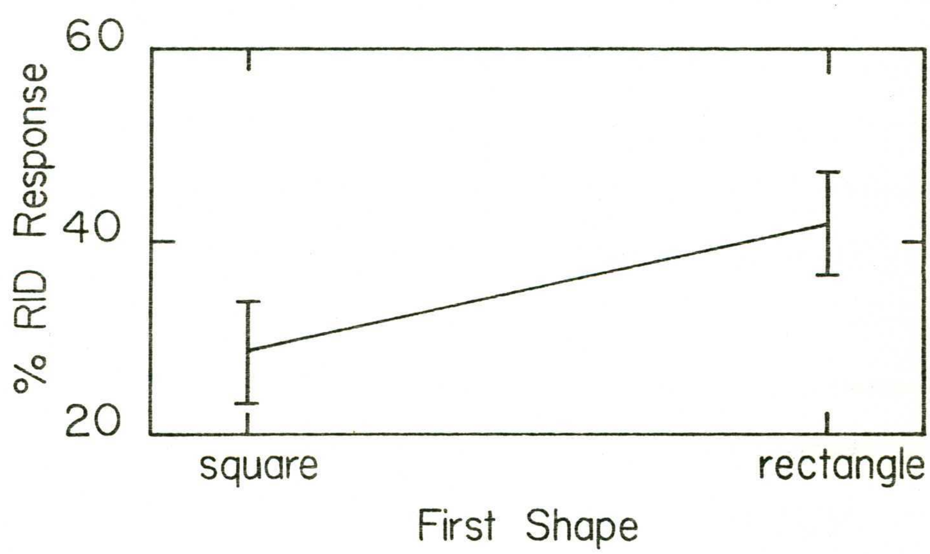


Figure 4.17 The effect of presentation order from Experiment 4.6.

DISCUSSION

Figure 4.16 graphs the effect of Stimulus Configuration and it can be seen that even without the spikes these configurations follow a similar pattern to the stimulus configuration effect found in the preceding experiment. The graph shows that there was a monotonic increase in the number of RID responses elicited by stimulus configurations 0 to 3. Since none of these stimulus configurations had direction markers in the form of spikes, this result cannot be due to such markers. Similarly, the sort of context effect hypothesised in the last experiment cannot account for the results. The data suggest that the configurations themselves exercise an effect, irrespective of whether they have spikes on them or not.

Figure 4.17 graphs the effect of Order and shows that the number of RID responses was smaller when the square appeared first than when the rectangle appeared first. This result could be interpreted as suggesting that in the greatest number of RID responses will occur when the shape with the best direction (in this case, the rectangle) is presented first rather than second. The presentation of the shape with better direction first may act as a cue to the possibility that there might be an apparent orientation change. This hypothesis requires a more careful examination than is possible from this study.

The results of the last two experiments suggest that the presentation of a shape with hardly any directional properties (a square) followed by a shape with ambiguous directional properties (a rectangle) will result in a significant number of RID responses. It might be argued that this presents a serious problem for the model described above since the effect of shape was bound up in the directional properties of the shapes. It should be noted, however, that simple translation will not turn a square into a rectangle. Therefore, the visual system must apply some other transformation to these shapes. The stimulus configurations used in the last two experiments are consistent with the parallel projection of a rectangle rotating through an angle of less than 180 degrees. It may be the case that with these particular configurations, which have poor direction information and non-mirror image pairs, the most easily applied non-translation transformation is a rotation in depth, albeit through an angle of less than 180 degrees.

The data collection techniques used were too crude to provide any information on the question of whether the subjects actually saw a rotation of less than 180 degrees when they reported rotation in depth. There is no doubt, however, that reports of rotation in depth were relatively frequent. This was contrary to expectation since neither of the two shapes used had very well defined directions and the shapes were superimposed half the time. It is felt that the paradoxical success of these stimulus configurations in producing RID responses lies in the superimposed stimulus configurations. The data are consistent with the idea that superimposition introduces a new factor into the experiment which confounds the usual relationship between variables by suggesting new perceptual organizations of the stimulus material. However, the data also suggest that the model advanced earlier cannot completely account for all possible situations where rotation in depth can occur.

SUMMARY OF QUADRILATERAL EXPERIMENTS

The experiments described in Chapter 3 examined the role of shape in relation to a number of other variables such as ISI and Separation. A model was developed from these data where a number of factors were shown to influence the production of RID responses, but in which the factors were assigned different weights. It was concluded that for the experiments reported in this study, Shape was the single most important factor in determining RID responses. The experiments reported in this Chapter concentrated on determining which aspects of the shapes were important in determining RID responses. Some of the data collected in this series of experiments also constitute supporting evidence for the proposed model but these findings were incidental to the main aim.

The starting point for the experiments described in this Chapter was the idea that there might be some minimum feature that would induce rotation in depth. Many apparent motion displays consist of shapes that can be considered as translations of one another, such as two squares side by side. These displays will not, under ordinary circumstances, appear to rotate in depth. Rotation in depth generally only occurs when the shapes are no longer translations of one another. It seems to occur most frequently when the shapes are mirror images, that is, when they are 180 degree rotations in depth of one another. The initial experiments in the series started with two shapes that were translations of one another (upright rectangles). A number of features of different sizes (small triangles or spikes) were added to them. It was considered that there might be a continuous increase in the number of RID responses as the features indicating the shapes to be mirror images were made larger or more numerous. The results indicated that once a feature indicating the shapes were mirror images was discriminable, the full effect was achieved. Making the mirror image nature of the display more obvious did not increase the number of RID responses.

The question then arose of whether it was the mirror image nature of the display that was important or whether it was simply the indication of opposed directions. The results were consistent with the idea that all the mirror image nature of the display achieved was to ensure that the two shapes had opposed directions. This was the starting point for a number of experiments where the shapes were not in fact mirror images. The first experiment in this group simply had differing numbers of spikes (one or two) on the two shapes. Later it was found that combinations of arrows and rectangles and squares and rectangles would also produce frequent reports of rotation in depth. These experiments show conclusively that it is not necessary that the two shapes be mirror images for rotation in depth to be reported. There may be some advantage to using mirror image pairs in that no distortion need be involved in the percept. In more exotic combinations (e.g. a sqaure and a rectangle) there may be a degree of distortion of the shape during rotation in depth.

The experiments discussed in this Chapter suggest that two constraints must be placed on the stimulus configurations in order to produce RID responses. The first is that the two shapes must not be identical (i.e. translations of one another) and the second is that it must be possible to interpret the shapes as pointing in opposite directions or having different orientations. It is possible to manipulate the degree to which a shape appears to be pointing in a particular direction. An arrow, for example, specifies a particular direction very well, a rectangle seems to specify two directions (along its long axis) and a square seems to have very poor direction specification properties. It was found that the number of RID responses did depend on how well the two shapes specified opposite directions.

However, the data from Experiments 4.5 and 4.6 indicate the situation is not a simple one. The stimulus configurations used in these experiments did not consist of shapes that were identical and it was possible to interpret the shapes as having different orientations. However, the shapes themselves (squares and rectangles) do not seem to be particularly good indicators of direction. It seems likely that the way in which particular shapes are combined in an apparent motion display may also have some effect on the number of RID responses. It is worth noting that the stimulus configurations under discussion sometimes consisted of superimposed shapes, a condition which appears to lead to anomalous results. Until further studies have been undertaken, no satisfactory reason can be offered as to why these anomalous results occur.

The results obtained in these experiments provide support for the proposed model in two ways. In the first instance, the results clearly show that some global property of the stimulus configurations is important. Small details and features, such as exact mirror images, do not seem to be important. This is consistent with the proposed model in that it suggested that the global property of shape "direction" is the only property that contributes to RID responses. The model does require some modification in this regard, however, since "direction" cannot easily account for the results of Experiments 4.5 and 4.6. At this time, it is not clear just what these modifications should be. The second area of support comes from the fact that other factors, such as ISI and Separation, did not play a prominent role in these experiments. In these experiments, the shapes used, generally seemed to have very well defined direction. Only a few different ISI and Separations were used. The model predicts that this will increase the relative prominence of the Shape factor at the expense of the Separation and ISI factors. This is, in fact, exactly what happened.

At this point the idea that shapes specify direction is a rather vague one. There does not seem to be any literature that deals with the problem of how well a shape points in a particular direction. The next few experiments attempt to come to grips with the problem of how does one specify the ability of a shape to indicate a direction and how is this related to the number of RID responses.

CHAPTER 5

THE DIRECTION RATING EXPERIMENTS

Introduction

In Chapter 3 a model was developed which described how RID responses were determined by a number of different factors. These factors were assigned different weights which depended on particular experimental situations. It was argued that in these experiments, the Shape factor was the most important. Separation and ISI did affect the number of RID responses but not to the same extent as Shape. In Chapter 4 a more detailed examination of Shape was undertaken in an attempt to gain a better understanding of what aspects of the shapes were important.

The model suggested that shapes had a property called "direction" and that this played a major role in producing RID responses. The experiments in Chapter 4 showed that a global property was involved and that this property was, in the main, consistent with the idea of "direction". However, no measurement of this property has been undertaken.

The model was represented as an equation where the weights of the various factors were shown as coefficients. This equation is

$$RID = (1 \times o)(a+a1)D + (b+b1)S + (c+c1)I + E$$

Of all the variables in this equation, the one about which the least is known is the variable which is related to the amount of direction exhibited by the shape. This is the variable a. Up to this point, values of this variable have been subjectively determined by the experimenter. It does appear that an arrow has more direction than a rectangle but there have not been any objective data to substantiate this impression. The aim of the following experiments is to try and provide some objective measurement of direction for the various shapes used in the experiments discussed in Chapters 3 and 4, and to see if those measurements can be used to predict RID responses.

EXERIMENT 5.1

The aim of this experiment was to try to get an independent measure of the degree to which the shapes used in all the previous experiments specified a particular direction. The aim was not only to determine that a particular shape had direction but to devise a measure that would enable shapes to be compared and ranked relative to one another.

METHOD

Apparatus. A PDP-11/20 was programmed to control the following experiment. A series of questions appeared on the face of a Visual 2000 video display terminal (VDT). The questions referred to a shape within a clock face projected onto the screen of a Tektronix 608 monitor placed next to the VDT. Subjects answered the questions by typing their responses on the keyboard attached to the VDT. The subjects performed the experiment in the Psychology Department computer room which contained various terminals and computers and had normal lighting.

Procedure. Twenty different shapes were used at four different orientations, making eighty trials in all. (The shapes are illustrated in Figure 5.2 which takes up 5 pages at the end of the discussion of this experiment.) At the beginning of each trial a shape was presented within a clock face on the Tektronix 608 monitor (see Figure 5.1). The following question appeared on the VDT:

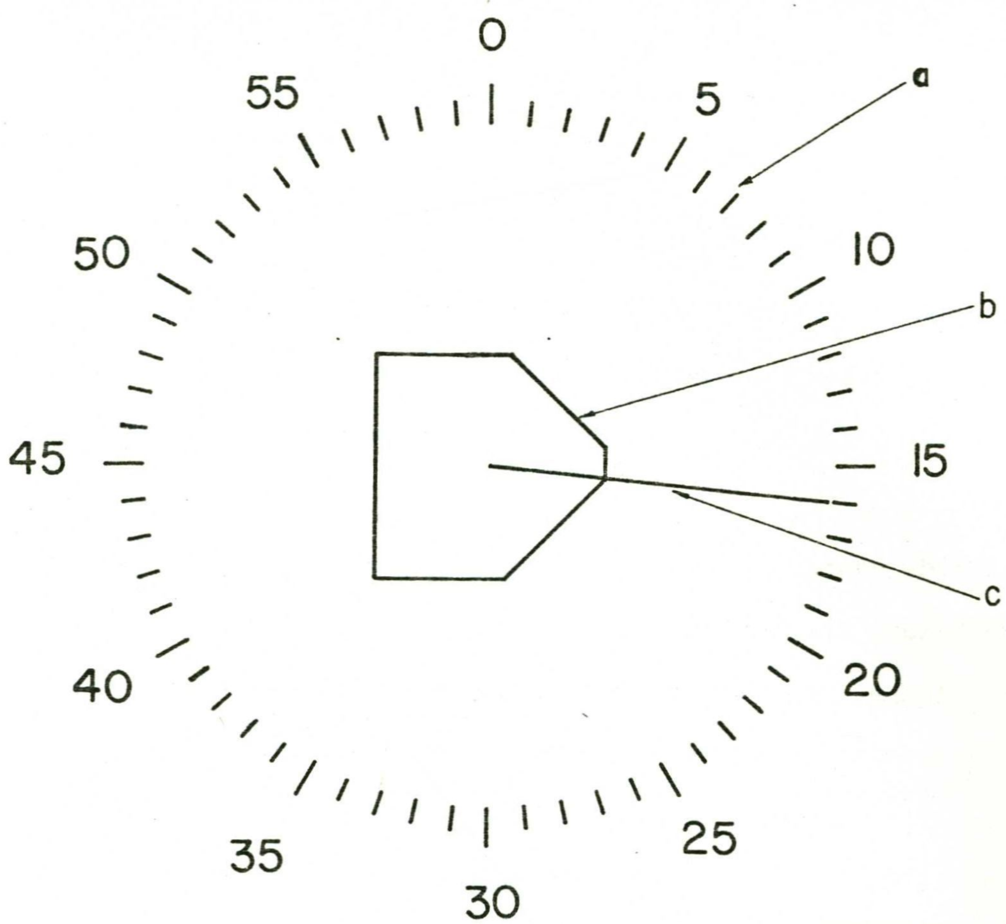


Figure 5.1 An illustration of the displays used in Experiment 5.1. The figure shows the clockface (which was constant throughout the experiment) with one of the shapes centred inside it. The radius was only presented to the subject after he had chosen a direction for the shape. This radius enabled the subject to check the direction he had chosen and could be removed and a new direction specified if the subject judged it unsatisfactory.

> Q1. What number on the clock face is the shape pointing to?

The subject typed in a number between 0 and 59 and a radius was then drawn by the computer onto the clock face so the subject could verify that this was the correct direction. If the direction indicated was incorrect the subject could cancel that selection and try again. The subject was thus able to specify where he thought the shape was pointing in 6 degree steps. Vertically upward was defined to have a direction of 0 degrees.

Once the subject was happy with the direction he had chosen the next question was asked:

> Q2. On a scale of 1 to 10, how well does the shape specify the direction you have indicated?

The subject was told that a rating of 10 meant that the shape specified the direction very well and that a rating of 1 meant that the shape hardly specified the direction at all.

A third question was asked which tried to probe whether or not these shapes could be interpreted as pointing in more than one direction. A rectangle or a double ended arrow, for example, might be thought of as pointing equally in two directions. Subjects had been told earlier that if they thought a shape was ambiguous in this regard, they were to pick the best direction in answer to Question 1. The third question was

> Q3. How many other directions does this shape have?

The eighty different conditions were presented in random order. In all 15 subjects were used. They could work at their own pace and most took about 30 to 40 minutes to complete the task.

RESULTS

This experiment yields four separate measures of how well a particular shape specifies a direction. The first measure is the rating (RAT) assigned to the shape: the higher the rating the better that shape specified the chosen direction. The second measure was the number of other possible directions (OPD): this was the number that subjects gave in answer to Question 3. High values of OPD indicate that subjects thought that the shape could be considered to be pointing in a number of directions. The third measure was the total number of directions (TND) assigned to that shape: this measure was found by examining the data from all subjects for a particular shape. If all the subjects chose the same direction for a given shape then that shape would have a TND value of 1. Values of TND greater than 1 indicate that different subjects assigned different directions to the shape concerned. The fourth measurement was the actual direction assigned by a subject to the shape in question. The RAT, OPD and TND data can easily be analysed quantitatively whereas the assigned direction data is more difficult to analyse in this manner.

Table 5.1 shows that the RAT, OPD and TND data are highly correlated and in the expected directions. RAT is negatively correlated with both TND and OPD because as the rating increases a decrease in the confusion regarding the direction of the shape is expected. TND and OPD are positively correlated because as subjects think that more directions could be assigned to the shapes, it is inevitable that different subjects will select different directions from the number of possibilities available.

The data were examined to see if orientation affected the RAT, OPD and TND data, although the analysis presented some problems. Consider the RAT and OPD data. The data from individual subjects consist of numbers drawn from a relatively small range (about 1 to 10)

TABLE 5.1

Correlation Matrix for Experiment 5.1

	RAT	TND	OPD
RAT	1.000	-.682	-.736
TND	*	1.000	.543
OPD	*	*	1.000

with the distribution heavily skewed towards the lower numbers. In these circumstances it is inappropriate to use the scores from each subject in an analysis of variance. The procedure adopted was to sum all the data across subjects, which increases the range of the numbers and reduces the skew. This sum was used as the scores in a RAT (or OPD) by Orientation, two way analysis of variance. Since there is only one observation per cell in the RAT (or OPD) by Orientation matrix, there was no MS(error) term. In its place, the MS for the interaction was used as the denominator to calculate the F ratio. A consequence of this is that the interaction between the variables cannot be tested.

When this procedure was applied, it was found that there was a significant effect on the RAT data due to the shapes (F=151.63, p<.05) but there was no significant effect due to orientation (F=0.92, p>.05). For the ODP data there was a significant effect due to shape (F=38.44) but there was no significant effect due to orientation (F=2.55, p<.05).

The TND data were numbers found by summing over subjects. They were found to be drawn from a relatively small range (from 1 to 10) with the distribution heavily skewed towards the lower numbers. The TND data were analysed by a Friedman two way analysis of variance by ranks (Ferguson, 1959, pp 272-274) to determine the effect of orientation: no significant effect was found (chi-square= 3.50, 3 df, p>.05). The TND data were then re-arranged in order to determine whether shapes had a significant effect on the TND index: they did not (chi-square=5.34, 19 df, p>.05). Most of the shapes were only assigned one or two different directions which means that there, were, in fact few differences between shapes in terms of the value of the TND index.

The first three measures can be assigned numerical values and averages across subjects can be calculated. Averaging assigned directions across subjects does not result in a meaningful index. If half the subects assigned a direction of 15 degrees to a shape and the other half assigned a direction of 45 degrees to the same shape (this is not an unlikely occurrence), the average assigned direction would be 0 degrees which is totally misleading. It is also highly likely that the assigned direction will depend on the orientation of the shapes. An arrow pointing upwards, for example, is likely to have an assigned direction of 0 degrees whereas the same arrow pointing downwards is likely to have an assigned direction of 180 degrees. For these reasons the assigned direction data is represented graphically, without averaging across subjects (see Figure 5.2). In Figure 5.2, the lengths of the radii drawn on the shapes are proportional to the number of subjects who chose the direction represented by the radius. Sometimes the length of a given radius is so short (because only one or two subjects chose that particular direction) that it is difficult to make out in the diagram. For this reason the TND data is also shown on Figure 5.2, to assist in the interpretation of each diagram.

Most shapes exhibit regular differences in the assigned directions with orientation (Figure 5.2). These shapes were originally chosen for the apparent motion experiments because they seemed to have direction and it is not surprising the assigned directions should follow the "point" or direction of the shape as it moves from up to down, from left to right. The only real excptions were the square (Shape 10) and, to a lesser extent, the rectangle (Shape 9). Neither of these shapes seemed to have a well defined direction and the assigned directions tend to be vertical, irrespective of the orientation of the shape. It is as though when a subject has been told that he must say the shape is pointing in some particular direction, and it is not clear that it is pointing in any direction, then the vertical is some sort of default for pointing objects. While this is true for many subjects, others in this situation chose a corner of the shape so it would be imprudent to suggest general rules in situations where shapes have ill defined direction.

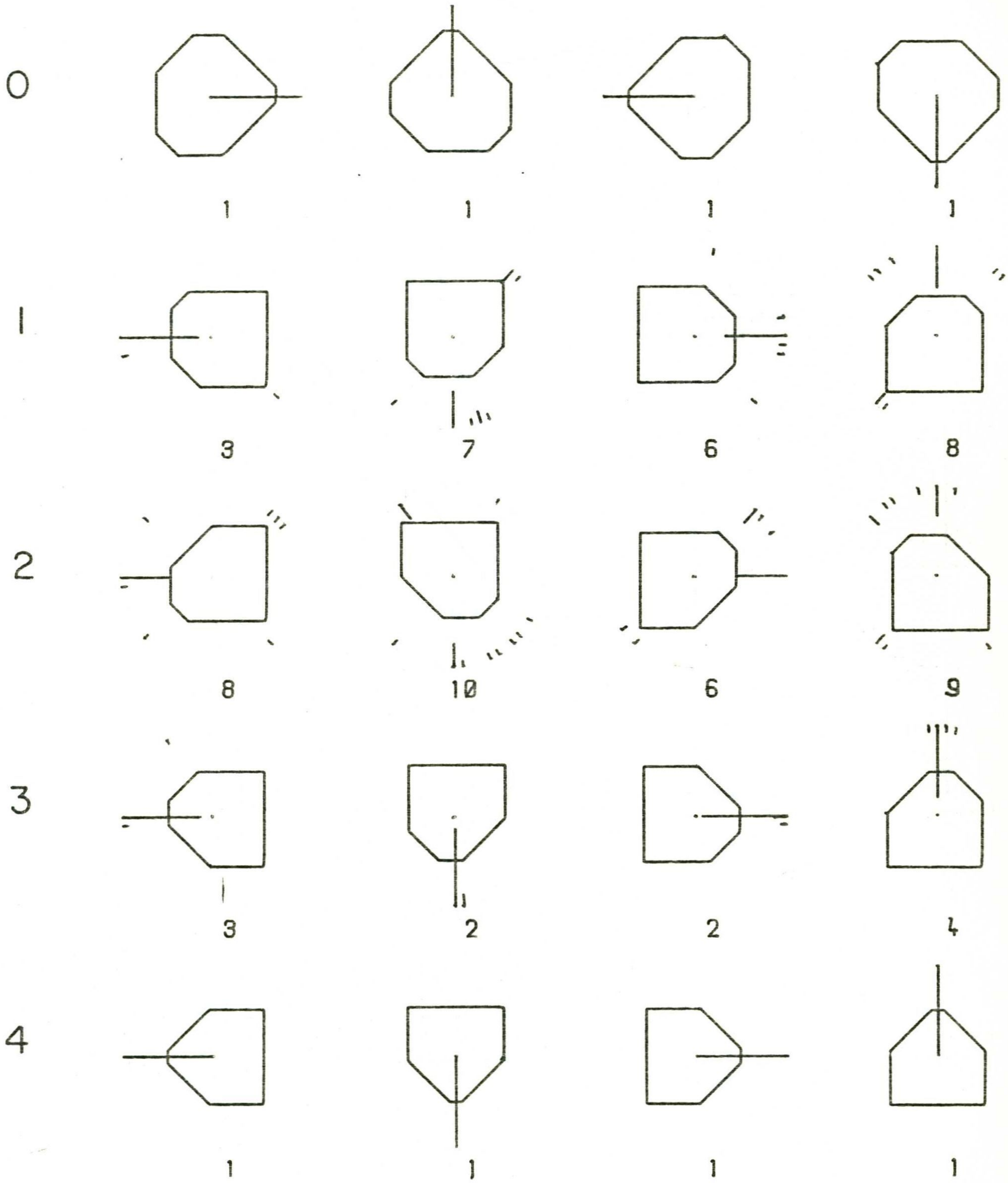
DISCUSSION

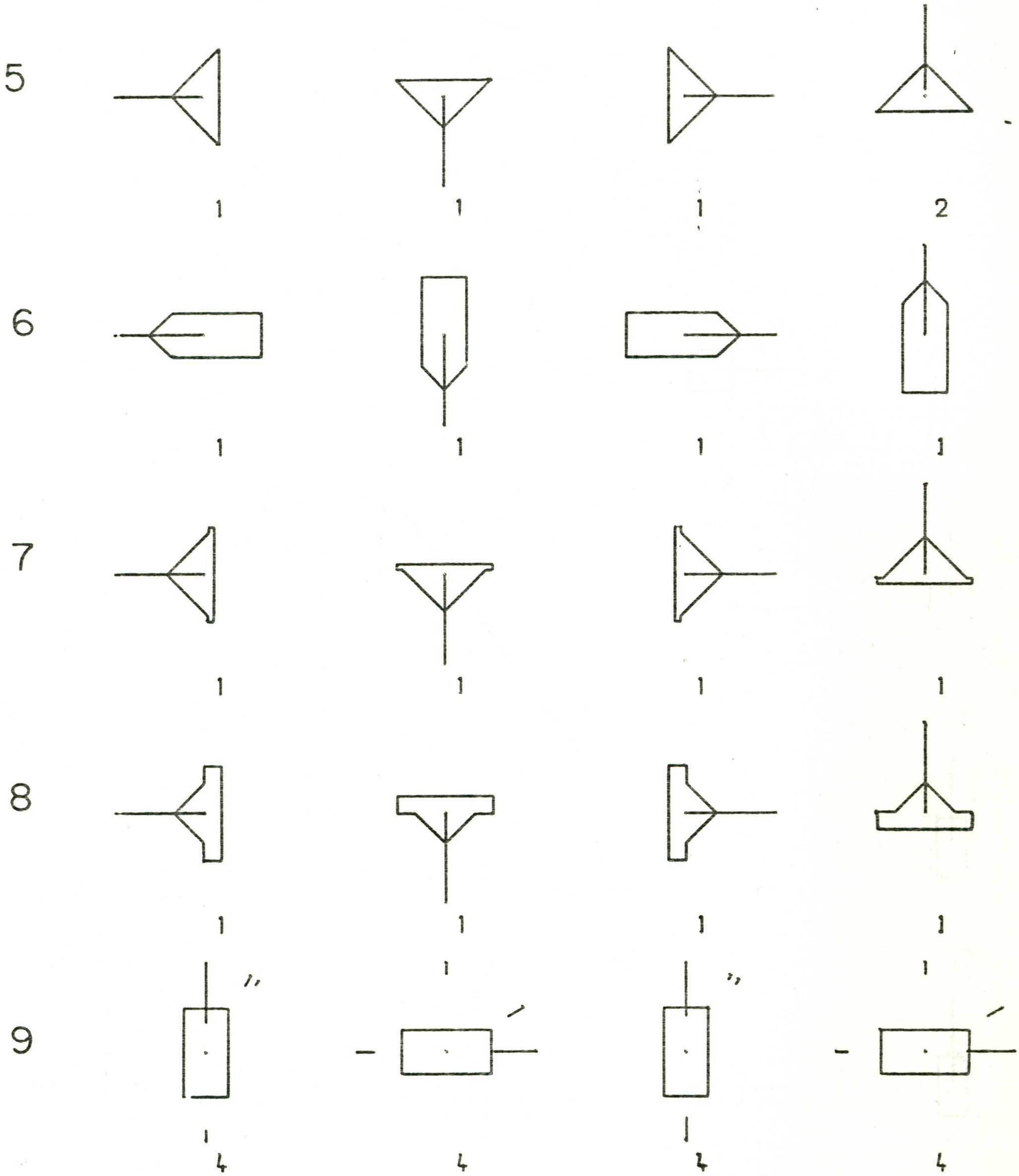
While the assigned direction data is important because it indicates where each subject thought each shape was pointing, it is difficult to use in a quantitative way. For this reason the attempt to generate a predictive index for RID responses will be concentrated on the RAT, OPD and TND data.

Orientation did not have a significant affect on the value of any of these three indices. This suggests that the data can be collapsed across orientation when this data is being used to generate predictive indices. The lack of any orientation effect seems reasonable in that a shape which has direction to a certain degree would be expected to retain that degree of direction irrespective of whether it is pointed up or down, left or right.

The data from this experiment clearly show that directions can be assigned to shapes and that different shapes have the property of direction to different degrees. The indices of the degree of direction examined in this experiment in the main differentiate between the shapes and are not specific to the orienation of the shape but it remains to be seen if they can be used to predict number of rotation in depth responses.

Figure 5.2 The following figures are the 20 shapes, at four different orientations, used in Experiment 5.1. The small segments of radii around the periphery of the enclosing circle represent the different directions chosen by the subjects. The position of the segment indicates the direction chosen and the length of the segment is proportional to the number of subjects choosing that direction (1 radius = 15 subjects). The centre of the circle is shown as a dot within the shape: this centre corresponds to the centre of the clockface shown in Figure 5.1. To assist in the interpretation of these figures, the Total Number of Directions (TND) chosen by the subjects for each shape is shown underneath each shape. Shapes 11 and 13 carry a single spike which is obscured by the radius.


0
1 1 1 1
1
3 7 6 8
2
8 10 6 9
3
3 2 2 4
4
1 1 1 1


5
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7
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8
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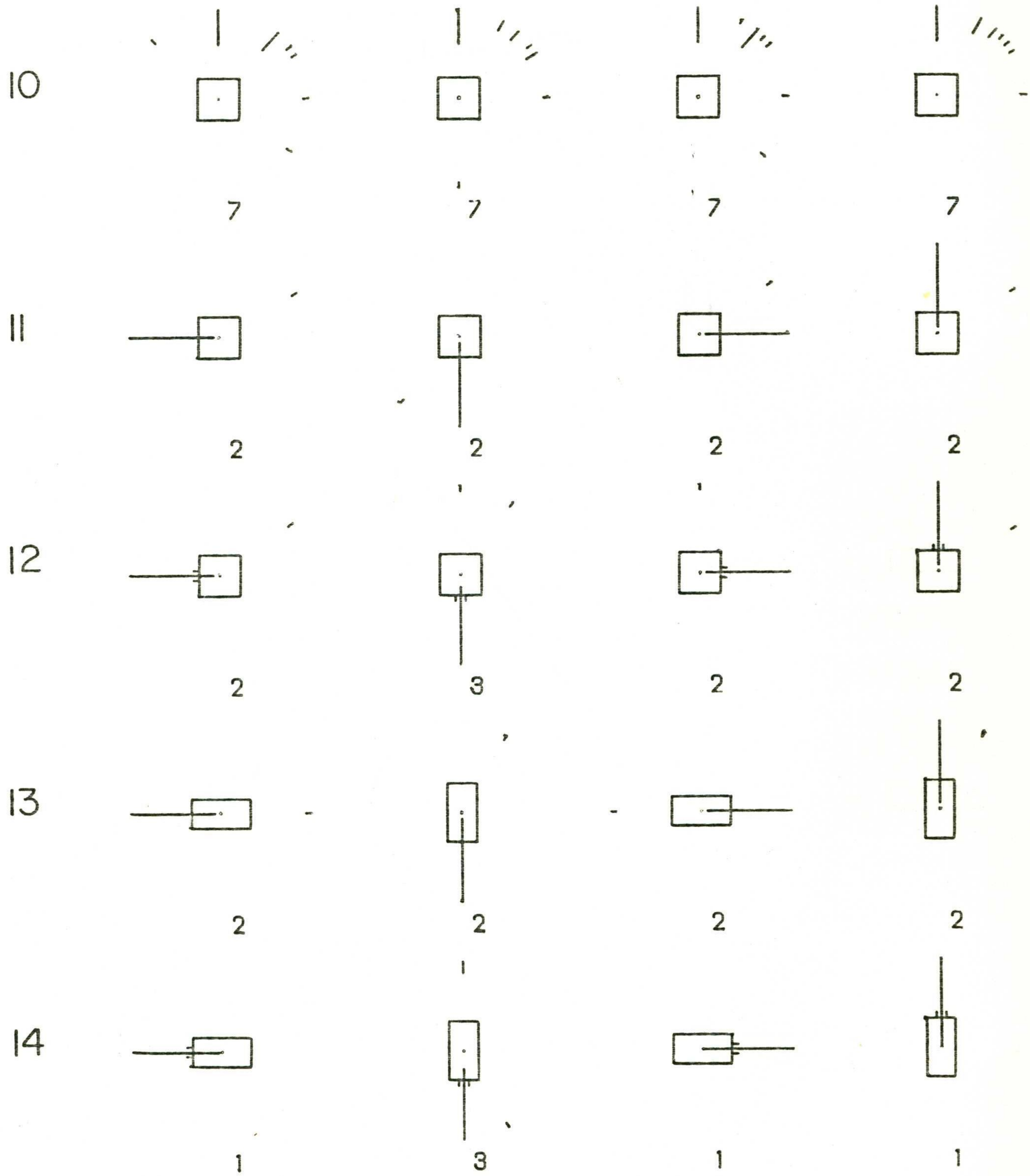
9
4 4 4 4


10
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14
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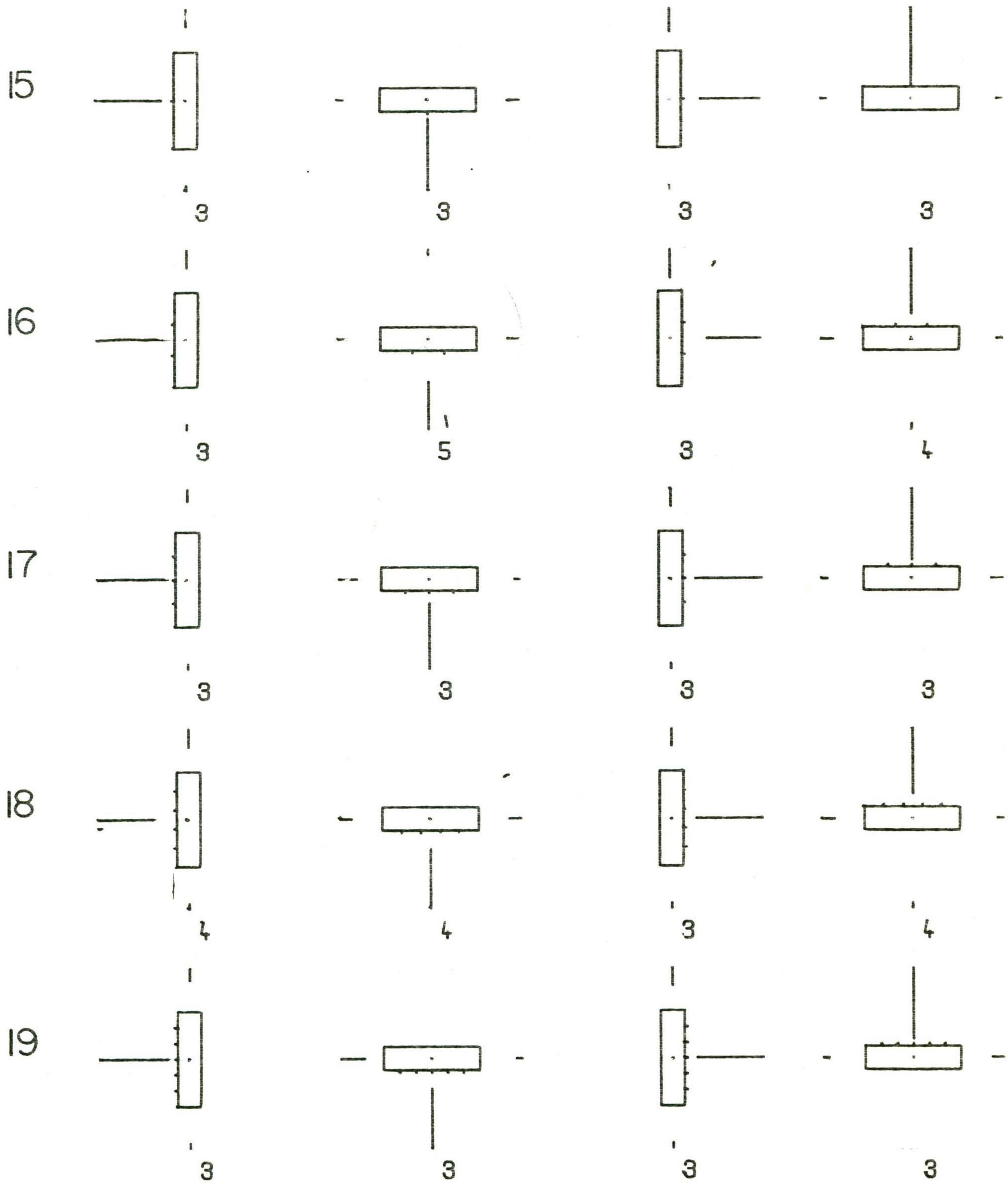
15
3 3 3 3
16
3 5 3 4
17
3 3 3 3
18
4 4 3 4
19
3 3 3 3

EXPERIMENT 5.2

This experiment was an apparent motion experiment of the type used in Chapters 3 and 4: the same equipment, procedures, instructions, etc. were used. Twenty different shape pairs were used. They are a representative sample of all the shapes used in the previous series of experiments. The aim of this experiment was to collect data on the number of RID responses for all these shape pairs and to see if a relationship between the number of RID responses and the indices suggested in Experiment 5.1 could be found.

METHOD

Stimuli. Figure 5.3 illustrates the twenty different shape pairs used in this experiment. The figures were taken from the experiments in Chapters 3 and 4 and are the same size as the figures in the experiment from which they were taken. Where a shape was used at a number of different sizes, the most common size was chosen.

Procedure. The procedure was very similar to the method of previous apparent motion experiments. The twenty different stimulus configurations were presented at a stimulus duration of 200 msec and ISI of 25 msec. Unlike the previous experiments, the required tally of RID and 2D motion responses for a particular condition was 20, rather than 25. This was adopted for convenience: it meant that the experiment could be run within a half hour experimental session. Ten subjects were used in this experiment.

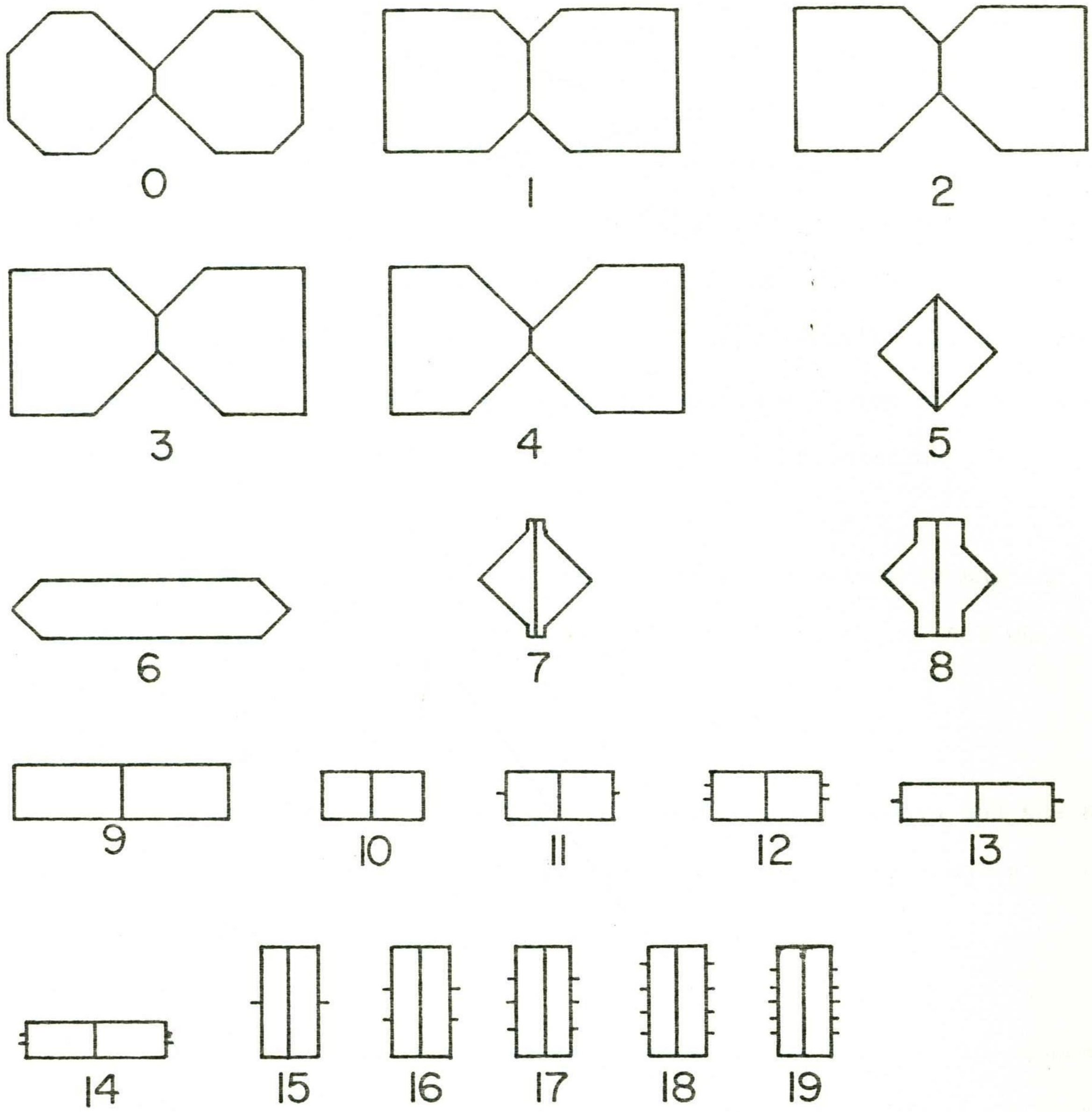

Figure 5.3 The stimulus configurations used in Experiment 5.2.

RESULTS

The primary interest of this experiment was to see if there was a relationship between the number of RID responses and the indices of the previous experiment. The values of RAT, OPD and TND were averaged across subjects and orientations to give a single number for each of the twenty shapes. This value was then correlated with the average number of RID responses to the corresponding stimulus configuration.

Figure 5.4 is the scatter diagram of values of RAT and RID responses. The Pearson product moment correlation is .503 which is significant ($t=2.47$, 18 df, $p<.05$).

Figure 5.5 is a scatter diagram of the OPD data and the RID responses. The Pearson product moment correlation is -.099 which is not significant ($t=0.42$, 18 df, $p>.05$).

Figure 5.6 is the scatter diagram of the TND and RID response data. The Pearson product moment correlation is -.204 which is not significant ($t=0.88$, 18 df, $p>.05$).

DISCUSSION

The RAT data provide strong support for the proposed model. The significant positive correlation between the RAT index and the number of RID responses means that it is possible to predict RID responses from a judgement about the direction of the shapes. In general, the shapes that were thought to specify the direction in which they pointed particularly well were also reported to rotate in depth the most.

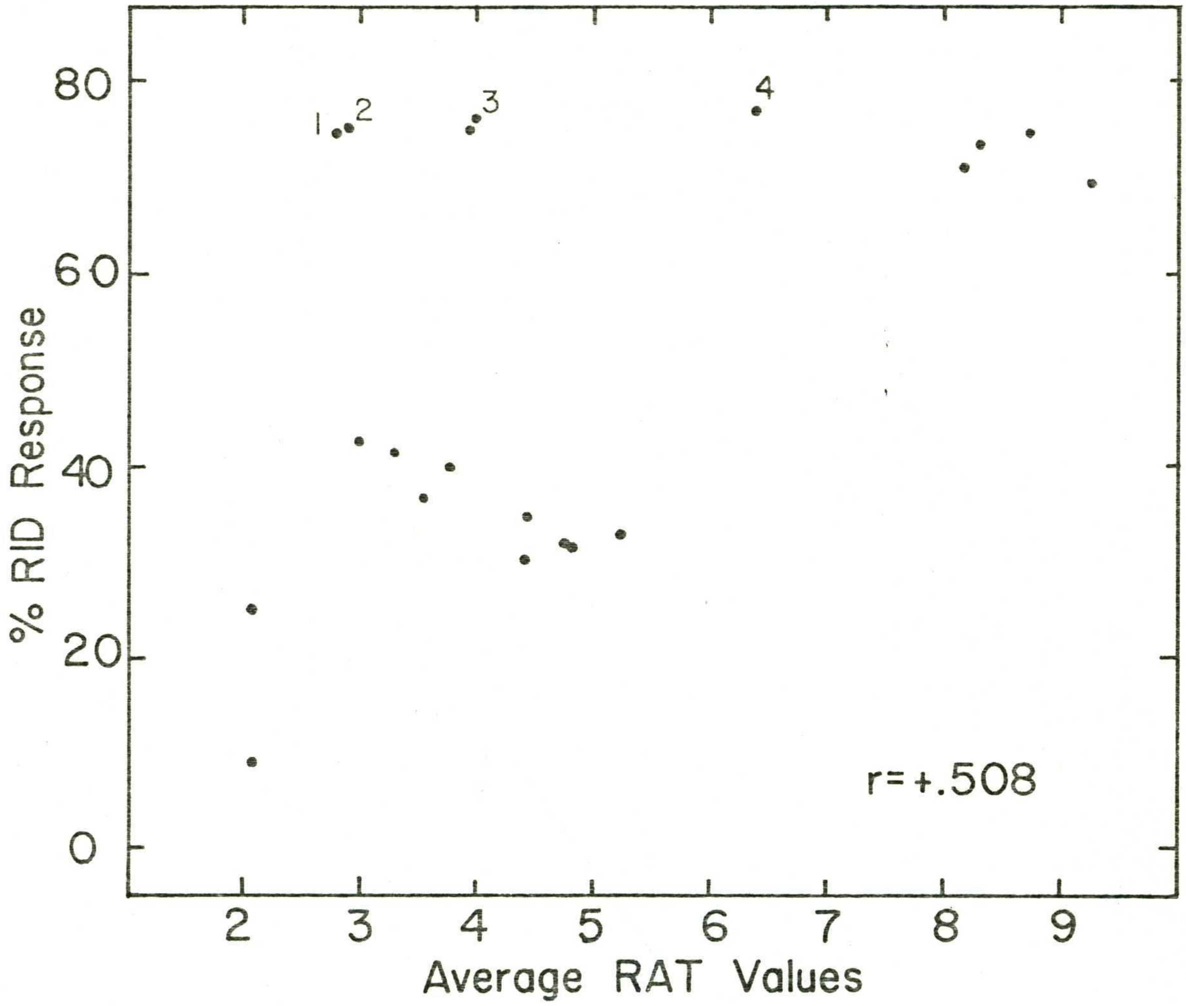

Figure 5.4 Scatter diagram of average RAT values (from Experiment 5.1) and RID responses (from Experiment 5.2).

It was expected that there should be a negative correlation between the TND index and RID responses. High values of TND indicate some confusion about the direction of the shape. This should be reflected in lower numbers of RID responses. The small correlation between the TND data and RID responses may reflect the fact that values of TND were not found to vary significantly with the different shapes used in this study (Experiment 5.1). However, given that the expected negative correlation was obtained, the TND index may be useful with shapes other than the ones used here.

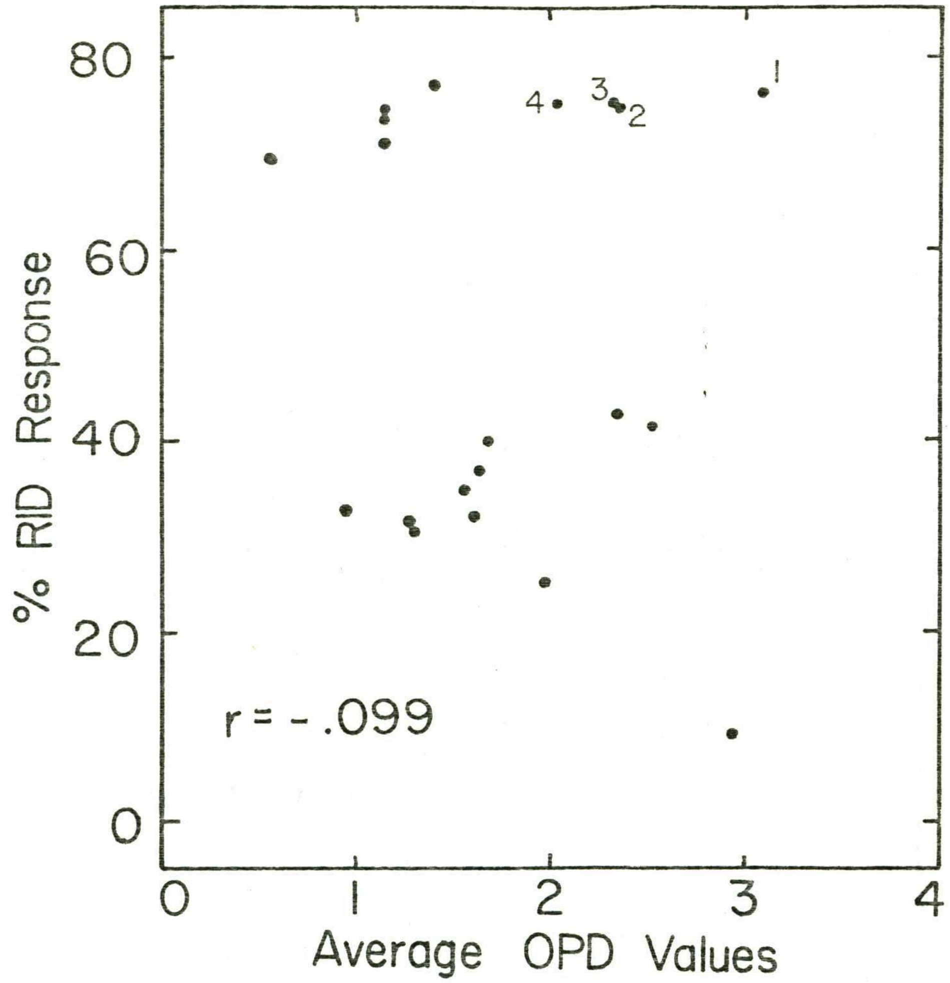

Figure 5.5 Scatter diagram of average OPD values (from Experiment 5.1) and RID responses (from Experiment 5.2).

The OPD index has practically no power to predict RID responses. When subjects were asked how many other directions were possible (Question 3) in Experiment 5.1, different subjects seemed to have different criteria on which to base their answers. Many subjects decided that no other directions were possible whereas others decided that all the corners of the shape were other possible directions! Many subjects asked numerous questions about how to answer this question: obviously hoping for some clue from the experimenter. It seems that the concept of other possible directions is too vague and ill defined to be of any real value.

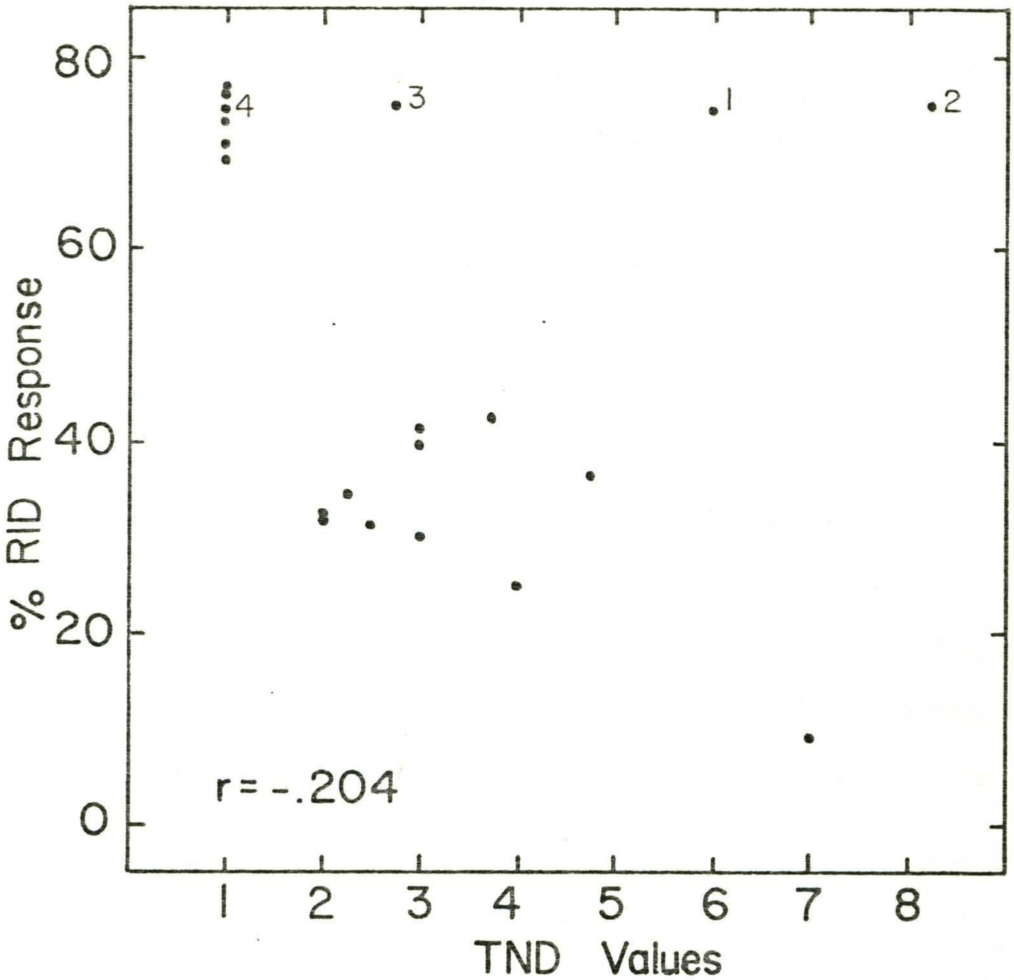

Figure 5.6 Scatter diagram of average TND values (from Experiment 5.1) and RID responses (from Experiment 5.2).

Inspection of the scatter diagrams revealed that shape pairs 1, 2, 3 and 4 were notable exceptions to general trends. These shape pairs were reported as rotating in depth quite frequently yet they received low ratings for direction and had relatively high values of TND (since the OPD index was found to be practically useless, the values of OPD for these four shapes is of little interest). That is, from the results of Experiment 5.1 one would have expected these shapes to elicit few RID responses in the apparent motion experiment but this was not the case. An observation that may help to explain this paradox is that although the shapes were rated poorly for direction, the directions that they were assigned in Experiment 5.1 would have resulted in the two shapes having opposed directions in this experiment. That is, the small amount of direction that these shapes had was at least opposed in the apparent motion sequence. Other shapes that were rated poorly for direction, such as the square, would have have tended to have parallel directions in the apparent motion sequence. However, this is not a strong argument and the fact that shape pairs 1, 2, 3 and 4 rotate as well as they do represents a problem for the model advanced in this study.

EXPERIMENT 5.3

A criticism that can be levelled at the the previous experiment is that different groups were used to collect the RID response data and the index data. Furthermore, the subjects in Experiment 5.1 saw a wider range of shapes than the subjects in Experiment 5.2. Even though in both experiments the same 20 basic shapes were used, the first group of subjects saw them in 4 different orientations, whereas the second group only saw them in two different orientations. This experiment addresses this criticism by having the same subject do both procedures and by using exactly the same shapes in both experiments.

METHOD

Stimuli. The stimuli are illustrated in Figure 5.3. In the apparent motion part of the experiment the stimulus configurations were used as depicted. In the rating part of the experiment only one of the pair of shapes was used at a time.

Procedure. The apparent motion part of this experiment was identical in every detail to Experiment 5.2. The only differences between the rating part of the experiment and Experiment 5.1 were that Question 3 was dropped and there were only 40 trials rather than 80.

Six subjects were used: 3 subjects did the apparent motion part and then the rating part, the other 3 performed the experiment in the reverse order.

RESULTS

Interest in this experiment was centred on the relationship between the index of direction and RID responses for each subject. For this reason only the RAT data were examined. TND data was available but was not examined. This was because of the small sample (6) and the fact that TND was not found to be a particularly useful index in the previous experiment.

Pearson product moment correlations between the RAT data and the number of RID responses for each shape were calculated for each individual subject and for the data averaged over subjects. As can be seen in Table 5.2, the correlations for the individual subjects were not significant, whereas the correlation for the average data is significant.

Subject 5 gave a rating of 10 for nearly all the shapes: those that were not rated 10 were rated no less than 8! It is felt that this subject did not quite understand the nature of the question asked.

DISCUSSION

In Experiments 5.1 and 5.2, different subjects did the rating experiment and the apparent motion experiment. It was thought that by having every subject do both parts of the experiment that it might be possible to obtain a stronger relationship between the rating shapes received for their directional properties and the number of times they appeared to

TABLE 5.2

Correlation between RAT data and RID Responses for Experiment 5.3

SUBJECT	CORRELATION	t (18 df)
1	0.353	1.601
2	0.160	0.688
3	0.245	1.072
4	0.114	0.487
5	-0.446	2.114
6	0.273	1.204
Av.	0.582	3.036 *

* -Significant at the .05 level

Note- Av. is the correlation for the data averaged across subjects.

rotate in depth. The correlations obtained in the current experiment do not provide any support for this hypothesis.

Better correlations were obtained between values of RAT and RID responses for the group data, rather than individual data. It seems that the measures of how well shapes specify directions suggested so far do not enable one to predict the number of RID responses a particular subject will make to a particular stimulus configuration. However, when individual differences are cancelled out by averaging the data across subjects, then a significant relationship between RAT values and RID responses emerges. This relationship between averaged data is marginally better in this experiment than that found in Experiment 5.2. There may have been some benefit in having all subjects do both procedures although no firm conclusion can be reached on this question.

The ultimate goal of this research must be to take an apparent motion stimulus and predict what proportion of responses will be rotation in depth responses for a particular subject. In Chapter 3 it was established that the stimulus configuration was the most important predictor of RID responses. The experiments in Chapter 2 demonstrated that the local features of the shapes making up the stimulus configuration were not as important as more global properties of the shapes. The property of "direction" was suggested as a likely candidate. These last three experiments have tried to establish an experimental basis for this property. The attempt was not wholly successful and, at best, direction is a necessary but not sufficient condition for RID responses to occur.

There are at least two further problems. The first is that individual differences ensure that indices of direction have varying success at predicting the number of RID responses a given subject will make. The second is that the indices of "goodness" of direction suggested in this Chapter require considerable refinement. However, the group data were encouraging enough to suggest that further experimental work should be carried out on this aspect of pattern perception and its relationship to depth ambiguous apparent motion.

CHAPTER 6

GENERAL DISCUSSION & CONCLUSIONS

The results of this experimental study suggest that the type of depth ambiguous apparent motion under investigation is a phenomenon intimately related to the processing of pattern information. This conclusion arises from the findings in this series of experiments, that the shapes play a greater role in determining subjects' responses than other variables such as the spatial and temporal separation between the shapes. It was found, however, that nearly all the factors that were studied influenced the perception of rotation in depth to some extent and that these factors tended to interact with one another.

A model was developed on the basis of the results of the experiments reported in Chapter 3. This model proposed that the degree to which each of these factors affected the number of RID responses could be represented by a weight assigned to that factor. It was suggested that these relative weights would vary as the experimental conditions were changed.

In Chapters 4 and 5 a closer examination was undertaken of the Shape factor and a number of the model's predictions were confirmed. The most important prediction concerned the role of the perceived "direction" of the shapes. The results of the experiments reported in

Chapter 4 showed that the stimulus configurations did not need to be mirror images for RID responses to occur. This showed that local features were relatively unimportant and that more general properties of the shapes must play a role. The data were consistent with the hypothesis that the global property of "direction" was important. Further strong support for the model came from the experiments reported in Chapter 6. In these experiments, significant correlations were obtained between measures of the direction of a shape and the number of RID responses obtained when that shape was used in an apparent motion display.

The model presented in these pages represents an attempt to arrange the information gathered about depth ambiguous apparent motion into a more general framework. The model was able to describe results effectively and concisely. It was able to predict the results of new experiments. It also offered an explanation for some of the apparent discrepancies between the results of Kolers and Pomerantz (1971) and White et al. (1979). Nevertheless, there are problems with this model. It cannot account for the results of Experiments 4.5 and 4.6, where the direction of the shapes does not seem to be a major factor. The anomolous results obtained by using superimposed shapes also present another problem. However, the results obtained to date suggest that further development of this model would be profitable.

The model provides a description of the conditions under which depth ambiguous apparent motion occurs. There is, as yet, no way to link the results described by the model to a theory of the processes occurring in the visual system which mediate this phenomenon. However, there are various visual phenomena and processes which seem to be relevant to the study of depth ambiguous apparent movement. The following discussion examines some of these areas with a view to proposing a theory of depth ambiguous apparent movement.

6.1 Apparent Motion and Sustained & Transient Channels

The final goal in all perceptual research is to be able to state the biological events in the visual system which are responsible for the particular perceptual phenomenon under consideration. A discussion of the sustained-transient dichotomy seems particularly relevant to the study of apparent motion.

Microelectrode studies in animals (e.g. Enroth-Cugell & Robson, 1966; Ikeda & Wright, 1972a, 1972b) have found that there appear to be at least two types of cell systems in the visual pathway. In the physiological literature there is a continuing debate in this area with some researchers preferring the sustained-transient distinction and others preferring a 3 part system of X, Y and W cells. However, it appears that there are groups of cells that respond maximally to small targets that contain relatively high spatial frequencies. These cells are called sustained cells because they have a sustained firing rate although they often have relatively long latencies. The transient cells respond to stimulation with short latency bursts of firing and are relatively insensitive to high spatial frequencies. In the cat sustained cells predominate in the area centralis whereas transient cells predominate in the periphery of the retina. It has been suggested that the characterisitics of the transient cells are ideally suited for the detection of temporal modulations of the stimulus and that sustained cells are best suited for signalling the spatial properties of the stimulus (Ikeda & Wright, 1974). Thus, it seems that the detection of movement and pattern may be relatively independent although there is some evidence that the sustained and transient systems inhibit one another.

Physiological evidence for sustained and transient channels in humans is relatively difficult to obtain. Kulikowski (1978) measured the VEP in the occipital cortex to various temporally modulated gratings. He found an extra component in the VEP for higher spatial frequencies which he argued indicated a pattern response, that is, the firing of the sustained channel. Usually the evidence to suggest that there are sustained and transient channels in human vision comes from psychophysical experiments using gratings (e.g. Tolhurst, 1973, 1975a, 1975b; Kulikowski & Tolhurst, 1973; Kulikowski, 1975; Legge, 1978). Kulikowski and Tolhurst (1973) showed that there were two different contrast thresholds for the detection of temporally modulated sinusoidal gratings: the contrast at which the flicker could be perceived and the constrast at which the structure became distinct. The flicker threshold was lowest for low to medium spatial frequencies which is consistent with the operation of a transient channel. The pattern threshold was lowest for medium to high spatial frequencies, suggesting the operation of the sustained system. There are many refinements to be added to this sketch of the processing of pattern and movement in the human visual system (e.g. Georgeson, 1976) but the bulk of the evidence does suggest that human beings are able to process the movement and pattern of a target relatively independently.

These findings have generated interest in a number of areas. Breitmeyer and Ganz (1976) suggest that sustained and transient channels can account for some of the phenomena associated with metacontrast. Sekuler and Levinson (1974) have been interested in direction selective units and have drawn on previous findings to propose a model which takes into account the independence of channels at threshold and their mutual inhibition at suprathreshold levels. Their model can explain motion aftereffects and direction reversals in ambiguous moving stimuli and has generated further research (e.g. Levinson and Sekuler, 1975; Pantle, 1978).

Of particular interest to this study is a series of experiments by von Grunau (1978a, 1978b, 1979) which examined the role of sustained and transient cells in the perception of apparent movement. In the first study von Grunau found that blurring the stimulus resulted in a facilitation of the perception of movement and that the ISI for optimal movement was reduced. This result was explained by reference to the properties of the sustained and transient systems. In the first instance, blurring the stimulus will result in the loss of high spatial frequencies and thus reduce sustained system activity. Ordinarily it is held that the activity of the sustained system inhibits the transient system but blurring the stimulus would release the transient system from inhibition. Since activity in the transient system is likely to be interpreted as movement in the visual field, this release from inhibition means that the perception of movement is more likely to occur. The optimal ISI will be reduced because the faster transient system will now dominate the processing of the stimulus.

In the second study von Grunau masked both the first stimulus and the the second stimulus, in different experiments. Masking the second stimulus had the same effect as blurring the stimuli and for much the same reasons. Masking the first stimulus results in a decrease in the likelihood of reporting movement and the optimal ISI is increased. This was consistent with the removal of transient cell inhibition from the first stimulus on the sustained cell activity due to the second stimulus. When the first stimulus is masked, the processing of the apparent motion stimulus is now dominated by the sustained system with the resulting increase in optimal ISI (because the sustained system is slower) and decrease in likelihood of reporting movement (because the sustained system is not concerned with movement).

Von Grunau noted that even when one of the stimuli was masked the motion was always of a disk, rather than of "objectless" movement. Von Grunau suggested that one explanation for this was that some form information was still available to the visual system, despite the masking. He also suggested that it could be the case that whichever stimulus is not masked also provides the form information for the whole episode. This latter idea received more attention in the third study where both stimuli were masked simultaneously. In this case no apparent movement was reported which suggests that some form information must be available for motion perception to occur. Transient cells are still stimulated but not sufficiently to give rise to seen movement. The phenomenon of objectless phi, suggests von Grunau, occurs at short ISI's because in these circumstances the transient information can be coupled with incomplete information from the sustained system but nevertheless some sustained (i.e. form or object) information is required. Von Grunau concluded that form and motion information in the visual system are processed independently but that the processes interact with each other. He noted that the phenomenon of apparent movement requires some form information to be present but, paradoxically, form information tends to inhibit apparent movement.

Most studies in this area tend to use very simple stimuli such as gratings or disks. While it is true that these are patterns in a sense, it is difficult to apply the work on sustained and transient cells to the problem of the apparent movement of more complex patterns, like the octagons used in some of the preceding experiments. A disk seems to be more of a position marker than a pattern and von Grunau's results can be considered as suggesting that as long as the visual system has some information about the position of an object (i.e. has some sustained information) then apparent motion is enhanced by precise information about the temporal parameters of the change in position (i.e. by maximum transient cell information, inhibited as little as possible by sustained cell activity).

The question arises of the importance of the sustained-transient distinction to depth ambiguous apparent movement. The operation of these channels is reflected in temporal fluctuations so an examination of the effects of ISI and stimulus durations should provide an answer. The ISI effect found by Kolers and Pomerantz (1971) does seem to reflect the operation of sustained and transient channels, if it is assumed that plastic (two dimensional) movement indicates that the visual system has poor information about the shape or pattern of the stimulus whereas rigid (three dimensional) movement suggests good pattern information. At short ISI's, when inhibition of the sustained (pattern) information about the first stimulus by transient information from the second stimulus is at a maximum, reports of rotation in depth are few. At long ISI's, when transient inhibition would not be a problem, rotations in depth predominate. However, the effect of ISI observed in the experiments reported in this study was that increasing ISI tended to reduce reports of rotation in depth. This ISI effect cannot readily be explained by transient inhibition of sustained information. It is of interest to note that Kolers and Pomerantz superimposed their shapes which might facilitate any transient inhibition of contours, due to the reduced spatial range over which this inhibition would have to act.

The effect of stimulus duration may also reflect the operation of the sustained and transient channels. In these experiments the stimulus duration was always 200 msec. This is a very long time in terms of transient inhibition and it seems likely that any inhibition of sustained information after that interval would have little effect on the ability to perceive the pattern. However, two unreported experiments were run which sought to investigate the role of ISI and stimulus duration in depth ambiguous apparent movement. In the first the stimulus durations were 100, 200 and 400 msec. and in the second the stimulus durations were 20, 50 and 100 msec. In both cases the ISI's were 25, 50 and 100 msec. The data in both cases were meaningless with no significant effects of any kind being found. Thus no conclusions could be reached about the role of stimulus duration.

Kolers and Pomerantz (1971) did find that stimulus duration affected the number of rigid rotation responses. They tended, however, to use short stimulus durations, for example, 200 msec. was the second longest one they used. Their data seemed to be consistent with transient inhibition of pattern information. Similarly, von Grunau (1978a, 1978b, 1979) used short stimulus durations in his work where he established the sustained-transient interaction in apparent motion. It may be the case that the activity of the sustained and transient systems are only important in apparent motion displays where the temporal intervals are relatively short.

It is not entirely clear what role the sustained and transient channels play in the experiments reported in Chapters 3, 4 and 5. However, the evidence tends to suggest that it is a relatively minor role and that these experiments are dealing with a situation in which the pattern information for both stimuli has been established and is relatively unperturbed by the transients generated by the temporal sequencing.

6.2 Apparent motion and metacontrast

Metacontrast is a phenomenon related to the perception of the pattern of briefly presented stimuli whereas apparent movement is related to the perception of movement arising from briefly presented stimuli. There has long been a suggestion that a relationship exists between metacontrast and apparent movement (e.g. Werner, 1935). Kahneman (1967, 1968) proposed that metacontrast was an instance of "failed" movement and noted that the the dependence of the two effects on temporal factors was very similar, for the conditions he used. However, Weisstein and Growney (1969) showed that with different conditions to the ones used by Kahneman, the exact relationship between apparent movement and metaconstrast breaks down. It seems unlikely, therefore, that metacontrast is simply a special case of apparent movement. Nevertheless, Weisstein and Growney did allow that apparent motion and metacontrast may be related and that they may both involve units in the visual cortex that are involved with the initial analysis of pattern.

Given the similarity of the conditions required for the two phenomena to occur, it seems possible that metacontrast could occur in apparent motion experiments (and vice versa). Breitmeyer, Love and Wepman (1974) found that there was contour supression (masking) during apparent movement. In another study by Brietmeyer, Battaglia and Weber (1976) it was shown that the contour supression during apparent movement was a U-shaped function of stimulus onset asynchrony, similar in form to the usual masking function. A simple model was proposed that suggested that the transient activity produced by the second stimulus inhibited the sustained activity (indicating pattern) produced by the first stimulus. It was argued that the inhibitory effect will be maximised at some particular stimulus onset asynchrony which depends on the latency of the two channels, which accounts for the U shaped function. A corollary of this model is that only the first stimulus should be masked. One might also expect that if the two stimuli are side by side (as they usually are in apparent motion experiments) that different parts of the first stimulus will be masked to a different degree.

In the experiments reported in Chapters 3, 4 and 5, a certain amount of masking might have been expected since the shapes were often side by side and ISI's of 25 msec were often employed. The experiments tended to meet the conditions of close spatial proximity and short temporal intervals between shapes which are a feature of masking experiments. On the other hand, the stimulus duration was 200 msec which should be long enough for the shape information to be fully processed. Nevertheless, masking might account for the tendency for features on the periphery of the shapes to be more important than those close to the axis of rotation. It might have been the case that the latter features suffered a certain amount of masking. Evidence against masking being an important factor in this study is the finding that rotation in depth responses decrease with increasing distance. If masking was an important factor one would expect the opposite trend.

On balance, it does not appear likely that masking is an important factor in the experiments reported in Chapters 3, 4 and 5. The reasons for this conclusion are similar to those put forward in the discussion of the role of the sustained and transient systems in depth ambiguous apparent movement. In general, there are important differences between the two phenomena, such as the fact that metacontrast occurs only when target and mask are close together, whereas apparent movement can operate over a much larger distance. However, the continuing research into the relationship between apparent motion and metacontrast suggests that similar processes are involved in both of these phenomena (e.g. Growney, 1976; Fisicaro, Bernstein & Narkiewicz, 1977; Hellige, Walsh, Lawrence & Cox, 1977; Stoper & Banffy, 1977). In view of these findings, it may be the case that metacontrast does have some role to play in depth ambiguous apparent movement, particularly when short ISI's and stimulus durations are used.

6.3 Apparent movement and pattern transformations

Researchers in the field of pattern recognition or detection have been interested in the perception of pattern constancy during continuous transformations. A person's face, for example, continually changes but it is always recognised as being a face or some paricular person's face. Interest in this discussion is centred on research which examines the role of transformations during apparent movement. Other researchers, notably Johansson (see Johansson, 1977, for a summary), have used continuous movement in the study of transformations.

In a series of mathematical papers, Foster examined the relationship between transformations of shape and apparent motion. Foster (1972a) put forward two propositions: that a transformation is an invariance transformation if apparent movement can be induced between an object and its transform, and that given apparent motion does occur then the visual system is able to apply some transform to change the first shape to the second. In an experimental test of these propositions, Foster (1972b) presented subjects with two superimposed Landolt rings with the gaps in different positions. The subjects were required to say whether or not the ring appeared to rotate. Using this procedure, Foster uses his data to suggest that a rotation through about 50 degrees in the fronto-parallel plane is one invariant transformation available to the visual system.

Foster (1973a, 1973b) extended this work by presenting two random dot patterns simultaneously to subjects and asking them to say whether or not the two patterns were the same pattern in different orientations. He then used the same stimulus pairs in an apparent motion experiment and confirmed the hypothesis that if a pair of patterns underwent smooth rotation in the plane, then the two patterns were recognised as being the same. However, the reverse was not true: the fact that two patterns were recognised as being the same did not necessarily mean that smooth motion was seen between them. Foster

(1975, 1978) also discussed three dimensional transformations and examined the findings of Kolers and Pomerantz (1971).

Foster concluded that a "pure figural theory" can best account for most results in apparent motion experiments where the the shape can undergo a number of different possible transformations, such as in the case of depth ambiguous apparent motion. The data from Kolers and Pomerantz (1971) is not consistent with a "pure figural theory" in that ISI was found to play an important role in the the determinatin of which transformation was applied to the shapes by the visual system. However, the experiments in Chapter 3 suggest that shape, not ISI, is the principal determinant of depth ambiguous apparent movement. The results are thus consistent with Foster's "pure figural theory". Foster suggested that a corollary of his theory was that ISI is only important insofar as the apparent motion sequence should not be incompatible with a possible real movement. Foster's theory is one that can accommodate the possibility of multiple transformations, like three dimensional rotation and two dimensional deformation, by referring to the figural properties of the apparent motion display rather than the temporal properties. As such it is seen as support for the ideas developed in Chapters 3, 4 and 5.

Pittenger and Shaw (1975) argue that the basis for the perception of identity of shapes lies in characteristics left invariant under transformation while the particular transformation involved specifies what kind of event has occurred. They emphasise the concept of "ecologically valid" transformations which are transformations that are appropriate to the shape and the context in which it appears. For example, if a person is walking towards an observer, it is not "ecologically valid" for that person's face to appear to shrink. Pittenger and Shaw argue that object identity will not be retained if a transformation that is not "ecologically valid" for a particular shape is applied to it. Pittenger and Shaw developed their theory in relation to transformations of non-rigid patterns such as the changes in people's faces with emotions or the changes associated with walking, running, etc.

Warren (1977) contrasted the ideas of Pittenger and Shaw with a local feature theory. The local feature theory predicted that object identity would be based on the similarity between features of two successive projections of a moving figure, rather than the ability to transform one view into the other as in Pittenger and Shaw's theory. To test these theories Warren (1977) devised an apparent motion experiment where the pairs of shapes varied along two dimensions: the dimensions were transformability and similarity. The dependent variable in Warren's experiment was not reports of movement but reports of object identity during apparent movement. Warren found that "... the two phases of a display are not compared and judged for identity on the basis of their featural similarity, ... perception seems to be based on the transformation relations specified across the two phases of the display" (Warren, 1977, p 267).

There are a number of problems associated with Warren's study. Criticism has been levelled at Warren's definitions of "similarity" and "transformability" (Ullman, 1977) which do not seem to take into account non-rigid transformations. In the case of depth ambiguous apparent motion, non-rigid transformations are frequently reported although, as Warren points out, experimenters in this area have not required their subjects to report on object identity. Pittenger and Shaw (1977) point out that their theory was developed in terms of non-rigid transformations of biological patterns and that Warren's application of this theory to geometric figures may result in slightly different conclusions. The concept of "ecologically valid" transformations may not be applied as easily to geometric figures as it is to faces. Warren, for example, seems to have assumed that only rigid transformations are "ecologically valid" for such shapes. This may be too restrictive, given the wide variety of non-rigid transformations applied to patterns in nature.

Nevertheless, many of the ideas put forward by Warren are useful to an understanding of depth ambiguous apparent movement. In studies on depth ambiguous apparent movment the two dimensional phase is often described as a smooth, continuous, non-rigid transformation of the first shape into the second. Kolers and Pomerantz (1971) described it in this way and it was assumed in the experiments reported in Chapters 3, 4 and 5. However, in the view of Warren's study, it may be worthwhile to take a more critical look at what appears to be happening when rigid rotation is not perceived. There now exists a theoretical position which predicts that smooth continuous transformations are not always expected. In some of the experiments reported above, sudden replacement of parts of the figures occurred in that extraneous spikes or arrowheads appeared to blink on or off. This may be indicative of a change of identity in the shapes and may bear closer examination. Warren's findings that reports of object identity do not depend on featural similarities between the two phases of the display are analogous to the conclusions reached in Chapters 3, 4 and 5 which were that RID reports do not depend on local features of the shapes. It seems quite plausible that there should be a link between the concept of object identity during movement, as suggested by Pittenger and Shaw and Warren, and reports of rotation in depth.

6.4 The Dual Motion Detection Systems Theory

It has been suggested that there may be two different types of movement detection systems (Pantle & Picciano, 1976; Anstis, 1980; Braddick, 1980). In the context of apparent motion, the first type signals movements over small displacements (Braddick, 1974), during short ISI's (Braddick, 1973; Pantle & Picciano, 1976) and between elements of similar brightness (Pantle & Picciano). Anstis has also suggested that this system mediates the phenomenon of "reverse phi" (Anstis, 1970; Anstis & Rogers, 1975) which occurs when one pattern of random black and white elements is faded into another and is characterised by element movement between elements of similar brightness. This system has been called a "low level" process (Braddick, 1980) because it is thought to reflect the operation of simple motion detectors relatively low down in the visual pathway.

The second motion detection system deals with "cognitive apparent motion" (Anstis, 1980) which is thought to be involved in the classic type of apparent motion experiment. This system is not mediated by simple motion detectors, it signals apparent movement over large displacements and ISI's and is insensitive to contrast reversals between the two phases of the display (Pantle & Picciano, 1976). This type of apparent movement is the result of an interpretive analysis of incoming information by the visual system. However, the "low level" and "interpretive" systems can interact. This interaction is demonstrated by certain mutlistable apparent motion displays (Braddick, 1980).

It is probable that depth ambiguous apparent motion reflects the operation of the interpretative system. Depth ambiguous apparent motion displays fit the classic pattern of relatively large displacements and ISI's. Depth ambiguous apparent motion also depends on complex features of the shapes used in the apparent motion display. These complex features could not be analysed by simple motion detectors responding to temporal modulations of light and dark. Depth ambiguous apparent motion not only requires that the visual system interpret the incoming to determine if it is consistent with movement, but also to determine what type of movement has occurred. It seems unlikely that depth ambiguous apparent motion can be explained in terms of a motion detection system alone.

6.5 A Theory of Depth Ambiguous Apparent Movement

It is proposed that depth ambiguous apparent motion occurs when a wealth of information about the position, shape, orientation, etc. of the two flashes in the sequence is made available to the visual system during the presentation. This information is not necessarily an exact copy of the original stimulus but may be degraded by neural factors (such as masking), inattention or eye movements on the part of the subject during the presentation and may be subject to decay within the visual system during processing. The available information is assessed to determine if movement has occurred and which type of movement it was. It is this second assessment that gives rise to the depth ambiguity.

It is further proposed that the processes underlying reports of "object identity" (Warren, 1977) are involved in determining what type of movement is seen. Let us assume that the information available to the visual system is consistent with movement. If the processes underlying object identity signal that the same shape was present in both flashes in the apparent motion sequence, then the types of movement than can occur will be automatically constrained to those that preserve object identity. In the particular displays used in the experiments reported in Chapters 3, 4 and 5, a rotation in depth is an obvious "transformation", or type of movement, that preserves object identity. It is at this point that the information about the relative directions of the shapes becomes particular important. If the two shapes are not recognised as being the same, then the "transformation" or movement required need not be identity preserving. Two dimensional movement probably represents a default condition for movement and the disparity between the shapes in this case is accommodated by the perception of an amorphous shape during movement followed by sudden replacement at the endpoint of the movement, as suggested by Foster (1978) and Warren (1977).

The model developed in Chapter 3 suggested that the different variables used affected RID responses to a different degree. Shape was observed to have the greatest effect which is consistent with this theory which is based on determining whether or not the same shape has been used in both flashes. The observed effects of separation and ISI may reflect how these variables affect the quality of the information available to the visual system during the process of determining the type of movement that has occurred, if any.

It seems plausible that the entire pattern produced by the two shapes, including the relative positions of the shapes, is required in order to determine what type of movement has occurred. This happens because it is not sufficient to know that a rotation in depth has taken place. Also required is the location of the axis of rotation. Increasing the separation between the shapes would increase the size of the pattern that would need to be assessed which would reduce the probability that the appropriate transformation would be detected. It is envisaged that the separation effect is analogous to the finding in studies of the symmetry of static patterns where it is found that features closer to the midline of the pattern are more salient and affect the perception of symmetry more than features on the periphery of the pattern (Bruce and Morgan, 1975).

Increasing the ISI is likely to increase the decay of information within the visual system so that when the comparison comes to be made for object identity, the remaining information is less likely to be consistent with a single object rotating in depth.

This theory minimises the role of small local features since they would presumably be lost early in the decay process or perhaps not even be stored at all. This is consistent with the finding that exact mirror images are not required. Global properties would be important, however, since they form the basis for the processes underlying object identity (Pittenger and Shaw, 1975). A corollary of the idea that small, local features may be lost or minimised, is that complex patterns might appear to rotate less than simple patterns. While the patterns used where not assessed for their complexity, the octagons used in Chapter 3 seem more complex shapes than the rectangles and arrows of Chapter 4. In the octagon experiments the effect of shape was less marked than in the quadrilateral experiments.

Previous studies of depth ambiguous apparent motion (e.g. Kolers and Pomerantz, 1971; White et al. 1979) have suffered from a lack of generality because only a small range of conditions were used. This study has used a much wider variety of shapes, in particular and has shown that the shapes themselves are particularly important. A theory of the processes involved in the production of the phenomenon of depth ambiguous apparent motion has been proposed but at this stage it must be regarded as tentative. The results of these experiments, however, suggest that the phenomenon of depth ambiguous apparent motion may itself be used a tool to investigate the properties of shapes, as other researchers have begun to do. It seems certain that an understanding of the processes that give rise to the perception of an object rotating in depth from the presentation of two discrete images will contribute to a general understanding of pattern perception and recognition.

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THE APPARENT MOTION INSTRUCTIONS

These instructions were delivered verbatim to the subjects.

"This experiment is concerned with apparent motion which is the phenomenon that you are looking at when you watch a film or T.V. In a film for instance, a series of stationery images are being projected onto the screen but your visual system is integrating those stationery images to give you the illusion of motion. Aparent motion is the perception of movement from a series of stationery images.

In this experiment I just use simple geometric figures rather than pictures of complex scenes as in a film. It turns out that the figures I use generate ambiguous apparent motion, that is, two different kinds of motion and it will be your task to look at the experimental figures and to decide which type of motion it is that you see.

Now the first type of motion is where the object appears to slide across the screen so that it is a flat, two dimensional type of motion. This type of movement is often accompanied by a sensation of the shape distorting or deforming as it moves, as in this example. You can see that the movement is just flat and how the sides appear to bend in and then bend out.

The second type of movment is where the object appears to come out of or go into the screen, that is, it is a three dimensional type of movement. In this type of movement the object appears to remain rigid as it moves, much like a gate or a door rotating on its hinges, as in this example.

This particular example happens to be a bit ambiguous because even though it looks like a gate or a door rotating most of the time, sometimes it looks like a square skewing into a diamond shape. That is, it looks like it is moving two dimensionally and deforming. This is what I mean by the term 'ambiguous apparent motion'. It's where exactly the same stimulus conditions can, over time, give rise to two quite different percepts.

The experimental shapes will do exactly the same sort of thing. However, the procedure is a little bit different in the experiment. Instead of presenting the display continuously as in the examples, I simply give you a single cycle of motion, that is, just the two shapes once each. What you will see is a very brief movement across the screen, which will either be rigid and three dimensional or flat and two dimensional, and this will be followed by a two second blank.

During this blank interval you will indicate what you have seen by pressing one of these three buttons. This left hand button is if you see the rigid, three dimensional type of motion. This right hand button is if you see the two dimensional type of motion and this middle button is if you don't see any motion. Because it is an illusion, sometimes it appears just not to work.

So the procedure will be that you will see two shapes flash on the screen which should produce the illusion of some sort of movement. During the blank interval you will first ask yourself, 'Can I say I saw something move?'. If you can, then you will ask yourself 'Was it three dimensional or two dimensional movement?'. At the end of the two seconds, another trial will be presented and you will make another response and so on. Every time you see two shapes flash on the screen you will end up pressing one of these three buttons.

It's important in this experiment that you try to make a new decision for each new trial. It is a fairly long and tedious experiment and it becomes very easy and tempting to lapse into habits or to develop strategies. Things like 'I've seen these shapes before and they did that so they'll do it again' or 'I've been pressing this button for too long, I should press the other one'. The nature of this experiment is such that you might get the same thing happening for a while and then it will suddenly change and, of course, it's those changes that I am vitally interested in.

Throughout the experiment I would lke you to rest your chin on this rest. It's very important to have your head at a fixed distance from the screen so that's what this is for."

NOTES

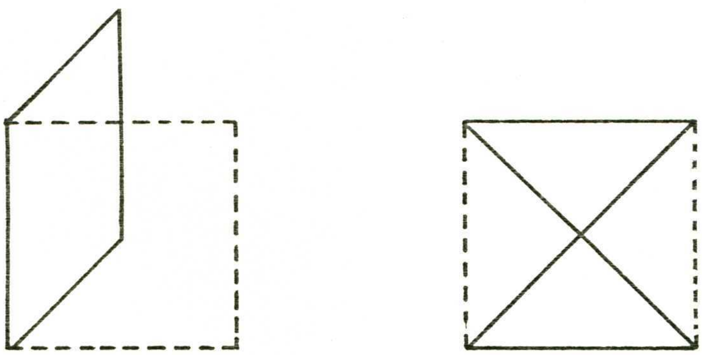
1. These instrucions were delivered with the subject sitting in front of the screen. At the appropriate time the example displays were

presented to the subject and they ran continuously throughout the delivery of the instructions.

2. Subjects were encouraged to watch the examples until they were certain they could identify the types of motion referred to. In the second example, subjects readily reported three dimensional movement but there was often a significant pause before subjects could see the two different perceptual arrangements of the stimulus. However, the rest of the instructions were not delivered until subjects could see the two different arrangements.

3. When describing which buttons signified which responses, the button referred to was actually pointed to and subjects were encouraged to press the buttons to get the "feel" of them.

4. The instructions were rarely delivered without interruptions and frequent pauses to clarify matters and to answer subjects' questions.



0 1

The stimulus configurations shown to subjects to illustrate rotation in depth (shape pair 0) and 2D motion (shape pair 1). The dotted figure appeared first, followed by the solid figure.

APPENDIX B

The following pages tabulate the raw frequencies of each type of response for each subject in each experiment. The data tables for each subject show the condition code number first, the RID response frequency, the 2D motion response frequency, the no motion response frequency and finally the number of times no response was made to that condition. Averages across subjects are given in the main text.

For each experiment, a decoding table is given. This table allows the reader to match the condition code numbers to the various treatment levels used in the experiments.

Presenting the data in this way does not allow the reader to examine the sequence of responses. It may be of general interest to know if RID responses predominated early in the session, or whether or not no motion responses tend to occur together, etc. However, these questions were not at issue in this thesis so the data were condensed to give the overall frequencies. A full presentation of the raw data would fill approximately 200 pages.

EXPERIMENT 3.1

The following data are the frequencies of the four categories of responses for each subject. The categories were: RID responses (RID), 2D motion responses (2D), no motion responses (NM) and no response (NR). The particular shape pair seen by the subject is indicated by the Shape Pair code.

The first table indicates the relationship between the code numbers and the ISI's and separations used. The ISI is given in units of milliseconds while the separation is given in multiples of 6.25 mm.

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Sep.	0	0	0	0	1	1	1	1	2	2	2	2	4	4	4	4
ISI	25	50	100	200	25	50	100	200	25	50	100	200	25	50	100	200

SUBJECT 1 SHAPE 1

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RID	24	23	24	22	23	24	22	17	19	21	21	16	5	8	6	6
2D	1	2	1	3	2	1	3	8	6	4	4	9	20	17	19	19
NM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NR	1	0	1	0	0	0	0	0	0	1	0	0	0	0	0	1

SUBJECT 2 SHAPE 2

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RID	25	20	21	12	19	19	21	5	19	12	15	9	6	8	8	4
2D	0	5	4	13	6	6	4	20	6	13	10	16	19	17	17	21
NM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NR	1	0	0	0	0	0	0	1	0	1	0	0	0	0	0	1

SUBJECT 3 SHAPE 3

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RID	23	21	20	23	16	11	18	11	0	2	1	0	0	0	0	0
2D	2	4	5	2	9	14	7	14	25	23	24	25	25	25	25	25
NM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NR	0	2	0	0	1	2	3	1	1	2	2	0	0	0	0	1

SUBJECT 4 SHAPE 4

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RID	25	25	22	23	6	7	2	9	7	0	4	6	6	6	3	4
2D	0	0	3	2	19	18	23	16	18	25	21	19	19	19	22	21
NM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NR	2	0	2	0	0	3	1	1	0	0	1	1	1	2	3	0

SUBJECT 5 SHAPE 4

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RID	17	13	16	11	13	12	18	16	14	10	11	13	9	4	7	8
2D	8	12	9	14	12	13	7	9	11	15	14	12	16	21	18	17
NM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NR	13	12	9	13	17	18	17	27	11	17	14	9	11	8	9	15

SUBJECT 6 SHAPE 3

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RID	8	5	6	3	7	5	6	0	5	4	6	5	4	4	6	3
2D	17	20	19	22	18	20	19	25	20	21	19	20	21	21	19	22
NM	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
NR	2	0	1	2	0	3	2	2	1	1	3	0	1	1	1	1

SUBJECT 7 SHAPE 3

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RID	10	16	6	10	13	9	14	14	14	14	14	16	12	13	17	10
2D	15	9	19	15	12	16	11	11	11	11	11	9	13	12	8	15
NM	0	0	0	0	2	0	0	1	0	1	0	0	0	0	0	0
NR	7	2	7	8	6	11	4	12	7	4	9	10	6	15	7	6

SUBJECT 8 SHAPE 1

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RID	20	23	20	21	25	25	20	23	24	22	21	20	23	13	19	21
2D	5	2	5	4	0	0	5	2	1	3	4	5	2	12	6	4
NM	0	0	1	3	2	2	4	9	0	5	2	11	5	6	8	12
NR	0	0	0	0	0	0	0	2	0	4	1	1	1	1	1	1

SUBJECT 9 SHAPE 2

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RID	14	20	13	15	16	10	11	7	12	8	6	1	7	6	7	7
2D	11	5	12	10	9	15	14	18	13	17	19	24	18	19	19	18
NM	0	1	0	0	0	0	0	0	1	0	0	1	0	1	0	0
NR	1	1	0	0	0	0	0	0	0	1	0	1	1	0	0	0

SUBJECT 10 SHAPE 2

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RID	11	3	9	14	3	4	4	0	2	1	5	0	2	1	1	3
2D	14	22	16	11	22	21	21	25	23	24	20	25	23	24	24	22
NM	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
NR	1	2	1	2	2	5	1	0	2	0	1	2	1	0	3	3

SUBJECT 11 SHAPE 2

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RID	22	24	24	20	18	17	20	9	16	15	18	13	15	16	15	17
2D	3	1	1	5	7	8	5	16	9	10	7	12	10	9	10	8
NM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NR	0	0	0	0	0	0	0	1	0	1	0	1	1	1	0	0

SUBJECT 12 SHAPE 1

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RID	17	7	8	0	6	5	3	0	2	1	0	0	0	1	0	0
2D	8	18	17	25	19	20	22	25	23	24	25	25	25	24	25	25
NM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NR	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0

SUBJECT 13 SHAPE 1

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RID	24	21	24	23	9	16	16	16	7	7	8	11	1	0	3	0
2D	1	4	1	2	16	9	9	9	18	18	17	14	24	25	22	25
NM	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0
NR	1	0	0	2	0	0	1	0	0	0	0	1	0	0	1	0

SUBJECT 14 SHAPE 1

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RID	23	21	19	17	22	21	23	17	19	20	17	12	1	4	3	0
2D	2	4	6	8	3	4	2	8	6	5	8	13	24	21	22	25
NM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NR	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0

SUBJECT 15 SHAPE 4

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RID	7	4	7	3	9	7	5	7	1	7	7	2	4	8	8	7
2D	18	21	18	22	16	18	20	18	24	18	18	23	21	17	17	18
NM	4	0	1	0	0	0	0	4	2	0	0	0	0	0	1	0
NR	0	0	0	0	0	1	0	0	0	0	0	1	1	0	1	0

SUBJECT 16 SHAPE 3

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RID	3	9	9	7	4	6	5	2	2	3	6	3	4	1	2	0
2D	22	16	16	18	21	19	20	23	23	22	19	22	21	24	23	25
NM	0	0	1	1	0	0	0	1	0	0	0	1	0	1	0	0
NR	2	0	1	1	1	0	0	0	0	1	2	1	2	0	2	1

SUBJECT 17 SHAPE 4

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RID	22	17	19	13	14	18	16	10	17	20	9	10	12	14	10	4
2D	3	8	6	12	11	7	9	15	8	5	16	15	13	11	15	21
NM	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NR	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

SUBJECT 18 SHAPE 4

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RID	20	19	12	2	17	21	15	2	14	12	8	2	5	7	4	1
2D	5	6	13	23	8	4	10	23	11	13	17	23	20	18	21	24
NM	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1
NR	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	1

SUBJECT 19 SHAPE 3

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RID	21	19	14	10	11	14	13	6	6	3	11	3	2	4	2	1
2D	4	6	11	15	14	11	12	19	19	22	14	22	23	21	23	24
NM	0	1	2	6	2	1	3	20	2	3	4	18	6	12	8	31
NR	0	0	1	0	0	0	1	0	0	0	0	1	0	0	0	1

SUBJECT 20 SHAPE 2

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RID	18	19	19	12	20	18	20	14	16	19	13	16	16	18	13	15
2D	7	6	6	13	5	7	5	11	9	6	12	9	9	7	12	10
NM	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
NR	3	0	0	4	0	2	3	1	0	1	2	2	3	2	0	0

SUBJECT 21 SHAPE 3

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RID	7	7	8	6	11	6	10	7	9	5	7	9	7	6	7	9
2D	18	18	17	19	14	19	15	18	16	20	18	16	18	19	18	16
NM	19	5	10	5	5	11	6	8	18	9	10	12	17	7	6	11
NR	2	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0

SUBJECT 22 SHAPE 4

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RID	19	16	18	15	15	21	19	15	13	14	15	7	10	7	15	8
2D	6	9	7	10	10	4	6	10	12	11	10	18	15	18	10	17
NM	0	2	1	0	0	0	0	0	0	0	1	1	1	0	0	0
NR	0	3	0	0	0	0	0	0	0	0	0	0	1	1	0	1

SUBJECT 23 SHAPE 1

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RID	23	24	21	20	17	18	22	13	14	14	16	15	8	3	9	7
2D	2	1	4	5	8	7	3	12	11	11	9	10	17	22	16	18
NM	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NR	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1

SUBJECT 24 SHAPE 2

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RID	17	20	17	21	20	17	16	17	18	18	18	21	18	17	17	23
2D	8	5	8	4	5	8	9	8	7	7	7	4	7	8	8	2
NM	1	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0
NR	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0

SUBJECT 25 SHAPE 1

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RID	11	8	10	11	6	11	10	3	5	10	9	2	12	11	7	5
2D	14	17	15	14	19	14	15	22	20	15	16	23	13	14	18	20
NM	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
NR	1	1	0	0	1	0	0	1	0	2	1	0	0	0	0	0

SUBJECT 26 SHAPE 4

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RID	24	23	22	24	6	6	6	6	2	5	7	2	2	1	2	2
2D	1	2	3	1	19	19	19	19	23	20	18	23	23	24	23	23
NM	0	0	0	0	1	2	0	0	0	0	1	0	0	0	0	0
NR	0	0	0	0	1	0	0	2	2	1	1	1	0	1	0	0

SUBJECT 27 SHAPE 3

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RID	13	14	19	12	17	15	9	5	13	12	11	5	13	11	14	4
2D	12	11	6	13	8	10	16	20	12	13	14	20	12	14	11	21
NM	0	1	0	0	0	1	1	0	0	0	1	0	1	0	1	0
NR	0	0	0	1	2	0	1	0	1	1	0	1	0	0	0	0

SUBJECT 28 SHAPE 2

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RID	23	20	19	19	23	18	20	20	13	13	11	11	9	5	6	5
2D	2	5	6	6	2	7	5	5	12	12	14	14	16	20	19	20
NM	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
NR	1	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0

SUBJECT 29 SHAPE 1

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RID	24	24	20	16	22	23	22	19	25	25	24	16	22	19	20	15
2D	1	1	5	9	3	2	3	6	0	0	1	9	3	6	5	10
NM	0	0	0	0	0	0	0	1	1	0	0	1	0	0	1	0
NR	2	0	0	2	1	0	1	1	2	1	1	3	2	1	3	3

SUBJECT 30 SHAPE 4

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RID	23	21	19	14	19	17	17	6	16	16	16	10	11	11	11	14
2D	2	4	6	11	6	8	8	19	9	9	9	15	14	14	14	11
NM	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0
NR	0	0	0	0	1	0	0	0	0	0	1	0	0	2	0	0

SUBJECT 31 SHAPE 3

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RID	20	23	22	19	12	20	18	21	13	15	14	13	6	5	8	10
2D	5	2	3	6	13	5	7	4	12	10	11	12	19	20	17	15
NM	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0
NR	1	0	0	0	1	1	2	2	0	2	1	0	1	0	1	0

SUBJECT 32 SHAPE 2

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RID	13	12	15	7	10	14	12	7	8	11	8	9	10	6	3	6
2D	12	13	10	18	15	11	13	18	17	14	17	16	15	19	22	19
NM	4	4	5	5	14	7	4	4	9	10	14	8	17	18	11	6
NR	1	2	3	2	1	1	3	3	1	0	2	0	4	5	4	2

SUBJECT 33 SHAPE 3

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RID	11	12	14	14	7	17	15	12	14	10	6	8	9	12	11	8
2D	14	13	11	11	18	8	10	13	11	15	19	17	16	13	14	17
NM	3	1	2	2	0	0	0	0	0	1	0	2	0	0	1	0
NR	1	3	1	2	2	2	1	3	1	0	1	0	2	1	0	4

SUBJECT 34 SHAPE 4

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RID	23	20	17	3	23	20	15	0	12	14	9	0	4	9	2	1
2D	2	5	8	22	2	5	10	25	13	11	16	25	21	16	23	24
NM	0	1	2	3	1	0	4	0	5	5	7	2	1	2	2	1
NR	1	0	0	2	2	2	1	0	0	1	0	0	1	2	0	0

SUBJECT 35 SHAPE 1

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RID	17	23	15	16	18	16	16	12	12	12	13	10	11	7	4	3
2D	8	2	10	9	7	9	9	13	13	13	12	15	14	18	21	22
NM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
NR	0	0	2	1	0	1	1	2	0	1	0	1	2	1	0	0

SUBJECT 36 SHAPE 2

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RID	19	9	12	12	15	12	15	10	12	13	13	8	9	10	7	14
2D	6	16	13	13	10	13	10	15	13	12	12	17	16	15	18	11
NM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NR	0	2	2	5	0	1	3	3	0	1	1	4	1	1	1	5

SUBJECT 37 SHAPE 3

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RID	8	15	21	9	10	8	16	11	14	9	13	13	9	13	13	13
2D	17	10	4	16	15	17	9	14	11	16	12	12	16	12	12	12
NM	0	1	0	1	0	1	0	0	0	0	0	0	1	0	0	0
NR	0	0	0	0	2	1	0	0	1	0	1	0	0	0	0	1

SUBJECT 38 SHAPE 1

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RID	23	19	18	17	16	13	14	5	1	4	1	1	1	1	0	0
2D	2	6	7	8	9	12	11	20	24	21	24	24	24	24	25	25
NM	0	0	1	0	1	0	1	0	0	1	2	0	1	0	0	0
NR	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0

SUBJECT 39 SHAPE 2

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RID	9	11	10	10	6	5	13	5	7	13	9	9	6	6	8	6
2D	16	14	15	15	19	20	12	20	18	12	16	16	19	19	17	19
NM	0	0	0	0	0	1	2	0	0	0	0	0	0	0	0	1
NR	0	0	0	0	0	1	0	1	0	0	0	1	2	0	0	1

SUBJECT 40 SHAPE 4

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RID	14	8	14	7	15	13	8	3	8	8	8	5	2	4	0	3
2D	11	17	11	18	10	12	17	22	17	17	17	20	23	21	25	22
NM	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0
NR	0	0	0	1	0	0	0	0	2	0	1	0	0	0	0	0

SUBJECT 41 SHAPE 2

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RID	21	16	19	16	19	10	19	6	11	11	16	12	11	15	6	10
2D	4	9	6	9	6	15	6	19	14	14	9	13	14	10	19	15
NM	0	0	0	1	0	1	0	1	0	1	0	4	0	0	0	4
NR	0	0	0	0	1	0	0	1	0	0	1	0	0	0	1	0

SUBJECT 42 SHAPE 1

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RID	23	24	22	18	17	19	19	20	10	17	12	15	7	7	4	5
2D	2	1	3	7	8	6	6	5	15	8	13	10	18	18	21	20
NM	0	1	1	2	0	0	0	1	1	4	2	1	1	4	2	4
NR	1	1	0	0	1	1	1	3	0	4	1	1	1	0	1	2

SUBJECT 43 SHAPE 4

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RID	18	19	20	18	18	14	19	16	14	21	17	12	19	18	16	9
2D	7	6	5	7	7	11	6	9	11	4	8	13	6	7	9	16
NM	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NR	0	1	0	0	0	0	0	0	1	1	1	1	0	0	1	0

SUBJECT 44 SHAPE 3

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RID	17	20	21	19	15	19	17	18	16	16	15	12	3	8	11	6
2D	8	5	4	6	10	6	8	7	9	9	10	13	22	17	14	19
NM	1	0	2	4	2	6	1	2	1	0	0	5	5	4	5	8
NR	0	0	0	0	1	1	1	0	0	0	0	2	0	1	0	0

EXPERIMENT 3.2

The following data are the frequencies of the four categories of responses for each subject. The categories were: RID responses (RID), 2D motion responses (2D), no motion responses (NM) and no response (NR).

The first table sets out the relationship between the code numbers and the shape pairs and separations used. The shape pair code is given. Values of Separation are given in multiples of 6.25 mm.

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Shape	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Sep.	0	0	0	0	1	1	1	1	2	2	2	2	4	4	4	4

SUBJECT 1

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RID	21	7	13	22	13	8	4	21	14	5	3	22	9	1	0	15
2D	4	18	12	3	12	17	21	4	11	20	22	3	16	24	25	10
NM	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	1
NR	1	0	1	1	1	1	1	2	2	1	4	1	0	0	0	0

SUBJECT 2

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RID	20	10	14	22	21	12	19	23	20	12	13	23	20	9	11	20
2D	5	15	11	3	4	13	6	2	5	13	12	2	5	16	14	5
NM	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0
NR	2	0	0	0	5	4	1	5	2	3	3	3	2	3	1	4

SUBJECT 3

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RID	17	19	14	17	22	13	10	17	15	10	7	11	14	8	3	10
2D	8	6	11	8	3	12	15	8	10	15	18	14	11	17	22	15
NM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NR	0	0	0	0	0	1	0	1	0	0	1	0	1	1	0	0

SUBJECT 4

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RID	25	23	18	24	25	22	17	22	23	19	15	20	21	14	1	14
2D	0	2	7	1	0	3	8	3	2	6	10	5	4	11	24	11
NM	0	0	0	0	0	1	0	1	0	1	0	0	0	0	0	0
NR	0	1	0	0	0	0	0	0	1	1	1	0	0	0	0	0

SUBJECT 5

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RID	25	14	14	23	17	5	10	24	17	6	0	20	8	1	2	14
2D	0	11	11	2	8	20	15	1	8	19	25	5	17	24	23	11
NM	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
NR	0	0	1	1	1	1	3	1	0	3	2	0	0	1	1	0

SUBJECT 6

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RID	14	5	6	3	13	10	6	7	11	12	7	4	9	8	3	2
2D	11	20	19	22	12	15	19	18	14	13	18	21	16	17	22	23
NM	1	12	23	0	2	10	33	4	2	15	14	1	2	16	7	4
NR	0	1	0	1	2	0	1	1	0	1	1	0	1	0	0	0

SUBJECT 7

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RID	21	9	6	20	20	9	7	22	21	7	5	21	18	6	2	20
2D	4	16	19	5	5	16	18	3	4	18	20	4	7	19	23	5
NM	0	0	2	1	1	1	2	0	0	1	0	0	0	0	6	0
NR	0	4	0	3	2	1	2	7	0	3	4	2	0	3	1	2

SUBJECT 8

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RID	16	4	8	25	20	4	7	25	15	6	10	20	14	4	5	22
2D	9	21	17	0	5	21	18	0	10	19	15	5	11	21	20	3
NM	1	1	0	1	0	1	0	0	0	0	1	1	0	0	2	1
NR	3	0	2	2	1	3	0	2	1	2	2	2	1	1	1	2

SUBJECT 9

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RID	23	5	5	17	19	2	2	21	20	2	5	23	19	3	6	22
2D	2	20	20	8	6	23	23	4	5	23	20	2	6	22	19	3
NM	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0
NR	1	2	1	1	1	0	1	1	0	1	0	2	2	4	2	1

SUBJECT 10

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RID	25	23	22	25	24	20	22	23	23	20	19	24	25	17	20	25
2D	0	2	3	0	1	5	3	2	2	5	6	1	0	8	5	0
NM	0	0	0	0	0	1	0	0	1	0	0	0	0	1	0	0
NR	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0

EXPERIMENT 3.3

The following data are the frequencies of the four categories of responses for each subject. The categories were: RID responses (RID), 2D motion responses (2D), no motion responses (NM) and no response (NR).

The first table sets out the relationship between the code numbers and the shapes and ISI's used. The Shape Pair Codes are given. The ISI's are in milliseconds.

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Shape	0	1	2	3	0	1	2	3	0	1	2	3	0	1	2	3
ISI	25	25	25	25	50	50	50	50	100	100	100	100	200	200	200	200

SUBJECT 1

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RID	3	17	16	1	5	14	15	2	2	16	18	3	0	15	13	3
2D	22	8	9	24	20	11	10	23	23	9	7	22	25	10	12	22
NM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NR	1	1	6	3	0	5	1	1	1	2	1	1	0	3	4	0

SUBJECT 2

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RID	20	21	23	16	20	21	21	21	21	22	22	20	19	20	19	21
2D	5	4	2	9	5	4	4	4	4	3	3	5	6	5	6	4
NM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NR	1	1	2	1	0	4	2	1	0	0	0	1	0	0	0	0

SUBJECT 3

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RID	11	9	7	7	8	12	9	8	6	6	5	8	8	4	4	10
2D	14	16	18	18	17	13	16	17	19	19	20	17	17	21	21	15
NM	3	5	16	3	2	6	5	4	4	8	4	3	0	8	2	3
NR	2	6	1	4	2	3	5	10	6	6	4	2	4	2	5	6

SUBJECT 4

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RID	20	2	3	21	21	3	1	22	24	0	3	24	22	3	1	21
2D	5	23	22	4	4	22	24	3	1	25	22	1	3	22	24	4
NM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NR	0	0	1	0	0	0	0	1	0	0	0	0	0	0	1	1

SUBJECT 5

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RID	25	0	1	22	23	2	1	25	24	1	0	24	24	3	1	21
2D	0	25	24	3	2	23	24	0	1	24	25	1	1	22	24	4
NM	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
NR	2	1	0	1	3	3	2	2	0	2	1	0	2	0	4	0

SUBJECT 6

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RID	21	7	14	24	19	6	7	24	24	7	6	23	24	7	7	20
2D	4	18	11	1	6	19	18	1	1	18	19	2	1	18	18	5
NM	0	0	0	2	0	0	0	1	0	1	2	1	0	2	1	0
NR	2	3	1	0	0	1	1	0	0	1	1	1	1	0	0	0

SUBJECT 7

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RID	7	9	10	5	4	9	9	8	7	9	9	8	3	10	4	9
2D	18	16	15	20	21	16	16	17	18	16	16	17	22	15	21	16
NM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NR	0	0	0	1	0	1	0	2	1	0	1	0	0	0	0	0

SUBJECT 8

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RID	6	1	0	1	10	1	0	9	19	9	8	14	22	18	10	23
2D	19	24	25	24	15	24	25	16	6	16	17	11	3	7	15	2
NM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NR	0	0	0	0	0	0	0	0	0	1	1	0	1	0	0	0

SUBJECT 9

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RID	21	18	12	20	23	13	18	19	24	17	15	21	21	17	14	16
2D	4	7	13	5	2	12	7	6	1	8	10	4	4	8	11	9
NM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NR	4	1	6	2	4	1	4	4	3	5	3	2	2	4	3	4

SUBJECT 10

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RID	12	5	10	17	12	4	3	21	18	12	4	16	20	6	3	20
2D	13	20	15	8	13	21	22	4	7	13	21	9	5	19	22	5
NM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NR	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0

EXPERIMENT 3.4

The following data are the frequencies of the four categories of responses for each subject. The categories were: RID responses (RID), 2D motion responses (2D), no motion responses (NM) and no response (NR).

The first table sets out the relationship between the code numbers and the shapes and separations used. The shape Pair Codes are given and the separations are in multiples of 6.25 mm.

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Shape	0	1	2	3	0a	1a	2a	3a	0	1	2	3	0a	1a	2a	3a
Sep.	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1

SUBJECT 1

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RID	20	25	25	23	24	25	25	23	24	24	20	22	23	24	24	21
2D	5	0	0	2	1	0	0	2	1	1	5	3	2	1	1	4
NM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NR	0	0	1	0	0	1	0	0	0	0	0	0	1	0	0	0

SUBJECT 2

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RID	25	23	24	25	25	25	24	24	3	2	5	2	3	3	3	3
2D	0	2	1	0	0	0	1	1	22	23	20	23	22	22	22	22
NM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NR	3	2	1	2	1	0	2	1	2	4	0	1	1	2	3	0

SUBJECT 3

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RID	16	14	7	17	17	20	23	18	7	12	11	14	18	18	20	22
2D	9	11	18	8	8	5	2	7	18	13	14	11	7	7	5	3
NM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NR	3	1	1	2	8	2	3	1	2	2	2	4	2	4	2	6

SUBJECT 4

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RID	7	9	11	3	13	10	5	11	6	6	9	10	0	8	8	7
2D	18	16	14	22	12	15	20	14	19	19	16	15	25	17	17	18
NM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NR	0	0	1	1	0	0	0	0	1	0	1	0	0	0	0	0

SUBJECT 5

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RID	25	24	21	18	15	17	12	13	22	21	20	23	18	19	11	11
2D	0	1	4	7	10	8	13	12	3	4	5	2	7	6	14	14
NM	0	0	1	0	0	0	0	1	0	1	2	1	0	0	2	2
NR	0	1	0	0	0	1	1	0	1	2	1	1	1	1	1	1

SUBJECT 6

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RID	21	13	18	16	18	11	10	16	5	4	3	3	2	3	3	2
2D	4	12	7	9	7	14	15	9	20	21	22	22	23	22	22	23
NM	1	3	4	6	2	2	0	8	1	1	0	0	0	0	0	0
NR	3	4	9	3	9	5	4	6	1	6	4	3	2	3	3	4

SUBJECT 7

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RID	10	16	22	15	23	24	19	18	7	14	4	7	23	22	25	23
2D	15	9	3	10	2	1	6	7	18	11	21	18	2	3	0	2
NM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NR	0	0	1	1	0	0	0	0	0	0	0	0	1	0	0	0

SUBJECT 8

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RID	21	13	18	16	18	11	10	16	5	4	3	3	2	3	3	2
2D	4	12	7	9	7	14	15	9	20	21	22	22	23	22	22	23
NM	1	3	4	6	2	2	0	8	1	1	0	0	0	0	0	0
NR	3	4	9	3	9	5	4	6	1	6	4	3	2	3	3	4

SUBJECT 9

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RID	18	22	25	24	24	25	23	25	9	8	10	4	9	11	9	12
2D	7	3	0	1	1	0	2	0	16	17	15	21	16	14	16	13
NM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NR	0	1	2	0	0	0	0	2	1	0	1	0	1	3	1	0

SUBJECT 10

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RID	25	23	25	25	24	25	24	22	9	9	12	8	5	13	13	8
2D	0	2	0	0	1	0	1	3	16	16	13	17	20	12	12	17
NM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NR	2	5	5	0	1	1	2	3	3	5	1	3	1	1	3	1

EXPERIMENT 3.5

The following data are the frequencies of the four categories of responses for each subject. The categories were: RID responses (RID), 2D motion responses (2D), no motion responses (NM) and no response (NR).

The first table sets out the relationship between the code numbers and the sizes and separations used. The Size code numbers are given. The values of Separation are multiples of 6.25 mm.

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Sep.	0	1	2	4	0	1	2	4	0	1	2	4	0	1	2	4
Size	0	0	0	0	1	1	1	1	2	2	2	2	3	3	3	3

SUBJECT 1

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RID	7	11	6	6	20	16	15	13	17	14	18	16	18	20	17	11
2D	18	14	19	19	5	9	10	12	8	11	7	9	7	5	8	14
NM	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0
NR	1	0	2	1	1	3	1	1	3	1	1	1	1	4	1	1

SUBJECT 2

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RID	12	13	15	19	13	11	10	13	6	9	13	11	12	10	13	11
2D	13	12	10	6	12	14	15	12	19	16	12	14	13	15	12	14
NM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NR	0	0	0	1	1	0	0	0	0	0	0	1	1	0	2	0

SUBJECT 3

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RID	13	1	3	3	22	18	22	16	24	19	19	11	24	18	7	11
2D	12	24	22	22	3	7	3	9	1	6	6	14	1	7	18	14
NM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NR	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0

SUBJECT 4

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RID	7	1	1	0	16	4	0	1	13	1	1	2	15	10	4	1
2D	18	24	24	25	9	21	25	24	12	24	24	23	10	15	21	24
NM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NR	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0

SUBJECT 5

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RID	6	5	9	14	17	16	16	16	22	13	19	19	21	19	24	20
2D	19	20	16	11	8	9	9	9	3	12	6	6	4	6	1	5
NM	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0
NR	1	0	0	0	1	1	0	2	1	1	1	1	0	0	0	0

SUBJECT 6

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RID	5	4	6	4	17	15	10	13	19	17	21	18	21	21	17	22
2D	20	21	19	21	8	10	15	12	6	8	4	7	4	4	8	3
NM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NR	1	1	0	0	0	0	0	0	0	0	0	1	0	1	2	1

SUBJECT 7

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RID	6	8	15	8	13	6	17	11	18	17	5	7	10	12	15	7
2D	19	17	10	17	12	19	8	14	7	8	20	18	15	13	10	18
NM	0	0	0	1	0	2	0	0	0	0	2	1	0	1	0	0
NR	3	4	3	3	2	6	2	2	0	2	2	6	1	0	6	2

SUBJECT 8

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RID	18	12	8	4	20	10	6	2	19	10	6	4	19	7	12	7
2D	7	13	17	21	5	15	19	23	6	15	19	21	6	18	13	18
NM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NR	1	0	1	1	1	1	0	1	1	0	1	0	0	1	3	1

SUBJECT 9

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RID	15	16	13	4	15	12	16	10	15	16	15	16	17	17	19	16
2D	10	9	12	21	10	13	9	15	10	9	10	9	8	8	6	9
NM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NR	2	0	1	2	0	0	0	1	0	1	0	1	0	1	5	0

SUBJECT 10

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RID	24	15	4	0	23	17	13	6	23	20	15	5	22	22	15	8
2D	1	10	21	25	2	8	12	19	2	5	10	20	3	3	10	17
NM	1	0	2	3	1	2	1	2	0	0	1	3	2	3	2	2
NR	0	0	1	0	1	1	0	0	1	0	0	2	4	1	2	0

EXPERIMENT 3.6

The following data are the frequencies of the four categories of responses for each subject. The categories were: RID responses (RID), 2D motion responses (2D), no motion responses (NM) and no response (NR).

The first table sets out the relationship between the code numbers and the shapes and directions used. The Shapes are coded by the length of the parallel element (in mm) whereas the direction codes are R (Right), L (Left), U (Up) and D (Down).

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Shape	5	5	5	5	10	10	10	10	15	15	15	15	20	20	20	20
Dir.	R	U	L	D	R	U	L	D	R	U	L	D	R	U	L	D

SUBJECT 1

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RID	24	22	17	16	16	21	23	22	22	22	20	21	15	18	17	21
2D	1	3	8	9	9	4	2	3	3	3	5	4	10	7	8	4
NM	2	2	1	2	5	2	0	1	2	0	2	1	4	1	2	2
NR	0	0	1	3	1	2	2	0	1	1	1	0	2	1	0	2

SUBJECT 2

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RID	18	8	18	13	2	20	4	25	22	4	12	21	6	14	7	22
2D	7	17	7	12	23	5	21	0	3	21	13	4	19	11	18	3
NM	1	4	0	3	5	3	8	0	1	7	3	3	5	1	1	2
NR	3	2	1	2	1	3	4	2	0	1	1	2	6	0	1	0

SUBJECT 3

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RID	23	14	12	16	18	22	14	12	17	18	21	18	18	16	15	23
2D	2	11	13	9	7	3	11	13	8	7	4	7	7	9	10	2
NM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NR	2	1	0	2	0	1	1	1	1	0	0	0	2	0	0	1

SUBJECT 4

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RID	25	11	23	17	14	17	16	19	25	16	22	20	13	21	12	20
2D	0	14	2	8	11	8	9	6	0	9	3	5	12	4	13	5
NM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NR	2	6	3	6	1	4	1	1	3	5	1	5	4	3	2	4

SUBJECT 5

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RID	18	9	23	5	4	18	1	21	19	4	17	11	10	22	7	18
2D	7	16	2	20	21	7	24	4	6	21	8	14	15	3	18	7
NM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NR	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0

SUBJECT 6

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RID	25	25	25	24	25	22	24	25	25	23	24	24	23	25	25	23
2D	0	0	0	1	0	3	1	0	0	2	1	1	2	0	0	2
NM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NR	0	0	0	0	1	2	0	0	0	0	1	0	1	0	0	0

SUBJECT 7

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RID	22	10	18	13	5	20	2	22	22	4	15	16	9	19	10	22
2D	3	15	7	12	20	5	23	3	3	21	10	9	16	6	15	3
NM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NR	2	1	2	1	1	2	2	0	1	0	1	1	1	3	1	1

SUBJECT 8

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RID	22	19	23	24	17	22	19	20	25	23	20	17	23	22	21	20
2D	3	6	2	1	8	3	6	5	0	2	5	8	2	3	4	5
NM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NR	0	2	0	0	0	2	0	1	0	0	3	1	0	1	3	0

SUBJECT 9

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RID	5	4	23	14	23	3	11	24	25	18	7	4	8	23	23	3
2D	20	21	2	11	2	22	14	1	0	7	18	21	17	2	2	22
NM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NR	1	5	1	5	0	1	1	2	2	4	2	1	4	2	2	1

SUBJECT 10

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RID	16	14	21	9	17	19	10	19	22	11	17	12	11	17	16	18
2D	9	11	4	16	8	6	15	6	3	14	8	13	14	8	9	7
NM	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NR	6	12	4	7	4	10	3	6	5	6	9	3	8	9	6	8

EXPERIMENT 4.1

The following data are the frequencies of the four categories of responses for each subject. The categories were: RID responses (RID), 2D motion responses (2D), no motion responses (NM) and no response (NR).

The first table sets out the relationship between the code numbers and the shapes, ISI's and separations used. The Shape Pair Codes are shown. The ISI's are in milliseconds and the separations are in multiples of 11.7 mm.

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Shape	0	0	0	0	1	1	1	1	2	2	2	2	3	3	3	3
ISI	50	50	100	100	50	50	100	100	50	50	100	100	50	50	100	100
Sep.	0	1	0	1	0	1	0	1	0	1	0	1	0	1	0	1

SUBJECT 1

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RID	8	12	7	4	5	5	2	9	23	13	21	18	23	18	24	13
2D	17	13	18	21	20	20	23	16	2	12	4	7	2	7	1	12
NM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NR	0	0	0	1	1	0	0	0	1	0	0	0	0	0	0	0

SUBJECT 2

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RID	7	7	8	4	13	4	11	2	21	19	17	8	22	16	15	16
2D	18	18	17	21	12	21	14	23	4	6	8	17	3	9	10	9
NM	0	4	1	0	0	2	0	1	0	1	0	0	0	0	0	3
NR	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0

SUBJECT 3

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RID	14	13	15	7	13	8	10	7	20	15	21	9	22	13	21	14
2D	11	12	10	18	12	17	15	18	5	10	4	16	3	12	4	11
NM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NR	2	0	2	2	1	0	2	0	1	3	0	2	1	0	1	0

SUBJECT 4

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RID	13	18	10	15	17	18	5	15	12	5	5	16	9	13	6	15
2D	12	7	15	10	8	7	20	10	13	20	20	9	16	12	19	10
NM	1	1	0	0	0	0	1	0	0	0	1	1	3	1	0	0
NR	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

SUBJECT 5

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RID	4	2	5	5	1	1	5	4	11	16	15	17	13	17	11	17
2D	21	23	20	20	24	24	20	21	14	9	10	8	12	8	14	8
NM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NR	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1

SUBJECT 6

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RID	4	0	0	2	4	0	3	0	19	10	14	9	19	6	19	9
2D	21	25	25	23	21	25	22	25	6	15	11	16	6	19	6	16
NM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NR	1	6	3	4	2	3	1	3	4	2	1	5	9	13	10	3

SUBJECT 7

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RID	14	5	11	5	11	6	17	5	25	25	25	24	25	24	25	25
2D	11	20	14	20	14	19	8	20	0	0	0	1	0	1	0	0
NM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NR	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

SUBJECT 8

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RID	17	2	7	1	12	7	9	0	20	12	24	9	20	10	22	11
2D	7	23	18	24	12	18	16	24	4	13	1	16	4	14	2	14
NM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NR	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

SUBJECT 9

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RID	0	0	2	1	1	0	2	0	5	3	7	3	6	4	6	4
2D	25	25	23	24	24	25	23	25	20	22	18	22	19	21	19	21
NM	0	0	0	0	0	0	0	0	4	0	1	0	4	0	0	0
NR	0	0	0	0	2	0	0	0	1	0	2	0	0	1	1	1

SUBJECT 10

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RID	8	5	7	2	6	2	8	2	19	14	14	12	17	14	14	18
2D	17	20	18	23	19	23	17	23	6	11	11	13	8	11	11	7
NM	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
NR	4	1	1	4	3	2	4	2	1	3	4	1	5	3	1	6

EXPERIMENT 4.2

The following data are the frequencies of the four categories of responses for each subject. The categories were: RID responses (RID), 2D motion responses (2D), no motion responses (NM) and no response (NR).

The first table sets out the relationship between the code numbers and the shapes and separations used. The Shape Pair codes are shown. The values of Separation are multiples of 11.7 mm.

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Shape	0	1	2	3	4	5	6	7	0	1	2	3	4	5	6	7
Sep.	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1

SUBJECT 1

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RID	4	18	19	19	19	21	9	25	12	22	17	13	9	5	14	25
2D	21	7	6	6	6	4	16	0	13	3	8	12	16	20	11	0
NM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NR	2	8	7	7	8	4	6	4	2	4	1	4	6	5	4	1

SUBJECT 2

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RID	0	15	21	24	22	23	24	25	0	11	16	18	22	19	18	25
2D	25	10	4	1	3	2	1	0	25	14	9	7	3	6	7	0
NM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NR	2	1	2	3	2	4	0	1	0	1	4	3	4	2	1	1

SUBJECT 3

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RID	0	22	23	24	24	25	25	25	0	22	25	24	25	22	25	25
2D	25	3	2	1	1	0	0	0	25	3	0	1	0	3	0	0
NM	2	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0
NR	0	1	2	1	0	0	1	0	1	3	0	1	0	0	0	0

SUBJECT 4

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RID	1	3	15	17	18	16	20	25	0	1	13	12	18	10	12	25
2D	24	22	10	8	7	9	5	0	25	24	12	13	7	15	13	0
NM	0	0	3	1	0	0	1	0	0	0	4	1	3	0	2	0
NR	1	1	0	0	0	1	0	0	0	0	1	1	1	1	1	0

SUBJECT 5

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RID	0	22	17	25	25	23	24	25	0	19	19	24	25	24	21	25
2D	25	3	8	0	0	2	1	0	25	6	6	1	0	1	4	0
NM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NR	0	6	4	4	3	3	5	0	3	7	5	2	3	5	3	1

SUBJECT 6

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RID	1	11	23	17	23	21	20	25	2	9	9	15	20	20	21	25
2D	25	13	2	8	2	4	5	0	23	16	16	10	5	5	4	0
NM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NR	0	0	1	0	0	0	0	0	0	0	0	0	1	1	0	0

SUBJECT 7

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RID	3	16	14	13	11	12	12	24	5	15	16	18	17	18	20	23
2D	22	9	11	12	14	13	13	1	21	9	8	7	8	7	5	2
NM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NR	2	6	9	7	5	4	1	1	2	1	4	2	2	7	1	1

SUBJECT 8

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RID	0	18	22	17	24	23	25	25	1	11	17	21	20	20	23	25
2D	25	7	3	8	1	2	0	0	24	14	8	4	5	5	2	0
NM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NR	0	0	1	2	0	1	1	0	2	2	2	1	1	3	4	0

SUBJECT 9

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RID	3	10	20	19	22	17	22	24	1	5	10	13	13	10	13	24
2D	22	15	5	6	3	8	3	1	24	20	15	12	12	15	12	1
NM	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
NR	1	0	0	0	1	0	1	0	0	1	1	0	0	0	0	0

SUBJECT 10

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RID	3	22	22	23	24	24	25	25	0	5	5	14	14	10	12	25
2D	22	3	3	2	1	1	0	0	25	20	20	11	11	15	13	0
NM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NR	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0

EXPERIMENT 4.3

The following data are the frequencies of the four categories of responses for each subject. The categories were: RID responses (RID), 2D motion responses (2D), no motion responses (NM) and no response (NR).

The first table sets out the relationship between the code numbers and the separations, spikes and shapes used. The shape codes are S (Square) and R (Rectangle), and the spike codes are shown. The separations are multiples of 11.7 mm.

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Shape	S	S	S	S	R	R	R	R	S	S	S	S	R	R	R	R
Sp.	0,0	1,1	1,2	2,1	0,0	1,1	1,2	2,1	0,0	1,1	1,2	2,1	0,0	1,1	1,2	2,1
Sep.	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1

SUBJECT 1

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RID	0	11	15	18	0	15	16	16	0	11	14	21	0	15	16	21
2D	25	14	10	7	25	10	9	9	25	14	11	4	25	10	9	4
NM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NR	2	3	7	2	1	4	1	4	1	2	4	2	1	3	4	2

SUBJECT 2

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RID	6	14	11	22	4	8	11	11	3	10	17	17	3	7	12	15
2D	19	11	15	3	21	17	14	14	22	15	8	8	22	18	13	10
NM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NR	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

SUBJECT 3

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RID	1	5	10	3	6	2	5	5	3	1	2	3	3	2	6	0
2D	24	20	15	22	19	23	20	20	22	24	23	22	22	23	19	25
NM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NR	0	1	1	0	1	0	0	1	0	0	0	1	0	0	0	0

SUBJECT 4

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RID	3	14	11	11	2	10	10	11	4	5	14	8	5	10	13	8
2D	22	11	14	14	23	15	15	14	21	20	11	17	20	15	12	17
NM	5	0	0	0	1	1	0	0	0	1	0	0	0	0	0	0
NR	0	0	1	0	0	1	1	0	1	1	0	1	0	1	1	0

SUBJECT 5

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RID	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2D	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25
NM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NR	0	2	1	1	0	1	0	1	0	0	0	1	1	0	1	0

SUBJECT 6

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RID	0	9	7	10	7	12	4	8	0	4	7	7	1	8	4	8
2D	25	16	18	15	18	13	21	17	25	21	18	18	24	17	21	17
NM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NR	0	1	4	3	3	3	0	0	0	2	1	0	1	0	2	1

SUBJECT 7

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RID	2	21	13	21	0	20	15	15	0	11	15	15	1	16	20	13
2D	23	4	12	4	25	5	10	10	25	14	10	10	24	9	5	12
NM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NR	1	2	3	1	0	2	3	1	0	2	0	3	1	1	2	0

SUBJECT 8

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RID	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2D	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25
NM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NR	0	2	1	1	0	1	0	1	0	0	0	1	1	0	1	0

SUBJECT 9

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RID	2	11	9	12	0	7	7	8	0	14	8	9	0	11	4	16
2D	23	14	16	13	25	18	18	17	25	11	17	16	25	14	21	9
NM	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
NR	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

SUBJECT 10

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RID	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2D	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25
NM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NR	0	2	1	1	0	1	0	1	0	0	0	1	1	0	1	0

SUBJECT 11

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RID	2	16	12	23	0	15	12	14	1	12	12	21	3	13	14	15
2D	23	9	13	2	25	10	13	11	24	13	13	4	22	12	11	10
NM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NR	3	6	6	1	4	1	6	3	4	4	4	3	3	4	4	4

SUBJECT 12

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RID	11	15	18	8	8	10	14	14	10	17	17	12	12	12	16	15
2D	14	10	7	17	17	15	11	11	15	9	8	13	13	13	9	10
NM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NR	0	0	0	1	0	0	0	1	0	0	1	0	0	0	0	0

SUBJECT 13

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RID	2	6	6	20	0	8	6	5	0	7	3	20	2	14	4	6
2D	23	19	19	5	25	27	19	20	25	18	22	5	23	11	21	19
NM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NR	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0

SUBJECT 14

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RID	16	9	13	13	9	7	6	10	4	5	6	6	4	1	0	2
2D	9	16	12	12	16	18	19	15	21	20	19	19	21	24	25	23
NM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NR	0	1	0	0	0	0	0	0	0	0	0	2	0	0	1	0

SUBJECT 15

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RID	3	25	24	24	12	24	23	23	0	21	19	19	2	19	19	22
2D	22	0	1	1	13	1	2	2	25	4	6	6	23	6	6	3
NM	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1
NR	0	0	0	0	0	1	0	0	0	0	0	0	0	0	3	0

EXPERIMENT 4.4

The following data are the frequencies of the four categories of responses for each subject. The categories were: RID responses (RID), 2D motion responses (2D), no motion responses (NM) and no response (NR).

The first table sets out the relationship between the code numbers and the shapes and separations used. The Shape Pair Codes are shown. The separations are mutltiples of 10 mm.

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Shape	0	0	1	1	2	2	3	3	4	4	5	5	6	6	7	7	8	8
Sep.	0	1	0	1	0	1	0	1	0	1	0	1	0	1	0	1	0	1

SUBJECT 1

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
RR	7	7	11	16	9	11	18	19	13	7	12	17	10	14	8	10	8	11
PD	18	18	14	9	16	14	7	6	12	18	13	8	15	11	17	15	17	14
NM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NR	1	2	0	2	2	0	1	0	0	0	0	0	0	1	0	0	0	0

SUBJECT 2

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
RR	3	1	25	21	20	20	19	20	4	1	14	8	21	18	15	10	1	1
PD	22	24	0	4	5	5	6	5	21	24	11	17	4	7	10	15	24	24
NM	2	3	2	7	4	11	10	15	1	1	3	5	16	69	8	7	6	1
NR	1	0	3	1	1	1	1	0	1	2	3	0	1	14	1	1	1	0

SUBJECT 3

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
RR	3	4	2	3	2	3	2	9	1	1	7	11	2	1	6	14	0	0
PD	22	21	23	22	23	22	23	16	24	24	18	14	23	24	19	11	25	25
NM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
NR	1	0	0	0	0	0	1	0	1	1	0	0	0	0	0	0	0	0

SUBJECT 4

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
RR	0	2	0	0	0	0	2	9	1	0	0	0	2	3	0	0	0	0
PD	25	23	25	25	25	25	23	16	24	25	25	25	23	22	25	25	25	25
NM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NR	0	1	0	1	0	0	1	0	0	0	0	0	2	1	0	0	0	0

SUBJECT 5

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
RR	16	3	10	4	7	7	2	5	3	1	23	23	1	0	23	24	0	2
PD	9	22	15	21	18	18	23	20	22	24	2	2	24	25	2	1	25	23
NM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NR	0	0	1	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0

SUBJECT 6

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
RR	2	1	13	12	7	7	17	11	10	10	19	13	8	5	14	19	5	3
PD	23	24	12	13	18	18	8	14	15	15	6	12	17	20	11	6	20	22
NM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NR	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0

SUBJECT 7

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
RR	7	1	12	3	12	9	13	11	2	1	19	22	5	0	21	18	1	0
PD	18	24	13	22	13	16	12	14	23	24	6	3	20	25	4	7	24	25
NM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NR	1	0	0	1	0	2	0	1	1	2	1	3	1	2	1	2	2	0

SUBJECT 8

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
RR	2	4	17	9	13	9	19	16	5	11	22	23	6	6	25	25	7	6
PD	23	21	8	16	12	16	6	9	20	14	3	2	19	19	0	0	18	19
NM	9	5	1	0	0	1	1	0	4	3	0	0	0	0	0	1	3	2
NR	3	1	2	2	5	5	4	4	1	3	2	1	3	2	7	0	2	5

SUBJECT 9

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
RR	7	2	10	9	8	4	12	10	10	9	24	24	8	8	24	23	1	0
PD	17	23	15	16	17	21	13	15	15	16	1	1	17	17	1	2	24	26
NM	17	1	0	1	1	0	0	0	1	0	0	0	1	0	0	0	3	0
NR	0	1	0	1	1	0	0	1	0	0	0	0	0	1	2	2	1	0

SUBJECT 10

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
RR	0	0	0	0	0	0	0	1	0	0	21	22	0	0	6	6	0	0
PD	25	25	25	25	25	25	25	24	25	25	4	3	25	25	19	19	25	25
NM	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NR	0	0	1	1	1	1	3	2	0	0	3	0	1	0	1	2	3	1

EXPERIMENT 4.5

The following data are the frequencies of the four categories of responses for each subject. The categories were: RID responses (RID), 2D motion responses (2D), no motion responses (NM) and no response (NR).

The first table sets out the relationship between the code numbers and the stimulus configurations, spikes and ISI's used. The Stimulus Configuration codes are shown. The ISI's are in milliseconds and the spike codes are 0 (absent) and 1 (present).

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Shape	0	0	0	0	1	1	1	1	2	2	2	2	3	3	3	3
Sp.	0	0	1	1	0	0	1	1	0	0	1	1	0	0	1	1
ISI	25	100	25	100	25	100	25	100	25	100	25	100	25	100	25	100

SUBJECT 1

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RID	2	3	3	1	1	8	2	8	19	21	17	25	24	23	22	23
2D	23	22	22	24	24	17	23	17	6	4	8	0	1	2	3	2
NM	0	0	0	0	0	0	1	0	2	2	0	0	1	0	3	0
NR	1	0	3	1	1	1	1	0	2	2	3	1	2	0	2	0

SUBJECT 2

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RID	4	2	4	4	4	2	4	3	15	17	17	8	20	20	19	17
2D	21	23	21	21	21	23	21	22	10	8	8	17	5	5	6	8
NM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NR	3	1	1	1	1	1	1	2	2	1	0	1	0	1	1	0

SUBJECT 3

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RID	3	3	0	4	6	4	3	6	11	15	7	14	13	18	17	19
2D	22	22	25	21	19	21	22	19	14	10	18	11	12	7	8	6
NM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NR	0	0	2	0	0	0	0	0	1	0	0	1	0	0	0	0

SUBJECT 4

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RID	8	4	14	12	11	17	13	14	15	21	15	18	16	14	15	18
2D	17	21	11	13	14	8	12	11	10	4	10	7	9	11	10	7
NM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NR	0	3	0	1	0	0	3	3	0	2	0	0	2	1	0	0

SUBJECT 5

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RID	1	0	23	23	0	0	24	22	0	0	24	24	0	0	18	22
2D	24	25	2	2	25	25	1	3	25	25	1	1	25	25	7	3
NM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NR	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

SUBJECT 6

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RID	8	3	12	15	2	4	18	17	16	15	20	22	19	18	25	22
2D	17	22	13	10	23	21	7	8	9	10	5	3	6	7	0	3
NM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NR	2	1	7	4	2	6	3	3	4	2	5	2	5	3	2	1

SUBJECT 7

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RID	4	2	3	5	5	5	7	5	8	5	5	5	17	15	12	12
2D	21	23	22	20	20	20	18	20	17	20	20	20	8	10	13	13
NM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NR	3	2	0	2	0	2	0	1	3	0	2	1	1	1	0	2

SUBJECT 8

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RID	1	1	1	0	0	0	0	1	13	13	14	18	20	17	17	15
2D	24	24	24	25	25	25	25	24	12	12	11	7	5	8	8	10
NM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NR	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1

SUBJECT 9

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RID	1	0	0	0	0	1	0	0	14	13	22	18	25	23	24	24
2D	24	25	25	25	25	24	25	25	11	12	3	7	0	2	1	1
NM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NR	1	0	1	1	0	0	0	0	0	1	1	1	0	0	0	0

SUBJECT 10

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RID	8	12	16	16	10	11	14	18	5	5	9	9	1	1	12	5
2D	17	13	9	9	15	14	11	7	20	20	16	16	24	24	13	20
NM	0	0	2	0	0	1	0	0	0	0	0	0	0	0	0	0
NR	1	2	1	1	2	2	1	1	0	1	2	2	1	1	3	7

EXPERIMENT 4.6

The following data are the frequencies of the four categories of responses for each subject. The categories were: RID responses (RID), 2D motion responses (2D), no motion responses (NM) and no response (NR).

The first table sets out the relationship between the code numbers and the stimulus configurations and orders used. The stimulus configuration codes are shown. The order codes are R (rectangle first) and S (square first).

	0	1	2	3	4	5	6	7
Shape	0	1	2	3	0	1	2	3
Order	S	S	S	S	R	R	R	R

SUBJECT 1

	0	1	2	3	4	5	6	7
RID	15	19	4	3	14	12	2	7
2D	10	6	21	22	11	13	23	18
NM	0	0	0	0	0	0	0	0
NR	0	0	0	1	0	0	0	1

SUBJECT 2

	0	1	2	3	4	5	6	7
RID	7	10	0	0	14	11	0	0
2D	18	15	25	25	11	14	25	25
NM	0	0	0	0	0	0	0	0
NR	0	0	0	0	0	0	0	0

SUBJECT 3

	0	1	2	3	4	5	6	7
RID	3	2	3	18	7	7	14	24
2D	22	23	22	7	18	18	11	1
NM	0	0	0	0	0	0	1	6
NR	6	4	2	4	9	8	7	6

SUBJECT 4

	0	1	2	3	4	5	6	7
RID	0	0	0	19	4	7	17	23
2D	25	25	25	6	21	18	8	2
NM	0	0	0	1	0	1	0	0
NR	2	6	1	2	1	2	0	4

SUBJECT 5

	0	1	2	3	4	5	6	7
RID	9	5	22	25	15	15	25	25
2D	16	20	3	0	10	10	0	0
NM	0	0	0	0	0	0	0	0
NR	0	1	2	1	1	0	0	0

SUBJECT 6

	0	1	2	3	4	5	6	7
RID	1	13	19	17	2	3	22	20
2D	24	12	6	8	23	23	3	5
NM	1	0	7	15	1	1	5	6
NR	0	0	0	1	3	1	0	2

SUBJECT 7

	0	1	2	3	4	5	6	7
RID	0	0	1	19	0	1	4	21
2D	25	25	24	6	25	24	21	4
NM	0	0	0	0	0	0	0	0
NR	0	2	0	0	0	0	0	2

SUBJECT 8

	0	1	2	3	4	5	6	7
RID	2	2	3	4	4	7	7	3
2D	23	23	22	21	21	18	18	22
NM	0	0	0	0	0	0	0	0
NR	21	40	28	21	14	35	35	20

SUBJECT 9

	0	1	2	3	4	5	6	7
RID	0	0	3	9	0	6	13	22
2D	25	25	22	16	25	19	12	3
NM	0	0	0	0	0	0	0	0
NR	0	0	0	0	0	0	0	0

SUBJECT 10

	0	1	2	3	4	5	6	7
RID	0	4	0	3	0	2	12	17
2D	25	21	25	22	25	23	13	8
NM	0	0	0	0	0	0	0	0
NR	1	1	0	1	0	2	6	2

EXPERIMENT 5.1

The following tables are values of RAT and OPD for each of the shapes at each orientation, averaged across 15 subjects. The columns marked "QUAD. 1", "QUAD. 2", etc. are the four orientations. The "AVERAGES" column is the average for the four orientations.

AVERAGE RAT VALUES (N=15)

Shape	QUAD. 1	QUAD. 2	QUAD. 3	QUAD. 4	AVERAGES
0	4.19	3.73	3.66	4.26	3.96
1	2.66	2.86	2.73	2.8	2.76
2	3.06	3	3	2.4	2.86
3	4	4.26	3.66	3.73	3.91
4	6.4	6.73	6.66	5.6	6.35
5	8.26	7.93	8.86	8.06	8.28
6	9.33	9.06	9.26	9.33	9.25
7	8.6	8.73	8.6	8.93	8.71
8	8.06	8.26	7.8	8.46	8.15
9	2.2	2.13	2.06	1.86	2.06
10	2.06	2.33	2	1.86	2.06
11	4.93	3.93	5.2	4.86	4.73
12	4.66	4	4.86	4.13	4.41
13	5.26	4.53	4.86	6.2	5.21
14	5.2	4.6	4.6	4.8	4.8
15	4.06	4.4	4.4	4.8	4.41
16	3.73	3.2	4	3.2	3.53
17	4	3.73	4.06	3.26	3.76
18	3	2.86	3.46	2.6	2.98
19	2.86	3.66	3.33	3.26	3.28

AVERAGE OPD VALUES (N=15)

Shape	QUAD. 1	QUAD. 2	QUAD. 3	QUAD. 4	AVERAGES
0	2.93	3.13	3.2	3.13	3.1
1	2.33	2.66	1.93	2.46	2.35
2	2.2	2.13	2.26	2.66	2.31
3	2.06	2.4	2.06	1.6	2.03
4	1.46	1.26	1.66	1.2	1.4
5	.93	1.46	.93	1.26	1.15
6	.33	.4	.66	.86	.56
7	1.26	.93	1.46	.93	1.15
8	1.2	1.06	1.2	1.13	1.15
9	2	1.86	1.86	2.2	1.98
10	2.66	3.26	2.73	3.13	2.95
11	1.53	1.93	1.46	1.46	1.6
12	1.8	1.46	1.33	1.66	1.56
13	.73	1	1	1.06	.95
14	1	1.4	1.2	1.53	1.28
15	1.2	1.2	1.26	1.53	1.3
16	1.6	2	1.4	1.53	1.63
17	1.6	1.66	1.6	1.86	1.68
18	2.13	2.73	2.06	2.46	2.35
19	2.73	2.6	2.33	2.46	2.53

EXPERIMENT 5.2

The following data are the frequencies of the four categories of responses for each subject. The categories were: RID responses (RID), 2D motion responses (2D), no motion responses (NM) and no response (NR). The code numbers are the Shape Pair code numbers.

APPARENT MOTION DATA

SUBJECT 1

	0	1	2	3	4	5	6	7	8	9
RID	17	18	16	17	18	18	10	14	19	2
2D	3	2	4	3	2	2	10	6	1	18
NM	0	0	0	0	0	0	0	0	0	0
NR	1	0	0	2	0	1	0	1	1	0

	10	11	12	13	14	15	16	17	18	19
RID	1	2	5	5	2	4	3	8	14	11
2D	19	18	15	15	18	16	17	12	6	9
NM	0	0	0	0	0	0	0	0	0	0
NR	2	0	1	2	0	1	1	1	3	2

SUBJECT 2

	0	1	2	3	4	5	6	7	8	9
RID	20	20	20	18	19	20	19	20	20	3
2D	0	0	0	2	1	0	1	0	0	17
NM	0	0	0	0	0	0	0	0	0	0
NR	0	1	0	0	2	0	1	0	0	0

	10	11	12	13	14	15	16	17	18	19
RID	0	0	0	3	0	2	0	0	1	0
2D	20	20	20	17	20	18	20	20	19	20
NM	0	0	0	0	0	0	0	0	0	0
NR	1	1	1	0	0	0	0	0	0	1

SUBJECT 3

	0	1	2	3	4	5	6	7	8	9
RID	19	17	19	16	18	18	17	19	19	7
2D	1	3	1	4	2	2	3	1	1	13
NM	0	0	0	0	0	0	0	0	0	1
NR	0	0	1	0	0	0	0	0	0	1

	10	11	12	13	14	15	16	17	18	19
RID	3	5	13	6	9	6	11	11	10	10
2D	17	15	7	14	11	14	9	9	10	10
NM	0	0	0	0	0	0	0	0	0	0
NR	0	0	0	0	0	0	1	0	0	0

SUBJECT 4

	0	1	2	3	4	5	6	7	8	9
RID	18	17	17	19	19	17	15	17	15	9
2D	2	3	3	1	1	3	5	3	5	11
NM	0	1	0	0	0	0	1	0	2	1
NR	0	1	0	0	1	0	0	2	1	0

	10	11	12	13	14	15	16	17	18	19
RID	1	5	2	4	7	4	9	7	8	7
2D	19	15	18	16	13	16	11	13	12	13
NM	2	7	5	2	3	4	2	1	2	0
NR	0	1	0	0	0	1	0	0	0	0

SUBJECT 5

	0	1	2	3	4	5	6	7	8	9
RID	20	19	19	19	19	20	19	20	20	0
2D	0	1	1	1	1	0	1	0	0	20
NM	0	0	0	0	0	0	0	0	0	0
NR	2	3	0	0	1	0	1	0	2	0

	10	11	12	13	14	15	16	17	18	19
RID	0	19	19	18	15	18	19	20	19	20
2D	20	1	1	2	5	2	1	0	1	0
NM	0	0	0	0	0	0	0	0	0	0
NR	0	0	0	3	4	0	1	0	0	0

SUBJECT 6

	0	1	2	3	4	5	6	7	8	9
RID	20	20	20	20	19	20	19	20	19	1
2D	0	0	0	0	1	0	1	0	1	19
NM	0	0	0	0	0	0	0	0	0	0
NR	0	2	0	2	0	0	0	0	0	0

	10	11	12	13	14	15	16	17	18	19
RID	0	2	0	1	0	0	2	2	4	2
2D	20	18	20	19	20	20	18	18	16	18
NM	0	0	0	0	0	0	0	0	0	0
NR	0	0	0	0	0	0	0	0	0	0

SUBJECT 7

	0	1	2	3	4	5	6	7	8	9
RID	20	18	19	19	20	19	19	17	20	15
2D	0	2	1	1	0	1	1	3	0	5
NM	0	0	0	0	0	0	0	0	0	0
NR	0	0	0	0	0	0	0	0	0	0

	10	11	12	13	14	15	16	17	18	19
RID	7	16	18	14	17	9	13	13	16	14
2D	13	4	2	6	3	11	7	7	4	6
NM	0	0	0	0	0	0	0	0	0	0
NR	0	0	0	0	1	0	0	0	1	0

SUBJECT 8

	0	1	2	3	4	5	6	7	8	9
RID	16	18	18	20	20	16	18	12	19	15
2D	4	2	2	0	0	4	2	8	1	5
NM	9	0	1	0	0	0	0	0	0	0
NR	0	0	0	0	1	0	0	0	0	0

	10	11	12	13	14	15	16	17	18	19
RID	8	10	9	11	9	10	14	11	9	19
2D	12	10	11	9	11	10	6	9	11	1
NM	0	1	0	2	2	0	0	2	0	3
NR	0	1	0	0	0	0	1	1	0	0

SUBJECT 9

	0	1	2	3	4	5	6	7	8	9
RID	20	20	20	20	20	20	19	20	20	1
2D	0	0	0	0	0	0	1	0	0	19
NM	0	0	0	0	0	0	0	0	0	0
NR	0	1	0	0	0	0	1	0	0	1

	10	11	12	13	14	15	16	17	18	19
RID	0	17	17	16	15	20	20	20	20	20
2D	20	3	3	4	5	0	0	0	0	0
NM	0	0	0	0	0	0	0	0	0	0
NR	0	0	0	0	0	0	0	0	1	0

SUBJECT 10

	0	1	2	3	4	5	6	7	8	9
RID	20	19	19	19	20	15	18	18	15	9
2D	0	1	1	1	0	5	2	2	5	11
NM	0	0	0	0	0	0	0	0	0	0
NR	0	0	0	0	1	0	0	0	0	0

	10	11	12	13	14	15	16	17	18	19
RID	3	3	3	3	4	2	0	7	5	0
2D	17	17	17	17	16	18	20	13	15	20
NM	0	0	0	1	0	0	0	0	0	0
NR	0	0	0	0	0	0	0	0	0	0

EXPERIMENT 5.3

The following data are the frequencies of the four categories of responses for each subject. The categories were: RID responses (RID), 2D motion responses (2D), no motion responses (NM) and no response (NR). The code numbers are the Shape Pair code numbers.

SUBJECT 1

	0	1	2	3	4	5	6	7	8	9
RID	5	3	3	3	1	20	14	19	16	3
2D	15	17	17	17	19	0	6	1	4	17
NM	0	0	0	0	0	0	0	0	0	0
NR	0	0	0	0	0	0	0	0	0	0

	10	11	12	13	14	15	16	17	18	19
RID	0	1	13	11	11	8	9	12	16	16
2D	20	19	7	9	9	12	11	8	4	4
NM	0	0	0	0	0	0	0	0	0	0
NR	0	0	0	0	0	0	0	0	0	0

SUBJECT 2

	0	1	2	3	4	5	6	7	8	9
RID	15	19	18	14	15	7	19	8	8	5
2D	5	1	2	6	5	13	1	12	12	15
NM	0	0	0	0	0	0	0	0	0	0
NR	0	1	1	0	2	1	1	2	0	1

	10	11	12	13	14	15	16	17	18	19
RID	2	16	10	14	13	18	14	12	17	16
2D	18	4	10	6	7	2	6	8	3	4
NM	0	0	0	0	0	0	0	0	0	0
NR	1	1	2	0	2	1	1	2	1	2

SUBJECT 3

	0	1	2	3	4	5	6	7	8	9
RID	13	15	16	19	20	15	6	20	15	8
2D	7	5	4	1	0	5	14	0	5	12
NM	1	0	1	0	0	0	0	0	0	3
NR	0	0	0	0	0	0	0	0	0	0

	10	11	12	13	14	15	16	17	18	19
RID	3	9	3	9	5	13	13	11	18	10
2D	17	11	17	11	15	7	7	9	2	10
NM	0	1	1	0	1	0	0	1	0	1
NR	1	0	0	0	0	0	0	0	0	0

SUBJECT 4

	0	1	2	3	4	5	6	7	8	9
RID	19	18	17	18	16	16	12	16	18	11
2D	1	2	3	2	4	4	8	4	2	9
NM	0	0	0	0	0	0	0	0	0	0
NR	0	0	0	1	0	0	0	0	0	0

	10	11	12	13	14	15	16	17	18	19
RID	1	0	4	4	5	2	1	2	3	8
2D	19	20	16	16	15	18	19	18	17	12
NM	0	0	0	0	0	0	0	0	0	0
NR	0	0	0	0	0	1	0	0	0	0

SUBJECT 5

	0	1	2	3	4	5	6	7	8	9
RID	14	15	17	19	16	17	6	20	20	3
2D	6	5	3	1	4	3	14	0	0	17
NM	0	0	0	0	0	0	0	0	0	0
NR	0	0	0	0	2	0	0	0	0	0

	10	11	12	13	14	15	16	17	18	19
RID	1	4	8	1	5	7	7	8	4	8
2D	19	16	12	19	15	13	13	12	16	12
NM	7	2	1	0	0	7	0	1	1	0
NR	1	0	0	0	0	0	0	1	1	0

SUBJECT 6

	0	1	2	3	4	5	6	7	8	9
RID	16	19	19	19	18	18	18	20	19	2
2D	4	1	1	1	2	2	2	0	1	18
NM	0	0	0	0	0	0	0	0	0	0
NR	1	0	0	0	0	0	0	0	0	0

	10	11	12	13	14	15	16	17	18	19
RID	0	11	13	9	7	16	19	20	19	17
2D	20	9	7	11	13	4	1	0	1	3
NM	0	0	0	0	0	0	1	0	0	1
NR	1	0	0	0	0	0	0	0	1	0

VALUES OF RAT (averaged across two orientations)

Shape	0	1	2	3	4	5	6	7	8	9
Subject 1	7.0	4.5	5.5	5.0	7.5	7.5	10	9.5	8.5	4.5
Subject 2	10	9.0	9.0	10	10	10	10	10	10	5.0
Subject 3	3.5	2.0	2.0	5.0	10	10	10	10	10	1.0
Subject 4	8.0	7.0	8.0	8.0	7.0	7.5	10	10	10	6.0
Subject 5	7.5	9.0	8.5	7.5	10	10	10	10	10	10
Subject 6	3.0	4.0	4.0	2.0	6.5	7.0	8.0	7.0	8.0	4.0

Shape	10	11	12	13	14	15	16	17	18	19
Subject 1	1.5	8.5	7.0	7.5	7.0	4.0	4.0	5.0	2.0	6.0
Subject 2	1.0	7.0	3.0	6.0	4.0	4.5	3.0	3.0	1.5	2.0
Subject 3	1.0	4.0	7.5	3.0	7.0	3.5	2.5	5.0	5.0	3.0
Subject 4	2.0	9.0	9.0	8.5	9.0	8.0	8.0	8.0	7.5	5.0
Subject 5	10	10	10	10	10	10	10	10	10	9.0
Subject 6	1.0	3.5	3.5	4.0	3.0	3.0	2.0	2.0	1.0	1.5