Illusions disrupting the accurate perception of velocity and position

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Abstract

This study constitutes the generation of a new kind of motion illusion. Stimuli are created that distort not only the perception of object velocity, but also its position. The long-range and short-range motion detection mechanisms are stimulated with separate signals to create a powerful illusion of either accelerated or retarded velocity. The consequences of such an illusion are explored with respect to the distinctive dynamic patterns displayed by certain cephalopod species when hunting prey or escaping predators.

Contents

1 Introduction

The initial aim of this research project was to study stimuli similar to that created by the common cuttlefish, *Sepia officinalis.* Adults possess two million pigment-filled chromatophores in three colour classes; yellow, orange and brown, which are layered at increasing depth in the dermis and so overlap when dilated. These are combined with the iridescent colours of iridophores and leucophore reflecting elements that control the degree of surface luminance to produce an enormous diversity of colour hues and patterns [1]. Each of these cells is under direct motor neurone innervation from the brain and so colouration patterns can be changed extremely precisely and swiftly (in under a second). One dynamic pattern, known as *Passing Cloud*, consists of blanching of the entire body and the display of thick black bands travelling rapidly over the dorsal surface from the base of the body forwards to the tip of the tentacles. Passing Cloud has been reported in two different situations. Hanlon and Messenger [1] classify it as a secondary anti-predator defence. Secondary defences are initiated when the prey has already been detected and identified, and the predator is now in the third stage, approaching for attack. This is a time when maintaining cryptic camouflage would be of limited value. They describe Passing Cloud as:

> *A kinetic pattern, lasting only a second or two, characterized by broad transverse bands of chromatophore expansion moving rapidly forward from the posterior mantle tip across the dorsal body surface to the anterior tip of the arms*

Boycott (1958) [2] also describes the Passing Cloud pattern, but when the cuttlefish is approaching prey before shooting out its tentacles to capture. Octopi are also known to flash this display before lunging at prey.

Hanlon and Messenger [1] attribute the pattern only as a rapid colour change that confuses the predator. In my mini research project I hypothesised that it functioned to generate a specific kind of motion illusion. The Passing Cloud stimulus may disrupt the accurate assessment of cuttlefish velocity or even position in the visual system of predator or prey. Cuttlefish are epibenthic and so spend the majority of the time being viewed from above. This perspective and their flattened bodies provides ideal conditions for the dorsal area to act as a display surface.

It was originally intended, therefore, to perform psychophysical experimentation on the human visual system in an investigation into a class of illusions that might disrupt velocity or location perception. It was hoped that an optimal configuration of the illusion could be found, possibly even through artificial evolution using genetic algorithms. Certain combinations of physical speed, and spatial and temporal frequency of the drifting grating (relative to size and speed of the envelope) would be expected to generate more powerful illusory effects than others. If this optimal configuration (to the human visual system at least) were compared to the parameters of the Passing Cloud display and found to be equivalent the argument could be made that this behaviour is an adaptation to generate the hypothesised illusions. Additionally, recordings of the actual display could be presented under experimental conditions and the perceptual effect studied. Unfortunately, no further data on Passing Cloud could be found. Many of the leading cephalopod researchers were contacted, including John Messenger, Daniel Osorio and Anne Crook, but none had videos or even good quality photographs of this display. In light of this, the research project concentrated solely on human psychophysical experimentation.

The Introduction continues with an overview of previous research into factors affecting accurate perception of velocity and position, to provide a background to the research conducted in this project.

1.1 Distortion of velocity perception

Many factors are known to affect the perception of speed, distorting the mapping from actual speed of an object to its representation in the brain. The size of the object, nature of the background over which the object moves, stimulus spatial frequency, and contrast of the stimulus are all relevant aspects. (see review by Blakemore *et al* 1999 [3]). Landmarks on the background make relative motion easier to perceive, and so decrease motion detection thresholds. An increase in the reference point density gives a greater number of relative motion cues, increasing the perceived object velocity.

Contrast

Pattern contrast plays an important role in the perception of speed. Low contrast gratings are perceived as moving more slowly than high contrast ones scrolling at identical physical speed – the so-called Thompson effect. The apparent velocity of other stimuli, such as single dots, discs and random dot patterns, have also been found to be a function of contrast. This contrast-dependent influence on velocity perception has even been proffered as an explanation for the high incidence of automobile accidents in fog. Snowden *et al* (1998) [4] created a virtual reality simulation of driving in clear, misty or foggy conditions. They found that test subjects consistently perceived themselves to be travelling more slowly than reality when the contrast of the visual field was reduced by fog.

Blakemore (2000) [5] looked at how velocity perception was affected by contrast between mean luminance of texture background and object, and contrast within the background, as shown in Figure 1. When moving over a homogenous background, increasing object contrast increased apparent speed. Against a high contrast patterned background, whereby the object obviously occludes and reveals texture elements as it moves, varying contrast of the object was largely irrelevant. It was suggested that this is due to a strong second-order motion signal (not intensity-dependent, but contrast-modulated motion: region of low contrast moving over region of high contrast) swamping the first-order motion signal (which is dependent on the contrast between the object and the background).

Texture orientation

The orientation of object texture is also important. Georges *et al* (2002) [6] displaced a Gabor patch (a sine grating enveloped in a Gaussian curve along both axes) between successive time-frames to give the impression of motion. They found that the apparent speed of the moving Gabor is much greater if the orientation of the enveloped sine grating is parallel, rather than orthogonal or other orientation angles, to the direction of motion. This strong 'speed-up' illusion peaked at Gabor speeds of $64°/s$, decreasing at slower or faster physical speeds. Furthermore, if the Gaussian blob is elongated along the axis of motion into a ellipse the speed bias is increased, relative to circular Gaussian blobs or ellipses orientated orthogonal to velocity.

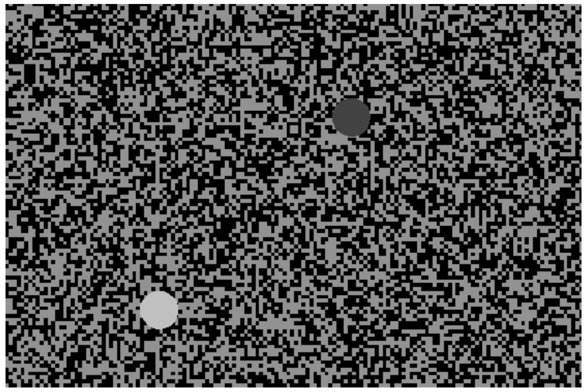

Figure 1: A schematic representation of the stimuli used by Blakemore(2000) [5] showing low contrast within the background texture and two objects with different contrasts between their own luminance and the mean luminance of the background. Graphic produced by the author.

1.2 Interactions between velocity and location perception

It has been demonstrated that the perception of velocity can be affected by a number of factors. Equally relevant to this study is previous research into how perception of location can also be distorted, and the interaction between speed and position assessment. The processing pathways dealing with the motion and position of an object were historically believed to be independent. Evidence cited for this included the motion after effect (MAE), whereby prolonged viewing of motion in one direction causes a stationary test pattern, subsequently presented at the same location, to appear to be moving in the opposite direction. In this case, motion is perceived without a corresponding shift in position, and so these two information channels were assumed to be processed independently.

Work by Nishida and Johnston [7] has recently challenged this commonly-held belief that a MAE is not accompanied by a corresponding shift in perceived position. Their paper presents results showing that after adapting to a rotary windmill stimulus, the MAE creates a perceived orientation shift of a static windmill in the same direction as illusory rotation. If the MAE rotation is annulled by physical counter-rotation of the windmill then the orientation-shift disappears. In other words, a moving pattern does not appear to be spatially displaced if it is perceived as static (in this case because the actual and illusory motions cancel out).

Other research has further explored the subtle, intertwined, relationship between the coding of position and motion. Although motion and positional processing are largely distinct streams, certain visual phenomena demonstrate how strongly these two signals interact. For example, it is known that the perceived position of an object can be strongly influenced by motion of either that object, or other objects nearby in the visual field. The visual system therefore appears to incorporate the motion signal into the assessment of position. The mechanisms involved, or possible evolutionary reasons for such an interaction, are not clear, and there is currently much debate on this subject [8].

Perceptual Latency

One set of illusions demonstrate how the timing of perception of moving objects can influence their apparent position. If one object is perceived slightly before a neighbouring object, it will appear more advanced in the direction of motion. For example, in the Hess effect two objects move in physical alignment, but one is slightly brighter (has a higher luminance) and can appear to lead the dimmer one. This illusion is thought to be due to the differing processing times required to perceive objects of different luminance (contrast against the background). High contrast objects are more apparent and are thought to be perceived more rapidly than lower contrast ones, and thus the perceived relative position is further forward in the direction of motion. This perceptual latency is a popular explanation for illusions generating spatial distortion [8] .

Another class of illusions, known as the flash-lag effect, also manipulate the localisation of objects. A flashed stimulus is presented physically aligned with a smoothly moving object, but the moving object appears to lead the flash [8]. The perceptual latency explanation is that the moving object is perceived before the flashed object, and so seems further advanced. However, this task is effectively one of judging instantaneous position, which introduces a certain amount of ambiguity into the interpretation of results. The task is both a spatial and temporal one, requiring judgment of *where* the bar was when the flash appeared, and *when* the flash occurred. Matin *et al* (cited in [8]) designed an elegant experiment to examine spatial displacement without relying on an arbitrary time marker. Two bars rotate about a central point, with the percept that each seems slightly displaced in the direction of motion, resulting in an illusory vernier (misalignment of the two bars). The spatio-temporal ambiguity is removed, as well as the problem of comparing different stimuli (such as a moving object and a stationary flash), and so this study is an important demonstration of how motion signals can influence perception of position.

Motion Extrapolation

The afore-mentioned illusions, except for Matin's, can be explained in terms of differential perceptual latencies (temporal coding, see Whitney (2002) [8] for a review). An alternative, strictly spatial, mechanism is equally popular, and furthermore can explain Matin's results. The visual system may be shifting the coded position of an object in the direction of its motion. One hypothesis is that this is an adaptation to compensate for neural delays. There is a significant amount of processing involved between the initial detection of light on the retina and perception of an object further along the visual pathway. The processing delay, or lag, results in a mismatch between the actual location of a moving object and the neural representation. In order to interact with the world, to evade approaching predators, capture prey, or catch a cricketball, the brain needs real-time data on the current position of objects. For example, a cricket ball travels 4 metres over a typical 100 ms processing delay [9]. It has been conjectured, therefore, that the visual system automatically compensates for this processing lag-time. The perceived spatial position of an object is shifted along the axis of motion in order to retrieve instantaneous position information.

In order for such a compensatory system to work, however, the visual system must have accurate estimates of the actual delays involved. Zanker *et al* (2001) [9] use a stimulus that demonstrates the human visual system does not perfectly account for neural delays, resulting in an illusory deformation of moving contours. Three equiliuminant Gaussian dots were moved horizontally in a strictly vertical formation, but the central dot always appeared to lead the flanking two. The authors attributed this motion-induced illusory deformation to an imperfect motion extrapolation mechanism.

Much of the literature on velocity/position-coding is concerned with attempting to demonstrate the action of either the perceptual lag or spatial extrapolation mechanisms. One study has shown without doubt that a solely spatial mechanism (not dependent on perceptual latency) can create a shift in perceived position. De Valois and De Valois (1991) [10] created a stimulus of 3 vertically aligned stationary Gabors. The phase of the middle sine grating was incremented between time steps so that the texture visible through the Gaussian window scrolled to either the left or right. The perceived position of the middle (physically stationary) Gabor is shifted in the direction of the enclosed scrolling texture, and the alignment of the three objects appears broken. By physically offsetting the actual position of the middle Gabor against the scroll direction and noting when subjects perceived the three to be in perfect alignment, De Valois and De Valois were able to measure the magnitude of apparent displacement. The motion-related positional bias increased with retinal eccentricity (ie. away from the fovea into the periphery of the visual field), and peaked at a temporal frequency of 4-8Hz and low spatial frequencies. The effect was similar if the Gabors were presented in a horizontal or vertical array, but larger biases were found if the direction of grating motion was towards or away from the fovea rather than in a tangential direction. The crucial conclusion of the paper is that it is the motion signal alone causing the shift in apparent position. The envelope is physically static and the sine grating scrolls continuously, and so perceptual latency or temporal explanations cannot be invoked.

De Valois and De Valois (1991) [10] also explored how the 'hardness' of the envelope can affect speed perception. If the window is 'hard' there is a sharp boundary between the grating window and the background, whereas if the window is 'soft' the grating smoothly merges into the background (by convoluting the sine grating with a Gaussian function to create a Gabor patch, for example). The intention of the paper was to study under which conditions motion contrast or motion integration occurs. A stationary Gabor may appear to move in the same direction (motion integration) or in the opposite direction (motion contrast) of the grating drift. They found that, in general, increasing viewing eccentricity (i.e. presentation of the stimulus away from the fovea and in the periphery of the visual field) favours motion integration for both hard and soft windows. Decreasing aperture softness appears to favour motion contrast. Table 1 summarises these findings.

	Hard aperture	Soft aperture
Foveal	Motion contrast	
Peripheral		Motion Integration

Table 1: Summary of conditions favouring motion integration or contrast

Motion contrast is believed to occur when the grating and aperture are perceived as distinct entities with their own motions, such as with a hard window that reveals an abrupt discontinuity between sine grating and homogenous background. On the other hand, the boundary of a Gabor patch with soft aperture is very indistinct, and the grating and envelope are perceived as a single object with coherent motion. The motion of the grating 'captures' the window, and affects the perception of Gabor patch velocity. Motion integration was also maximised when the mean luminance of the patch was the same as the background.

Thus, motion signals in a local region of space (regardless of whether they are created by actual motion or adaptation as in the MAE) can influence the apparent position of an object in the same region. The visual system (in humans at least) does not seem able to attribute a motion signal to only the object creating it. For example, a stationary object flashed alongside a moving pattern (either translating or rotating) is displaced in the direction of motion, even if they are separated by quite a distance [8]. Again, since the motion stimulus is continuous the spatial shift cannot be explained by temporal mechanisms. Durant and Johnston (2004) [11], however, found the spatial shift to be a more local effect. Bars breifly flashed to the sides of a rotating bar had their apparent position shifted in the direction of bar-tip rotation. They found that the rotational speed of the bar (ie. the distance covered over a set time period after the flash), and not relative position of the bar at time of flash, was critical in determining the magnitude of the spatial shift. This motion induction is a local effect, with the magnitude decreasing if the flash is moved away from the rotating stimulus (the effect of visual eccentricity was controlled for). Such spatial illusions are believed to be similar to well-known motion illusions such as motion capture (or induced motion), whereby the perceived speed of one object is affected by the velocity of surrounding objects. Thus, both the perceived motion and position of an object can be influenced by motion signals in a large region of visual space. Although many of the described illusions can be explained by a strictly spatial mechanism, it is likely that both spatial and temporal processes are active in the visual system.

1.3 Two motion-detection pathways

Motion in the visual field is detected and characterised by two distinctive mechanisms [12]. The first, called the short-range or Fourier mechanism, is based on orientated space-time filters detecting luminance (intensity) features. An example of a stimulus that strongly excites such a motion detection mechanism is a smoothly drifting sinusoidal luminance grating. The second mechanism is the long-range, or sometimes called the non-Fourier, mechanism. This seems to be based on the successive matching of corresponding features on an object as it moves across the visual field. A similar stimulus at different time steps is identified as the same object (by matching salient features such as texture, colour, brightness contrast, etc) and its trajectory is tracked.

Most 'natural' stimuli trigger both of these detection mechanisms, and so the short-range sense of motion occurs simultaneously with the long-range shifting of position. These separate, but mutually supportive, mechanisms can be teased apart, however, by certain artificial stimuli. For example, the long-range but not the short-range mechanism can be activated by simply flashing an object sequentially between different locations on a computer screen. This generates a compelling perception of motion, even though no single object has moved smoothly across the visual field. Conversely, the short-range but not the long-range mechanism was activated in the stimulus used by De Valois and De Valois (1991) [10]. The central Gabor was physically stationary and so was not activating the long-range mechanism, but the drifting sine grating was generating a motion signal through the short-range pathway. The Motion After Effect (MAE) is another illusion whereby motion sensation and positional change detection become dissociated. The short-range motion signal is itself illusory (due to adaptation to a previous actual motion), but results in the perception of movement without an associated shift in spatial position through the long-range pathway.

1.4 The VSG system

The visual stimulus generator (VSG) graphics card, supplied by Cambridge Research Systems Ltd, has become the standard experimental hardware in psychophysical research. Programmes to generate stimuli can be created in a selection of languages, including C++, Pascal, or Matlab. Furthermore, the software the video card is supplied with was custom-designed for researchers and has many common functions, such as Gabor drawing, already coded.

The VSG has an onboard 16Mb of dedicated video RAM that can stream data to be displayed on the screen extremely quickly, and even synchronised with the screen refreshes (typically at 70-120Hz). The usual programming paradigm is to generate stimuli as a sequence of still frames, with a variable (such as grating phase or y position) incrementing each time. These are written to the video memory as an array of images. After the relatively slow writing phase an apparently dynamic stimulus is presented on the screen by rapidly cycling through the designated areas of video memory. This was the paradigm employed in this research, with the programme structure explained in the General Methodology. Alternatively, in situations when temporal resolution is less critical, stimuli can be generated and displayed on the fly.

The VSG card also gives access to many physical parameters that must be exactly controlled for psychophysical research. These include precise synchronisation between different stimuli on the screen, or between stimuli and reading from the response box; colour, luminance, and contrast calibration; millisecond control over temporal features such as exact timing of appearance or presentation duration. All in all, the VSG system provides an enormously powerful approach for generating exactly the stimulus required, although CRSltd warns that ”it does require an intimate understanding of graphics technology and substantial programming experience”.

2 General Methodology

2.1 Stimulus programming

In all experiments, stimuli were presented on a high resolution SONY CRT monitor (1024 x 769 pixels, 120 Hz refresh) controlled by a VSG graphics board (VSG2/3F www.crsltd.com) programmed in Matlab (www.math-works.com) on a PC (www.dell.com).

Although the VSG application does come with a software library, none of the examples were immediately suitable and the required programmes needed to be coded from scratch. The reiterative process of design, coding, testing, debugging, and expanding functionality consumed the vast majority of the available time. Achieving the necessary control over writing to, and cycling from, the video memory is the most conceptually difficult aspect of programming with VSG. A display error, such as a flickering Gabor, could have any number of causes. The problem may lie in the Matlab coding controlling the loops, the VSG Gabor-drawing command, the calculation of where in the video memory to write the next frame, where to find the next frame from when cycling, or in the positioning of the overlay window. The task of debugging such a programme is thus far from trivial. The code for the Matlab programme used in Experiment 1 is given as an example in Appendix 1. Figure 2 shows a flow diagram representation of the programme structure and the specialised VSG functions used.

The 16Mb of video RAM onboard the VSG card is arranged into a series of 16 memory pages, each with dimensions of 1024 x 1024 pixels. These pages can be subdivided and organised by the user. During the earliest stages of programme planning and design a maximum Gabor size of 100 pixels was decided upon. This balances a window size sufficiently large to view the drifting grating, and an object small enough to make velocity and position assessment a challenge. A maximum vertical displacement range of 500 pixels was chosen. Thus the page organisation of 2 rows of 5 strips was designated. The dimensions of each strip frame (200 x 512 pixels) are the important units of distance when calculating where to write and read each Gabor in the sequence. Figure 3 illustrates the video memory organisation used in the programme.

2.2 Testing

Subjects were seated directly facing the visual display, with the head stabalised in a chin and forehead rest 57 cm from the monitor. With the monitor correctly calibrated and viewed from 57 cm, an object 1cm long on the screen subtends 1° in the visual field. Subjects had normal or corrected-to-normal visual acuity. Gabor luminance varied in the range between black (0 cd/m^2) and white (53 cd/m^2). Stimuli backgrounds were always 50% grey. All experiments took part in dim ambient light. The subjects' responses were recorded using a CT3 response box in Experiments 1 and 3, and a computer mouse in Experiment 2. Subjects were requested to fixate on a bulls-eye fixation spot located in the centre of the monitor. Such a design of fixation spot is believed to facilitate constant fixation, compared to a more simple black dot fixation point.

A fixation spot was used to control the eccentricity of presentation, so as to minimise problems of differing responses to stimuli presented in the fovea or periphery of the visual field, such as those reported by De Valois and De Valois (1991) [10]. Fixation on a set point also prevented pursuit eye movements and circumvented the problem of

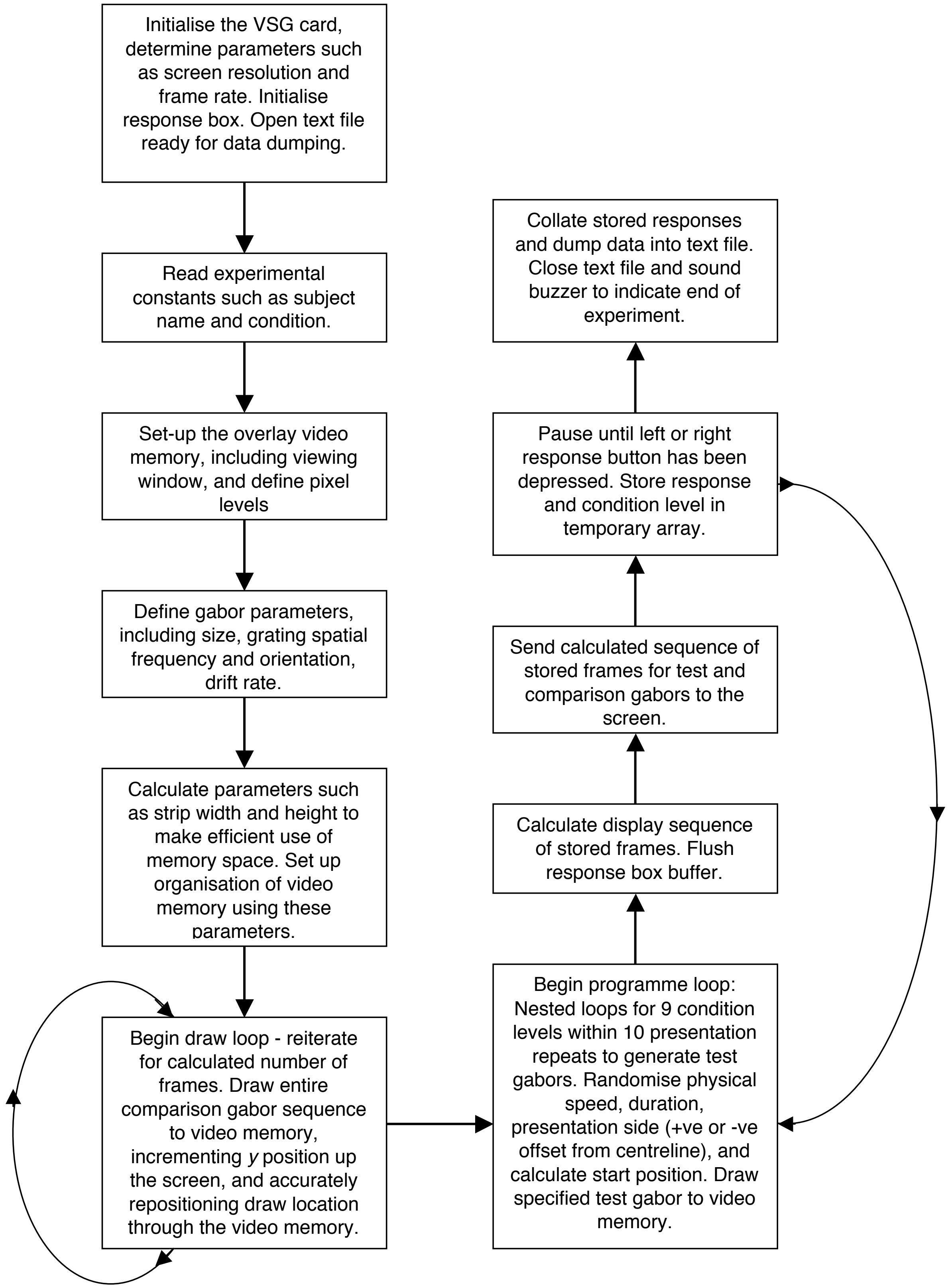

Figure 2: Flow diagram of programme written for Experiment 1

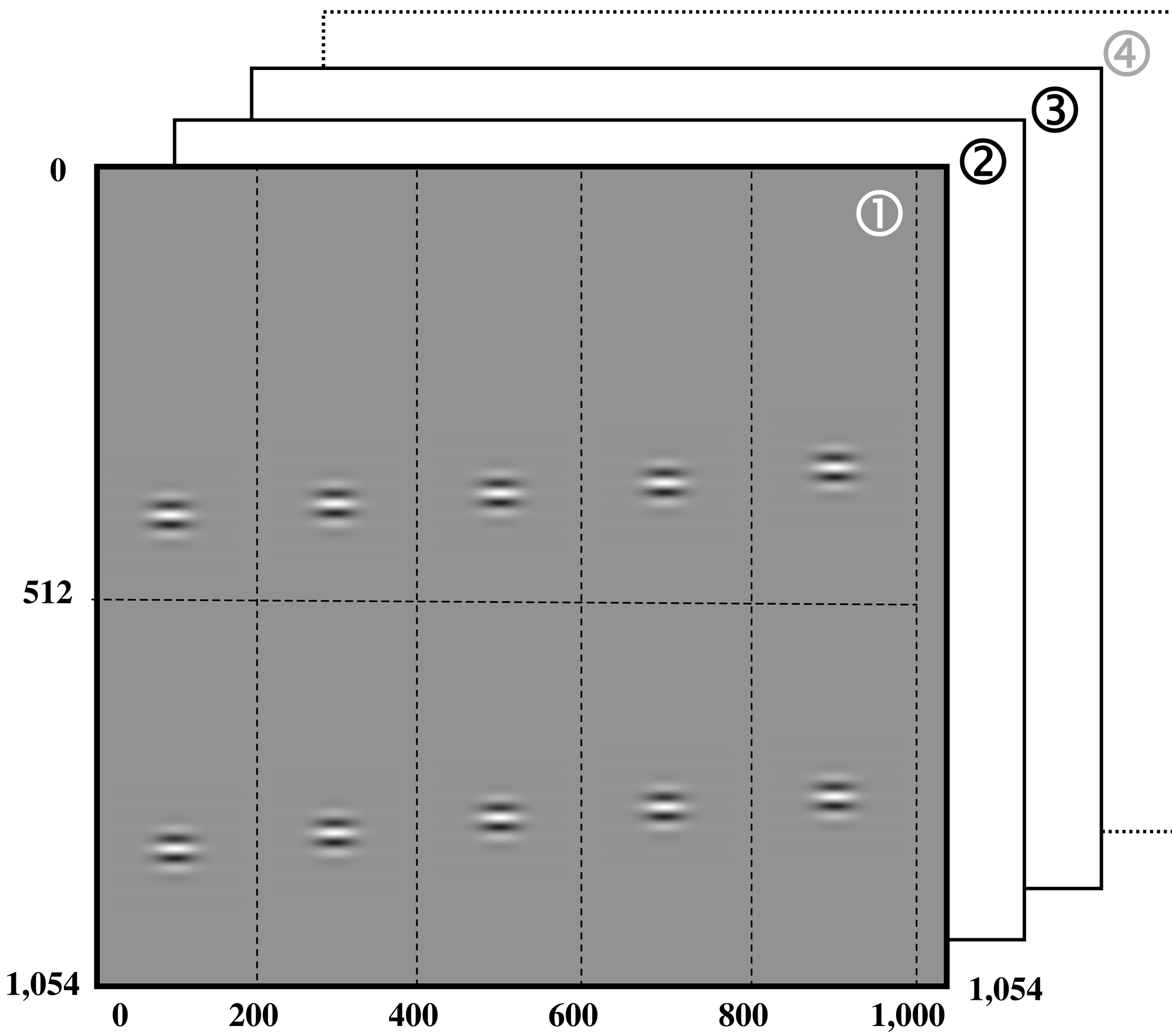

Figure 3: Four pages of video memory, with the subdivision into two rows of five strips shown. Each strip contains one frame of the sequence that is cycled to generate a moving Gabor on the screen. Diagram produced by the author.

tracking. Tracking a moving Gabor with scrolling sine wave is difficult because features of the grating move at a different velocity to the envelope, and near-by features (such as bright peaks) are very similar. This complicates the identification of the corresponding feature over successive time frames. The eye tracks the Gabor imperfectly, giving the perception of juddering or jittering, and non-smooth motion, particularly at higher scroll rates.

A number of textured objects could have been used; the physical speed of the envelope and drift direction and rate can also be varied independently in a square-windowed random dot kinetogram, for example. The hard-edge of the window could create problems, however. De Valois and De Valois (1991) [10] noted that similar stimuli with a hard window and viewed foveally produce motion contrast, whereby the motion signals of the drifting pattern and physical movement of the window become dissociated and are perceived as two independent objects. This study aims to distort the perception of velocity and location, which would not be viable if the stimulus appears to dissociate into separate entities. Also, a distinct border between object and background may generate undesirable edge effects, particularly along the leading and trailing edges, that may effect the perception of velocity and position in unknown ways.

Furthermore, a drifting sine grating is known to provide a very clear signal to populations of velocity-detectors. An area of drifting dots may not generate such a coherent motion signal. Thus, a Gabor function, with the underlying sine grating enveloped in a Gaussian blur, provides a good stimulus combining both a strong motion signal and soft-window. For all experiments the Gabor grating had a spatial frequency of 2.25 cycles per degree subtended at the eye.

3 Experiment 1: Disruption of velocity perception

3.1 Methods

In the first experiment, the distortion of velocity perception was studied. A two alternative binary choice experimental paradigm was used, as illustrated in Figure 4. The test consisted of a Gabor appearing on one side of the screen, close to the fixation point and therefore well within the fovea of the visual field. The Gabor moved up the screen for a random length of time, from a position below the fixation point to a position above the fixation point, before being removed from view. A second Gabor then appeared on the opposite side of the fixation spot, again at a randomised location, and moved up the screen for a randomised period. Motion in this experiment was always strictly upwards. The order of presentation (test Gabor or comparison Gabor) and the side of presentation (left or right of fixation point) were randomised. The subject was requested to press the left or right button on the response box to indicate which of the two Gabors they perceived to have been moving with the greatest velocity. The next stimulus was displayed only after the decision had been made.

The physical speed of the comparison Gabor was constant throughout runs, as was the drift rate of the test Gabor grating. Three drift conditions were tested in separate sets of runs: drift in same direction as envelope motion (upwards drift), no drift (grating stationary with respect to the window), and drift in opposite direction to envelope motion (downwards drift). In this experiment the drift rate was a sinusoidal phase shift of $\pi/18$ each frame (ie. just over 3 complete cycles a second). The physical upwards velocity of the test Gabor was the variable manipulated between runs. Nine levels of test Gabor velocity were used, in the range of 1 pixel/frame to 3 pixels/frame. This equates to a range of $4.7°$/s to $14.2°$/s (in degrees subtended at the eye). The comparison Gabor had a constant velocity of 2 pixels/frame ($9.4°$/s). An odd number of levels is chosen so that the middle level (ie. 2 pixels/frame, when the test and comparison Gabor have identical physical velocities) is explicitly tested. A pilot study determined that 9 was a large enough sample to obtain adequate resolution over the sigmoidal region and allow accurate calculation of the PSE. The size of the Gabor was 100 pixels ($3.9°$ subtended at the eye).

Each level was repeated ten times, in a random order, yielding a total of 90 presentations in one set. The set was repeated for each of the three drift conditions. These 270 runs were repeated on six subjects, each with normal or corrected-to-normal visual acuity. The author, LD, and supervisor, AA, were both aware of the experimental design and the visual effect being investigated. All other subjects, AW, ST, CM and AK, were naive to both the experimental design and the effect under investigation.

Steps were taken to eliminate the possibility that subjects were using other cues to judge speed. The duration of each presentation, namely the number of frames displayed from the stored sequence, was randomised between 25 and 75 (200ms - 620ms). This denied the subject duration information, and so the task could not be performed by simply judging which of the two Gabors moved a greater distance along the screen over a set time. Furthermore, the path of the Gabors was centred on the mid-line of the monitor, so that the stimulus passed alongside the fixation point exactly halfway through the presentation time. This denied the subjects spatial information, and the

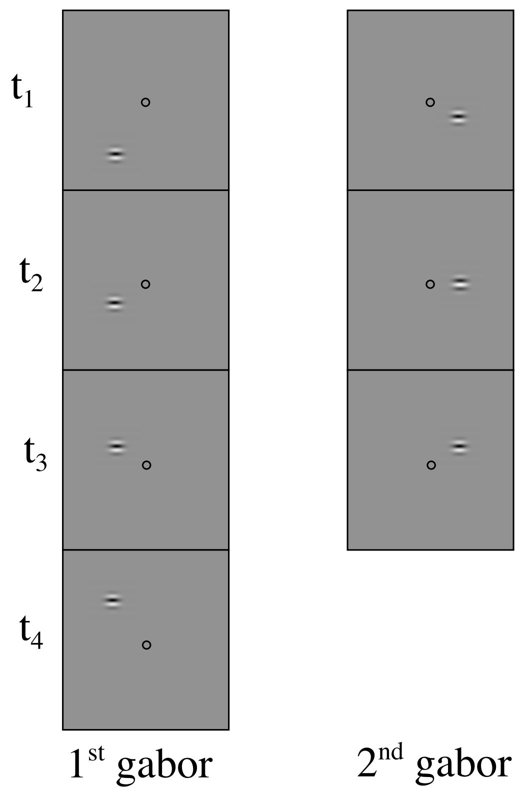

Figure 4: Schematic representation of one trial of Experiment 1. Here the 1st Gabor to be displayed is the static-drift comparison Gabor, which appears to the left of the fixation point and has a long presentation duration. After response from the subject the second Gabor is displayed on the opposite side of the screen. The test Gabor has a slow physical speed and fewer frames are displayed to give a shorter duration of presentation.

velocity discrimination task could not be performed by assessing which Gabor finished higher up the screen. A fixation point was used to keep constant, as far as possible, the eccentricity of stimulus presentation. For runs where the randomly-assigned presentation duration was longest, the Gabor began and ended its motion further away from the fixation point than for other runs. However, the Gabors were never more than 10° from the fixation point, and so fovea-periphery discrepancies were minimised.

The MatLab programme collated the responses corresponding to the same level within one set and dumped the data into a text file as two columns: drift speed and proportion of times that the subject selected the test Gabor as moving faster.

In experiments 1 and 2, the subjects were requested to use a response box to indicate which of the two Gabors in each run appeared to be moving faster or was more advanced, respectively. This two alternative binary choice (2ABC) experimental paradigm is well documented, and very widely used in psychophysical studies. The responses are collected, and plotted on a graph with the variable state along the x-axis and the proportion of occasions that the subject selected the test Gabor up the y-axis. For example, the results from Experiment 1 would have physical speed of the test Gabor (ranging from 1 to 3 pixels/frame) along the x-axis, and proportion of test Gabor responses (ranging from 0 to 1) up the y-axis, as seen in Figure 5.

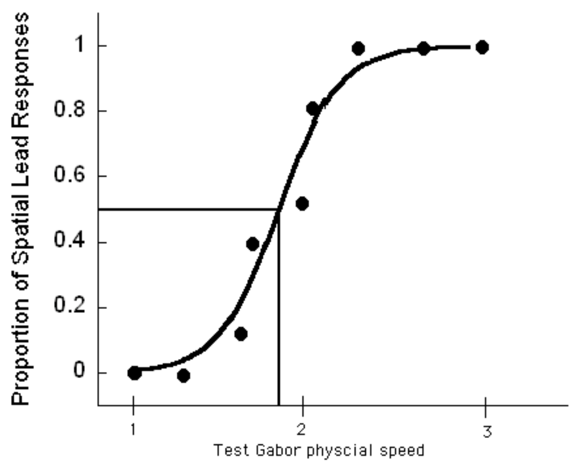

Figure 5: Example Psychometric plot with fitted sigmoid curve from Experiment 1. The y=0.5 line and calculated Point of Subjective Equality are marked. Here, the PSE is shifted below a test Gabor physical speed of 2 pixels/frame, and so the grating has created an accelerated velocity percept.

For a hypothetical subject with perfect perception that is unaffected by the illusion being generated the only responses would be 0.0 (always chose the comparison Gabor as fastest) and 1.0 (always chose the test Gabor as fastest). The switch would occur at x=2 (when test and comparison Gabor physical velocities are in fact identical), and so the psychometric data would follow a perfect step-function. In reality, however, subjects are not so invariant, and the cross-over between selecting mostly the test Gabor and selecting mostly the comparison Gabor is much less distinct, and a sigmoidal function is fitted to the data points. When the subject is unable to reliably detect which Gabor is moving fastest they will be effectively guessing randomly. So y=0.5 on the graph corresponds to the state when the subject can perceive no difference between test and comparison Gabor. This is known as the point of subjective equality, PSE. If this point on the fitted sigmoidal curve falls at x=2 the stimuli is generating no illusion – the subject's perception of the test Gabor's speed is unaffected by the drifting grating. A significant shift in the PSE indicates a perceptual distortion. If the PSE falls below 2 it means that the subject is perceiving test and comparison Gabors to be moving at the same speed when in fact the test Gabor has a lower physical speed. The interpretation is that the drifting grating has generated an accelerated speed percept. Conversely, if the PSE is shifted to higher physical speeds it signifies a retarded percept – the test Gabor has to be moving physically faster before it is perceived as equal to the comparison.

3.2 Results

Six subjects were tested, with the raw data collected presented in Appendix 2. Table 2, below, summarises the PSEs for the 6 subjects, and the calculated mean for each condition.

	Condition		
	Against	Static	With
ST	2.14	1.69	1.62
CM	2.09	1.77	1.16
AW	2.18	1.88	1.71
AK	2.18	1.81	1.53
LD	2.18	1.96	1.68
AA	2.11	1.86	1.66
Mean	2.15	1.83	1.56
S.D.	0.040	0.086	0.206
S.E.	0.016	0.032	0.084

Table 2: Calculated PSEs, with the mean, standard deviation (S.D.), and estimated standard error of the sample mean (S.E.) of the distributions.

These results are displayed graphically in Figure 6 , showing both the relative positions of the PSEs and the estimated standard error (the standard deviation of the sample means).

A standard statistical procedure can be used to test whether there is a significant difference between the means of these three samples. A two-tailed Student's T-test was performed to compare the Against condition to the Static condition, and the With condition to the Static condition, as shown in Table 3. The null hypothesis in both of these cases is that the samples have been drawn from a population with the same mean. The alternative hypothesis is that data has not been sampled from the same population, and thus that the grating drift condition has had a significant effect on the perception of velocity. The calculated p-values for both tests, given to 5dp, are displayed below.

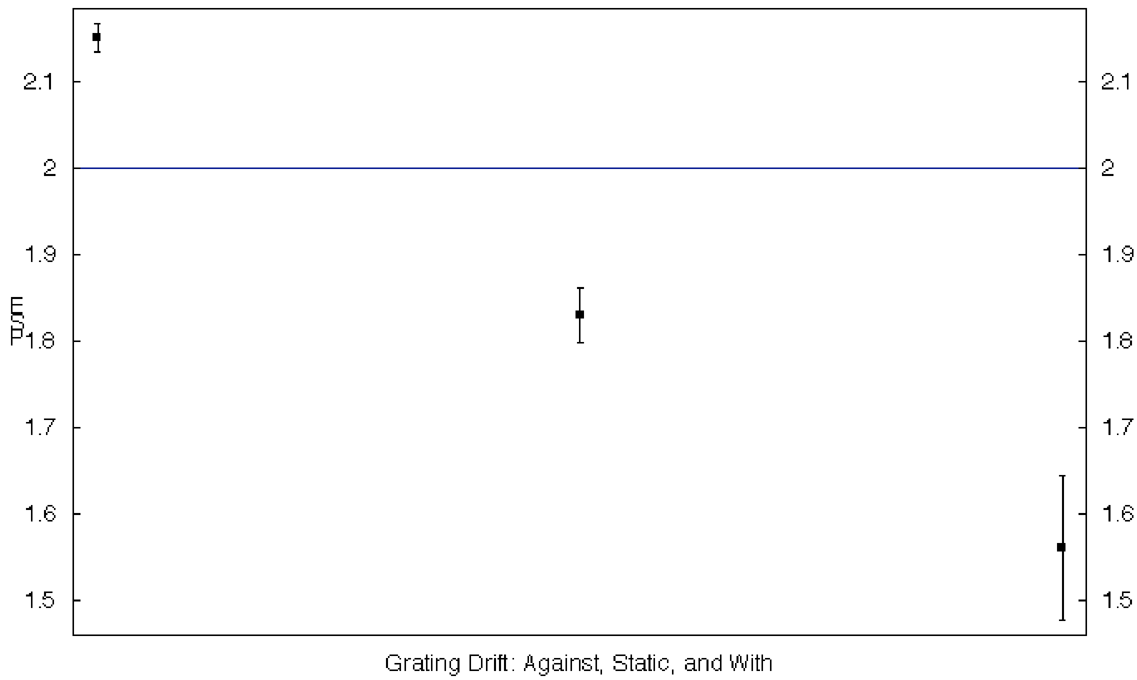

Figure 6: The PSE means and standard errors of the three grating drift conditions: Against, Static, and With.

	Test	
	Against-Static	With-Static
p-value	0.00001	0.02232

Table 3: p-values calculated by applying a two-tailed Student's T-test

The p-value is the probability that two randomly-selected samples from the same population have means as different as the two being tested. The null hypothesis can be rejected if the calculated p-value is less than an alpha-value of 0.05. This represents the 2.5% of the area under the t distribution in the extreme of both tails.

Thus, in both of these comparisons (especially the Against condition) the null hypothesis can be rejected, and the alternative hypothesis accepted. The effect of the drifting sine grating has indeed had a statistically significant effect upon the perceived envelope velocity. Drift in the same direction as motion creates a perceptual acceleration of 28% (relative to the physical speed of 2 pixels per frame), and drift against actual motion creates a 8% slow-down effect. The fact that even when the test Gabor has a static grating the subjects consistently perceive it to be moving faster than the comparison is a curious result. Assuming that this is not an artifact of the program generating the illusions, there is a known effect that might account for this anomaly. It will be treated in the Discussion.

A brief study was conducted into the magnitude of the generated velocity distortion, and the disparity between the speed-up and slow-down effect. A single test subject, LD, was used to gather extra data points at additional drift rates. The raw data is presented in Appendix 2, and the calculated PSEs in Table 4.

Drift Rate (pixels per frame in direction of motion	PSE
20	1.73
15	1.68
10	1.56
5	1.80
0	1.83
-5	2.00
-10	2.15
-15	2.38
-20	2.56

Table 4: Calculated PSEs for a greater range of drift rates

The strength of the velocity distortion (displacement of PSE) is a function of both the physical envelope velocity and grating drift rate and so can be thought of as a two-dimensional surface. So far only two points on this illusion landscape have been sampled for each subject. This extension is an attempt to explore more widely. The envelope velocity was kept constant, and the grating drift rate varied between a phase shift of $\pi/9$ per frame in the direction of motion and $\pi/9$ per frame against motion. This pilot study is effectively taking a slice through the illusion surface to see how the velocity distortion varies with grating scroll rate, as shown in Figure 7.

As can be seen, the retarded velocity perception is linear in the region studied. The relationship between forward drift and velocity distortion is less clear. The data points are more widely scattered and the PSE does not decrease monotonically. A further point to note is that the magnitude of the distortion created is greater for reverse drifts

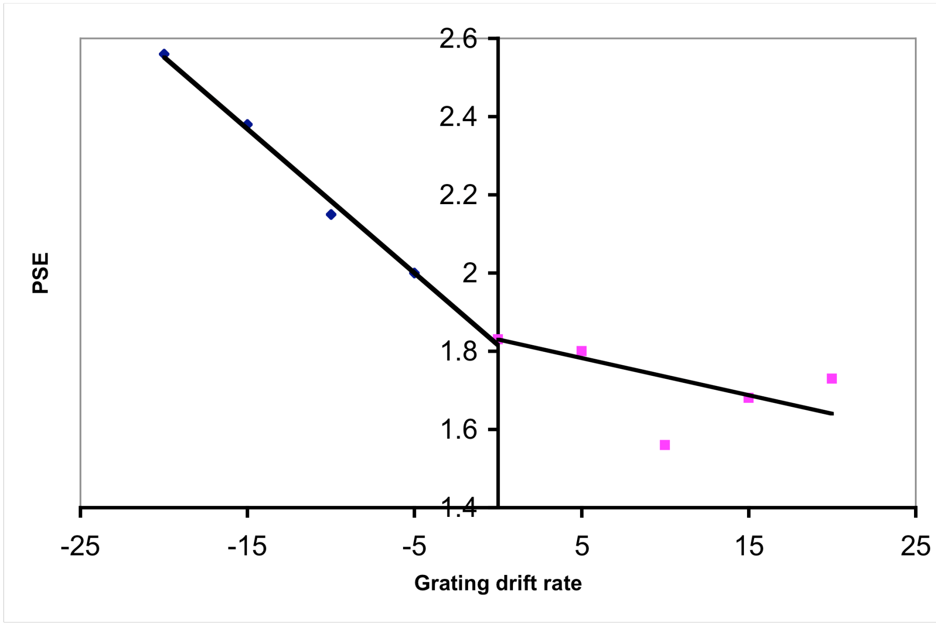

Figure 7: Graph of calculated PSEs against grating drift rate (+ve indicates drift in same direction as motion)

than forward drifts. A backwards scrolling grating is more effective at generating a motion illusion.

4 Experiment 2: Disruption of position perception

4.1 Methods

The second experiment was an attempt at measuring the magnitude of spatial mislocalisation caused by the scrolling sine grating. As in Experiment 1, the test Gabor was presented for a random duration and with a random start location below the fixation point. The physical speed was kept constant, and the sine grating drifted either upwards or downwards with a phase shift of $\pi/18$ every frame (ie. just over 3 complete cycles per second). The side of presentation was randomised, but no comparison Gabor was used. The experiment was not a 2ABC design, and no choice box was used. Instead, the subject was displayed the test Gabor, and then requested to indicate the location that they perceived the patch to have reached when it disappeared. The subject used the computer mouse to move a Gabor patch, with identical size and spatial frequency but static grating, around the screen, and clicked the mouse button when satisfied with the positioning. Only then was the next stimulus displayed.

The MatLab programme collated data into two categories: runs with the grating drifting upwards, and runs with the grating drifting downwards. The distance between the actual end location of the test Gabor and the position indicated by the subject was calculated by the programme. Horizontal variance was ignored, and only the error in the elevation above the fixation point (only y co-ordinate compared) was recorded. Errors within the same condition (ie. upwards or downwards grating drift) were averaged across all runs. The programme saved the results in a four-cell table to a text file: two conditions (upwards and downwards grating drift) against the average number of pixels in error. A negative error indicated that on average the subject had underestimated the end position of the test Gabor, and selected a location nearer to the fovea. A positive error signified the converse, with the subject on average selecting locations ahead of the actual endpoint, towards the periphery.

4.2 Results

No useful data could be collected from the second experiment. The average positional error varied wildly between separate runs of the same experiment, even for the same subject. The magnitude of the effect varied between just a few pixels to as many as 40 (almost the radius of the test Gabor). Not even the sign of the error, ie. whether the subject estimated behind or in front of the actual position, was constant. None of the data collected was systematic, and after trying to persevere for a while the experiment was abandoned due to an impractical methodology. An alternative approach was envisioned, and implemented as Experiment 3.

5 Experiment 3: Disruption of position perception

5.1 Methods

The methodology of Experiment 2 had failed to produce systematic results, and so Experiment 3 was another attempt at measuring the extent to which this class of illusion could disrupt accurate localisation. The 2ABC paradigm was used again, with an experimental set-up very similar to that used in the first experiment. In this case, both the test and comparison Gabors were displayed simultaneously, appearing at the same instant and running up the screen with the same physical speed and for an equal length of time. The grating of the comparison Gabor was again static relative to the envelope, and the test Gabor grating scrolled at a set rate, in the same direction as envelope motion in the first condition and backwards in the second. Either the test or comparison Gabor was given a slight and constant displacement ahead of the other, as seen in Figure 8. The degree of physical advancement was varied between 0 and 6 pixels (0 - 0.24° subtended at the eye). The Gabor envelope size was 60 pixels (2.4° subtended at the eye). The subject was requested to press the left or right button on a response box to indicate which Gabor patch seemed to be more advanced.

With respect to the comparison Gabor, the test patch was advanced at 9 levels ranging from -6 to +6 pixels. Each of these levels was repeated 10 times in random order. These 90 runs were performed for both conditions (forwards or backwards test Gabor scrolling), yielding a total of 180 runs viewed by each subject. The author, LD, and two supervisors, AA and DA, were aware of the experimental design and visual effect being studied. Other subjects;, ST, TG, and AW, were naive to both the experimental design and effect under investigation.

The MatLab programme collated data, and output two tables (one for each condition) for each subject. The degree of test Gabor physical displacement (-6 to +6 pixels) was listed against the proportion of times the subject perceived the test Gabor to be further ahead.

5.2 Results

The last experiment was an attempt to manipulate the perception of location with the underlying sine grating. 6 subjects were tested, and the raw data collected is presented in Appendix 2. Table 5, below, summarises the PSEs for the 6 subjects, and the calculated mean for each condition. Figure 9 displays the means and estimated standard errors.

A two-tailed Student's T-test was performed on the PSE means for the two conditions, with the null hypothesis that they have both been sampled from the same population. A p-value of 0.01977 was calculated. Taking alpha to be equal to 0.05 again, the null hypothesis can be rejected and the alternative hypothesis accepted. The forwards or backwards-drifting gratings do indeed disrupt the accurate localisation of the moving Gabor. Grating drift in the same direction as envelope motion causes observers to overestimate position. On average the subjects perceived the test and comparison Gabors to be level when the test was in fact a pixel behind. Conversely, a reverse drift causes observers to perceive the Gabor's position behind the reality.

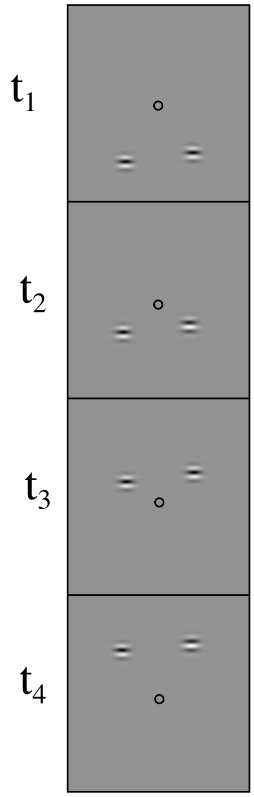

Figure 8: Schematic representation of one trial of Experiment 3. Here the left-hand Gabor is the comparison, and the right-hand one the test Gabor. Both appear simultaneously, move at the same physical velocity, and are presented for the same duration. The test Gabor has been physically displaced ahead of the comparison by a constant amount.

	Condition	
	With	Against
LD	-1.73	1.28
DA	-0.05	0.96
AA	-1.42	0.04
ST	-0.54	-1.45
TG	-1.11	0.15
AW	-1.63	0.73
Mean	-1.08	0.285
S.D.	0.662	0.973
S.E.	0.270	0.397

Table 5: Calculated PSEs, with the mean, standard deviation and estimated standard error.

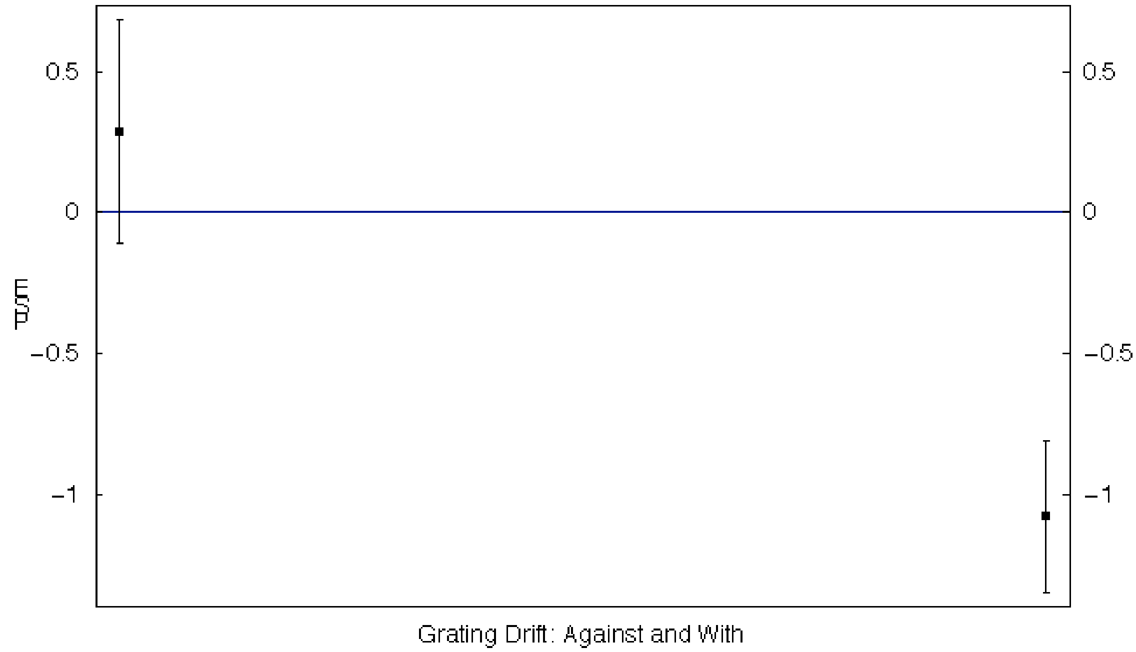

Figure 9: The PSE means and standard errors of the two grating drift conditions: Against and With.

6 Discussion

The literature review presented in the Introduction gives an overview of the current research landscape concerned with velocity detection mechanisms, and illusions which distort the neuronal representation of both an object's velocity and its position. Many factors are known to affect the correct assessment of velocity, including contrast, object size, and sine grating spatial frequency and orientation. Motion and location signals can also interact to modify the perceived object position. De Valois and De Valois (1993) [De Valois 1993] investigated how eccentricity of presentation and hardness of envelope affect the occurrence of motion integration or contrast. This present study is the first to explore the extent to which integration of an object's texture motion and physical movement can disrupt the perception of both its velocity and position.

Experiment 1 found very strong statistical support for the hypothesis that a grating drifting in the same direction as physical motion increases the perceived speed, and that a reverse drift creates a percept of retarded speed. Curiously, the data also demonstrated a perceptual acceleration when the test Gabor grating was in-fact static. The programme was checked to ensure that there was no bug creating a residual grating drift when it should have been static. There could, however, be a psychometric effect that is uniformly decreasing all of the calculated PSEs. Such an effect would only be detectable when the expected value is already known, ie. for the static condition (an expected PSE of 2 pixels/frame).

It is known that the human visual system is not equally sensitive to differences in velocity for all velocities. Within the optimal velocity range humans can perform accurately in a speed discrimination task with a velocity difference as little as 7% [13]. But for motion faster or slower than this the brain cannot discriminate the faster of two objects so accurately, even if the difference is quite large. Depending on whether the initial speed is greater or lower than the optimum, an increment in speed can result in an increase or a decrease in accuracy. There is a bias in the error distribution. Thus it is possible in this first experiment that the visual system can accurately determine the faster of the two Gabors when the test is moving rapidly but not when it is moving slowly. At lower test Gabor velocities the observer will still be guessing largely randomly, and this will shift the fitted sigmoidal psychometric function to the left, and hence the calculated PSE to a lower value. This would explain why Experiment 1 recorded a perceptual speed-up even when the test grating was static. All three calculated PSEs would have been decreased by biased sigmoidal functions, but only when the expected value was known, in the case of the static grating, would this effect be detectable. The influence of this bias in the error distribution for velocity discrimination is uniform, affecting the PSE of all three conditions, and so it does not invalidate the findings of this experiment. The statistical tests were based on the relative differences between the three conditions, and not the absolute value of the calculated PSE.

The perceptual speed-up or slow-down is a function of both physical speed of the object and grating drift rate, and so the magnitude of the illusion is a two-dimensional surface dependent on these two variables. The second part of Experiment 1 attempted to map a slice of this illusion surface. Only one subject was used and so this constitutes no more than a pilot study for further research, but the results were intriguing. The retardation effect is certainly stronger and less variable than the acceleration percept. One explanation for this may be the problem of dissociation of motion signals described by Zhang *et al* (1993) [12]. They found that hard apertures favoured motion contrast over of integration, and a similar effect may occur with higher envelope velocities. It can be conjectured that for physical velocities beyond a certain threshold (the fastest used here was 3 pixles/frame, equivalent to 14.2°/s subtended at the eye) the additional grating drift motion is apparent to the visual system as a distinct entity. The two motion signals begin to dissociate, and motion integration is less effective or consistent. This would explain the scattered data points with increasing drift rate seen in Figure 7. It is possible that at lower physical speeds the forwards drift generates a more powerful illusory percept, and the backwards drift is less effective. Further research could perform a more extensive surveying of this illusion surface, using a larger sample of observers. It would be expected that there exists a maximum on this surface, where increasing the drift rate reduces the magnitude of the motion illusion as the motion signals dissociate and integration fails.

The second experiment failed to generate any consistent results at all. The ideal set-up for this experiment would have involved displaying the moving stimulus on a touch-sensitive screen. The subject could then immediately indicate the precise location simply by pointing to it. This minimises the layers of abstraction in the task designed to estimate where the visual system perceived the Gabor to have disappeared. For lack of such equipment, the actual experimental design employed a computer mouse that the subject used to move a Gabor pointer around the screen. This is a much slower and less immediate method of assessing perceived position, and complicates the task with aspects of memory and recall of a location on a featureless background.

Furthermore, repositioning the Gabor pointer involved continually clicking the mouse button, and moving the mouse back to a suitable initial position between runs. These factors further hindered an already difficult task. The results are not reproduced here, but did not show a consistent difference between forwards and reverse grating drifts, even with a well-practiced subject.

Experiment 3 demonstrated that grating drift could also disrupt the accurate perception of spatial position. A statistically significant difference between the grating drift conditions (with or against physical motion) was found. Texture scrolling in the same direction as physical motion caused a forwards spatial shift, and reverse grating drift caused the perceptual position to lag behind the actual. The two motion detection pathways, long-range and short-range, are being fed contradictory input. The drifting sine grating activates the short-range mechanism, and displacement of the envelope activates the long-range mechanism. The sine grating will also activate the long-range system slightly, however, as the prominent black and white patches may be tracked across time frames.

Although this effect is consistent and statistically significant it does not cause a large spatial distortion. A Gabor with a diameter of 60 pixels (although the border region is indistinct as the Gaussian envelope merges the grating with the background) is shifted by only one pixel. It may be possible for the magnitude of this spatial distortion to be increased with an optimal combination of physical speed relative to Gabor size and grating drift rate. Research could be extended along this course.

7 Conclusion

The project has succeeded in its fundamental aim. Psychophysical experiments were designed to test the hypothesis that objects displaying a scrolling texture could disrupt the accurate perception of not only their velocity, but also their instantaneous position. Both of these illusions were indeed generated, and the effect was found to be statistically significant. These results complement the pre-existing literature on illusions that distort the perception of velocity or expose the interaction between motion and position encoding in the human visual system.

This research was originally intended to investigate the *Passing Cloud* dynamic pattern of the common cuttlefish and other cephalopod species. Unfortunately, no video recordings or even good quality photographs could be acquired. No data on the parameters of the display, such as duration or spatial or temporal frequency could be extracted, and so it was not possible to compare it to the stimuli used in the psychophysical experiments. Regarding the position-distortion experiment, a cuttlefish secondary defence generating a spatial distortion of only a few percent of body length would probably have little survival value. It is possible, however, that if the Passing Cloud display functions in this manner, natural selection may have found the optimal permutation of parameters to generate a much stronger illusion in its predators or prey. It is unknown whether the display is modified depending on the situation; attacking a prey item or fleeing a predator, as they are likely to have very different visual systems and susceptibilities to the illusion. Whether the visual systems of a cuttlefish's predators and prey are even susceptible to this kind of illusion is unknown. This class of motion illusions relies on the fact that the envelope motion can be captured by texture motion. The human visual system cannot dissociate the two motion signals, but this may not be true of other species.

There is thus a great expanse of further research that could be performed into this question of motion- and position-distorting illusions and their applicability to predation.

8 Appendix 1: Programme listing for Experiment 1

```
%***************** Define your global variable up here ************************

 subj='Derek';           % Enter the subjects initials here

 cond = 2;              % 0 for drift in opposite direction to motion (ie. down)
                        % 1 for static comparator
                        % 2 for drift in same direction as motion (ie. up)

%***************** Define your global variable up here ************************


fid = fopen('WackyFinish.txt','a');
%fclose(fid);

%Initialise the vsg card then check that it initialised O.K.
CheckCard = vsg(vsgInit,'');
if (CheckCard < 0)
return;
end;

CheckCard=vsg(vsgSetVideoMode,vsgPANSCROLLMODE);
if (CheckCard < 0)
return;
end;


Time = datestr(now);
fprintf(fid, '\n\n%s \n', Time);

vsg(vsgSetViewDistMM,570);

fprintf(fid,'Observer: %-s \n',subj);
fprintf(fid,'Condition 1=opposite 2=with \n\n');

if cond == 0
    CompDrift = -10;
elseif cond == 1
    CompDrift = 0;
else
    CompDrift = 10;
end;
```

```
% Find out the horizontal and vertical resolution of the vsg's
% drawing pages and screen dimensions.
Height = vsg(vsgGetSystemAttribute,vsgPAGEHEIGHT);
scrWd  = vsg(vsgGetScreenWidthPixels);
scrHgt = vsg(vsgGetScreenHeightPixels);


disp('Running . . .');
GabsPerPage = 10;


  %Now draw a mask onto the overlay page.
%***********************************

%Target overlay memory for drawing and set the vsg to use the overlay
%in the correct mode.
  vsg(vsgSetCommand,vsgOVERLAYMASKMODE);

%Set pixel-level(1) on the overlay palette to mean grey.
  Buff(1).a = 0.5;
  Buff(1).b = 0.5;
  Buff(1).c = 0.5;
  Buff(2).a = 0;
  Buff(2).b = 0;
  Buff(2).c = 0;
  Buff(3).a = 1;
  Buff(3).b = 1;
  Buff(3).c = 1;
  for k = 2:256
    Buff(k).a = 0;
    Buff(k).b = 0;
    Buff(k).c = 0;
  end
  vsg(vsgPaletteWriteOverlayCols,Buff, 1, 1);

%Clear overlay page(0) with pixel-level(1).
  vsg(vsgSetDrawPage,vsgOVERLAYPAGE, 0, 1);

%Set pen1 pixel-level to 0. (the transparent pixel-level
%in vsgOVERLAYCOLOURMODE.
  vsg(vsgSetPen1,0);

%Set the draw origin back to the centre of the screen and draw a
%square (this Willy be a window through the overlay) the same size as
%the Gabor.
  vsg(vsgSetDrawOrigin,(scrWd/2), scrHgt/2);
  % CHANGE THE 200 TO 150
```

```
  vsg(vsgDrawRect,0, 0, 200, 500);
  vsg(vsgSetPen1,2);
  vsg(vsgDrawOval,0,0,8,8);
  vsg(vsgSetPen1,1);
  vsg(vsgDrawOval,0,0,4,4);

  FrameRate = vsg(vsgGetSystemAttribute,vsgFRAMERATE);
  vsg(vsgSetSpatialUnits, vsgPIXELUNIT);

%Clear LUT table(0) with black then write it to the palette
  Black.a = 0.0;
  Black.b = 0.0;
  Black.c = 0.0;
  vsg(vsgLUTBUFFERClear,0, 0, 256,Black);
  vsg(vsgLUTBUFFERtoPalette,0);


  NumPages = vsg(vsgGetSystemAttribute,vsgNUMVIDEOPAGES);


%   Set the parameters of the Gabors:
% CycleNum      - Number of sine waves within the Gabor
% PhaseShift    - Scroll speed of sine, in degree per frame. +ve = upwards
% Ydisp         - the ypos dispalcement of the Gabor
% YSpeed        - shift in Yposn each frame
% Offset        - offset Gabor position from the centre line of the screen

  GaborSize = 60;
  GaborAngle = 0;
  CycleNum = 5;
  SpatFreq = 2;

 %Set the size of the Gabors so that we can draw 10 to a page of video memory.
  StripWidth = GaborSize*2;
  StripHeight = Height / 2;


% Gabor A = COMPARISON Gabor (static)
  PhaseA = 0;
  PhaseShiftA = 0;
  YdispA = 50;% - floor(100*rand(1))
  YSpeedA = 2;

% Gabor B = TEST Gabor
  PhaseRange = 30;
  % i.e. Phase runs from -15 to + 15
  % PhaseShiftB set in Presentation loop
```

```
 DurationA = 50


 %Calculate the YPos step size (dYPos).
 dYPos = floor( (StripHeight - GaborSize)/(GabsPerPage * NumPages) );


 %Change the drawing origin to the top-left of the page.
 vsg(vsgSetDrawOrigin,0, 0);



 vsg(vsgSetDrawPage,vsgVIDEOPAGE, NumPages-1, 127);
 vsg(vsgSetPen2,127);
 vsg(vsgSetCommand,vsgVIDEOCLEAR);
 vsg(vsgSetDisplayPage,NumPages-1);

 %Set the start and end colours to draw the Gabors with.
 vsg(vsgSetPen1,1);
 vsg(vsgSetPen2,255);


%%%%%%%%%%% Set up and Start Programme Loop %%%%%%%%%%%
 TotalTrial_X = zeros(100);
 TotalTrial_Y = zeros(100);
 vsg(cbboxOpen,respCT3);
 vsg(cbboxFlush);
 vsg(vsgSetDisplayPage,NumPages-1);

 Presentations = 10;
 Levels = 2;

 FirstTrial = -1;

 for f=1:Presentations;
     NumTrials = Levels;
     Trial = Randperm(Levels);
     for z=1:Levels

         if Trial(z) == 1
             CompDrift = -5;
         else
             CompDrift = 5;
         end;
```

```
%%%% SECOND Gabor:
ThisPage = -1;
Yfix = 0;

SpeedStepSize = (2/(Levels-1));
YSpeedB = 3;%1 + ((Trial(z)-1)*SpeedStepSize)


Phase = 0;

DurationB = (0.25*FrameRate) + floor(rand(1)*(0.25*FrameRate));

YdispB = DurationB;


DurationTotal = DurationB +2;
Order = rand(1);

if (rand(1) > 0.5)
    RandOff = -1;
else RandOff = 1;
end;
Offset = 0;%RandOff * 60;

for j = 0: DurationTotal

    if rem(j,GabsPerPage) == 0
        ThisPage = ThisPage+1;
        vsg(vsgSetDrawPage,vsgVIDEOPAGE, ThisPage, 127);
        if j > 0
            Yfix = Yfix+(2*StripHeight);
        end;
    end;

    XposB = floor((mod(j,5)*StripWidth)-(scrWd/2)+(GaborSize));


    YposB = floor(floor(j/5)*StripHeight)+StripHeight/2-Yfix-scrHgt/2;

    % Increment the Yinit and Sine phase each frame
    YdispB = YdispB - YSpeedB;
    Phase = Phase + CompDrift;
    PhaseB = rem (Phase,360);


    Xpos = floor(mod(j,5)*StripWidth)+StripWidth/2;
```

```
      Ypos = floor(floor(j/5)*StripHeight)+StripHeight/2-Yfix;


      vsg(vsgSetPen1,127);
      vsg(vsgDrawRect,Xpos,Ypos,StripWidth,StripHeight);
      vsg(vsgSetPen1,1);

      vsg(vsgDrawGabor,Xpos, Ypos+YdispB, GaborSize, GaborSize, GaborAngle,
                                         SpatFreq, GaborSize/6, PhaseB);

      if j == 0
          Willy(j+1).Page   = NumPages-1;
          Willy(j+1).Xpos   = 0;
          Willy(j+1).Ypos   = 0;
          Willy(j+1).Stop   = 0;
          Willy(j+1).Frames = 50;
      elseif j == DurationTotal
          Willy(j+1).Page   = NumPages-1;
          Willy(j+1).Xpos   = 0;
          Willy(j+1).Ypos   = 0;
          Willy(j+1).Stop   = 1;
          Willy(j+1).Frames = 50;
      else
          Willy(j+1).Page   = ThisPage;
          Willy(j+1).Xpos   = XposB;
          Willy(j+1).Ypos   = YposB;
          Willy(j+1).Stop   = 0;
          Willy(j+1).Frames = 1;
      end;
      Willy(j+1).ovPage = 0;
      Willy(j+1).ovXpos = 0;
      Willy(j+1).ovYpos = 0;
  end;


%Load a black to white ramp into a buffer and write it to LUT table(0).
  for k = 1:256
    Buff(k).a = (k-1)/255;
    Buff(k).b = (k-1)/255;
    Buff(k).c = (k-1)/255;
  end;
  vsg(vsgLUTBUFFERWrite,0,Buff);

%Load the page cycling data into the vsg card.
  vsg(vsgPageCyclingSetup,DurationTotal+1,Willy);

%Write the contents of LUT 0 to the palette.
```

```
  vsg(vsgLUTBUFFERtoPalette,0);

%Send the command to start the vsg page cycling.
vsg(cbboxFlush);
pause(0.25)
vsg(cbboxFlush);

vsg(vsgSetCommand,vsgCYCLEPAGEENABLE);



Dimensions = get(0,'ScreenSize');
rect=[0;0;Dimensions(3);Dimensions(4)];
set(gcf,'position',rect);
waitforbuttonpress

Stop = 0;
vsg(vsgSetPen1,0);
vsg(vsgSetPen2,255);
% vsg(vsgSetDrawMode,vsgCENTREXY);
vsg(vsgSetDrawOrigin,(scrWd/2), scrHgt/2);

vsg(vsgSetDrawPage,vsgVIDEOPAGE, NumPages-1, 127);
vsg(vsgDrawGabor,0, 0, GaborSize, GaborSize, GaborAngle, SpatFreq,
                                GaborSize/6, 0);

waitforbuttonpress;
XY_start = get(gcf,'CurrentPoint');
vsg(vsgSetCommand,vsgCYCLEPAGEDISABLE);
vsg(vsgSetCommand,vsgOVERLAYDISABLE);
vsg(vsgSetDisplayPage,NumPages-1);

while Stop < 1
    [x,y,button] = ginput(1)

    if button == 3
        Stop = Stop+1;
    end;


    XY = get(gcf,'CurrentPoint');
    Xdiff = XY_start(1) - XY(1);
    Ydiff = (XY_start(2) - XY(2))

    Yresult =  Ydiff - YdispB

    vsg(vsgSetDrawPage,vsgVIDEOPAGE, NumPages-1, 127);
```

```
    vsg(vsgDrawGabor,-Xdiff, Ydiff, GaborSize, GaborSize, GaborAngle,
                                SpatFreq, GaborSize/6, 0);


    [CT3Box status]=vsg(cbboxCheck);
    if (status ~= respEMPTY)
        Stop = Stop+1
    end;
end;
vsg(vsgSetDrawPage,vsgVIDEOPAGE, NumPages-1, 127);
vsg(vsgSetCommand,vsgOVERLAYMASKMODE);

%TotalTrial_X(Trial(z)) = TotalTrial_X(Trial(z)) +Xdiff;
TotalTrial_Y(Trial(z)) = TotalTrial_Y(Trial(z)) + Yresult;

%Change the drawing origin to the top-left of the page.
vsg(vsgSetDrawOrigin,0, 0);



end;

end;



for v = 1:NumTrials
    fprintf(fid, '%6.2f     %6.2f \n', v, TotalTrial_Y(v)/Presentations );
end;

fclose(fid);

vsg(cbboxBuzzer,respSEC05,respTONE1);
```

9 Appendix 2: Raw data

9.1 Experiment 1

ST					
Condition Against		Static		With	
1.00	0.00	1.00	0.20	1.00	0.30
1.25	0.20	1.25	0.10	1.25	0.40
1.50	0.10	1.50	0.60	1.50	0.50
1.75	0.30	1.75	0.30	1.75	0.50
2.00	0.30	2.00	0.80	2.00	0.30
2.25	0.70	2.25	0.80	2.25	1.00
2.50	0.70	2.50	1.00	2.50	0.90
2.75	0.80	2.75	0.80	2.75	0.90
3.00	0.90	3.00	1.00	3.00	0.90
PSE	2.14	PSE	1.69	PSE	1.62
D.T.	0.38	D.T.	0.38	D.T.	0.59

CM					
Condition Against		Static		With	
1.00	0.00	1.00	0.20	1.00	0.40
1.25	0.00	1.25	0.10	1.25	0.50
1.50	0.00	1.50	0.40	1.50	0.80
1.75	0.20	1.75	0.70	1.75	0.90
2.00	0.30	2.00	0.40	2.00	0.90
2.25	0.80	2.25	0.70	2.25	0.90
2.50	0.80	2.50	0.90	2.50	1.00
2.75	1.00	2.75	1.00	2.75	1.00
3.00	1.00	3.00	1.00	3.00	1.00
PSE	2.09	PSE	1.77	PSE	1.16
D.T.	0.18	D.T.	0.43	D.T.	0.32

AW					
Condition					
Against		Static		With	
1.00	0.00	1.00	0.10	1.00	0.20
1.25	0.00	1.25	0.00	1.25	0.30
1.50	0.00	1.50	0.10	1.50	0.20
1.75	0.20	1.75	0.30	1.75	0.40
2.00	0.50	2.00	0.70	2.00	0.90
2.25	0.30	2.25	0.90	2.25	0.90
2.50	0.90	2.50	0.90	2.50	1.00
2.75	1.00	2.75	0.90	2.75	1.00
3.00	0.90	3.00	1.00	3.00	1.00
PSE	2.18	PSE	1.88	PSE	1.71
D.T.	0.26	D.T.	0.17	D.T.	0.26

AK					
Condition					
Against		Static		With	
1.00	0.00	1.00	0.00	1.00	0.00
1.25	0.00	1.25	0.00	1.25	0.40
1.50	0.00	1.50	0.10	1.50	0.20
1.75	0.00	1.75	0.50	1.75	1.00
2.00	0.40	2.00	0.70	2.00	0.90
2.25	0.50	2.25	0.90	2.25	1.00
2.50	0.90	2.50	1.00	2.50	1.00
2.75	0.90	2.75	1.00	2.75	1.00
3.00	1.00	3.00	1.00	3.00	1.00
PSE	2.18	PSE	1.81	PSE	1.53
D.T.	0.19	D.T.	0.18	D.T.	0.16

LD					
Condition Against		Static		With	
1.00	0.00	1.00	0.00	1.00	0.00
1.25	0.00	1.25	0.00	1.25	0.00
1.50	0.00	1.50	0.20	1.50	0.30
1.75	0.00	1.75	0.20	1.75	0.70
2.00	0.40	2.00	0.60	2.00	0.70
2.25	0.50	2.25	0.70	2.25	0.90
2.50	0.90	2.50	1.00	2.50	1.00
2.75	0.90	2.75	1.00	2.75	1.00
3.00	1.00	3.00	1.00	3.00	1.00
PSE	2.18	PSE	1.96	PSE	1.68
D.T.	0.19	D.T.	0.22	D.T.	0.20

AA					
Condition Against		Static		With	
1.00	0.00	1.00	0.10	1.00	0.10
1.25	0.00	1.25	0.10	1.25	0.30
1.50	0.10	1.50	0.20	1.50	0.50
1.75	0.40	1.75	0.30	1.75	0.20
2.00	0.40	2.00	0.70	2.00	0.90
2.25	0.60	2.25	0.80	2.25	1.00
2.50	0.60	2.50	1.00	2.50	1.00
2.75	1.00	2.75	1.00	2.75	1.00
3.00	1.00	3.00	1.00	3.00	1.00
PSE	2.11	PSE	1.86	PSE	1.66
D.T.	0.33	D.T.	0.23	D.T.	0.30

Speed: 5	
1	0
1.25	0
1.5	0.1
1.75	0.4
2	0.8
2.25	1
2.5	1
2.75	1
3	1
PSE	1.8

Speed: 15	
1	0
1.25	0.2
1.5	0.3
1.75	0.5
2	0.9
2.25	1
2.5	0.9
2.75	1
3	1
PSE	1.68

Speed: 20	
1	0
1.25	0
1.5	0.3
1.75	0.6
2	0.7
2.25	0.9
2.5	0.9
2.75	0.9
3	1
PSE	1.73

Speed: -20	
1	0
1.25	0
1.5	0
1.75	0
2	0
2.25	0.2
2.5	0.3
2.75	0.9
3	0.9
PSE	2.56

Speed: -5	
1	0
1.25	0
1.5	0
1.75	0.1
2	0.3
2.25	1
2.5	1
2.75	1
3	1
PSE	2

Speed: -15	
1	0
1.25	0
1.5	0
1.75	0
2	0
2.25	0.3
2.5	0.7
2.75	0.9
3	1
PSE	2.38

9.2 Experiment 3

Observer: LD

Drift (+ve = with	Offset (+ve = Ahead	Proportion Test chosen
10.00	-6.00	0.00
10.00	-4.50	0.10
10.00	-3.00	0.10
10.00	-1.50	0.60
10.00	0.00	0.90
10.00	1.50	1.00
10.00	3.00	1.00
10.00	4.50	1.00
10.00	6.00	1.00

PSE : -1.73

-10.00	-6.00	0.00
-10.00	-4.50	0.00
-10.00	-3.00	0.00
-10.00	-1.50	0.00
-10.00	0.00	0.20
-10.00	1.50	0.60
-10.00	3.00	0.80
-10.00	4.50	1.00
-10.00	6.00	0.90

PSE : 1.28

Observer: DA

Drift(+ve = with	Offset(+ve = Ahead	Proportion Test chosen
10.00	-6.00	0.00
10.00	-4.50	0.00
10.00	-3.00	0.10
10.00	-1.50	0.10
10.00	0.00	0.50
10.00	1.50	1.00
10.00	3.00	0.90
10.00	4.50	1.00
10.00	6.00	1.00

PSE : -0.05

-10.00	-6.00	0.00
-10.00	-4.50	0.00
-10.00	-3.00	0.00
-10.00	-1.50	0.00
-10.00	0.00	0.40
-10.00	1.50	0.50
-10.00	3.00	1.00

-10.00	4.50	1.00
-10.00	6.00	1.00

PSE : 0.96

Observer: AA

Drift(+ve = with	Offset(+ve = Ahead	Proportion Test chosen
10.00	-6.00	0.00
10.00	-4.50	0.00
10.00	-3.00	0.00
10.00	-1.50	0.70
10.00	0.00	0.60
10.00	1.50	1.00
10.00	3.00	1.00
10.00	4.50	1.00
10.00	6.00	1.00

PSE : -1.42

-10.00	-6.00	0.00
-10.00	-4.50	0.00
-10.00	-3.00	0.10
-10.00	-1.50	0.00
-10.00	0.00	0.50
-10.00	1.50	0.90
-10.00	3.00	1.00
-10.00	4.50	1.00
-10.00	6.00	1.00

PSE : 0.04

Observer: ST

Drift(+ve = with	Offset(+ve = Ahead	Proportion Test chosen
10.00	-6.00	0.00
10.00	-4.50	0.10
10.00	-3.00	0.20
10.00	-1.50	0.40
10.00	0.00	0.50
10.00	1.50	0.80
10.00	3.00	0.90
10.00	4.50	1.00
10.00	6.00	1.00

PSE : -0.54

-10.00	-6.00	0.00
-10.00	-4.50	0.00
-10.00	-3.00	0.10
-10.00	-1.50	0.50

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-10.00       0.00       0.90
-10.00       1.50       0.80
-10.00       3.00       0.90
-10.00       4.50       1.00
-10.00       6.00       1.00
PSE : -1.45

Observer: AW
Drift(+ve Offset(+ve Proportion
= with    = Ahead    Test chosen
 10.00      -6.00       0.00
 10.00      -4.50       0.10
 10.00      -3.00       0.10
 10.00      -1.50       0.60
 10.00       0.00       0.80
 10.00       1.50       1.00
 10.00       3.00       0.90
 10.00       4.50       1.00
 10.00       6.00       1.00
 PSE : -1.63

-10.00      -6.00       0.00
-10.00      -4.50       0.00
-10.00      -3.00       0.00
-10.00      -1.50       0.30
-10.00       0.00       0.20
-10.00       1.50       0.70
-10.00       3.00       1.00
-10.00       4.50       1.00
-10.00       6.00       1.00
 PSE :  0.73

Observer: TG
Drift(+ve Offset(+ve Proportion
= with    = Ahead    Test chosen
 10.00      -6.00       0.00
 10.00      -4.50       0.00
 10.00      -3.00       0.20
 10.00      -1.50       0.40
 10.00       0.00       0.70
 10.00       1.50       1.00
 10.00       3.00       0.90
 10.00       4.50       1.00
 10.00       6.00       1.00
 PSE : -1.11

-10.00      -6.00       0.00
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-10.00      -4.50       0.00
-10.00      -3.00       0.20
-10.00      -1.50       0.30
-10.00       0.00       0.30
-10.00       1.50       0.80
-10.00       3.00       1.00
-10.00       4.50       1.00
-10.00       6.00       1.00
 PSE :  0.15
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