Stellingen

behorende bij het proefschrift
Influence of context on visual space

1
Ruimtepercept is vormpercept.

2
De invloed van context kan zo groot zijn dat vrijwel geen enkel model van de visuele ruimte bruikbaar is voor het voorspellen van de waarneming in alledaagse situaties.
(Dit proefschrift)

3
Het toevoegen van context leidt niet altijd tot het beter naar het doel wijzen.
(Dit proefschrift)

4
Een exocentrische wijstaak geeft een inzicht in visuele ruimtelijke waarneming dat niet met behulp van de gebruikelijke methoden kon worden verkregen.

5
Mensen richten hun blik niet nauwkeuriger dan de taak vereist.
(Zie bijvoorbeeld Epelboim et al., Vision Research 37, 2597-2607, 1997)

6
Binnen het curriculum van Industrieel Ontwerpen is bij het leren ontwerpen te weinig aandacht voor het leren kijken, luisteren en voelen.

7
Het op tijd onderkennen van het gevaar van Repetitive Strain Injury kan veel economische, emotionele en lichamelijke schade voorkomen.

8
Het alleen voor de namen van vrouwen verwijzen naar hun geslacht suggereert dat vrouwen uitzonderingen zijn.

9
Emancipatie wordt meer met de mond beleden dan met daden.
Influence of context on visual space
Influence of context on visual space

Proefschrift

ter verkrijging van de graad van doctor
aan de Technische Universiteit Delft
op gezag van de Rector Magnificus prof. ir. K.F. Wakker,
in het openbaar te verdedigen ten overstaan van een commissie,
door het College voor Promoties aangewezen,

op maandag 14 juni 1999 te 13.30 uur
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geboren te Baarland, gemeente Borsele
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“It is now known to science that there are many more dimensions that the classical four. Scientists say that these don’t normally impinge on the world because the extra dimensions are very small and curve in on themselves, and that since reality is fractal most of it is tucked inside itself. This means either that the universe is more full of wonders than we can hope to understand or, more probably, that scientists make things up as they go along.”

Terry Pratchett, ‘Pyramids’
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Chapter 1

Introduction
We humans continuously perceive our environment. Such perception is an essential requirement for interacting with our environment. You must first note the whereabouts of a cup before you can pick it up and drink from it. You must be aware of the position of other traffic and pedestrians in order to avoid a collision when driving your car. For sighted people, the eyes provide the main source of information about what is where.

Locating objects in our 3-D environment is a complex task. In 1818 Schopenhauer wrote: "A man must be forsaken of all the gods to dream that the world we see outside of us, filling space with its three dimensions, (...) should stand there outside of us, quite objectively real with no complicity of ours, and thereupon by subsequent act, through the instrumentation of mere sensation, that it should enter our head and reconstruct a duplicate of itself as it was outside". The brain combines the images that fall on the retina of the two eyes. These images contain various cues, such as perspective, occlusion and shading. The two images combined provide us with another cue to spatial perception, namely, relative disparity. As well as retinal information, the brain also receives information from motion of the body and the eyes, and combines all the cues to retrieve important spatial parameters of objects such as shape, direction, orientation and distance. As a result of a functioning brain we perceive the world around us 3-dimensionally at every moment of the day. While a great deal is known about the way the brain functions we still do not fully understand how the brain accomplishes this complex task and which mechanisms are involved.

![Figure 1.1: The visual angle is the angle occupied by an object in the eye's view of the world. It expresses the size of the image of an object on the retina of the eye, and the size of an object relative to its distance from the eye.](image)

The question of why humans perceive objects at a certain location in depth has aroused the curiosity of many scientists, philosophers and artists for centuries. Euclid (300 BC) was the first to describe how an object occupies a certain angle in the visual field (the so-called visual angle, see figure 1.1). He assumed that there was a strong relationship between the size of the visual angle occupied by an object and the perceived size of that object. He used this to attempt to explain the visual perception of the world. He also understood that each eye had a slightly different view of the world. Da Vinci (1452) claimed that binocular vision makes it impossible for a picture to possess the same relief as an object in nature, unless such an object is viewed over a long distance with a single eye. Wheatstone (1838) and Brewster (1847) clearly demonstrated that combining the images on the retina of the two eyes (stereopsis) contributes to spatial perception. They built stereoscopes which could present a picture to one eye and another, slightly different, picture to the other eye. This resulted in a strong sensation of depth. Helmholtz (1866) did the first elaborate, empirical investigation of spatial perception.
The quote from Schopenhauer was included to illustrate that there is more to spatial perception than a retinal image sent to the brain. The first to recognise this was the philosopher and mathematician Descartes (1637). He believed that the distance between object and observer is reconstructed via knowledge about the distance between the eyes, the so-called base, and the angles that the lines of sight of each eye make with that base. This retrieval of distance is accomplished by what he called 'natural geometry'. Berkeley (1709) attacked the geometric accounts of vision current at that time. He was the first to state that distance relationships/relationships in distance are learned from visual cues, although he did not specify what these cues are. He believed that we learn to associate these cues with tactile shapes. Both geometrical and non-geometrical approaches to perceived distance relationships still co-exist in vision research today.

Figure 1.2: An example of an Ames-room. The photographed room (on the left) is perceived to be similar to a typical rectangular room. Only the perceived size of the identical twin appears strange in relation to the size of the room. In reality the room is not rectangular at all and has a perspectively misleading shape. The solid black lines of the figure on the right illustrate schematically the real shape of the room, whereas the dashed lines illustrate the perceived shape of the room. In reality, the girl on the left side of the photograph is about 2.5 times further away from the camera than her sister on the right.

From early on it became clear that visual spatial perception does not perfectly correspond with the physical world and can thus be subject to illusions (for example: Poggendorff-illusion; Metzger, 1930; Pozzo, 1907) The rooms created by Ames (1953) are well-known examples. He created a number of distorted rooms that look normal provided that the observer views the room from a certain point. The obviously strange size of the identical twin is the only reason we suspect that the photographed room in figure 1.2 is not a normal rectangular room. Ames also created a distorted room that appears normal under binocular viewing. Such deviations of the perceived world from the physical world provide clues to the mechanisms used by the brain for spatial perception. In 1913 Blumenfeld noticed that asking an observer to construct an alley by placing two stakes at an equal distance from each other, and then asking them to construct the alley by placing the stakes in parallel lines, led to different results (as did Hillebrand in 1902). Thus parallel lines are not always perceived as being separated by a con-
stant distance, something that was also observed by Euclid (300 BC). This means that visually perceived space (visual space) cannot have a Euclidean geometry. This was the inspiration for Luneburg's (1947) mathematical model of visual space. He suggested that visual space is a Riemannian space of constant negative curvature. His theory inspired many researchers to pursue this idea and perform experiments to determine the exact value of the curvature (for example Blank, 1961; Zajackowska, 1956). However, Luneburg's theory relied on a number of assumptions which were not questioned until many years later (Indow et al., 1963; Foley, 1964). Criticism of the theory slowly increased (Indow, 1991; Wagner, 1985). For example, Koenderink and Van Doorn (1998) demonstrated that visual space does not have a constant curvature. The criticism, and results of experiments disproving the theory, have not led to a radical change in the models of visual space. The idea that some mathematical rules must apply to visual space still persists. One reason for this is the belief that each visually perceived object (shape and size) can also be perceived in any other position and orientation. When this is assumed, visual space can only be a Riemannian space of constant curvature. No satisfactory alternative for Luneburg's theory has yet been formulated.

Gestalt theory takes a different, non-geometrical approach to spatial perception. This school of thought adopts the basic idea that the senses of man and animal are designed to function in everyday life. The visual system has thus learned to retrieve the information that is needed to perform the tasks which are normal to life. Thus visual spatial perception is learned via feedback from ego-motion and haptic and proprioceptive information, which is an idea already put forward by Wundt (1894). From this, Gestalt theorists conclude that perception is dependent upon the task (Gibson, 1950) and that perception without context is meaningless (Koffka, 1935). These ideas have not led to a good alternative model of visual space, but have only led to a recent trend to perform experiments on visual space under more natural conditions (e.g. Ellis et al., 1991; Wagner, 1985; Koenderink and Van Doorn, 1998).

Research into visual spatial perception has been limited. It has been limited in the sense that many aspects of spatial perception, such as shape, orientation and the nature of visual space have been studied separately from each other. It has also been limited in the sense that many experiments into visual space have been restricted to a single plane. This thesis attempts to place spatial perception in a broader perspective and to find links between various aspects of spatial perception. It explores links between the perception of the location of objects relative to each other, and their surfaces, shape and orientation. It relates its results to both geometrical and Gestalt ideas about spatial perception. It explores new directions for research into visual spatial perception. The study comprises four sub-studies, described in chapters 2, 3, 4 and 5. Each sub-study has its own central question and examines different phenomena. What the chapters have in common is that they each deal with spatial perception. There follows a short description of the central question investigated in each chapter.
Chapter 2

Three objects can be perceived as either lying in one straight line or determining a plane. The human visual system can judge the straight line connecting two objects. This judgement is used for determining the direction in which one object lies relative to another. The human visual system can also judge the direction in terms of the straight continuation of a line or edge. Similar judgements are useful in the recognition of the shape and contour of an object when part of that object is occluded. We know that a mechanism exists which can generalise contours, since people sometimes perceive contours where none are physically present. These contours are called illusory contours. Central to chapter two is the question of whether or not the mechanisms underlying illusory contours can also be used for spatial judgement. This chapter also deals with the influence of shape upon spatial judgement.

Chapter 3

Most experiments dealing with visual space have been restricted to stimuli lying in one horizontal plane at eye-level. Only Indow used stimuli at other locations, either within a fronto-parallel plane (Indow and Wanatabe, 1984) or using lights high in the air, where they are usually perceived in a hemisphere (Indow, 1968). The results of these experiments can only be generalised to all three dimensions when visual space is isotropic. To investigate this we designed an experiment which is basically 3-dimensional. In this chapter, we also examine the contribution of binocular depth cues to the perception of exocentric direction, and compare the measured standard deviations to depth detection thresholds reported in literature.

Chapter 4

Objects do not usually float in otherwise empty space. Experiments in other fields of visual research, such as perceived vertical direction, hyperacuity and perceived orientation of planes, have demonstrated that context can influence visual perception. However, none of the models of visual space include a role for context. The aim of the experiments described in chapter 4 is to examine whether context influences spatial perception.

Chapter 5

In chapter 4 we demonstrate that context can influence spatial perception. In chapter 5 we examine the role for context in near space. First, this chapter tests the general belief that spatial perception within grasping space is learned to correspond to the physical space, because observers are accustomed to using their hands to manipulate this environment. In addition, we examine the influence of distance and orientation of the entire scene (contextual planes, pointer and target) on spatial perception. This is tested in an exocentric pointing task at 40 cm (within grasping space) and 120 cm (near grasping space) in the presence of context, with distance-scaled stimuli. The range and size of binocular depth infor-
mation is significantly different for these two distances. The experiment is expressly designed to test whether spatial perception depends more on the context than on the distance and orientation in relation to the observer.

In contrast with the computer generated stimuli in chapter 3 and 4, the stimuli used in the experiments described in this chapter were real in 3-D. Thus the results described in this chapter also allowed us to check whether the results from computer generated 3-D stimuli can be generalised to the perception of more realistic situations.

Finally, chapter 6 summarises the main results and conclusions from these sub-studies.
Chapter 2

Illusory contours and spatial judgement

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submitted to Perception & Psychophysics

Abstract

We investigated whether the human visual system has a single mechanism for estimating intermediate positions common to both the mechanisms underlying the perception of illusory contours and those underlying the perception of relative position. We asked subjects to align a dot with the oblique contour of an illusory surface, or to align a dot with two markers at an oblique orientation. The systematic errors differed in direction for these two conditions. All systematic errors were orientation dependent. The errors in aligning a dot with an illusory contour seem to be related to the asymmetrical shape of the single objects which are able to induce an illusory contour, as well as figure-ground segregation. There seems to be no simple relation between the mechanisms underlying perception of illusory contours and those underlying perception of relative position.
Introduction

In everyday life we make many judgements about intermediate positions; for example, arranging the items on our desk, estimating the situation when playing soccer or recognising a horse standing behind a fence or a caterpillar lying on a leaf. We can judge whether three objects are aligned or whether they define a plane. We can also estimate how a contour probably continues at those points where the contour is masked by other objects, or where it is indistinguishable from the background. These last two situations seem different in that the first is related to spatial judgement and the second is related to the recognition of the shape of objects (amodal completion; Grossberg, 1994). Nevertheless, in both cases the visual system could be using one common mechanism which can estimate the simplest connection between two objects. In this paper we examine whether such a common mechanism exists.

As already mentioned the human visual system is capable of making estimates of intermediate positions. For example, when two objects are present in the visual field, we would not normally perceive a connecting line with an immediate visible presence. Nevertheless, we can judge in which direction one object is located with respect to the other, and can thus reconstruct a straight line that could connect the two objects, and therefore we can also judge whether or not a third object is aligned with two other objects.

In other cases we can recognize contours while they are partially masked. Moreover, sometimes people can spontaneously perceive connecting contours where none exist. One example, a Kanizsa square (Kanizsa, 1955), is shown in figure 2.1. A ‘whiter than white’ surface with clear contours is perceived as an inner figure that could fit inside the gaps of the pacman-shaped objects. Such contours are called illusory contours. These contours are generally believed to be a result of mechanisms related to the recognition of (the shape of) objects, in spite of the presence of occlusions (Marr, 1982; Heitger and von der Heydt, 1993; Grossberg, 1994; Spillmann and Dresp, 1995, page 1339). The definition of illusory contours that we shall follow is one given by Petry and Meyer (Meyer and Petry, 1987, chapter 1). They state three defining characteristics for illusory contours. Firstly, there is a sense of a bounded surface which has some property that differentiates it from an abutting or surrounding surface. Secondly, there is a sense of a boundary or edge around this surface. Thirdly, the edge and surface connect through discontinuities of the inducing pattern.

Illusory contours were first reported by Schumann (1900) and the occurrence of illusory contours has been studied by many researchers (for reviews see Petry and Meyer, 1987; Spillmann and Dresp, 1995), because it is believed to be an important clue to how the human visual system works. It is not the aim of this study to provide a theory as to how the illusory contours arise, but to examine how likely it is that one common mechanism exists which can estimate the simplest connection between two objects in different situations.
Figure 2.1: A Kanizsa square. The contours of a square are perceived even where no physical contours are present.

One possible way of establishing whether such a common mechanism exists is to look at the similarities and differences in the results of tasks related to illusory contours and the alignment of objects. The greater the similarity in results the more likely it is that the two phenomena are closely linked. Such an approach has been successfully used for comparing real and illusory contours (for example: Gregory, 1972; Smith and Over, 1977; Pomerantz et al., 1981; Vogels and Orban, 1987). We used a similar approach. We made use of the fact that larger variable and systematic errors occur in tasks performed under an oblique orientation than in the same tasks performed under horizontal or vertical orientation. This effect is known as the oblique-effect (see Appelle for review, 1972).

The aim of this study is to examine the possibility of a link between the mechanisms underlying the judgement of whether objects lie collinearly and the mechanisms underlying the perception of illusory contours. In this paper we describe the psychophysical experiments we did for this purpose. In our first experiment we compare the results of placing a dot on an oblique illusory contour, and aligning a dot with two other dots. Three more experiments were done to test hypothesised explanations of the first results.

Sittig and De Graaf (1994) reported results of a three-dot-alignment-task. They measured a strong orientation-dependency in this task. Under horizontal and vertical orientation their subjects made no systematic errors, but only variable errors in alignment. Under oblique orientation the subjects systematically placed the middle dot below the straight line that could connect the two outer dots. If very similar systematic and variable errors are made in the alignment of a dot to an illusory contour, then we have an indication that there is a strong link between the mechanisms underlying the two tasks. It would support the hypothesis that there is one common underlying mechanism. If no similarity occurs then there is no support for the existence of such a mechanism. In the latter case, the illusory contour might provide additional information, since it might be possible, as with real contours, to minimise the distance between the illusory contour and the dot. This should result in smaller variable errors, since aligning a dot with a real contour can be done very precisely.
Experiment 1

Methods

Subjects

Seven subjects (4 female, 3 male), who all gave informed consent, participated in this experiment. Their age varied from 22 to 28 years. Five subjects were naive as to the purpose of the experiment. Two subjects (NS, RB) were aware of the purpose of the experiment, but their results did not differ from the results of the other subjects. All subjects had normal or corrected to normal eyesight.

Task

Before the actual experiment, the experimenter explained the task and showed examples of the stimuli to the subjects. The experimenter also asked the subjects to report what they saw when they were shown four circular white discs with a gap of 90° (four pacmen) on a black background, so grouped that a square surface could fit inside the gaps. All subjects reported seeing a black square which was darker than the background.

The subjects had to align a white dot, appearing near the middle of two markers (specified in one of a number of ways). They could move the dot by pressing the arrow keys on a keyboard. The subjects’ task was to align the dot as accurately as they could with an illusory contour if present, or else to place the dot on what they thought would be the connecting line between the two outer markers. The dot could only be moved in a direction perpendicular to the ‘line’ that had to be judged.

Apparatus

The stimuli were computer controlled and displayed on a screen with a pixel resolution of 0.27 x 0.27 mm². The screen had a black cardboard annulus in front of it, so that only the inner circular part of the screen was visible. This was done to exclude possible reference directions indicated by the edges of the screen. The screen was viewed from a distance of 60 cm.

Stimuli

The stimuli that specified to what the dot must be aligned in this experiment are sketched in figures 2.3 to 2.5: a Kanizsa square placed on one of its corners (Kanizsa diamond, 2.3A), two dots determining an oblique straight line that could connect these dots (2.3B-C), two pacmen that specified one of the four contours of the diamond (half Kanizsa diamond, 2.4), and an arrangement of four pacmen with two of them rotated by 90° so that the four discs did not enclose a diamond (fake-Kanizsa diamond, 2.5). All stimuli indicated an oblique orientation at an angle of 45° with the vertical. Each stimulus had a small dot, which could be repositioned by the subject near to the midway position between two outer objects.
The distance between the outer objects subtended 9.5 deg visual angle which corresponds to a distance of 10 cm on the computer screen. The stimuli were white and appeared on a dark background. The white pacmen had a radius of 2 cm (1.9 deg visual angle). The dots were single white pixels.

**Procedure**

The angle between the straight line connecting the starting position of the dot and the centre of one of the outer markers and the straight line between the centres of the outer markers, was chosen randomly and varied between 6° in either direction (See figure 2.2). The stimuli were presented in pseudo-random order. The whole set of stimuli was presented 10 (LV, PE, MV), 11 (YM, RB, AS) or 12 (NS) times to the subjects.

The subjects were told to keep their heads upright at all times during the experiment. Eye movements were allowed. The experiment took place in a dark room so that only the stimuli were visible. The experiment lasted about half an hour.

![Diagram](image)

**Figure 2.2:** The angle of deviation, \( \alpha \), is the angle between the straight line that connects the centres of two markers and the straight line that connects the dot with the centre of one marker.

**Analysis**

We recorded the angle between the straight line connecting the centres of the outer two markers and the line between the centre of one of the outer markers and the adjusted position of the dot (See figure 2.2). Note that this is an angle in the stimulus plane and not the visual angle. This angle was equal to zero when the adjustable dot was placed exactly on the specified line segment. The sign-convention is such that a positive value indicates that the dot was placed above the actual straight line that would connect the outer two markers.

**Results**

Figures 2.3, 2.4 and 2.5 summarise the results of all subjects in all conditions. To make it easier to see where subjects put the adjustable dot when instructed to align it with an illusory contour, or to align it with two markers, we present these results superimposed on a schematic outline of the respective stimuli. For example, figure 2.3A shows the results in the four cases where a Kanizsa diamond was presented and the dot appeared near one of its four illusory contours, and figure...
**Figure 2.3:** Results of experiment 1 superimposed on sketches of the stimuli. In the experiment white figures were shown on a circular black background, the pacman had a radius of 2 cm (1.9 deg visual angle), the distance between the centres of the pacman or the two outer dots was 10 cm (9.5 deg visual angle), the gap between two pacman was 6 cm. (5.7 deg visual angle) and a dot was 0.27 x 0.27 mm² (0.26 x 0.26 deg visual angle). Bars indicate mean systematic errors of one subject for the corresponding dot location: 2.3A combines the results of the four stimuli where the adjustable dot appeared near one of the illusory lines of the Kanizsa diamond, 2.3B oblique three-dot alignment task slanted to the left, 2.3C oblique three-dot alignment task slanted to the right. The systematic errors are expressed in degrees (°) of the angle between the straight line connecting the outer two markers and the straight line connecting the average end-position of the dot and the centre of one of the outer markers (see also figure 2.2). Whiskers indicate standard errors of the mean. The averages and standard errors mean were based on 10 (LV, PE, MV), 11 (YM, RB, AS) or 12 (NS) repeated measurements. Different subjects are denoted by different bar patterns. From left to right: YM (lines slashed to the left), NS (clear), RB (squares), LV (horizontal lines), PE (diamonds), MV (vertical lines), AS (lines slashed to the right). Same legend applies for figures 2.4, 2.5, 2.6, 2.8 and 2.9.

2.3B shows the results in one case where two dots plus the adjustable dot were presented. On each alignment line of the stimuli, bars indicating the various subjects’ systematic errors in degrees (°) were plotted. The direction of the bars indicates the true direction of the systematic errors. The whiskers indicate the standard error mean. We averaged the mean results of individual subjects. We also performed a two-tailed t-test to test whether this value equalled zero. The results are shown in table 2.1.

**Comparison of the Kanizsa diamond task and three-dot alignment task**

Figure 2.3A shows the systematic errors in the Kanizsa task. The subjects consistently misplaced the dot: i.e. they did not place it on the contour but generally placed it too far towards the centre of the Kanizsa diamond. The standard deviation is about 0.8° on average over edges and subjects.

Figures 2.3B and 2.3C show the systematic errors in the three-dot alignment task. The subjects systematically placed the middle dot below the actual straight line that could connect the outer dots. These results are in agreement with the 0.5°-1° systematic errors in comparable experiments by Sittig and de Graaf (1994). The standard deviation is about 0.8° on average over edges and subjects.

The general impression is that the systematic errors in the Kanizsa diamond are larger than in the three-dot alignment task (comparing absolute size: paired two-tailed t-test, N=28, df=27, t=3.7, p<0.01) and that they are directed towards the inner part of the Kanizsa diamond (sign-test, N=28, T=26, p<0.001). This means that in the lower half of the Kanizsa-diamond the errors in alignment are in the opposite direction to the errors in alignment in the oblique three-dot-task. There appears to be no systematic difference in the standard deviations between these two tasks.
Table 2.1: summary of results of experiment 1

<table>
<thead>
<tr>
<th>stimulus: location adjustable dot</th>
<th>Mean value of subject means (°)</th>
<th>Sd (°)</th>
<th>H0: mean value = zero two-tailed t-test value of P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kanizsa-diamond: right top</td>
<td>-1.1</td>
<td>0.6</td>
<td>&lt;0.005</td>
</tr>
<tr>
<td>Kanizsa-diamond: right bottom</td>
<td>0.8</td>
<td>0.8</td>
<td>&lt;0.05</td>
</tr>
<tr>
<td>Kanizsa-diamond: left top</td>
<td>-1.8</td>
<td>0.4</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Kanizsa-diamond: left bottom</td>
<td>1.0</td>
<td>0.7</td>
<td>&lt;0.05</td>
</tr>
<tr>
<td>three-dot: slanted to the right</td>
<td>-0.8</td>
<td>0.6</td>
<td>&lt;0.05</td>
</tr>
<tr>
<td>three dot: slanted to the left</td>
<td>-0.5</td>
<td>0.4</td>
<td>&lt;0.05</td>
</tr>
<tr>
<td>half-Kanizsa-diamond: right top</td>
<td>-1.0</td>
<td>0.4</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>half-Kanizsa-diamond: right bottom</td>
<td>0.8</td>
<td>0.7</td>
<td>&lt;0.05</td>
</tr>
<tr>
<td>half-Kanizsa-diamond: left top</td>
<td>-1.8</td>
<td>0.5</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>half-Kanizsa-diamond: left bottom</td>
<td>0.8</td>
<td>0.8</td>
<td>&lt;0.05</td>
</tr>
<tr>
<td>fake-Kanizsa-diamond: right top</td>
<td>-0.8</td>
<td>1.0</td>
<td>0.07</td>
</tr>
<tr>
<td>fake-Kanizsa-diamond: right bottom</td>
<td>-0.3</td>
<td>0.9</td>
<td>0.47</td>
</tr>
<tr>
<td>fake-Kanizsa-diamond: left top</td>
<td>-0.7</td>
<td>0.4</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>fake-Kanizsa-diamond: left bottom</td>
<td>-0.3</td>
<td>0.5</td>
<td>0.12</td>
</tr>
</tbody>
</table>

The half Kanizsa diamonds

While performing the task in a half-Kanizsa diamond, about half of the subjects no longer reported seeing an illusory diamond. Subjects YM, MV and AS reported that they perceived a part of a diamond while performing the alignment task, subjects LV and PE reported that they were able to see a part of a diamond surface if they concentrated on seeing it (which they usually didn’t when performing the alignment task) and subjects NS and RB reported that they only saw a vague dark-darker transition. Despite these differences between the subjects, there was no systematic difference in aligning the dot.

The systematic errors for all subjects with the half Kanizsa-diamonds are plotted in the figures 2.4A to 2.4D. As one can see, the half-Kanizsa-diamond tasks led to an individual pattern of systematic errors that is very similar to the individual pattern observed in the Kanizsa-diamond task (2.3A)\(^1\). For example, the only subject with an average negative systematic error in the lower left contour in the Kanizsa-diamond task is again the only subject with an average negative systematic error in the lower left half-Kanizsa-diamond task. The systematic errors do not seem to depend on whether two or four inducing discs are shown to the subject. This is supported by the results of the ANOVA we performed. (The ANOVA showed that the hypotheses that all subjects respond in the same way,

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Note\(^1\): The pacmen that indicated the half-Kanizsa-diamonds were at the same position on the screen as they were in the Kanizsa-diamond. A pilot experiment (one subject, the first author), however, showed that the systematic errors did not depend on the position of the half-Kanizsa diamond on the computer screen.

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*Illusory contours and spatial judgement*
and that all contours induce the same systematic errors, could be rejected (P<0.05). The hypothesis that the half-Kanizsa diamond task and the Kanizsa diamond task are the same for corresponding contours and subjects could not be rejected (P= 0.90).) Apparently, only the nearest two pacmen determine how a dot is aligned with an illusory contour.

**The fake-Kanizsa diamonds**

Figure 2.5A and 2.5B show the results plotted for a dot that had to be aligned to two pacmen in a fake-Kanizsa-diamond. None of the subjects reported seeing a contour except subject YM, who claimed to see a vague line. The subjects generally put the dot below the straight line connecting the contour of two pacmen in these fake-Kanizsa diamonds. The average systematic errors over all subjects are not significantly different from zero for three of the four ‘edges’ (see table 2.1). The average size and direction are comparable to those in the three-dot alignment task. An individual pattern comparable to those observed in the Kanizsa diamond and the half Kanizsa diamonds is not apparent. The measured standard deviation is about 1° on average over all edges and subjects.
Figure 2.5: Results of experiment 1. The data are presented as in figure 2.3. 2.5A combines the results of the two stimuli where the adjustable dot appeared near to midway between two pacmen in the top half of a fake-Kanizsa-diamond, 2.5B combines the results of the two stimuli where the adjustable dot appeared near to midway between two pacmen in the bottom half of a fake-Kanizsa-diamond.
Discussion

The systematic errors measured in the Kanizsa-diamond task do not resemble those measured in the three-dot alignment task, although the standard deviations do not seem to differ. The results of the Kanizsa-diamond and the half-Kanizsa-diamond do show a strong similarity, in spite of the fact that what subjects claimed to see could vary. Therefore, it would seem less likely that the systematic errors measured in the Kanizsa-diamond are illusion dependent.

The rationale for including the fake-Kanizsa-diamonds was as follows. Any systematic errors in the Kanizsa-diamond could be induced by the illusion. The fake-Kanizsa-diamond consists of the same markers as the Kanizsa-diamond, but now no diamond can fit in the gaps. Therefore no illusory surface should be perceived. If systematic errors in the Kanizsa-diamond are illusion dependent, the fake-Kanizsa-diamond should lead to a different pattern. This is what we observed. Nevertheless, we cannot yet conclude that a large part of the systematic errors in the Kanizsa-diamond are illusion dependent. A single pacman may trigger mechanisms related to illusory form perception. This implies that the pacman in the Kanizsa-diamond and half Kanizsa-diamond enhance each other’s effect, and in the fake-Kanizsa-diamond compensate for each other’s effect. This line of reasoning is consistent with that of Dresp and Bonnet (1993), who measured an increased light detection threshold near an illusory border and a slightly reduced light detection threshold right on the illusory border. They continued to find this effect when two pacman, or even only one, was presented.

Experiment 2

Introduction

In the previous experiment, the data show that there was a Kanizsa-configuration dependent bias in the Kanizsa diamond. In the three-dot alignment-task there was an orientation dependent bias (Sittig and De Graaf, 1994), but there could not have been a Kanizsa-configuration dependent one. Could the systematic errors in the Kanizsa-diamond-task be the result of the sum of two biases, i.e., the sum of an orientation bias (as occurs in the three-dot-task) and a Kanizsa-configuration dependent bias (induced by the pacman, directed to the centre)? This hypothesis would explain why, in the Kanizsa-diamond, the systematic errors in the top half of the diamond are generally larger than those found in the lower half of the diamond. If the two effects add up, they would co-operate in the top half of the Kanizsa diamond but work against each other in the lower half. Such an additive effect would also explain why, on average, the adjustable dot is placed slightly too low in the fake-Kanizsa diamond. If the pacman compensate for each other’s effect, only the orientation dependent bias remains. We know that the orientation-dependent bias disappears under a vertical or horizontal orientation (Sittig and De Graaf, 1994). This means that when subjects are asked to align a dot to a contour of an illusory square, thus with the contours oriented vertically and horizontally, we should find systematic errors that are a result of the Kanizsa-configuration bias only. If the hypothesis of additive effects holds, these systematic
errors are expected to be as large as the systematic errors found in the top half of the Kanizsa-diamond minus the systematic errors in the oblique three-dot alignment-task. We investigate this in experiment 2.

**Methods**

Five of the previous seven subjects (2 female, 3 male) participated in this experiment. The experiment differed from experiment 1 only in the stimuli. Now all markers could be connected via horizontal or vertical straight lines and we used only the Kanizsa-square and two dots marking a horizontal or vertical line (see figure 2.6). All stimuli were presented 10 (PE) or 12 (YM, NS, RB, MV) times. The sign-convention is that a positive value for the errors from a vertical indicated ‘line’ means that the dot was placed too far to the left, and a positive value for the errors from a horizontal indicated ‘line’ again means that the dot was placed above the actual straight line.

**Results**

Most subjects volunteered the information that this experiment was easier to do than the previous one. The systematic errors and standard errors of the mean were plotted for all subjects and for each stimulus in figure 2.6, as in figure 2.3. Both the systematic errors (average size 0.6°) and the variable errors (average standard deviation 0.44) with the Kanizsa-square were much smaller than in experiment 1. The systematic errors lie within the Kanizsa-square in 16 of the 20 cases. Thus a small but significant effect remains (one sided sign test p<0.01). Table 2.2 lists the systematic errors averaged over subjects per indicated ‘line’. We predicted that the size of the systematic errors would be the difference between the systematic errors in the Kanizsa-diamond and the systematic errors in the three-dot alignment-task, measured under the same orientation. For each of the subjects we calculated the average predicted size of the systematic errors and compared these with the measured systematic errors in the Kanizsa-square. The systematic errors with the Kanizsa-square are smaller than those we predicted via our hypothesis (paired two-tailed t-test, n = 20 p< 0.001). In the three-dot alignment task the systematic errors were also almost zero, and the average standard deviation of 0.33° is smaller than that in the oblique alignment task. These results are in agreement with those of Sittig and de Graaf (1994).

**Table 2.2: summary of results of experiment 2**

<table>
<thead>
<tr>
<th>stimulus: location adjustable dot</th>
<th>Mean value of subject means (°)</th>
<th>Sd (°)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kanizsa-square: top</td>
<td>-0.7</td>
<td>0.4</td>
</tr>
<tr>
<td>Kanizsa-square: left</td>
<td>-0.6</td>
<td>0.5</td>
</tr>
<tr>
<td>Kanizsa-square: right</td>
<td>0.2</td>
<td>0.6</td>
</tr>
<tr>
<td>Kanizsa-square: bottom</td>
<td>0.2</td>
<td>0.5</td>
</tr>
<tr>
<td>Three-dot: horizontal</td>
<td>0.3</td>
<td>0.3</td>
</tr>
<tr>
<td>Three-dot: vertical</td>
<td>-0.3</td>
<td>0.4</td>
</tr>
</tbody>
</table>
Figure 2.6: Results of experiment 2. The data are presented as in figure 2.3. In 2.6A the four stimuli in which an adjustable dot appeared near one of the illusory contours of the Kanizsa square are combined, 2.6B vertical three-dot alignment task, 2.6C horizontal three-dot alignment task. The systematic errors are indicated in degrees (°) of the angle between the straight line connecting the outer two markers and the straight line connecting the average position of a dot, placed by the subject, and the centre of one of the outer markers (see also figure 2.2). Whiskers indicate standard errors of the mean. The averages and standard errors mean were based on 10 (PE) or 12 (YM, NS, RB, MV) repeated measurements. The subjects are from left to right YM, NS, RB, PE, MV.
**Discussion**

The subjects did not place the dot as far towards the centre of Kanizsa-square as they did in the Kanizsa-diamond. Thus the systematic (and variable) errors found in the Kanizsa diamond task appear to be subject to an oblique effect as well. The systematic errors are even smaller than expected assuming that results with the Kanizsa-diamond were the summed effects of two independent biases: a Kanizsa-configuration dependent bias and a orientation dependent bias. Thus the two biases are not combined in a simple additive way.

A remaining bias to place the dot too far towards the centre of the square is consistent with the results reported by Pomerantz et al. (1981). They presented a Kanizsa-square to their subjects and asked them if an appearing dot was inside or outside the square. They measured reaction times and the percentages of correct responses. Although in their case the dot appeared at distances twice as large as the average systematic error made by our subjects, Pomerantz et al. do report that their subjects more often wrongly claim the dot to be outside the square than the other way around. They do not offer an explanation for this finding.

The results of this second experiment can exclude three other possible explanations for the systematic errors in aligning a dot to an oblique illusory contour. The first could be that the perceived surface is smaller than the square that fits within the pacmen. The light-dark border of the pacmen could have been perceived to be further away from the white pacmen than the actual border. Secondly, the square could be perceived as smaller than the square that can be fitted into the pacmen, because it is perceived to be closer than the pacmen (Coren et al., 1986). This is consistent with the explanation of the Kanizsa illusion by means of the figure ground segregation (Petry and Meyer, 1987). These two suggestions, however, do not predict the strong orientation dependency we observed.

A third possible explanation concerns the role of binocular viewing. The stimuli were always viewed binocularly in our experiments. When viewing the contour of a surface with both eyes, one is able to look beyond the contour with one of the eyes. If the dot is perceived to be at a different depth from that of the illusory surface, it can lead to a bias in perceived fronto-parallel position. Since one eye is displaced horizontally with respect to the other, it would predict maximal systematic errors for an illusory contour under vertical orientation, and minimal systematic errors for an illusory contour under horizontal orientation. Contrary to this, we observed the largest systematic errors under oblique orientation. Therefore, binocular viewing also fails to explain the observed effect.

**Experiment 3**

**Introduction**

One of the results of experiment 1 was to show that the systematic errors were the same for all subjects, irrespective of whether two or four pacmen were shown.
Note that this finding does not depend on what the subjects saw when they were presented with the half Kanizsa-diamonds. We concluded that only the two nearest pacmen determine the systematic errors. Perhaps the shape of the individual pacmen causes systematic errors. In the next experiment we examined the influence of a single pacman.

Methods

The same five subjects from experiment 2 participated in this experiment. It was similar to experiments 1 and 2 in that the subjects were asked to align a dot, but now only one pacman at a time was shown. The contours of the gap of the single pacman-shaped markers were oriented obliquely, as in experiment 1. The subjects were instructed to place the dot on the straight line that would extend from the nearer of the two straight contours of the presented pacman. They had to extrapolate $4^\circ \times 2=8$ contours of pacmen: both oblique contours of each single pacman which, when presented together, would form a Kanizsa diamond. The distance between the dot and the pacman and the dimensions of the pacmen were the same as in the previous experiments. The single pacmen appeared in the same position as in the Kanizsa diamond. Within any one set the 8 possible extrapolations were presented in quasi-random order. A set of stimuli was presented 10 (PE) or 12 (YM, NS, RB, MV) times.

Results

In figure 2.7, for each subject and each marker, the average systematic errors were plotted on the line extending the contour of a pacman. This is similar to figure 2.3. As seen in figure 2.7, with one pacman the subjects also put the dot too far towards the inner part of the diamond. The systematic errors vary more among subjects and contours than in experiment 1 for the same 5 subjects. The average systematic errors vary from $1.6^\circ$ outside the diamond to $5.0^\circ$ inside the diamond in the single pacman experiment, compared to $0.7^\circ$ outside the diamond and $2.4^\circ$ inside the diamond in the half Kanizsa diamonds in experiment 1. Thus, the systematic errors from the straight extrapolation of the contour of one single pacman are comparable to those found in the half Kanizsa diamonds of experiment 1, but are somewhat more variable. The average measured standard deviation equals $0.8^\circ$ and is similar to that observed in experiment 1.

Are the systematic errors found in the half Kanizsa-diamonds equal to the average effect of extrapolating the two single pacmen that form this half diamond? In figure 2.8 we plotted, for each contour and each subject, the systematic errors in the half Kanizsa diamonds against the corresponding average systematic errors from the two single pacmen which together form that half Kanizsa diamond. The line of perfect correspondence is drawn as a solid line. The broken line indicates the best fit through the plotted points. This best fit has a slope equal to $1.1 \pm 0.2$ and intersects the y-axis at $0.4^\circ \pm 0.2^\circ$. Thus, the line of perfect correspondence lies within the confidence limits of the fit. In the same way, the systematic errors found when extrapolating a contour of a single pacman can also explain the systematic errors that were found in the fake-Kanizsa-diamond
Figure 2.7: Results of experiment 3. The results are presented in almost the same way as in Figure 2.2. Bars indicating average systematic errors are plotted for all subjects and are superimposed on the straight line that could extend the straight contour of a pacman: 2.7-A shows the combined results of extrapolating a contour towards the upper right and of extrapolating a contour towards the lower right of the left single pacman, 2.7-B shows the combined results of extrapolating a contour towards the lower right and of extrapolating an contour towards the lower left of the top single pacman, 2.7-C shows the combined results of extrapolating a contour towards the upper right and of extrapolating a contour towards the upper left of the bottom single pacman, 2.7-D shows the combined results of extrapolating acontour towards the upper left and of extrapolating a contour towards the lower left of the right single pacman. The systematic errors are indicated in degrees(°) of the angle between the straight line extending the contour of a pacman and the straight line connecting the average end position of the dot and the centre of the pacman. Whiskers indicate standard errors of the mean. The averages and standard errors of the mean were based on 10 (PE) or 12 (YM, NS, RB, MV) repeated measurements. The subjects are from left to right YM, NS, RB, PE, MV.

Figure 2.8: The systematic errors in the half Kanizsa diamonds for each contour and each subject were plotted against the corresponding average of systematic errors from two single pacmen that together form that half Kanizsa diamond. The straight line \(y = x\) indicates the line of perfect correspondence. The dashed line indicates the best fit through the plotted points \(y = (1.1 \pm 0.2) x + (0.4 \pm 0.2)\). The whiskers indicate the standard errors.

Discussion

From this last result we can conclude that the observed systematic errors in aligning a dot with a contour of a Kanizsa diamond can be explained as the
average systematic error in extrapolating the two pacmen which indicate that contour. Why would our subjects extrapolate when asked to put a dot on an illusory contour? This could indicate that perception of the illusory surface and the location of the dot can not be done simultaneously. This hypothesis is supported by two facts known from literature. Firstly, the dot itself might also function as an inducing element. In the Kanizsa square the pacmen induce the perception of a square. Single dots cannot evoke an illusory surface by themselves (Gregory, 1972). However, when dots are shown in combination with line elements or pacmen they do influence the contour (Gregory, 1972; Kanizsa, 1976). Although our subjects never complained that the task was impossible, it might be difficult to judge the position of a dot relative to an illusory contour when that same dot co-determines that illusory contour. This problem would lead to larger variable errors in our experiment, since the dot appeared randomly inside and outside the illusory surface. Secondly, Kanizsa already noticed that the illusory contours fade when a person concentrates on looking at one of the illusory contours, and that the illusory contours are seen most clearly when the configuration is 'watched as a whole'. In our experiments the task involved only one of the contours at a time, drawing attention to that one.

**Experiment 4**

*Introduction*

The results of the previous experiment suggest that subjects did not perform the task in experiment 1 as they were instructed: i.e. align the adjustable dot with the illusory contour. This raises the question of the role, if any, of the illusory contour in the performance of that task. There may be no influence of the illusion, perhaps because it is not seen when the dot is being aligned. Why then is there such a difference in results between the task with the dots and the one with the pacmen? This could imply an influence of the (asymmetry of the) shape of objects from which the position has to be judged. Alternatively, the mechanisms for figure-ground segregation are triggered already by one single pacman, as Dresp and Bonnet (1993) suggest. To test this we presented the subjects with diamonds, which were indicated by pacmen, Xs, Ls or dots, and asked them to place a dot on the average extrapolation of the edges of the pacmen, Xs or Ls, or to align the dot with the two other dots which were nearest. It is known the Xs and Ls do not evoke the perception of an illusory surface (Kanizsa, 1979), but do differ in (a-) symmetry. The diamond indicated by the dots was included to bridge the gap between the three-dot alignment-task and the Kanizsa-diamond-task.

*Methods*

This experiment was set up in a similar way to the previous experiments. Five subjects participated, four who had participated in the previous experiments and one new naive subject (KA). All subjects gave informed consent. The subjects were told that they would be presented with diamond-like shapes indicated by 4 Xs, 4 Ls, 4 pacmen or 4 dots. They were instructed to place the dot on the intersection of the apparent straight lines that would extend from the nearest two straight edges or, in the case of the dots, to place the dot on the straight line
that would connect the nearest two dots. Each stimulus was presented ten times and appeared at a location in the centre of the screen with some random jitter in that location from trial to trial.

Results

Figure 2.9 shows the results for a diamond indicated by four Xs or four Ls. The systematic differences from a straight line are small in both cases (about 0.4°); about the size of the standard error of the mean (0.6° on average). However, there is a difference. With the Ls the systematic errors are generally directed towards the centre of the figure (sign-test, n= 20, T= 14, p<0.005), while with the Xs the systematic errors seem to be randomly distributed in either direction (t-test, t= 1.62, df = 199, p = 0.11).

![Figure 2.9: The results of extrapolating the two nearest edges of L-shapes (2.9A) or X-shapes (2.9B). The results are presented in the same way as in figure 2.3.](image)

Figure 2.10 shows the results for the dots. Surprisingly, the systematic errors are not always directed below the straight line that could connect two dots (t-test, t = 1.60, df = 199, p = 0.11). This holds particularly for the systematic errors in the upper half of the diamond. The systematic errors generally seem to be directed outside the figure. (t-test, t = 6.34, df = 199, p<0.001) and are about equal in size to those with the Ls and Xs. The standard deviations equal 0.8° on average, which is larger than those observed with the Ls and Xs.

The results with the pacman reproduce the results of experiment 1; for all five subjects and all four edges of the diamond the systematic errors were directed towards the centre of the figure, and the systematic errors (1.9° on average) were usually larger than the standard deviations (0.9° on average). This reproduction of results occurs in spite of the fact that we now asked our subjects to extrapolate the two nearest edges of the pacmen. This is in agreement with the results from the single pacmen.
**Discussion**

Since large (and very significant) effects only occur with the pacman, we must assume that there is something special about them which causes these effects. One way in which pacmen differ from the other objects is that they can induce an illusory figure. However, this is not the only difference. The size of the luminant surface is different and they have an incomplete circular edge. Nevertheless, the results do seem to suggest some influence of figure-ground segregation. Such an influence could also explain why the results with the dots are different when four instead of two fixed dots are shown. However, this is only speculation because the deviations are small and Sittig and de Graaf (1994) found less clear effects when the dots could mark a straight oblique line downwards as compared to the same line running upwards.

The results of this experiment clearly demonstrate that relative localisation depends upon the shape of objects in relation to the location which has to be judged.

**General discussion**

In the introduction we stated that there are at least two types of situation in which the human visual system can make judgements about intermediate positions. On the one hand we spoke of illusory contours (Schumann, 1900), i.e. contours that are perceived as if they were real, and the amodal completion of the shape of objects. On the other hand we spoke of judgement of relative location, for example whether three objects were aligned or were indicating a plane. We wanted to know if the visual system uses one common mechanism that can
estimate the simplest connection between two objects in both situations; or are the mechanisms for estimating intermediate positions in the two cases independent of each other, because the task of judging location is fundamentally different from the task of recognizing objects? And if they are different, could the mechanism underlying illusory contours help in the localisation of objects? To attempt to answer these questions we compared the results of a psychophysical experiment in which a dot had to be aligned either to two markers that could be connected by a straight oblique line (two dots) or to an oblique illusory contour.

Prior to the experiment we had anticipated two possible outcomes: the results of the two tasks would be very similar, indicating a strong link between the two mechanisms, or no systematic errors would occur in aligning a dot to an illusory contour, indicating two independent mechanisms. The results of the two tasks were clearly different. In the oblique three-dot-alignment task the middle dot was systematically placed too low. This reproduces the Sittig and De Graaf results (1994). In the alignment task with the illusory contour, rather larger systematic errors were made which were directed to the centre of the illusory surface. From this we concluded that there is no strong link between the mechanisms underlying the illusory contours and those related to spatial judgement.

This supports the idea that illusory contours arise from mechanisms related to object recognition which is fundamentally different from spatial judgement. There are a number of computational models which assume that illusory contours result from the same mechanisms which account for the perception of real form (Marr, 1982; Heitger and von der Heydt, 1993; Grossberg, 1994). These models are supported by experimental results in which an illusory contour has a very similar effect to a real contour. Vogels and Orban (1987) have demonstrated the largest just-noticeable-differences in orientation under oblique orientation for both real and illusory contours. Gregory (1972) demonstrated that the Poggendorff illusion also occurs when the parallel vertical lines are illusory. Smith and Over (1977) demonstrated that illusory contours, like real ones, can produce tilt after-effects. If illusory and real contours are functionally equivalent at some level, we might have expected our subjects to be able to minimise the distance between the dot and the illusory contour, as is possible with a real contour. The mechanisms underlying the illusory contour could then have helped in localising the dot. However, we did not observe a reduction in either the systematic errors or the variable errors when the Kanizsa diamond was perceived. Thus, the illusory contour does not help in localising objects and thus, in this case, illusory contours differ from real contours.

We then hypothesised that the Kanizsa-configuration introduced its own bias, and that this bias linearly added to the one associated with the mechanisms related to localisation. The results of experiment 2 rejected this hypothesis, by demonstrating too strong an oblique effect in the results.

Experiment 1 also showed that the results of aligning a dot to an illusory contour did not differ whether four or only two pacmen were presented, while the

Chapter 2
strength of the illusion did differ. This raised questions about the role of a single pacmen and of the illusory contour. Experiment 3 showed that the errors in aligning a dot to an oblique illusory contour can be described as the average result of interpolating the two nearest edges of the pacmen. This suggested that the difference in results between the pacmen and the dots was not caused by the illusion, but by the difference in symmetry of their shape. We tested this idea in our last experiment, where we asked subjects to extrapolate from pacmen, Ls and Xs. The results with the pacmen were very similar to those in experiment 1 and they were the only stimuli with clear large effects. The Ls did show a much weaker effect, also directed towards the centre of the figure, while no systematic or significant effect occurred with the Xs. This suggests that there is something special about the pacmen shape which causes large effects. The pacmen have a larger bright surface and an incomplete circular edge which the other objects do not have. The pacmen are also the only objects which can induce an illusory surface by themselves. The question remains whether the bright surface and incomplete circular edge of the pacmen cause large effects because they can induce illusory contours at the location of the perceived interpolation. One thing is clear; the shape of the markers influences the localisation of objects relative to these objects. The influence of the shape of an object on a more global localisation has been demonstrated (Brenner and Smeets, 1995).

Our experiments were psychophysical experiments and they can only provide an explanation at that level. There are also several reports, concerning illusory contours, of neural responses at a physiological level. However, to combine the results of these different levels of explanation is not a trivial task (Spillman and Dresp, 1995) for several assumptions are needed. There are cell-recordings which show firing patterns sensitive to figure-ground segregation (Baumann et al., 1997). We would expect the figure to be detectable from the ground at some neural level, because the direction of the systematic errors is always in the direction of the centre of the figure, independent of orientation. Heitger and Von der Heydt (1993) have made a neural model based upon the firing patterns of complex cells. It would be interesting to measure the cell activity as a result of the same stimuli that we used. We predict that cells with a firing rate which is dependent on the position of the dot will show a change in firing pattern when the dot is just inside the figure, and that the precise position of the dot when this happens is dependent on the orientation for which the cells are sensitive. The neural model of Heitger and Von der Heydt strongly depends upon the role of so called end-stop-cells. One major difference between the pacmen and the Ls or Xs is that the pacmen also trigger end-stop-cells because of the non-continuation of the circular edge which is present in the pacmen. Perhaps this reflects in the results of experiment 4.

In conclusion, the experiments described in this paper do not give one clear answer to the question we set out to answer. The relation between mechanisms underlying spatial judgement and those that give rise to illusory contours appeared too complex to be solved here. However, we have shown that a link between these mechanisms is possible. An illusory contour does not act in the same way as a real contour when aligning a dot to an illusory contour. In this
task our subjects appeared to be interpolating the edges of the two nearest pacman. The results clearly demonstrated that the shape of objects influences the extrapolation and interpolation (of edges) of those objects.
Chapter 3

Exocentric pointing in three dimensional space

N. Schoumans, J.J. Denier van der Gon
submitted to Perception

Abstract

This paper describes an exocentric pointing task in all three dimensions, in near space, using only two visible luminous objects - a pointer and a target. The task of the subject was to aim a pointer towards a target. The results clearly show that visual space is not isotropic, since every set direction appeared to consist of two independent components - one in the projection on a fronto-parallel plane (tilt), the other in depth (slant). The tilt component shows a general trend across subjects, an oblique effect, and can be judged monococularly. The slant component is symmetrical in the mid-sagittal plane, requires the use of binocular information and shows considerable differences between subjects. These differences seem to depend on the amount of binocular information used by each subject.

It was also found that there was a remarkably high level of consistency in the exocentric pointing, despite the absence of environmental cues. The variability in the settings of the pointer corresponds to a variability of about one arcmin visual angle in disparity of its tip, even though the pointer and target are separated by more than a 5 degree visual angle.
Introduction

Localisation of one object in relation to another plays an important role in a great many of the tasks performed by humans on a daily basis. Think, for example, of preventing a collision while driving a car, threading a needle, judging who is looking at whom in a group of people, or simply reaching for a cup of tea. In these examples the judgement of direction is an important parameter which must be retrieved by the visual system. More specifically, taking the example of reaching for a cup of tea, van Sonderen et al. (1988) have shown that relative direction is a major determinant in the programming of movement, and that relative direction is easily accessed. Although the judgement of direction is important, relatively little study has been done into how well humans can perform this (Ellis et al., 1991; de Graaf et al., 1996; Koenderink and van Doorn, 1998; Wagner, 1985; Brenner and Smeets, 1995). One of the two goals of the experiments reported in this paper is to explore how reliably humans can judge exocentric direction in near 3-D space.

Studying the direction in which an object is located relative to another (exocentric direction) can also provide useful information about the relationship between visually perceived space (visual space) and physical space (Ellis et al., 1991; Koenderink and van Doorn, 1998). Until now experiments involving visual space have been restricted to a single plane, usually the horizontal plane at eye-level (Blumenfeld, 1913; Hildebrand, 1902; Blank, 1958; Wagner, 1985; Koenderink and van Doorn, 1998) or a fronto-parallel plane (Indow and Wanatabe, 1984). The second goal of the experiment was to examine whether the results obtained in a single plane also hold for exocentric pointing through all three dimensions. Indow and Wanatabe have shown that the results of an alley experiment differ, in the fronto-parallel plane, from those performed in a horizontal plane. What does this imply for spatial judgements that are not restricted to one of these planes? Is visual space isotropic?

Subjects were asked to aim a pointer from various locations towards a target. In such a judgement task a great many visual cues may contribute to the performance. To allow for interpretation of the results, in this study we confined ourselves to an extremely simple set-up in which only a target and a pointer were visible to the subject in an otherwise dark 'environment'. Thus, no environmental cues were available. The use of a few luminous objects is in line with most experiments into visual space, and the reduced stimulus configuration allowed examination of the lower limits of the consistency of pointing. Also, in this situation, all available cues are known.

The results revealed several interesting facts. For example, the deviations from veridical in the pointer settings could be divided into two independent components - one in the projection on to a fronto-parallel plane, and one in depth. The latter component showed marked differences between subjects. The results of the second experiment suggest that this was caused by the extent to which subjects used binocular information. There was also a remarkably high level of consistency in the exocentric pointing.
Methods

Virtual 3-D set-up

The stimuli were presented in stereoscopic 3-D via a Silicon Graphics Indy computer set-up which draws a perspective projected image from each eye on the screen, one for the right eye and one for the left eye alternately. The images were viewed through LCD shutter goggles which were synchronised with the monitor to ensure that each eye received the appropriate images. The images were drawn in red phosphor, because this was the phosphor for which the glasses were most opaque. They were drawn at a rate of 120 images per second (thus 60 times per eye per second) on the computer screen. The screen consisted of 1280 x 1024 pixels, which were 0.27 x 0.27 mm² in size. In front of the computer screen stood a circular band of black cardboard, occluding possible reference directions provided by the straight edges of the screen.

Stimuli

The stimuli consisted of a target and a pointer, both of which were wire-frame figures. The pointer consisted of a line segment of 4 cm and a ring with a diameter of 3.2 cm. The line segment stood perpendicular to the ring, from the centre of the ring onwards (see figure 3.1). The pointer could rotate around the mid-point of the ring. The target was a dot (1 pixel). Around the target two rings, with a diameter of 1.2 cm, were drawn in depth, in such a way that they intersected each other above and below the dot. These rings were added to prevent the task from becoming a visual search task without presenting reference directions, while still using a small well-defined target (i.e. the single pixel).

Figure 3.1: A perspective drawing of the pointer and the variables used for analysing the orientation of the pointer. The pointer consists of a ring that is 3.2 cm in diameter and a pin perpendicular to this ring that is 4.0 cm long. The origin of the variables used for analysing the orientation of the pointer lies at the centre of the ring. This is also the point around which the pointer rotates. The x-axis is horizontal, the y-axis is vertical and the z-axis is the depth axis through the rotation point of the pointer. The slant, θ, is the angle the pin makes with the axis perpendicular to the fronto-parallel-plane (or z-axis), towards the subject. The tilt, φ, is the angle in the projection on the fronto-parallel-plane.

Procedure

Before the actual experiment was started four things were done. Firstly, the
experimenter explained to the subjects, among other things, how the computer set-up could present 3-D objects at any location in depth, and this was demonstrated with the help of an example programme which showed cubes rotating in space. Secondly, the subjects were asked for their informed consent. Thirdly, they were tested to see if they were able to fuse two images, as presented in the experimental set-up. Finally, they were given 15 to 20 minutes in which to familiarise themselves with the requirements of the task.

The task for the subjects was to aim the pointer at the target. They could manipulate the orientation of the pointer by pressing the arrow keys on the keyboard. The left and right arrow keys made the pointer turn around a vertical axis, and the up and down arrow keys made the pointer change the angle with the vertical axis. Subjects could take as much time as they needed to adjust the pointer. The final orientation of the pointer was recorded.

Each subject was seated 120 cm in front of a computer screen, with his or her head supported in a chinrest. They were told that on each trial the pointer and target could appear to float somewhere in 3-D space. The programmed location of the target was fixed at 120 cm in front of the cyclopean eye of the subject on the computer screen. The pointer was programmed to appear at 1 out of a possible 20 locations on a virtual hemi-sphere above the target, keeping the distance between pointer and target fixed at 20 cm. The programmed locations (the rotation point) of the pointer relative to the target are listed in table 3.1, and illustrated in figure 3.2.

![Figure 3.2: An illustration of the pointer locations as used in experiment 1. Cross-fusing the two images least to the right leads to a 3-D impression of the pointer locations in front of the target, and the two images least to the left leads to a 3-D impression of the pointer locations in front of the target. The distance between the target (always at the centre) and the pointer was kept constant at 20 cm. The pointer locations lie on a sphere. The images can also be fused with a parallel gaze-direction of the eyes, but this will give an overestimated impression of depth.](image)

Both the location of the pointer and the orientation at which it appeared were randomised during the experiment. This random orientation was somewhere between plus and minus 12 degrees, with respect to the veridical direction towards the target, in any direction.

The group of 20 locations of the pointer was presented twice, after which there was a break. The breaks were inserted to ensure the concentration of the subjects. Per subject, 4-7 settings per location of the pointer were recorded. It varied because the duration of the experiment was limited, and because the subjects
were allowed to set the pointer at their own pace.

The experiment took place in darkness and lasted about two hours. This included giving instructions, practice time and short breaks. No feedback was given, either at the practice trials, or at the experimental trials.

Table 3.1: Positions at which the pointer could appear relative to the target and the corresponding values of slant, tilt, total visual angle, visual angle of the pointer. For subject CE, it lists the standard deviations in the slant and the calculated thresholds (see text).

<table>
<thead>
<tr>
<th>Stimulus</th>
<th>right (cm)</th>
<th>up (cm)</th>
<th>forward (cm)</th>
<th>slant (°)</th>
<th>tilt (°)</th>
<th>total visual angle (deg)</th>
<th>visual angle of pointer (deg)</th>
<th>Sd slant subject CE (°)</th>
<th>Thresholds subject CE (arcmin)</th>
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<tr>
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<td>14.1</td>
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<td>3.1</td>
<td>1.38</td>
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<td>-14.1</td>
<td>135.0</td>
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<td>1.26</td>
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</tr>
</tbody>
</table>

Subjects

Seven subjects, who were unaware of the purpose of the experiment, participated in this experiment. They all had eyesight which was normal, or was corrected to normal via contact lenses. An eighth subject was rejected because she could not fuse the images of the two eyes as presented in the experimental set-up.

Analysis

The final orientations of the pointer, as set by each subject, were analysed. This
**Figure 3.3:** The settings of the orientation of the pointers by subject JN in a plot of the set slant against the set tilt. A dot indicates a single setting of an orientation of a pointer at a certain position. For each position at which a pointer could appear the orientation was set six times. For each cluster of six repetitions: the cross indicates what the orientation of the pointer should have been in order to point towards the target, the open circle indicates the average setting of the orientation of the pointer of the subject, and the straight line through the cluster indicates the fit of least squares.

Orientation can be expressed in terms of two angles - one indicating slant, the other indicating tilt. The terms slant and tilt have been used in various ways in literature (Howard and Rogers, 1995), therefore it will be made quite clear how they are used from here on. Figure 1 shows a pointer with a slant \( \theta \) and a tilt \( \phi \). These angles belong to polar co-ordinates \((r, \theta, \phi)\), with the polar axis \((z\text{-axis})\) perpendicular to the fronto-parallel-plane at the side of the subject, and its origin at the midpoint of the ring of the pointer. The slant, \( \theta \), is the angle which the line segment of the pointer forms with the polar axis. A 0° slant means that the pointer points perpendicular to the fronto-parallel-plane towards the subject and a 90° slant means that it points in the fronto-parallel plane. The tilt, \( \phi \), is the angle between the projection of the line segment of the pointer on the fronto-parallel-plane and the horizontal. A 0° tilt means that the pointer points horizontally to the right, and a -90° tilt means that it points straight down.

**Results**

Figure 3.3 shows the raw data of subject JN, expressed in terms of the slant and tilt, as described above. The figure shows 20 clusters of points, each corresponding with one location of the pointer. Within one cluster a dot marks a single recording of the final set orientation of the pointer, a cross marks the orientation at which the pointer would have aimed at the target, and an open circle marks the average of the set orientation of the pointer. This subject had representative standard deviations (size and orientation of the groups of settings). She made the largest systematic errors, thus providing a clear example of possible results.

**Correlation between slant and tilt**

When looking at the various clusters of raw data points, the first thing to notice is that the variance in the slant is much larger than the variance in the tilt. Moreover, the various settings lie roughly along lines of constant tilt, i.e. the various settings of the pointer appear to lie in planes which are perpendicular to the fronto-parallel-plane. In order to quantify the correlation, least square fits through each of the 20 groups of settings were calculated (small lines in figure 3.3). In general, these fitted lines do not differ significantly from vertical ones. A Kolmogorov-Smirnov test over all stimuli and subjects did not reject the hypothesis that the measured orientations of the fitted lines are normally distributed around a vertical orientation (Kolmogorov-Smirnov \( Z = 0.84, p=0.48 \)). A two-tailed t-test of the orientation of the fitted lines showed that the hypothesis that the best fit lines have a vertical orientation \( (p=0.32) \) cannot be rejected. Thus, there seems to be no correlation between these variables, because the various settings lie parallel to
Figure 3.4: For each position where the pointer could appear, the cross indicates what the orientation of the pointer should have been in order to point towards the target, the open circle indicates the setting of the orientation of the pointer averaged over the subject averages. The straight line through the open circle equals the orientation of the least square fits averaged over subjects. The speckled grey area indicates plus and minus twice the standard deviation in the orientation of the least square fits, indicating the variance between subjects (see text).

One of the axes of the two variables that were chosen to express the orientation of the pointer. This is illustrated in figure 3.4. It shows the orientation of the best fitted lines, averaged over all subjects, for each of the 20 pointer locations. The speckled grey area indicates the variance in the orientation of the fitted lines between subjects. They measure plus and minus twice the standard deviation in the orientation. The average lines and grey areas are drawn at the average location of subject averages, and have a length plus and minus twice the average standard deviation in the slant for that location of the pointer.

It is important to note that the slant and tilt were not the angles over which the subjects could adjust the orientation of the pointer. Thus, the lack of correlation between the slant and the tilt emerges purely from the data, and is not a product of the interface. This is also reflected in the typical adjustment behaviour of the subjects, who continuously alternated their use of the two pairs of arrow keys.

Systematic errors in the tilt

Figure 3.5: The systematic error in the tilt plotted against the veridical tilt for each subject. When there was more than one pointer position with the same veridical tilt (but different slant), the errors were averaged. The variable error is approximately 1° - 1.5° for oblique angle and about 0.5°-0.7° for horizontal or vertical orientation (tilt equals 0°, ±90° or -180°). The thick solid line indicates the average over subjects.
Figure 3.5 plots the systematic errors in the tilt, against the value of the tilt. These systematic errors are defined as the veridical value of the tilt minus the average angle of tilt as it was set by the subject for that location of the pointer. In other words, a positive value means that the pointer was aimed above the target. When there was more than one pointer location with the same veridical tilt (but different slant), the errors were averaged. In our set-up this means an averaging of the errors in the tilt of two pointer locations which lie symmetrically with respect to the fronto-parallel-plane of the target. A two-tailed paired t-test could not reveal a significant difference (p = 0.06, t = 1.90, df = 6).

The systematic errors are generally smallest for a value of the tilt of 0°, -90° or -180°, where the smallest standard deviations were also measured (figure 3.5). Furthermore, the systematic errors are largest near -30° and -150°. The systematic errors in the tilt show a general trend common to all subjects. This pattern means that under oblique angles the subjects tend to point below a straight line that could connect the target and the pointer. This tendency seems to be somewhat stronger for pointers located in the right hemi-field (tilt between -180° and -90°) than for those located in the left hemi-field (tilt between 0° and -90°).

The trend in the systematic errors in the tilt (figure 3.5) is very similar to that found in the experiments by Sittig and de Graaf (1994). Their subjects were asked to perform a three-dot alignment task on a fronto-parallel-surface (computer screen). Under oblique orientations the subjects generally placed the middle dot below the straight line that could connect the outer two dots. The size of these errors is comparable to the errors found in our experiment. Their task can be interpreted as two dots being a simplified pointer pointing towards a third. The similarity between the two sets of results would suggest that the physical presence of a plane was of little consequence/little significance in their experiment.

As we have already said, the systematically smallest errors and standard deviations were found at a tilt of 0°, -90° and -180° (see figure 3.5). These angles represent a vertical or horizontal orientation in projection on a fronto-parallel-plane. These orientations are special to the human visual system (oblique-effect, Appelle, 1972). Lederman and Taylor (1969) suggested that locations or orientations are perceived in terms of their distance from anchors or references, and that systematic errors increase with increasing distance from the anchor. In these terms our results indicate that the vertical and horizontal were used as orientation anchors. Since a black circular band occluded the horizontal and vertical edges of the computer screen, these reference directions could not be derived from the visual scene. The minor irregularities near -45° and -135° suggest that an orientation midway between anchors may also be special.

**Systematic errors in the slant**

The systematic errors in the slant are plotted against the value of the slant in figure 3.6. These systematic errors are defined in the same way as the systematic errors in the tilt. The errors were averaged for pointer locations with the same veridical slant (but different tilt). This averaging does not lead to a loss of
information when the errors in the slant are symmetrical with respect to the mid-sagittal plane, as will be shown in figure 3.7.

Figure 3.6: A similar plot to figure 3.5, this time for the slant. The variable error is approximately 2.5°-5°.

The first point of significance is that the systematic errors in the slant can be much larger than those found in tilt (comparison of figures 3.5 and 3.6). Secondly, unlike the systematic errors in the tilt, the systematic errors in the slant do not show a clear trend over all subjects. Each subject has quite different but significant and consistent errors. At least three types of pattern emerge from the systematic errors in the slant. Subjects JN and DL can be seen to constantly underestimate the depth difference between the locations of the target and the pointer, without compressing the target or the pointer. This underestimate is about 40% for subject JN, and about 25% for subject DL. Subject MA points too steeply (i.e. is biased towards vertical) when the pointer points forwards, from the back half of the virtual sphere towards the target, but does the reverse in the opposite half of pointer locations. In other words, these results fit the pattern of a target location further back in the virtual sphere, with a slight overestimate of the depth difference between the target and the pointer. The pattern of subjects CE, JH, MI fits well with the veridical, because their systematic errors are about equal in size with the measured standard deviations. Finally, the results of subject DA are rather chaotic and difficult to describe. This subject also presented the largest standard deviations, around 7 degrees, as compared with the typical standard deviations of 3-5 degrees.

Another way in which the systematic errors in the slant component differ from those in the tilt is that, with respect to the mid-sagittal plane, the former do appear to be symmetrical. This is the one thing all subjects have in common in their slant settings. It is illustrated in figure 3.7, which plots the systematic error
in the slant of a stimulus in the right hemi-field against that of the stimulus located symmetrically to it with respect to the mid-sagittal-plane. In the graph the line of perfect symmetry is drawn, and is a fairly good fit through the points.

![Graph showing slant comparison between left and right hemispheres.](image)

**Figure 3.7:** A plot of the systematic error in the slant for a stimulus in the right hemi-field against the systematic error in the slant of the stimulus in the left hemi-field which is the mirror image of that in the mid-sagittal-plane. One point in the graph represents one pair of stimuli for one subject. The solid line is the line of perfect correspondence. The least square fit through the points is the line $y = (0.9 \pm 0.1)x - (0.8 \pm 0.9)$.

**Standard deviations**

The measured standard deviations are small. The standard deviations in the tilt are about $0.5^\circ$-$0.7^\circ$ for the vertical and horizontal orientation (these correspond to 1 arcmin visual angle shift of the endpoint of the pointer), and about twice this value for oblique angles. The standard deviations in the slant vary between $2.5^\circ$ - $5^\circ$. Subject CE has the smallest standard deviations in the slant, with an average standard deviation of about $3^\circ$. This value is roughly constant over all locations of the pointer, and thus does not seem to depend on the eccentricity of the pointer (see table 3.1). To which changes in depth of the tip of the pointer do these standard deviations correspond? It can certainly be assumed that the subject is able to see the difference in slant between a pointer oriented at the mean set slant plus twice the standard deviation and one oriented at the mean set slant minus twice the standard deviation (since 95% of his or her slant settings lie within this range). It can therefore be assumed that the subject can detect the...
relative disparity between those outer limits of the moveable endpoint of the pointer (see figure 3.8: α–β). This will be defined as the depth detection threshold in this experiment, and these thresholds are listed in table 3.1, as calculated for each of the 20 pointer locations for subject CE. This threshold is about 1 arcmin in size, which is very small.

**Figure 3.8:** Illustration of defined depth detection thresholds via a schematic top view of the target, the pointer and both eyes of the subject. The solid outlined pointer represents the pointer at an average set orientation, and the dashed pointer pins represent the pointer at an orientation equal to the average plus or minus twice the standard deviation. The moveable endpoint of the pointer has a well-defined disparity which changes in depth. The subject can detect the depth difference of this tip of the pointer between these two outer orientations. In other words; the subject can detect a change in relative disparity of α–β.

**Discussion of standard deviations**

It is not an easy task to compare the depth detection thresholds with those reported in literature, for two reasons. First of all, the literature reports results of hyperacuity tasks. The smallest depth-detection threshold ever reported (by Westheimer and McKee, 1977) was 5 arcsec disparity for a hyper acuity task with two foveal lines in the plane of fixation. They reported that this threshold increased rapidly when the separation between the lines became larger than 5 arcmin. The second reason which makes comparison difficult is the fact that the thresholds are reported to depend upon the distance to the fixation point (Blakemore, 1970), and we did not know, during our experiment, where the subjects were looking. Nevertheless, the data reported by Blakemore (1970) were used to attempt a tentative estimate for the experiment. In agreement with the reported dependencies, Blakemore’s data (averaged over subjects and averaged over convergent/divergent) were fitted with a function that changed exponentially with increasing depth difference between the detection plane and the plane of fixation (depth pedestal), and changed quadratically with increasing eccentricity. In our experiment there are two distinct points, with well defined disparity, at which subjects could be looking - the mid-point of the ring around which the pointer rotated and the target. With respect to the moveable endpoint of the pointer, the midpoint of the ring is on average, at 1.5 deg eccentricity and 3.5 arcmin depth pedestal, and the target is on average at 6 deg eccentricity and 10 arcmin depth pedestal in the opposite direction. If these values are applied to
the fit of the Blakemore data, we find thresholds of 0.7 arcmin and around 2 arcmin respectively. Thus, a threshold of 1 arcmin in a pointing task is indeed small, especially when taking into account that - a) the task extends over a total visual angle between 6.3 and 9.4 deg, b) the task is not one in which the depth difference between two lines presented very closely together and c) a wide measure of 4 times the standard deviation was used to calculate the thresholds.

Finally, it should be noted that the subjects were allowed to move their eyes freely. However, vergence eye movements are a much weaker cue to depth than relative disparity (Collewijn and Erkelens, 1990)

Conclusions experiment 1

Exocentric pointing in all three dimensions simultaneously has shown that the deviations consist of two independent components. We can therefore conclude that visual space is not isotropic. The same split in independent components was suggested by Wagner (1985), based on the results of his experiments, which were carried out in a much larger in volume and under full cue conditions. This split could explain why, for Indow and Wanatanabe(1984), alley-experiments performed on a plane at eye level produced different results from those performed on a fronto-parallel plane.

The small standard deviations in the slant suggest the conclusion that all depth information in the images of the two retinas is combined in an effective way. We shall investigate this in more detail in experiment 2.

Experiment 2

Introduction

In experiment 1, relative disparity is not the only source of depth information. As well as binocular information, there are two main sources of monocular information about the spatial orientation of the pointer - the perspective shape of the pointer and the slow movement during adjustment of the orientation of the pointer. Monocular cues such as these can dominate binocular cues (Stevens and Brookes, 1987; Ames, 1951). In our set-up the weak depth cue of the accommodation of the eyes is in conflict with the other cues. The purpose of this second experiment was to gain more insight into the contribution of various depth cues. Could an effective combination of depth cues explain the small standard deviations? Do subjects have a strategy dominated by monocular information, or a strategy dominated by binocular information, or does it depend upon the subject?

Methods

Five subjects participated in this experiment, which used the same experimental set-up. Three of these subjects (DL, JH and MI) had taken part in the previous
experiment. All subjects gave informed consent and all were unaware of the purpose of this experiment. They were tested for stereopsis using a standard TNO-test (Walraven 1975). All subjects passed this test.

The experiment began with a practice period for the subjects of about 15 minutes, using the same method as in the previous experiment, except that now only four locations of the pointer were used (slant and tilt: (64.3, -146.3), (138.6, -130.9), (120, -54.7), (45, 0)). In this practice trial the pointer appeared randomly around the veridical, at an orientation within 25 degrees. The practice series was followed by four experimental series where the pointer could appear at four other locations (slant and tilt: (64.3, -33.7), (127.8, -63.4), (158.9, -134), (60, -125.3)). Two of these locations were not used in experiment 1. The four experimental series were presented in order of increasing amount of binocular information. In the first series (= condition M) the pointer was presented only to the right eye, thus monocularly. In the second series (= condition CB) the circle of the pointer was presented binocularly, but the pin of the pointer was presented only to the right eye. In the third series (= condition PB) this was reversed and the circle was presented only to the right eye while the pin was viewed binocularly. In the last series (= condition B), as in the previous experiment, the whole pointer was viewed binocularly. The target was viewed binocularly in all four series. Throughout the series the pointer started at an orientation with the pin in a fronto-parallel-plane (slant =90°), with the tilt differing less than 30° from that of the veridical. Each location of the pointer was presented nine times in each of the four series.

Results

During the experimental series, all subjects made the following two comments. In the first series, M, they said that they could not see which way (forward or backward) the pointer was pointing. As they went from series M to series B, they claimed that they experienced increasingly “more depth”. The results of the practice series showed that all subjects who participated in experiment one generally reproduced their previous results well. Thus the errors did not vary significantly over time.

Figure 3.9 shows the results for the slant, grouped per subject and per location of the pointer. We only show the results of the subjects for whom we have also shown results in the previous experiment. Of the other subjects, the results of subject PT are similar to those of subject JH, and the results of subject ES are similar to those of subject DL.

When the pointer is viewed monocularly (M), all subjects set the slant of the pointer at an angle that does not differ significantly from a fronto-parallel orientation (= also starting orientation 2°). The systematic errors in condition B

Note 2: We performed a control experiment, which was as condition M but with a different starting position, and the pointer was presented monocular to either the right or the left eye (subject ES). The results revealed that the found average setting of approximately 90 degrees was not due to laziness on the part of the subject. The results were not significantly different for the two eyes.
are smaller than those in condition M. The results of subjects JH and MI are different from those of subject DL, as in experiment one.

![Graphs showing slant measurements for different conditions](image)

**Figure 3.9:** For four positions of the pointer (1, 2, 3, 4) grouped per subject (DL, JH, MI), the results are plotted for the conditions with variable binocular information about the pointer. The white bars belong to condition M (pointer viewed monocularly by the right eye). The dotted bars belong to condition CB (circle of the pointer was viewed binocularly and the pin of the pointer was viewed monocularly by the right eye). The dashed bars belong to condition PB (pin of the pointer was viewed binocularly and circle of the pointer was viewed monocularly by the right eye). The speckled grey bars belong to condition B (whole pointer was viewed binocularly). The length of a bar indicates the systematic error. The standard error mean is plotted, in each bar, once above and once below the average. The pointer always appeared at a starting orientation with the pin in a front-parallel-plane (slant = 90°). Sometimes the figure shows two bars with errors in condition PB. In these cases the group of repeated measurements was clearly divided into two subgroups: one pointing backward and one pointing forward. The black outlined bars and whiskers indicate the mean and standard error mean for the sub-group of set orientations in the right direction. The dotted outlined bars and whiskers indicate the mean and standard error mean of the whole group.

Subjects JH and MI (and PT) reduce both the systematic and the standard deviation dramatically in condition B, when compared to condition M. The results of conditions CB and PB generally lie between those of the other conditions. The large standard deviations which sometimes occur in condition PB are due to the fact that there the settings can be split up into two groups: one pointing forward and one pointing backward. This is consistent with the Necker-cube-like instability reported by subject JH in this condition. The sub-group of set pointer orientations pointing correctly forward or backward (indicated with the extra
lines with indicated standard error means in figure 3.9) have a standard deviation and systematic error that are very similar to those in condition CB, i.e. close to the systematic errors in condition B, but with a slightly larger standard deviation than in condition B.

The systematic errors made by subject DL (and ES) are smallest in condition B, but the improvement is much less than for subjects JH and MI (and PT). In condition B subject DL sets the pointer at an orientation which is even closer to an orientation with the pin in the fronto-parallel-plane than in the practice trials and the previous experiment. The standard deviations of subject DL remain approximately constant throughout the four series. Although she seems to make little use of the binocular information of the pointer, it must be remembered that she does have good stereopsis.

![Graphs showing tilt deviations](image)

**Figure 3.10:** A similar graph to figure 3.9, this time for the tilt.

Figure 3.10 plots the deviations for the tilt, similar to figure 3.9. For all subjects, the systematic and standard deviations in the tilt remain approximately constant throughout all conditions. In other words, the increase in binocular information has no measurable effect on the setting of the tilt.

**Discussion of experiment 2**

The results of this second experiment suggest that the tilt is judged solely on monocular information, since adding binocular information does not change the set tilts in any way. The amount of binocular information does influence the set slants for all subjects. Only the extent to which this binocular information is
used varies between subjects; JH, MI and PT seem to use binocular information from both the ring and the pin of the pointer, while subjects DL and ES seem to rely mainly on monocular depth information. This subject-dependent use of binocular information is probably one reason why there were such large differences in the slant results in experiment 1.

The idea that the amount of depth information influences the results can be found in literature. Luneburg (1947) formulated a theory which fitted the results of experiments, done in darkness, with a few luminous objects at eye level (Blumenfeld, 1913; Hillebrand, 1902). However, this theory cannot explain the results by Wagner (1985) and Koenderink and Van Doorn (1998), who did experiments under full cue conditions, nor the results of Ellis et al. (1991), who found an influence of reference lines seen from an oblique top view.

There are two factors which might influence the set orientations of the pointer that have not yet been mentioned. First, the dark circular band that occluded the straight edges of the computer screen was visible, because it was darker than the screen. Although it could not be used as a reference for orientation it could have been used as a reference in depth. It is not clear what kind of effect this had on the results. The possible role of a reference is not mentioned in existing models of visual space (Luneburg, 1947; Wagner, 1985). However, Eby and Braunstein (1995) have shown that a frame around a 3-D scene can reduce the perceived depth within the scene. This is not supported by the results of subjects JH, MI and PT in the B condition. The second factor concerns the possible influence of prior assumptions made by the subjects. Although they were given no information about the pointer and target locations which were used, they may have assumed that they could recognize a pattern in the locations where the pointer appeared. This seems unlikely, because it implies that the subjects could also orient the pointer in depth in the M condition. The results indicate otherwise.

**General discussion and conclusions**

Two experiments have been described, in which subjects had to perform an exocentric pointing task in all three dimensions. The results clearly demonstrated that the deviations from the vertical could be split up into two independent components - the tilt, which can be set monocularly, and the slant, which also needed binocular information. The extent to which binocular information was used varied between subjects.

The standard deviations measured were small for both tilt and slant. For the slant the standard deviations correspond to depth detection thresholds of about 1 arcmin change in disparity. This is less than would be expected on the basis of hyperacuity depth detection thresholds reported in literature (Blakemore, 1970).

For the systematic errors at least three possible explanations exist, because there are three possible sources of error in perception in the task. First, there could be an error (or bias) in the perception of the orientation of the pointer. Second, there could be an error (or bias) in locating the target and the pointer. Third, a straight
line that could connect objects in visual space could represent a curved line in physical space. These experiments cannot exclude any of these three options.

The results of the second experiment suggest that an error in perceived locations is likely. The depth difference between the target and the pointer, as indicated by the relative disparities, can not be retrieved from the monocular depth cues. Experiment 2 showed that some subjects rely mainly on monocular depth cues and make little use of the binocular cues. The depth at which these subjects saw the pointer is not known. The weak monocular depth cue of the accommodation of the eyes is in conflict with all other depth cues in our set-up, and indicates that the pointer is at approximately the same depth as the target (the accommodation cue leads to a depth difference detection threshold of 5 cm at a distance of 1.5 m, according to Piéron, 1927). This would suggest that the more subjects rely on the accommodation of the eyes as a cue for depth the more likely they are to perceive the pointer too close to the target. However, this hypothesis does not explain all the systematic errors found in depth.

The large differences between subjects make it difficult to fit them into a single theory. Existing theories about the relationship between visually perceived space (or visual space) and physical space generally assume that one transformation exists as a general property of the visual system (Luneburg, 1947; Wagner, 1985). Moreover, these theories of visual space assume that the difference between visual space and physical space occurs solely through a systematic misperception of the distance between a subject and any point in space as a function of that distance. The results of subjects CE, JH and MI do not disagree with this assumption. The results of subjects JN and DL suggest a misperception of depth with respect to the target (or computer screen) which does not affect the perceived size and shape of the pointer. The results of subject MA are better explained by an apparent fronto-parallel plane being perceived as slanting backwards, as shown by Cogan (1979).

In terms of the measured standard deviations, the quality of performance of exocentric pointing in 3-D space was high. With the target in a horizontal or vertical direction in projection on a fronto-parallel plane, the standard deviations were extremely small, less than one minute of arc visual angle. Under oblique angles the standard deviations were about twice as large. This was an impressive performance, taking into account the fact that empty space over a 5-8 deg visual angle had to be bridged. Also, the task was not restricted to the foveal boundaries. The slant performance was equally impressive. Here, relative disparities of a few minutes of arc appear to be detectable and interpretable as differences in direction.

Both the systematic errors and the observed variances indicate that they can be split into two independent components. Thus visual space is not isotropic. This has consequences for the generalisation of the results measured within a single plane. The difference in results observed by Indow and Wanatanabe (1984) between parallel and equidistant alley in the fronto-parallel plane and those on a horizontal plane at eye-height may be a consequence of these two independent
components: in the fronto-parallel plane only the tilt component is present and in a horizontal plane only the slant component is present. The similarity between the results in the tilt component and the results of Sittig and De Graaf (1994, see above) suggests that the physical presence of a plane is of little consequence.

To summarise, there are two important conclusions to be drawn from these results. Firstly, it would appear that in abstract visual space relative directions are accurately recognised, since 1 arcmin change in disparity can be interpreted as a change in direction. Within the tilt component the horizontal and vertical direction are recognised with particular accuracy, with standard deviations corresponding to 0.5 arcmin of visual angle. Secondly, visual space is not isotropic. Thus, the orientation in space of the direction that has to be judged determines the contribution of each of the components and thus the results.
Chapter 4

Change in perceived spatial directions due to context

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Abstract
We examined the influence of context on exocentric pointing. In a virtual 3-D set-up we asked our subjects to aim a pointer towards a target in two conditions: the target and the pointer were visible alone, or they were visible with planes through each of them. The planes consisted of a regular grid of horizontal and vertical lines. The presence of the planes had a significant influence upon the indicated direction. These changes in indicated direction depended systematically upon the orientation of the planes relative to the subject and the angle between the planes. When the orientation of the (perpendicular) planes varied from asymmetrical to symmetrical to the fronto-parallel plane, the indicated direction varied over a range of 15°: from a slightly larger slant to a smaller slant as compared to the condition without the contextual planes. When the dihedral angle between the two planes varied from 90° to 40°, the indicated direction varied over a range of less than 5°: a smaller angle leads to a slightly larger slant. The standard deviations in the indicated directions (about 3°) did not change systematically.

The additional structure provided by the planes does not lead to more consistent pointing. The systematic changes in indicated direction contradict all theories which assume the perceived distance between any two given points to be independent of what else is present in the visual field, i.e. they contradict all theories of visual space which assume its geometry to be independent of its contents (e.g. Gilinsky, 1951; Luneburg, 1947; Wagner, 1985).
Introduction

Human observers report a single, stable image of the surrounding three-dimensional space. For the normal observer, the two frontally spaced eyes provide the main source of information for localising objects. In every day life these objects are usually located on planes: a cup is placed on a table, a photograph hangs on a wall. Surprisingly, little is known about the influence, if any, of such contextual planes on spatial judgements. Few reports exist on the role of a floor (for example, Ellis et al., 1991). In this paper we investigate the influence of contextual planes on exocentric pointing.

Optically perceived space (or visual space for short) is distorted with respect to the physical space (see experiments by Blumenfeld, 1913; Foley and Richards, 1972; Indow and Wanatanabe, 1984; Wagner, 1985). Luneburg (1947) provided a classical theoretical description of visual space and its relation with physical space. He assumed, among other things, that visual space is Riemannian and that the geometry of visual space is independent of its contents. Although parts of his theory have been adapted (Blank, 1961) and some of his assumptions have been questioned (Battro et al., 1975; Foley, 1964; Indow and Wanatanabe, 1984), all models of visual space still assume visual space to have a metric, and to have a geometry independent of its contents (Blank, 1961; Foley, 1991; Gilinsky, 1951; Wagner, 1985). In other words, they assume that all perceived spatial relations depend only on the location of objects relative to the observer and do not depend on the context of those locations, i.e. what else is in the scene. Even though Wagner (1985) states that “the geometry of visual space itself appears to be a function of stimulus conditions”, his model does not incorporate a possible role for context.

However, certain experiments in other fields of research into visual perception have demonstrated a specific influence of context. We want to mention two examples: the depth-contrast effect and rod-frame experiments. The depth-contrast effect (Werner, 1938) is an effect of the orientation of the larger background plane on the perceived orientation of a smaller plane in front of it (e.g. van Ee and Erkelens, 1996; Kumar and Glaser, 1992). The rod-frame experiments (Witkin and Asch, 1948) have demonstrated that the perceived vertical depends upon the orientation of the largest visible frame. Both these types of experiment suggest that context is used as reference and suggest that context influences perceived spatial relations. However, these experiments are very different (different in focus, in experimental set-up and in task) from those performed with the purpose of investigating visual space and therefore they cannot be compared directly. There are other examples, from the field of hyperacuity (Mitchison and Westheimer, 1984), from illusions (Gogel, 1984; Poggendorff illusion, see for example Tolansky, 1964), but these are even less related to the experiments investigating visual space.

There also have been some theoretical statements and phenomenological reports that suggest an influence of context on perceived spatial relations. Gestalt theories do emphasise that perception is only meaningful in the presence of a context (e.g. Gibson, 1950; Koffka, 1935). More specifically Koffka states that “...lines will be determined in their direction and other aspects by the things or surfaces to
which they belong.” (page 215). The phenomenological reports mainly come from the arts such as architecture, theatre and painting. There it has been shown frequently that space perception can be influenced by adding a context with false perspective (see for examples Pirenne 1970, Pozzo ceiling pp 79-94, Piazza Spada and del Campidoglio in Rome, pages 153-157). Within visual science the Ames room and the trapezoid window are well known examples (Ames, 1953, 1951 respectively). Gogel (1977, 1984) has demonstrated that the suggested perspective in a trapezoid window can influence the perceived location in depth of an object close to the window. However, in spite of these theories and illusions, there has never been a clear systematic experiment that context influences spatial perception.

The major aim of this study is to find out if contextual planes have a significant influence on exocentric pointing in either the veridicality of pointing or the consistency of the pointing. To this end we compared exocentric pointing in conditions with and without contextual planes. We used a number of different contextual planes, because a demonstration of an influence of context would become even more convincing if the changes in exocentric pointing also varied systematically with variations in the planes.

In line with most studies of visual space we used a few luminous objects in an otherwise dark environment. Previously (Schoumans and Denier van der Gon, 1999) we measured an exocentric pointing task, with a pointer and a target as the only luminous objects in an otherwise dark room. We found standard deviations smaller than would be expected from the resolution of the retina and from psychophysically measured depth-difference detection thresholds. In other words: such a task can be performed with high accuracy in the absence of any context.

We chose an exocentric pointing task because it is a typical spatial task that we perform in every day life: monitoring who looks at whom in a group of people is probably the commonest example. Studying exocentric pointing is also a good method of studying spatial relations and has been used as such before (e.g. Ellis et al., 1991; Koenderink and van Doorn, 1998). It should be noted that any affine transformation (such as a scale, rotation or shear) like Wagner’s model (1985), or even projective transformation between visual space and physical space, would not result in systematic errors in pointing. Systematic errors in exocentric pointing indicate a more complex, non-linear distortion of visual space.

A clear demonstration of an influence of contextual planes on exocentric pointing will have immediate implications for the existing models of visual space, since most of these (such as Luneburg’s model, 1947) do not incorporate a possible influence of context in the theory. Thus this study is designed to disprove this clan of models.
Methods

Subjects

There were 5 subjects, who had given their informed consent and were naive as to the purpose of the experiments. All subjects had normal vision or corrected-to-normal vision via contact lenses. They all had good stereopsis for which they were tested via a standard TNO-test (Walraven, 1975). Their ages varied from 19 to 27 years. The subjects performed three experimental sessions. The first was considered to be a training session. One of the subjects was rejected after the second session because she showed a number of mirrored settings (towards her instead of away from her) in the condition without the context in this session.

Apparatus

We used a virtual 3-D set-up. The stimuli were generated on a Silicon Graphics Indy computer. This computer generates 120 images per second, and draws the projection of a three-dimensional image from each eye on to the screen, alternately one for the right eye and one for the left eye. The subjects wore LCD-goggles that closed one or the other eye synchronously with the images presented on the computer screen. The goggles work best for red images.

The computer screen consisted of 1280 x 1024 pixels. The pixels were 0.27 x 0.27 mm². We used anti-aliasing commands to increase the resolution. A circular band of black cardboard was placed around the computer screen in order to exclude possible reference directions indicated by the edges of the screen.

Stimuli

The subjects could always see a red pointer and a red target. The pointer was a wire frame figure that consisted of a line of 4 cm and a ring with a diameter of 3.2 cm. The plane of the ring was perpendicular to the line segment and it was located around one of the endpoints of the line. The target consisted of a dot (1 pixel) with two rings extending in 3-D drawn around it. The two rings had a diameter of 1.2 cm and met each other directly above and below the dot. The target and the pointer were located in a horizontal plane at eye-level. The midpoint between the target and the pointer was located on the computer screen and was 120 cm in front of the cyclopean eye of the subject. The pointer could appear at eight possible locations (see ellipses in figure 4.1). The target appeared at the opposite side (of the dashed lines in figure 4.1). The distance between the rotation point of the pointer and the target was 20 cm (7.3 or 8.6 degrees visual angle depending upon the orientation of the connecting line between target and pointer).

We performed three experiments: one without any context and two with context. In all experiments, the possible locations of the pointer and target remained constant while the context, if present, was varied. The context consisted of two flat planes. Figure 4.2 shows how these planes were varied for one possible combination of pointer and target location for the two experiments with context.
In the rotation-experiment (figure 4.2A), the two planes were always perpendicular to each other. The orientation of the two planes with respect to the subject’s fronto-parallel plane was varied in six steps from 0°/90° to 45°/45°, which we shall call rotations 0° to 45° respectively. In the angle-experiment (figure 4.2B), the planes were always oriented symmetrically with respect to the subject’s fronto-parallel plane. Here the dihedral angle was varied in six equal steps from 90° to 40° (i.e. with respect to the subject’s fronto-parallel-plane they varied from 45°/45° to 70°/70°).

Figure 4.1: A scaled top view of the eight possible locations at which the pointer and target could appear (at ellipses). Given the location of the pointer, the target appeared at the opposite sides of the dashed line. For each combination of pointer and target, its mirror image in the fronto-parallel-plane or the mid-sagittal-plane also exists. The connecting straight line between target and pointer could make an angle of 25° or 40° with the fronto-parallel-plane. The midpoint of the connecting line between target and pointer lay 120 cm in front of the cyclopean eye of the subject and in the computer screen. The symbols near the ellipses are those used in figures 4.4 and 4.5 for the corresponding location of the pointer.

The contextual planes met in one common vertical line (like two walls of a room). They consisted of a blue grid of horizontal and vertical lines, indicating squares of 2.5 x 2.5 cm². The grid extended from 2.5 squares above to 2.5 squares below the target and pointer, and from the intersection line between the planes to about 1.5 to 2.5 squares beyond the target and pointer. The planes were at least 4 squares wide. Two 5 cm long blue vertical lines were drawn, one through the target and one through the rotation point of the pointer, to emphasise that the target and pointer were located in the contextual planes.

Note 3: The colour of the grid was chosen to be different from the colour of the target and pointer in order to prevent ambiguities, such as possible disparity mismatches between the endpoint of the pointer and a line in the grid. However, a difference in colour can lead to differences in perceived depth (Helmholtz, 1866). In our experiments this could not influence the results, since the colour difference between the grid and the target and pointer was constant throughout the experiments with the contextual planes, and the pointer and the target were red in both experiments, with and without context.

Chapter 4
Procedure

The subject's task was to orient the pointer so that it aimed at the centre of the target. The orientation of the pointer in the horizontal plane could be manipulated by pressing the arrow keys on the keyboard. The subjects could use as much time as they needed. We recorded the final orientation of the pointer.

Our subjects completed three experimental sessions. The first session served as a training session and was identical to the third session. Each of the sessions started with the experiment in which no contextual planes were present, followed by one of the possible two experiments with contextual planes.

![Diagram showing variations in contextual planes]

**Figure 4.2**: Illustration of the variations in contextual planes as used in the experiments with context for a possible combination of pointer (one of the dots) and target (the other dot) location. In these experiments with context each possible combination of pointer and target location could appear with one of six possible contexts. Figure 4.2A illustrates the rotation experiment. In this experiment the contextual plane through the target and the contextual plane through the pointer intersected at a dihedral angle of 90°. The orientation of the contextual planes with respect to the subject was varied. This is indicated by a value of rotation that could be 0°, 15°, 25°, 35° 40° or 45°, that equals the smallest angle between one of the planes and the fronto-parallel plane. Figure 4.2B illustrates the angle experiment. In this experiment the contextual plane through the pointer and the one through the target made the same angle with the fronto-parallel-plane. The dihedral angle between the planes was varied and could be 90°, 80°, 70°, 60°, 50° or 40°. Note that in both experiments the condition exists with a dihedral angle 90° and a rotation of 45°. Also note that, to keep the pointer and target located in the planes, the point where the planes meet had to be translated and the length of the planes had to be adjusted.

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Change in perceived spatial directions due to context
The order of the experiments with the contextual planes (rotation or angle), the order of the stimuli and the starting orientation of the pointer were randomised. The pointer appeared at an orientation between plus and minus 25° around the veridical orientation, and could appear at one out of eight different locations with the target appearing opposite (see figure 4.1). Each possible location of the pointer could appear with 6 different contexts (see above), resulting in 48 stimuli per experiment with contextual planes. All the stimuli were presented 5 times. The experiment was divided into blocks of 15-30 minutes, followed by a short break of a few minutes to keep subjects alert. One complete experimental session took about two hours.

Analysis

We recorded the final orientation of the pointer at which the subjects judged the pointer to aim at the target. The pointer orientation was defined to be $-90^\circ$ when oriented perpendicular to the fronto-parallel plane pointing towards the subject, $0^\circ$ when oriented in the fronto-parallel plane of the subject, and $+90^\circ$ when oriented perpendicular to the fronto-parallel-plane pointing away from the subject. Thus, a pointer orientation mirrored in the mid-sagittal-plane has the same value. This was done because a previous study had shown that exocentric pointing is symmetrical with respect to the mid-sagittal plane (Schoumans and Denier van der Gon, 1999).

For each stimulus (a possible combination of the pointer and the target locations in a certain context) and for each subject we calculated the mean set orientation of the pointer and the standard deviation from the mean. To demonstrate an influence of contextual surfaces, we compared the set orientations of the pointer in conditions with and without contextual planes. We define a change in the set orientation of the pointer as the absolute mean value in the condition with the contextual planes minus the absolute mean value in the condition without contextual planes that were both measured within the same experimental session. Thus, a positive value of the change means that the subject oriented the pointer more steeply (i.e. at a larger slant) in the presence of the contextual planes, as compared to when those planes were not present.

Results

The experiment without contextual planes was measured twice, once before each experiment with context. A comparison of the two measurements shows that the set pointer orientations reproduced well. Figure 4.3 shows the mean orientation of the pointer in the condition without context (measured preceding the rotation-experiment) as a function of the veridical orientation of the pointer. Each subject is represented by a different symbol. Without context, subjects ML, PM and RO tend to set the orientation of the pointer at too large a slant; CN tends to do the opposite. The standard deviation of the means (calculated over 5 repetitions) is 3° for subjects ML, PM and RO and 4.5° for subject CN on average over all pointer locations. Therefore, the mean orientations in stimuli, which are mirror images of each other in the mid-sagittal plane, are generally equal within the errors of
the means. This is consistent with the earlier Schoumans and Denier van der Gon results (1999) and can be seen in figure 4.3 by comparing two equal symbols at each veridical orientation.

**Figure 4.3: Exocentric pointing without any context.** The mean orientation of the pointer is plotted for each of its possible locations as a function of the veridical orientation of the pointer. Each subject is indicated with a different symbol. Two identical symbols at one veridical orientation belong to two pointer (and target) locations, which are symmetrical with respect to the mid-sagittal-plane. The standard deviations are approximately 3° for subjects ML, PM and RO and approximately 4.5° for subject CN.

Figure 4.4 shows the results of the rotation-experiment. For all subjects, the change in set pointer orientation with respect to the condition without context is plotted as a function of the rotation of the planes. The rotation is defined as the smallest angle between one of the planes and the fronto-parallel plane. Thus a 45° rotation of the planes means that both planes are oriented symmetrical with respect to a fronto-parallel plane of the subject. (see figure 4.2A for an illustration of the variations in context.) Each possible location of the pointer is indicated by a different symbol (see figure 4.1). Similarly shaped symbols represent stimuli which are each others mirror image in the mid-sagittal plane. Dashed lines connect the symbols representing pointer locations located in front of the target.

Figure 4.4 shows that the presence of the planes influences the set pointer orientation systematically. This influence is reflected in changes in the set pointer orientation, ranging between +25° and −20°. Moreover, the changes vary systematically with the variation in the orientation of the planes with respect to the subject. There is a global trend in all subjects to set the pointer at a larger slant when one of the planes lies in a fronto-parallel-plane, and at a smaller slant when the planes are oriented symmetrically to the fronto-parallel-plane. The trend on
Figure 4.4: A graph is drawn for each subject. Each graph shows the change in orientation of the pointer as a function of the orientation of the planes with respect to the subject. The two planes are always perpendicular. 0° orientation of the planes means that one of the planes lay in a fronto-parallel-plane. 45° orientation of the planes means that the two planes were oriented symmetrically with respect to the fronto-parallel-plane. The change in orientation of the pointer is defined as its absolute value with contextual planes minus its absolute value without the contextual planes. In other words, a positive value for this change means an increase in the slant of the pointer as a result of the contextual planes. A different symbol indicates a different location of the pointer (see figure 4.1).

Orientation of the planes (°) →

Chapter 4
average over pointer locations has a gradient of 0.33, 0.32, 0.24 and 0.34 °/rotation for subjects CN, ML, PM and RO respectively. This trend is significant for each of the subjects (ANOVA per subject with the rotation entered as co-variate first; df=1, N=240= 5 repetitions x 8 pointer locations x 6 contexts, F>271, p<0.0005).

Figure 4.5 is similar to figure 4.4 except that it shows the change in set pointer orientation as a function of the dihedral angle between the planes (see figure 4.2B for illustration of context variation). For three of our four subjects, ML, PM and RO, there is a clear change in the set orientation of the pointer between the condition with and without the contextual planes. Furthermore, there seems to be a small global trend to set the pointer at a larger slant when the dihedral angle becomes smaller. This trend, on average over pointer locations, has a gradient of 0.096, 0.098, 0.016, 0.072 °/angle for subjects CN, ML, PM and RO respectively. This trend is significant for each of the subjects (ANOVA per subject with the angle entered as co-variate first; df =1, N=240= 5 repetitions x 8 pointer locations x 6 contexts, F>31, p<0.0005) except for subject PM (F=1.2, p=0.28). The condition in the angle-experiment where the angle is 90° equals the condition in the rotation-experiment when the rotation is 45°. A comparison of this condition in Figure 4 and 5 shows a reasonable reproduction of the measured change in the set pointer. To be more precise, the mean set orientations of the pointer are not significantly different in 27 of the 32 cases (two-tailed t-test, df = 4, p<0.05).

As can be seen in both figures 4.4 and 4.5, there are noticeable differences between the subjects. The most apparent difference between the subjects is that their plots are shifted with respect to each other. This is mainly due to the differences between subjects in set pointer orientation in the experiment without context. The deviations from veridical in the experiment with context lie in the same range of 35° for all subjects, between 20° too large a slant and 15° degrees too small a slant. In other words, our subjects resemble each other’s set orientations of the pointer more closely in the conditions with context.

An analysis of variances over all subjects also showed significant interactions between subjects and pointer locations, as can also be seen in the figures 4.4 and 4.5. For example, subject RO shows an asymmetry in his settings between the pointers pointing forward and pointing backward towards the target. In the rotation-experiment the trend is less strong for the pointers pointing backward. This results in segregation between the two groups at a rotation of the planes of 45°, which persists throughout the angle-experiment. In contrast to this, the settings of subject ML clearly do not show such an asymmetry between these two groups. As another example, the top line in the graph for subject CN in figure 4.4 has a noticeable displacement in relation to the other lines. Such a displacement may be due to the variance in the orientation set for that pointer location in the condition without context, which results in a relatively large standard error of the mean as it was calculated over only 5 repetitions. This error displaces all set orientations in the conditions with context for that corresponding pointer location by the same constant. In this case however, this displacement also appears in figure 4.5, because the mean set pointer orientation in the experiment without the context is reproduced.
Figure 4.5: This figure is similar to figure 4.4, except that it plots the change in set pointer orientation as a function of the dihedral angle between the planes. The two planes were always oriented symmetrically with respect to the fronto-parallel-plane.
Besides the influence of context on the average set orientation of the pointers, a context could also influence consistency in pointing. We compared the standard deviations in the conditions with, and all the conditions without, the contextual planes by performing an independent samples t-test for each of the subjects. Only for one subject, CN, could we reject the hypothesis that the standard deviations were the same with and without the planes (F= 16.7, df=558, p<0.001). The standard deviations in her settings were on average 1.5 deg larger in the experiment without context, as compared to the condition with a context. For the other three subjects, the standard deviations were not statistically different (p=0.81, 0.96 and 0.96 for subject ML, PM and RO respectively).

We also checked if the standard deviations changed systematically with the variations in the contexts. For both experiments with a context the measured standard deviations were fitted with a linear regression line as a function of the variations in the planes. None of these regressions deviated significantly from zero (N=48= 8 pointer locations x 6 contexts, df=46, for subjects CN, ML, PM and RO respectively p=0.19, 0.44, 0.10, 0.09 in the rotation-experiment and p= 0.50, 0.64, 0.36, 0.47 in the angle-experiment). The measured standard deviations in the experiments with context were about 3° for each of the subjects.

Possible origins of influence

The results have shown that contextual planes have a significant influence on the mean exocentric pointed direction. The experiments were designed to demonstrate the existence of an influence, not to find out the precise nature of this influence. Nevertheless, we can make several observations about the possible origins of the demonstrated influence.

First of all, we can exclude several strong candidates for the role of single determining factor underlying our results of both experiments with context. For example, the orientation of the contextual plane through the target with respect to the subject changed over a range of 45° in the rotation-experiment and over a range of 25° in the angle experiment (see figure 4.2). If this was the only determining factor in our results, we should have found a trend in the angle-experiment that was about half as large as the trend in the rotation-experiment. This is not what we observed. The same line of reasoning can exclude the orientation of the plane through the pointer, and the angle between the pointer orientation and the plane in which it lay. To keep the pointer and the target in the planes, we also had to vary other parameters besides the rotation and the dihedral angle. These parameters can also be excluded as a single determining factor. The range of depth and disparities over which the planes extended, and thus also the length of the planes which we had to present, as well as the area defined by the target, the pointer and the intersection line of the planes, varied most in the angle experiment (see figure 4.2), where we found the smallest effects. The eccentricity of the intersection line of the planes varied from the right hemi-field to the left hemi-field for one possible combination of the pointer and target location (see figure 4.2). If this were the sole determining factor, the trend in the rotation experiment should have been symmetrical with respect to the condition where
this line lies straight in front of the cyclopean eye of the subject (± rotation 25°). Again this was not what we observed. In conclusion, it would seem likely that there is more than one factor determining the measured results with the contexts.

Secondly, there is no apparent link between the demonstrated influence of context on perceived spatial relations and the specific influence of context demonstrated in other types of experiments reported in the literature. The experiments mentioned in the introduction suggest an influence of context on perceived orientation of objects and perceived depth differences. Those results are often explained in terms of reference frames for the horizontal and fronto-parallel planes (Howard, 1982; Kumar and Glaser, 1992). In depth-contrast experiments and rod-frame experiments a redefinition of the fronto-parallel plane or the horizontal plane is presumed to take place as the largest visible plane or frame is rotated. This would indicate a simple rotation of visual space in relation to physical space. However, such a rotation, or any other affine transformation, does not result in systematic errors in indicated exocentric direction. The observed influence on indicated direction needs a more complex explanation.

Finally, there are several possible directions in which to search for an origin of the influence of the contextual planes on perceived spatial relations. The contextual planes could provide more structure for visual space. They could distort visual space. They could provide planes of reference. Or the perceived spatial relations could be co-determined by shape-perception of the planes. The first two options do not seem likely. The first would predict the smallest standard deviations in the conditions with the contextual planes (see general discussion and conclusion), which we did not observe. The second option is not likely because a distortion of visual space would lead to a straight line in space being perceived as curved. In other words, two stimuli with their pointer and target locations interchanged should then lead to set orientations of the pointers so that they both point in front or behind the connecting line. This was generally not what we observed. The third option, the planes providing some sort of reference, might explain why our subjects’ set pointer orientations resemble each other more closely when a context is present than without. On the possible influence of shape perception of the planes we can only speculate. In summary, finding out the precise nature of the influence of context will require a diverse separate study.

General discussion and conclusions

We have shown that the addition of context in the visual scene has a significant influence on the indicated exocentric direction. Therefore, we conclude that exocentric pointing depends on the contents of the visual scene. This important conclusion is strengthened by the fact that the changes in indicated exocentric direction vary systematically with the main variations in the contextual planes: the orientation of the two contextual planes with respect to the subject and, to a lesser extent, the angle between the two contextual planes.

In contrast to the significant influence of contextual planes on the measured mean indicated exocentric direction, no such influence was found on the measured
standard deviations. The standard deviations did not even change between the condition with and without the contextual planes for three of our four subjects. This is somewhat remarkable, because without the contextual planes the visual scene is very barren and the contextual planes provide additional structure for the seen space, which could help in localising the target and the pointer. Therefore, we conclude that more structure in the visual field does not automatically lead to more consistent perception of spatial relations.

How the influence of context works precisely will require additional research before better theories of visual space can be constructed (see “possible origins of influence”). Gestalt theories have emphasised the importance of context, but only seldom give suggestions for the nature of the influence of context. Koffka (1935) mentions “the frameworks tendency to normality”, i.e. a horizontal ground-plane and a vertical perpendicular upon it. This does account for the results in the rod frame experiments, but it does not predict the significant and systematic changes in indicated exocentric direction reported in this paper. The planes in our experiments were deliberately upright and consisted of a grid of squares so that these planes would not give rise to illusions, nor suggest a false perspective cue. Nevertheless, we find that the average indicated exocentric direction changes significantly with the systematic variations in the planes.

Our main conclusion remains clear; the stable perception of the 3-D space surrounding us depends upon its contents. Thus the transformation between perceived visual space and physical space cannot be constant. A constant transformation, however, is assumed by most models of visual space (e.g. Gilinsky, 1951; Luneburg, 1947; Wagner, 1985), since they assume visual space to have a metric and to have geometry independent of its content. Thus, our results disprove all such models of visual space. New theories of visual space should include a role of context.
Chapter 5

Pointing in near space under the influence of context

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to be submitted

Abstract

Objects are rarely encountered in otherwise empty space. Gestalt theorists even claim that perception implies context (Koffka, 1935; Gibson, 1950). Nevertheless, little study has been done into the role of context in spatial judgement tasks in near space. We investigated the influence of context by performing an exocentric-pointing task at two distances: 40 cm (in grasping space) and 120 cm (near grasping space). The subjects could see two perpendicular planes with a target drawn on one of them and a rotatable pointer on the other. Their task was to aim the pointer at the target. The planes were white with grids of black horizontal and vertical lines on them. The planes, pointer and target were distance-scaled and always subtended to a visual angle of 11.5 deg. Results from all subjects showed a systematic pattern in the deviations of the aimed direction in relation to the veridical orientation. Despite the fact that the interocular separation provided an absolute reference, this pattern was very similar for both distances. Thus, the scale invariance is perhaps unexpected. Furthermore, a different context through the same absolute location of the pointer and the target produced a systematic shift in the subjective direction. It is therefore evident that the subjects used context. However, rotating the entire scene of planes, pointer and target in relation to the observer also results in a systematic shift in aimed direction, which shows that the subjects did not use the context provided by the planes in an absolute, Euclidean sense.
Introduction

One of the important functions of the human visual system is to see which objects are where in the 3-D environment and to relate them to each other and to the observer. Objects are usually perceived in the presence of the surfaces of other objects. For instance, most objects rest on a ground plane, but other planes are also present, for example: a clock hangs on a wall, or a knob is attached to the door. Such surfaces provide a possible context for spatial judgement. They add to the structure of the 3-D environment and provide additional perspective information about depth. Gestalt theorists, such as Koffka (1935) and Gibson (1950), state that perception necessarily involves context. However, they do not venture any speculations as to how the context interacts with spatial judgement. This paper describes an experiment that was designed specifically to examine the role of contextual planes in an exocentric-pointing task in near space.

It is common knowledge that perception is influenced by whatever else is present in the visual field. Most people know that the absolute size of an object becomes more obvious when there is a reference present, say a man standing close to it, or that markings on the road can influence the perception of distance and thus can be used to influence driving behaviour. The influence of context upon perception has also been demonstrated several times in visual science. Examples are: a demonstrated influence of adjacent objects on hyperacuity (Mitchison and Westheimer, 1984), a demonstrated influence of a frame around a scene on the amount of perceived depth (Eby and Braunstein, 1995), a demonstrated influence of a frame on the perceived vertical (Witkin and Asch, 1948), and a demonstrated influence of the orientation of a larger plane on the perceived orientation of a smaller plane in front of it (Werner, 1938, depth-contrast effect). Recently, we demonstrated that contextual planes influence exocentric pointing (Schoumans, Koenderink and Kappers, 1999). No doubt these various phenomena are due to a variety of causes, but—in an abstract sense— they all demonstrate the ubiquitous influence of context and suggest that perceived spatial properties, such as depth, orientation and location, depend on contextual cues and perhaps are judged relative to what else is nearby.

The experiment described in this paper is designed to examine the role of contextual planes in spatial judgement. More specifically, in this experiment, the observers had to aim a pointer towards a target while both the pointer and the target were located in contextual planes that were perpendicularly attached to each other. Thus the contextual planes were much like the two walls of a room meeting in a corner (see figure 5.2). The experiment was performed at two distances from the interocular midpoint of the observer, 40 cm and 120 cm. The dimensions of the stimuli were distance-scaled and were presented under normal room illumination.

This experiment had three aims. First, we wanted to study the nature of systematic deviations in spatial judgement within the grasping space of the observer, because this is the area of space in which our hands can be used to manipulate our environment. More specifically, humans are accustomed to interacting with the
environment within their grasping space, where one has co-variation of proprioceptive, haptic and optical depth cues. This suggests that in this space visual spatial judgement may be calibrated to correspond perfectly with the physical world. Alternatively, it seems possible that this spatial experience may be overruled when a spatial judgement task is performed in the presence of spatial context, but without the visual presence of hands or arms. In that case the context might conceivably be used for spatial judgement and as such cause systematic deviations.

The second aim was to examine the influence of distance upon spatial judgement. If context is used predominantly, then spatial judgements might be expected to depend more upon the context than upon the distance between the observer and the target and the pointer. In the extreme case this would imply scale invariance when the stimuli are distance-scaled. In our experiment, we looked explicitly for signs of such scale invariance. The distance to the stimuli is either 6 times or 18 times the interocular separation. In other words, the distances differ by a factor of three, and the stimuli differ significantly in the size and range of binocular depth cues. Binocularly perceived depth relations are known to depend critically upon the absolute distance to the observer in the absence of context. For example, it has been known since Helmholtz that the apparent fronto-parallel plane horopter is strongly concave at short distances, but becomes fronto-parallel at a distance of approximately 1 to 1.5 m, and convex at larger distances (see Graham, 1965; Indow, 1991). Thus if the binocular depth cues play a decisive role in performing the task, the results are not expected to be scale invariant.

Our third aim was to examine the main determining factor of any contextual effect. Is the subjective exocentric direction determined mainly by the orientation of the connecting line between the pointer and target relative to the observer or relative to the context? In order to investigate this we varied both the orientation of the contextual planes and the relative location of the target and pointer.

Methods

Experimental set-up

The stimuli consisted of a pointer, a target and two perpendicular contextual planes. These could be at a distance of either 40 cm or 120 cm in front of the subject. The stimuli were distance-scaled, thus the stimuli at a distance of 40 cm were about 1/3 the size of those at a distance of 120 cm (see figure 5.1). The planes were always presented in such a way that the centre of the stimulus was directly in front of the centre of the interocular segment of the subject. Figure 5.2 shows an example of a stimulus at 40 cm distance. The pointer consisted of a black ring, with a diameter of 1.8 cm or 3.0 cm, and a black pin, with a length of 1.4 cm or 4.0 cm respectively, which was perpendicular to the ring. The ring and the pin were connected to each other via a white vertical pin which was connected to a stepping motor. The target was a black dot, with a diameter of either 0.09 cm or 0.2 cm. A circle was drawn around the dot with a diameter of either 0.99 cm or 0.32 cm respectively. The two contextual planes were perpendicular to each other.
and joined in one common line, like the walls of a room. Each plane was made of white cardboard and had a grid of black horizontal and vertical lines on it. These lines were 0.03 cm or 0.1 cm in width respectively. The lines created a grid of 10 squares wide and 5 squares high. These squares were either 0.83 cm or 2.5 cm in size, respectively. At a height of 2.5 squares a target was drawn on one plane and a shape was cut out in the other plane so that the pointer could rotate freely through this plane.

**Figure 5.1:** A scaled top view of the possible locations of the planes relative to the observer. The centre of each stimulus could be located either at a distance of 40 or 120 cm in front of the cyclopean eye of the observer. Those at a distance of 40 cm were approximately 1/3 of the size of those at a distance of 120 cm. Usually (see figure 5.3), one of the two perpendicular planes was in the fronto-parallel plane.

**Figure 5.2:** A photograph of one of the stimuli at 40 cm (mirror image of scene D in the top row in figure 5.3).

Figure 5.3 shows a top view of half of the stimuli used in the experiment. Each column of this figure represents one of the six different combinations of the
location of the pointer and the target relative to the planes that were used in this experiment. The straight line that could connect the pointer and the target could make an angle with the plane of the pointer of either approximately 85°, 70°, 55°, 40°, 25° or 10° (figure 5.3, columns A to F, respectively; values vary slightly from scene to scene). The top row of figure 5.3 shows the stimuli that were presented to the subject with the pointer located in the fronto-parallel plane and the target located in the perpendicular plane. These scenes were also presented at a rotated by 90° orientation (see bottom row figure 5.3), thus with the target in the fronto-parallel plane and the pointer in the perpendicular plane. Two of the scenes, A and B, were also presented while both planes made an angle of 45° with the fronto-parallel. In this 45° orientation, scenes A and B had the pointer and target at the same location in space as in scenes C and D (top row in figure 5.3), respectively. In the scenes illustrated in figure 5.3, the subjects were required to point from left to right. To obtain a more balanced set of stimuli, they were doubled by the mirror stimuli in the mid-sagittal plane of the 14 stimuli drawn in figure 5.3, giving in total 28 different stimuli of each size.

![Figure 5.3: A top view of half of the stimuli. Columns A to F each represent one possible scene: one combination of locations of the pointer and the target relative to the planes. The pin of the pointer aimed at the target when it made an angle of approximately 85°, 70°, 55°, 40°, 25°, 10° with its plane, in scenes A to F respectively. Each row represents the possible orientation of a scene relative to the observer: in the top row the pointer is located in the fronto-parallel plane, in the middle row scene A and B are rotated 45°, so that both planes make an angle of 45° in relation to the fronto-parallel plane, in the bottom row the scenes of the top row are rotated 90° so that the target lies in the fronto-parallel plane.](image)

The distance between the pointer and the target was about five times the length of the pin of the pointer, thus approximately either 6.7 cm or 20 cm at a distance of 40 cm or 120 cm respectively. The vertical pin of the pointer was mounted on a small stepping motor, which could rotate the pointer in discrete steps of 0.18° around a vertical axis. The set-up was constructed in such a way that the position of the pointer, the planes and the target in relation to each other and in relation to the subject, was reproducible.
The target and the pointer were positioned at eye-level and the subject's head was held steady by means of a chin rest. The subjects' view of what was below the planes was blocked by a white vertical plate. A creamy white cloth, 6 m by 1.5 m, was hung symmetrically around the table. This cloth prevented the subject from seeing the rest of the experimental chamber during the experiment. The experiment took place with real objects under normal chamber illumination with a fluorescent-light source directly and symmetrically above the stimuli. Thus the planes used in this experiment did not contain any artificial cue conflicts as can occur in computer generated stimuli.

Procedure

The task of the subject was to aim the pointer towards the target. Pressing keys on a keyboard could change the orientation of the pointer. After the orientation of the pointer was set, the subject closed his or her eyes while the experimenter stored the orientation of the pointer and set the next stimulus. The 28 stimuli belonging to one distance were presented twice per experimental session in pseudo random order. There were four experimental sessions: two with stimuli at 40 cm distance and two with stimuli at 120 cm distance in front of the subject. The experimental sessions were also randomised. Each experimental session took about an hour.

Subject

Five subjects participated in this experiment. They had vision which was normal, or corrected to normal via contact lenses, and were aged between 18 and 22. Before the experiment started they were tested for stereopsis via the TNO standard test (Walraven, 1975). All five subjects could detect a relative disparity of 30 arcsec. A sixth subject was rejected, because she was not able to fuse the images of her two eyes. All subjects gave informed consent.

Analysis

Unless explicitly mentioned otherwise, we define the orientation of the pointer and the systematic deviations relative to the fronto-parallel plane of the subject. The orientation of the pointer is defined as the angle that the pin of the pointer makes with a fronto-parallel plane. The systematic deviations are defined as the difference between the set orientation of the pointer and the veridical orientation of the pointer. A positive value thus indicates a set orientation of the pointer at a larger angle with the fronto-parallel plane than the veridical orientation. In other words, it is pointing too steeply in depth.

Results

Figure 5.4 shows the mean deviations for both distances for each of the subjects. These deviations are plotted against the angle that the straight line that would connect the pointer and the target makes with the fronto-parallel plane of the subject. The closed squares belong to stimuli where the pointer is located in the...
fronto-parallel plane, thus where the pointer is located further from the subject than the target (see top row figure 5.3). The open squares belong to stimuli that were rotated 90° in relation to those belonging to the closed squares, thus with the target located in the fronto-parallel plane, further from the subject than the pointer (see bottom row figure 5.3). The mean deviations plotted in this graph were calculated over 8 repeated measurements: 4 of a stimulus where the pointer was aimed from left to right and 4 where the pointer was aimed from right to left. We determined standard errors of the mean from these repeated measurements. There is also a 0.2° error in the calibration of the veridical direction in our experimental set-up. The error bars in the graphs indicate the root of the sum of the squared errors.

The figure shows that significant deviations occur at both distances, thus also within the grasping space of the subject. These deviations can be as large as 15°. The deviations show a systematic pattern for each of the subjects, although between subjects there are quantitative differences in the size of the systematic deviations. In most cases, the pointer is set to aim too steeply in depth (positive deviations) when the veridical direction makes an angle between 5° and 60° with the fronto-parallel direction. This mispointing reaches its maximum at about 30° orientation of the veridical. When the orientation of the veridical is larger than 60°, the direction of mispointing changes and the pointer is generally set to aim at too shallow a depth (negative deviations). Thus the location of the pointer and target relative to the planes influences the mean set direction of the pointer.

In a graph in figure 5.4, when the lines through the closed squares and the open squares overlap, it means that there is symmetry between pointing forwards and pointing backward. In other words, exchanging the position of the pointer and the target in that case leads to an equal amount of pointing too steeply or too shallow in depth. This is true for subject LO at 40 cm and subject JA at 120 cm. In some graphs, for example those of AN, CN, LO at 120 cm and SU at 40 cm, the deviations for pointing forward and backward only partially overlap. In other graphs, as in those of CN and JA at 40 cm and SU at 120 cm, the deviations for pointing forward are systematically shifted in relation to the deviations for pointing backward. In the graph of subject AN at 40 cm the two types of deviations show no resemblance.

For most subjects, there appears to be a similarity between the systematic deviations that occur at a distance of 40 cm and those at a distance of 120 cm. In order to test for such a scale-invariance, we plotted the systematic deviations at 40 cm against those at 120 cm for the corresponding scenes. Figure 5.5 shows these scatter plots for each of the subjects. The solid line is the line of perfect correspondence, $y = x$. The dashed line is the calculated best fit through the points, where the squared sum of the distances of the points to the fitted line was minimised. To compare the best fit with the line $y = x$, we compared the distances of each point to the line of the best fit and to the line $x = y$. These distances were compared in a paired, two-tailed t-test (N=14, df=13). Table 5.1 shows that for none of the subjects is there a significant difference between the line of the best fit and the line of perfect correspondence, even though there is a fairly high

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Angle between veridical and fronto-parallel plane (°) →

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Figure 5.4: An overview of the results. The systematic deviations made by each of the observers are plotted as a function of the angle between the veridical orientation and the fronto-parallel plane. A positive value of the deviation means that the pointer is set to aim too steeply in depth. The graphs in the first column belong to a distance of 40 cm; those in the second column belong to a distance of 120 cm. The closed squares correspond to the deviations in scenes A through F (see figure 5.3, upper row) where the pointer was in the fronto-parallel plane, further from the observer than the target. The open squares correspond to the deviations in the scenes F through A (see figure 5.3 bottom row) where the pointer was located in the plane perpendicular to the fronto-parallel plane, closer to the observer than the target. The error bars indicate the standard errors of the mean.

Table 5.1: The relationship between systematic deviations at 40 cm and those at 120 cm. Of each plot in figure 5.5, this table lists the slope and offset of the line that is the best fit through the points, the square of the correlation coefficients, r^2, and the result of a pairwise comparison of the distances of each point to the line of the best fit and the line of perfect correspondence, y = x.

<table>
<thead>
<tr>
<th>observer</th>
<th>Slope</th>
<th>Offset</th>
<th>r^2</th>
<th>Line of best fit significantly different from line y=x?</th>
</tr>
</thead>
<tbody>
<tr>
<td>AN</td>
<td>0.8</td>
<td>-0.3</td>
<td>0.55</td>
<td>No, p = 0.73</td>
</tr>
<tr>
<td>CN</td>
<td>1.0</td>
<td>1.9</td>
<td>0.76</td>
<td>No, p = 0.08</td>
</tr>
<tr>
<td>JA</td>
<td>0.8</td>
<td>0.2</td>
<td>0.72</td>
<td>No, p = 0.36</td>
</tr>
<tr>
<td>LO</td>
<td>0.9</td>
<td>-0.7</td>
<td>0.67</td>
<td>No, p = 0.93</td>
</tr>
<tr>
<td>SU</td>
<td>1.1</td>
<td>1.8</td>
<td>0.26</td>
<td>No, p = 0.56</td>
</tr>
</tbody>
</table>

correlation in terms of r^2 between the systematic deviations of the two distances.

A priori, the systematic deviations can be influenced by the orientation of the veridical in relation to the contextual configuration, by the orientation of the veridical in relation to the subject or by a combination of the two. We investigated this by comparing the results of stimuli A₄₅ and B₄₅ (middle row figure 5.3) with stimuli A₀ and B₀ and with stimuli D₀ and E₀ (top row figure 5.3), respectively. The pointer always had to be pointed obliquely towards the subject and the orientation of the contextual planes changes over 45° with or without changing the location of the pointer and the target.

The graphs in the top row of figure 5.6 illustrate the influence of a different context through the same location of the pointer and target in relation to the subject. They compare the systematic deviations in the stimuli A₄₅ and B₄₅ (open circles) with those in stimuli D₀ and E₀ (closed circles), respectively for each of the distances and each of the subjects. The figure shows that the orientation of the pointer is set to aim more steeply in depth when one of the planes lies in the fronto-parallel plane than when both planes make an angle of 45° with the fronto-parallel plane. This is true for each of the veridical orientations and each subject, except once for subject AN at a distance of 40 cm from the stimuli. A paired t-test shows that this effect is significant for both distances (p<0.01, t= 3.6 or 6.5 at 40
cm or 120 cm, respectively). The systematic deviations differ 5.0° at a distance of 40 cm and 9.4° at a distance of 120 cm, on average over scenes and subjects.

\[ \text{Deviation at 120 cm} \]

\[ \begin{align*}
\text{AN} & \quad \text{CN} \\
\text{JA} & \quad \text{LO} & \quad \text{SU}
\end{align*} \]

\[ \text{Deviation at 40 cm} \]

\textbf{Figure 5.5: Scale invariance. For each observer, the systematic deviations made at a distance of 40 cm are plotted against those made in the corresponding stimulus at a distance of 120 cm. The solid line is the line of perfect correspondence, } y=x. \text{ The dashed line represents the best fit through the points. See Table 5.1 for further details.}

The graphs in the bottom row in Figure 5.6 illustrate the effect of rotating the entire scene of pointer, target, and planes over an angle of 45° in relation to the subject. It compares mean systematic deviations in stimuli A45 and B45 (open circles) with the ones in stimuli A0 and B0 (closed squares). In both orientations of the scenes, the pointer was aimed obliquely towards the subject. Rotating the entire scene has less effect on the systematic deviations than of rotation the planes only. The effect of rotating the entire scene is about 3.7° at a distance of 40 cm and 2.9° in the opposite direction at a distance of 120 cm, on average over scenes and subjects. A paired t-test (N=10, df=9) shows that this difference is significant at 40 cm (p<0.05, t=2.8), but not significant at 120 cm (t=2.1, p=0.06).

A possible effect of the orientation of the entire scene in relation to the subject is most clearly demonstrated by comparing the deviations made in the scenes that differ 90° in orientation. This is illustrated in Figure 5.7. In this figure, we redraw the data of Figure 5.4 in parameters defined relative to the context. In this figure, the deviations have a positive sign when the pin of the pointer made an angle with its plane that is too large and a negative sign when the pin of pointer made an angle with its plane that is too small. The deviations are plotted as a function of the angle that the pointer had to make with the plane in which it was located.
to aim at the target. Thus, the deviations belonging to the same scene, but different orientation in relation to the subject, are plotted directly above each other. Figure 7 shows that large and significant differences in pointing can occur as a result of rotating the scene in relation to the subject. This is most apparent in subjects CN and LO. However, subject JA always points in a similar way relative to the context regardless the orientation of the scene in relation to him.

Figure 5.6: The open circles in the top and bottom row represent the systematic deviations that were made in scene A and B when both the planes made an angle of 45° with the fronto-parallel plane of the observer. In the top row these systematic deviations are compared to those made in scene D and E (closed circles) in which the pointer and the target are in the same absolute location in space but at a different location in relation to the planes. In the bottom row these systematic deviations are compared to the systematic deviations that were made in scenes A and B when these scenes were presented with the pointer located in the fronto-parallel plane (closed squares). The left column corresponds to the systematic deviations that were made at a distance of 40 cm and the right corresponds to the systematic deviations that were made at a distance of 120 cm.

In a final analysis of the systematic deviations, we tested whether pointing from left to right results in the same systematic deviations as pointing from right to left. At first glance the data certainly appeared symmetrical in relation to the mid-sagittal plane. However, when we studied the data in more detail, there appeared to be a slight asymmetry in the data relating to a distance of 40 cm. The subjects tended to point around 2° more steeply in depth when there was a plane on the right than when there was a plane on the left. This slight shift was about equal to the standard error of the mean of four repetitions, but it occurred.
Pointing in near space under influence of context
Figure 5.7: In this figure, we redraw the data of figure 5.4 in parameters relative to the context. The deviations are plotted as function of the veridical angle between the pin of the pointer and the plane in which it was located. In this figure, the deviations have a positive sign when the angle between the pin of the pointer and its plane was too large. The error bars indicate the standard errors of the mean.

Systematically in all subjects when the stimuli were within grasping space. A sign test shows that, for the data relating to 40 cm, the means are significantly different for subjects AN, CN, JA and SU (N= 14, df = 13, p<0.05), but not for subject LO.

We also tested whether the measured values of the standard deviations (calculated over 4 repetitions) depended upon the distance (df=1) or scene (df=5), by performing a two-way ANOVA (N=56). This test indicated that the size of the standard deviations did not depend upon the distance for any of the subjects (p= 0.70, 0.62, 0.32, 0.18, and 0.19 for subjects AN, CN, JA, LO, and SU respectively). For all subjects, the size of the standard deviations did depend upon the scene (p<0.05) except LO (p=0.36). Generally, the standard deviations were smallest when the angle between the pointer and the plane it was in was close to 0° or 90°. Only for subject CN was there a significant interaction between distances and scenes (p=0.04). The standard deviations were about 4° on average.

Discussion and conclusions

The results described in this paper clearly show that systematic deviations in exocentric pointing of up to 4 times the standard deviation occur, within and near the grasping space of the observer (see figure 5.4). These deviations depend upon the scene as a whole and the orientation of the scene in relation to the observer, but they depend very little on distance, because we observed scale invariance within the error of our experiment. Hence, we conclude that the contextual configuration codetermines spatial perception in our paradigm.

Systematic deviations in exocentric pointing also occur within the grasping space of the observer. Here, humans habitually experience haptic, proprioceptive and optical afferent co-variation. Gibson (1950), (in the tradition of western philosophy) believed that simultaneous information about spatial properties from vision, haptics, and proprioception is essential in the learning of spatial perception. Our observations demonstrate that visual spatial perception does not correspond perfectly with the physical environment within this space.

The pattern of systematic deviations in our paradigm is almost independent of the distance of the stimuli from the observer (see figure 5.5). This scale invariance is remarkable for two reasons. First of all, the range of relative disparity and vergence angle varied widely for the two distances because the interocular distance remained constant. The relative disparity had a range of 0° to 1.8° and the vergence angle of about 9° for the stimuli within grasping space, while these values became 0° to 0.6° and about 3° for the stimuli near grasping space. Within the range of distances used in our experiment, binocularly perceived spatial
relations show marked changes when context is absent. The apparent fronto-
parallel plane changes from strongly concave to convex at a distance of 
approximately 1 and 1.5 m, and the parallel- and distance alleys are narrowest 
at a distance of about 1 m (see Graham, 1965; Indow, 1991). However, in our 
experiment with context the systematic deviations were roughly the same for 
both distances. This could imply that, compared to monocular depth cues, these 
binocular cues play a minor role, which is in agreement with several reports in 
the literature (for example: Ames window, 1951; Stevens and Brookes, 1987). It 
is also important to note that the stimuli contain enough perspective cues to 
makes it possible to aim the pointer correctly towards the target using only one 
eye, assuming that the planes are perpendicular. It appears unlikely that our 
subjects performed their task in this way, since they made large systematic 
deviations in pointing.

Many perceptions depend on spatial scale. For instance, most sculptors know 
that a small model of a sculpture appears different in shape from a large sculpture 
and that, when increasing the size of the sculpture, depth relief should not be 
scaled to the same extent (Hildebrand, 1907). The fact that we did find scale 
invaiance in the exocentric pointing task could reflect the fact that the results of 
a pointing task can be expected to remain the same when the entire space 
undergoes any transformation that preserves projective relations (such as a 
rotation, shear or compression). In this case, Hildebrand’s relief effect would go 
unnoticed in this task.

Traditional models of visual space (Gilinsky, 1951; Luneburg, 1947; Wagner, 1985) 
assume a well defined origin (the cyclopean eye of the observer) of visual space. 
Typically, they assume that only the depth depends systematically on the distance 
from the observer. The results of our experiment show that distance has little 
effect, while according to Luneburg’s theory the distance function is highly non-
linear within the space used in our experiment, which again disproves this model 
(see also Indow, 1991; Foley, 1964; Schoumans, Koenderink and Kappers, 1999). 
None of the models consider a role for context, while our results indicate that 
context does have a strong influence on spatial perception (see also next 
paragraph). This influence of context may indicate that the representation of the 
location of distinct points in relation to context is more fundamental to the abstract 
representation of 3-D space than to the representation of their absolute distance 
from the observer. He and Nakayama (1994) reached a similar conclusion via a 
study of apparent motion.

When another configuration of the planes was presented through the same 
absolute location of the pointer and the target (see figure 5.6, upper graphs), the 
systematic deviations were clearly shown to depend upon the context, because 
they differed between 5° or 9°, at 40 cm or 120 cm distance respectively. For most 
subjects, the systematic deviations also depended upon the orientation of the 
scene (of planes, pointer and target) in relation to the subject (see bottom graphs 
figure 5.6 and figure 5.7). This is illustrated most clearly in the comparison of the 
deviations in the same scenes with a 90° difference in orientation (see figure 5.7). 
Thus, deviations in exocentric pointing in the presence of contextual planes are
perhaps caused by some combination of the location of the pointer and target relative to the context and the orientation of that context with respect to the observer.

That context can influence the perceived relative location of objects has already been demonstrated in an experiment in virtual 3-D (Schoumans, Koenderink and Kappers, 1999). We can compare some of the results of this previous experiment with some results of the experiment described in this paper. In the experiment in virtual 3-D, we drew 11 different combinations of two planes through the locations of the pointer and target that were at a simulated average distance of 120 cm. This experiment took place in the dark, with the pointer and target as red luminous objects and the two planes as a grid of blue luminous lines. It contained a possible cue conflict for accommodation and it contained no other monocular cues except for linear perspective. Apart from these differences in the experimental set-up, the results plotted at the top left of figure 5.6 can be compared directly with the results from the previous experiment. In that experiment the pointer was generally set to aim too steeply in depth when one of the two perpendicular planes was in the fronto-parallel plane, and at too a shallow depth when the two planes made an angle of 45° with the fronto-parallel plane. The systematic deviations shift 10° to 15° between these two scenes. This is very similar to the results plotted in figure 5.6. Thus, whether the experiment takes place in the light or in darkness, colour, a conflicting or non conflicting accommodation cue or an inversion of contrast between objects and background play only a minor role in the aimed exocentric direction.

In the virtual 3-D experiment, there was symmetry between pointing from left to right and pointing from right to left. This is also true in the real 3-D experiment described in this paper, except for a slight asymmetry at near distance. We can only speculate about the origin of this asymmetry. It could be the result of the experimental set-up, of eye-dominance or asymmetric shading. The latter seems the most likely candidate, because this asymmetry occurs systematically when the stimuli are close to the observer, and the curtain used in the experimental set-up did end close to the observer. The illumination of the rest of the room was not perfectly symmetrical in relation to the set-up.

In conclusion, systematic deviations in exocentric pointing occur, even within the grasping space of the observer. In our paradigm, the context co-determines these deviations, while the influence of the absolute distance of the whole scene from the observer hardly matters. This distance independence is unexpected in view of results reported in literature, such as the apparent fronto-parallel plane horopters (Graham, 1965; Indow, 1991). The approximate distance independence suggests that context is used as an external frame of reference. Howard (1982) has suggested this for the perceived vertical. However, when context is the only frame of reference used, then the systematic deviations should only depend upon the location of the pointer and the target relative to this frame of reference. In contradiction, we observed that the deviations also depend upon the orientation of the entire scene. Therefore, we hypothesise that observers use both egocentric and exocentric reference points in the exocentric pointing task.
Chapter 6

Summary and conclusions
In every day life, we often need to know what is where. To give a few examples: when picking up a cup of tea, avoiding a collision while driving a car, catching a ball, watching a snooker match or noticing who is looking at whom in a group of people. We observe our environment almost continuously, although we are usually not aware of it. Observing the environment is a requirement for interaction with that environment.

We are taught to use Euclidean mathematics to describe and calculate locations, directions and distances in space. When perceiving the space around us we must rely on our senses. For sighted people vision provides the main source of information about spatial relations in unfamiliar situations. Perceiving spatial relations is a complex task for the human visual system. Our eyes receive two-dimensional projections of the three-dimensional world. The brain then combines the available depth information to retrieve important spatial parameters such as shape, orientation, direction and distance. As a result of this process we experience the world three-dimensionally. How this is achieved and which mechanisms are involved is one of many things about the brain that are still not understood.

How we visually perceive space (visual space) does not necessarily correspond perfectly with the physical space. In fact, it is known that it does not always to correspond with the physical space (Blumenfeld, 1913; Foley, 1972) and that it can be subject to illusions (Metzger, 1930; Poggendorff-illusion; Ames, 1953). In the past, people have tried to describe visual space mathematically. A classic example of this is Luneburg’s model (1947). Such mathematical models assume that a metric description of visual space is possible and that the distances in visual space are distorted when related to physical space. Luneburg’s model can describe phenomena such as the parallel alleys, equidistant alleys and the binocular rooms created by Ames (1953). However, his model is not entirely adequate and relies on a number of assumptions which have attracted criticism (Indow, 1991; Foley, 1964). Gestalt theorists, on the other hand, take a non-mathematical approach to visual space. The main advocates of this theory are Koffka (1935) and Gibson (1950) who state that visual space is learned via feedback from haptics, proprioception and ego-motion. This is the reason why they believe that actions play a major role in spatial perception. They also state that perception without context would be meaningless. Gestalt theorists have never attempted to develop an alternative model of visual space.

In the past, experiments designed to investigate visual space were limited. Traditionally, those experiments involved only a few luminous objects located at eye height or in a fronto-parallel plane in an otherwise dark environment. It is only in recent years that experiments began to take place under more natural conditions. One difference between traditional experimental conditions and every day life conditions is that in the latter objects are perceived within a context of other objects and surfaces. Perceived properties of objects and surfaces, such as orientation and shape, usually are studied separately from perceived spatial relations. However, there can be an interaction or inconsistency between the perceived context, shape, orientation, direction and distance. The main goal of the research in this thesis is to place perceived spatial relations in a broader...
perspective and to find links with other fields of vision research. The research is divided into the four sub-studies described in chapters two to five.

Chapter 2

Three objects can either lie on one straight line or define a plane. The human visual system can judge whether a third object lies on a line that is defined by two other objects. Such judgements can be useful when localizing objects relative to each other, as well as when recognising an object when its contour is partially masked by others. The human visual system possesses a mechanism that can generalise lines, because humans sometimes perceive lines where there are none physically present. The Kanizsa square is a well-known example of such illusory contours. The central question of this chapter is whether the mechanisms used when locating objects relative to each other are also involved in illusory contour. If the mechanisms are independent of each other then illusory contours could assist with relative location task. This is not what we observed. The results indicate that our subjects interpolated the edges of the two nearest figures when they were asked to align a dot with an illusory contour. This interpolation is shown to depend upon the asymmetry and orientation of the shapes that induce a contour. In other words, the orientation and shape of objects co-determine the perceived relative location of those objects. This supports the choice of a push-pin shape for the pointer used in the experiments in the chapters three to five, because this shape is symmetrical in relation to the direction that it had to indicate.

Chapter 3

In the past, experiments investigating visual space were usually restricted to a plane, either the horizontal plane at eye height or a fronto-parallel plane. The conclusions from these experiments are only valid for the entire visual space when visual space is isotropic. It was for this reason that we performed an experiment which was not restricted to a single plane. The results show that the aimed directions can deviate systematically from the veridical. These deviations can be as large as 25° and depend mainly on the individual and on the orientation of the veridical line that can connect the pointer and the target. The results demonstrate that visual space is anisotropic, because it is composed of two independent components. One component can be judged monocularly, while the other component also requires binocular information. The extent to which binocular information is used and the size of the deviations in this component depends strongly upon the individual. This study also showed that the precision of exocentric pointing is high in an empty environment (with only two luminous objects) with few depth cues. The standard deviations measured 3° to 4° in the binocular component and 1° to 1.5° in the monocular component. The values lie close to the resolution of the retina and thus suggest that all cues are used effectively. The 3-D stimuli in this chapter were computer generated, presenting a rapidly alternating image to the right or left eye, while goggles covered the other eye.
Chapter 4

Under normal circumstances our environment is filled with numerous objects and surfaces. However, the existing mathematical models of visual space only prescribe how a perceived location of a single point deviates from its location in physical space. These models assume that context has no influence on spatial perception. The results of our experiment demonstrate that this assumption is incorrect. In our computer generated experiment our subjects had to aim a pointer towards a target in conditions with and without two connected contextual planes. Adding the two planes shifts the subjective direction systematically up to 20°. In addition, the variations in the planes systematically shift the subjective direction over a range of 10° to 15°. However, there the contextual planes had no systematic influence on the precision of pointing. The measured standard deviations were between 3° and 4°, in both the presence and the absence of the planes. The size of the standard deviations is similar to that of the binocular component described in chapter 3. In conclusion, context does not automatically lead to more accurate pointing, although the planes do contain extra information about the location of the pointer relative to the target.

Chapter 5

In the previous chapter, we showed that context influences spatial perception. In this chapter we examine the role of context on exocentric pointing in and near grasping space. This experiment had three aims. First we examined the nature of exocentric pointing within the grasping space, in the presence of contextual planes. Grasping space is that part of space in which humans can use their hands to manipulate their environment. Within this space visual spatial perception receives feedback via haptics and proprioception. Gibson (1950) believed that this feedback is essential to the learning of spatial perception. The results showed that systematic deviations occur at a distance of 40 cm. These deviations can be as large as 15°, about four times the measured standard deviation. Thus, within the grasping space of a person, visual space does not correspond perfectly with the physical space. The second aim was to examine the influence of distance upon spatial perception in the presence of context. The same stimuli were distance-scaled and were also presented at a distance of 120 cm. At this distance the range and size of binocular depth cues is substantially different from those at a distance of 40 cm. Nevertheless, the deviations in pointing at the two distances are similar. Scale invariance occurs within the error of the experiment. The third aim was to examine what determines the systematic deviations: is it the orientation of the vertical direction relative to the planes or its orientation relative to the subject? The results showed that both have a systematic effect on the deviations. The distance independence suggests that context is used as an external frame of reference. If context was the only frame of reference used, then the systematic deviations would only depend on the location of the pointer and the target relative to this frame of reference. However, we observed that the deviations also depend upon the orientation of the entire scene. We therefore conclude that observers use both egocentric and exocentric reference points in spatial perception.
In contrast to the experiments described in chapters 3 and 4, this experiment was performed with real stimuli under normal room illumination. A number of the stimuli which were used in the previous experiment can be compared directly with a number of the stimuli which were used in this chapter. The results are roughly the same. We therefore reach the conclusion that light conditions, colour and accommodation have only a minor influence on the perceived spatial relations.

In conclusion

This thesis approaches, from various angles, the problem of how the human visual system locates objects relative to each other. We have demonstrated that relationship exists between where objects are perceived and the visual content of those objects. Shape and orientation as well as context influence perceived spatial relations. The results indicate that it would be useful to further examine the relationship between perceived shape and perceived relative location. All visual information about our 3-D environment comes from objects. Each object can be considered as a collection of relative positions defining a surface which surrounds a certain volume of space. Therefore, the human visual system cannot perceive shape and space independently. Research into these subjects should not consider one without the other.
Summary and conclusions
References


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Nederlandse Samenvatting

In het dagelijks leven willen we vaak weten waar wat is. Om een paar voorbeelden te geven: het oppakken van een kopje thee, het voorkomen van een botsing, het in de gaten houden wie naar wie kijkt, het vangen van een bal en het volgen van een snooker wedstrijd. Het observeren van de omgeving is een taak die we elke dag vrijwel continu uitvoeren zonder dat we ons daar altijd bewust van zijn. Het observeren is noodzakelijk voor interactie met die omgeving.

Voor de ruimte om ons heen gebruiken we een (Euclidische) wiskundige beschrijving om posities, richtingen en afstanden aan te geven en of te berekenen. Voor de perceptie van de ruimte om ons heen gebruiken wij onze zintuigen en ziende mensen vertrouwen in veel situaties hierbij vooral op hun ogen. Het lokaliseren van voorwerpen met behulp van de ogen is geen triviale taak, omdat dit gebeurt terwijl wij zelf bewegen, onze ogen bewegen en op het netvlies van beide ogen een tweedimensionale projectie van de driedimensionale wereld wordt geregistreerd. Al deze informatie wordt door het menselijk brein gecombineerd. De werking van het brein zorgt ervoor dat we wereld driedimensionaal ervaren. Hoe het brein deze taak verricht en welke mechanismen hierbij een rol spelen is een van de dingen die nog steeds niet goed zijn begrepen.


Experimenten die ten doel hadden de visuele ruimte te onderzoeken waren tot nu toe beperkt. Meestal kregen de proefpersonen een paar lichtgevende voorwerpen te zien gelegen in een vlak op ooghoogte of in een fronto-parallel vlak in een ruimte die verder meestal donker was. Pas de laatste jaren vinden experimenten plaats onder natuurlijkere omstandigheden. Onder natuurlijke omstandigheden bevinden voorwerpen zich zelden geïsoleerd van hun omgeving; er zijn ook andere voorwerpen en vlakken aanwezig. De waarneming van eigenschappen van voorwerpen, zoals vorm en oriëntatie, werd voornamelijk
bestudeerd apart van ruimtelijke relaties. Het lijkt echter aannemelijk dat er een interactie of een inconsistentie mogelijk is tussen waargenomen omgeving, vorm, oriëntatie, positie en richting. Het doel van het in dit proefschrift beschreven onderzoek is dan ook om visuele lokalisatie in een breder perspectief te plaatsen en verbanden te zoeken met andere takken van visueel onderzoek. Deze studie is opgebouwd uit vier deelstudies die worden beschreven in de hoofdstukken twee tot en met vijf.

Hoofdstuk 2

Drie voorwerpen kunnen op 1 lijn liggen of een vlak definiëren. Het menselijk visueel systeem kan uitspraken doen of een voorwerp op of in het verlengde van de rechte lijn ligt die door andere twee voorwerpen wordt gedefinieerd. Het kunnen trekken van denkbeeldige lijnen is niet alleen handig voor het lokaliseren van voorwerpen ten opzichte van elkaar, maar is ook handig bij het herkennen van een contour van een voorwerp waarvan een deel verborgen zit achter een ander voorwerp. Dat er een mechanisme is dat lijnen kan generaliseren blijkt uit het feit dat er soms verbindingslijnen worden waargenomen die net echt lijken, terwijl deze er in werkelijkheid niet zijn. Het Kanizsa-vierkant is een bekend voorbeeld van zulke illusoire contouren. De centrale vraag in dit hoofdstuk is dan ook of de mechanismen die bij lokalisatie worden gebruikt dezelfde zijn als die bij het ontstaan van illusoire contouren worden gebruikt. Als deze onafhankelijk zouden zijn, dan zou het zien van illusoire contouren kunnen helpen bij de localisatie van voorwerpen. Dit blijkt niet het geval te zijn. De resultaten duiden erop dat proefpersonen de randen van de pacmen-figuren van het Kanizsa-vierkant extrapoleren als ze gevraagd wordt om een stip op de illusoire contour te plaatsen. Het resultaat van de extrapolatie blijkt sterk af te hangen van de asymmetrische vorm van de figuren en van de oriëntatie van de figuren. Met andere woorden, oriëntatie en vorm bepalen mede de lokalisatie van voorwerpen. Het betekent ook dat de gekozen punaise-vorm van de wijzer die gebruikt is in de experimenten in de hoofdstukken 3 tot en met 5 een verstandige keuze was, omdat deze vorm symmetricisch is rond de richting die ermee dient te worden aangegeven.

Hoofdstuk 3

Experimenten gericht op het onderzoeken van de visuele ruimte beperken zich meestal tot een horizontaal vlak op ooghoogte of tot een fronto-parallel vlak. Conclusies die hieruit zijn getrokken hoeven dus niet noodzakelijk te gelden voor de gehele waargenomen ruimte. Daarom hebben we een experiment gedaan dat door alle drie de dimensies plaatsvindt. De resultaten laten zien dat er systematisch mis wordt gewezen afhankelijk van de oriëntatie van de denkbeeldige verbindingssluij tussen de wijzer en het doel. Dit miswijzen kan wel oplopen tot een fout van 25°. De visuele ruimte blijkt anisotrop, omdat zij blijkt te zijn opgebouwd uit twee onafhankelijke componenten. Eén component wordt met één oog beoordeeld, terwijl voor de andere component ook de combinatie van de beelden van de twee ogen wordt gebruikt. De mate waarin deze binoculaire diepte informatie in deze laatste component gebruikt wordt, is
evenals het miswijzen, sterk afhankelijk van de proefpersoon. In dit onderzoek hebben we tevens gezocht naar de ondergrens van nauwkeurigheid van perceptie. Het blijkt dat mensen in een vrij lege ruimte (met slechts 2 lichtgevende voorwerpen) met weinig cues toch al heel nauwkeurig kunnen wijzen. Voor de binoculaire component zijn standaard deviaties gemeten van 3° à 4° en voor de monoculaire component 1° à 1,5°. Deze waarden liggen rond de grens van de resolutie van de retina en suggereren dus dat het combineren van cues effectief gebeurt. De driedimensionale stimuli in dit hoofdstuk zijn door een computer gegenereerd door middel van een snelle afwisseling van beelden voor het linker en het rechter oog d.m.v. een speciale bril die synchroon met de beeldenwisseling het rechter of het linker oog afdekte.

**Hoofdstuk 4**

Onder natuurlijke omstandigheden is onze omgeving gevuld met talrijke voorwerpen en vlakken. De bestaande modellen van de visuele ruimte gaan er echter alleen van uit dat de positie van een enkel punt in de echte ruimte vervormd wordt waargenomen. Aangenomen wordt dat er geen invloed is van aangrenzende of verder afgelegen visuele informatie. De resultaten van dit hoofdstuk laten zien dat deze aannames onjuist zijn. In de experimenten beschreven in dit hoofdstuk hadden de waarnemers de taak om, in een computergegenereerde 3-D stimulus, een wijzer naar een doel te laten wijzen al dan niet in aanwezigheid van twee extra vlakken die elkaar raakten. Eén vlak ging door de positie van het doel en de ander ging door de positie van de wijzer. Er blijkt een duidelijke invloed te zijn van deze contextuele vlakken op de gemiddelderichting die aangegeven wordt voor waar een doel zich bevindt ten opzichte van een wijzer. Het wel of niet aanwezig zijn van de vlakken kon een verschil tot 20° in de aangewezen richting veroorzaken. Bovendien verschoof de aangegeven richting systematisch met de veranderingen in de getoonde vlakken over een bereik van 10° à 15° graden. Er was geen invloed van de vlakken op de nauwkeurigheid waarmee werd gewezen, want de standaard deviatie in herhaalde metingen bleek 3° à 4°, zowel in aanwezigheid van als in de afwezigheid van de vlakken. Deze spreiding is van gelijke grootte als de gemeten spreiding in het vorige hoofdstuk. Dit is verbazingwekkend, omdat de vlakken extra informatie bevatten over de positie van de wijzer ten opzichte van het doel. Dus context speelt duidelijk een rol, maar de extra informatie leidt niet automatisch tot een nauwkeuriger wijzen.

**Hoofdstuk 5**

In het vorige hoofdstuk lieten we zien dat de omgeving mede bepaalt hoe voorwerpen ten opzichte van elkaar worden waargenomen. In dit hoofdstuk bestuderen we welke rol context speelt bij het exocentrisch wijzen in de nabije ruimte. Het experiment had drie doelen. Ten eerste, hebben we de aard van het deel van de visuele ruimte onderzocht dat binnen de grijpruimte ligt van een proefpersoon. Binnen deze grijpruimte zijn mensen gewend om simultaan haptische, proprioceptive en visuele informatie te krijgen van voorwerpen, omdat men in deze ruimte zijn of haar handen gebruikt voor manipulaties van de omgeving. Gibson (1950) beweert dat dit essentieel is voor het leren van ruimtelijke
waarneming. De resultaten van het experiment laten zien dat het wijzen wel tot 15° (tot vier keer de standard deviatie) kan afwijken van de werkelijke richting. Dus, in de grijpruimte is de visuele ruimtelijke waarneming niet geheel om perfect overeen te komen met de fysische ruimte. Het tweede doel van het experiment was om de invloed van afstand te onderzoeken in de aanwezigheid van context. The stimuli die op een afstand van 40 cm werden getoond, werden ook getoond op een afstand van 120 cm, maar dan in dimensies geschaald met de afstand. Op 120 cm afstand is the groote en het bereik van de binoculaire diepte informatie substantieel anders dan op een afstand van 40 cm. Toch zijn de systematische fouten in het wijzen voor beide afstanden vrijwel gelijk. Binnen de fout van het experiment vinden we schaal invariantie. Het derde doel van dit experiment was om te bestuderen wat de systematische fouten voornamelijk bepaald: de orientatie van de verbindingssluit tussen de wijzer en het doel ten opzichte van de context of ten opzichte van de waarnemer. De resultaten laten zien dat beide een systeematische invloed hebben op de aangegeven richting. De gevonden schaal invariantie suggereerde dat de context gebruikt wordt als externe absolute referentie. Echter, als de context het enige gebruikte referentie kader zou zijn, dan de systematische fouten in het wijzen alleen moeten afhangen van positie van de wijzer en het doel ten opzichte van de context. Dit is niet in overeenstemming met onze resultaten. We concluderen dan ook dat waarnemers zowel egocentrische als exocentrische referentie punten gebruiken voor de ruimtelijke waarneming.

Het experiment beschreven in hoofdstuk 5 is uitgevoerd met echte stimuli onder normale kamerverlichting. Dit in tegenstelling tot de experimenten die beschreven zijn in hoofdstukken 3 en 4. Een aantal stimuli die in hoofdstuk 4 zijn gebruikt kunnen direct worden vergeleken met een aantal stimuli die gebruikt zijn in hoofdstuk 5. De resultaten blijken in grote lijnen overeen te komen. Dus lichtconditie, accommodatie en kleur kunnen hooguit in beperkte mate invloed hebben op de waargenomen relatieve lokatie van voorwerpen.

Tot slot

Dit proefschrift benadert het probleem hoe het menselijk brein voorwerpen op grond van visuele informatie ten opzichte van elkaar kan lokaliseren van verschillende kanten. Aangetoond wordt dat er een verband bestaat tussen het waarnemen van het wat en het waar. Zowel de vorm, de oriëntatie als de context blijken invloed te hebben op de relatieve lokalisatie. De resultaten beschreven in dit proefschrift duiden erop dat het zinvol is om het verband tussen de waarneming van vorm en de waarneming van relatieve positie verder te gaan onderzoeken. Immers, alle visuele informatie komt van voorwerpen af, omdat lege ruimte zelf niet zichtbaar is. Bovendien is elke vorm te beschouwen als een verzameling relatieve posities die een oppervlak vormen dat weer een bepaald stuk ruimte omsluit. Kortom, vorm en ruimte kunnen door het visueel systeem niet onafhankelijk van elkaar worden waargenomen en dus zou onderzoek naar visuele ruimte niet los moeten staan van onderzoek naar visueel waargenomen vorm.
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Wetenschap kan niet in eenzaamheid worden bedreven. Het heeft ondersteuning van anderen nodig op zowel mentaal als materieel gebied. Als ik die ondersteuning niet had gehad, had u nu niet deze woorden kunnen lezen in dit proefschrift, omdat het simpelweg dan niet had bestaan. Daarom wil ik op deze plek de mensen bedanken die meer of mindere mate hebben bijgestaan tijdens mijn promotie onderzoek.

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Curriculum Vitae


Naast mijn studie en promotieonderzoek ben ik betrokken geweest bij tal van andere activiteiten. Zo, heb ik het studierichtingsblad Amphora mee helpen oprichten, de lay-out voor te verzorgen, verhalen te schrijven en andere mogelijke redactietaken te verrichten. Tijdens mijn promotietijd heb ik gedurende twee jaar als vertegenwoordiger van de aio’s van de faculteit Industrieel Ontwerpen opgetreden, waardoor deze groep mensen meer met elkaar in contact zijn gekomen. Verder ben ik in mijn vrije tijd graag kreatief bezig met het maken van dingen door middel van o.a. (het leren van) edelsmeden en plastisch vormen.
Publications

Articles


N. Schoumans, J.J. Denier van der Gon, “Exocentric pointing in three dimensional space”, submitted to Perception.

N. Schoumans, J.J. Koenderink, A.M.L. Kappers, “Change in perceived spatial directions due to context”, accepted for Perception & Psychophysics.

Refereed abstracts


