Exploring a Visual Flow Display to Enhance Spatial Orientation during Flight

(HS-IDA-EA-02-503)

Kristian Helde (kristian@heureka.org)

Departement of Computer Science
University College of Skövde, Box 408
S-54128 Skövde, SWEDEN

Dissertation for the degree of BSc in Cognitive Science, written during the spring term of 2002.

Advisors: Paul Hemeren, Skövde and Lars Eriksson, FOI.

Exploring a Visual Flow Display to Enhance Spatial Orientation during Flight

Submitted by Kristian Helde to University College of Skövde as a dissertation for the degree of B.Sc., at the Department of Computer Science.

[2002-06-05]

I certify that all material in this dissertation which is not my own work has been identified and that no material is included for which a degree has previously been conferred on me.

Signed: ____

Exploring a Visual Flow Display to Enhance Spatial Orientation during Flight

Kristian Helde (kristian@heureka.org)

Abstract

The problem of spatial disorientation during flight of aircraft is briefly described, as are definitions of the phenomenon. Traditional countermeasure efforts that are often directed towards changes in the central visual field, are reconsidered in favour of presentation of information in the peripheral visual field. It is proposed to use optic flow to support spatial orientation, as well as to omit such information from the central visual field. An experiment was conducted, and results showed that forward visual flow gave very important spatial information. The flow could be cropped to a certain degree in the periphery (horizontally), as well as parts of the central presentation could be omitted without decreasing effects in the experiment. Implications relevant to possible implementations in aircraft are discussed.

Keywords: spatial disorientation, focal and ambient visual system, peripheral visual field, optic flow, postural instability

Table of contents

1 Introduction

1.1 Spatial disorientation

Imagine that you are watching an aircraft on a sloping course towards a runway. Some trouble comes in the way, so the aircraft, very close to landing on the runway, pitches up and increases its altitude again. On the way up, it enters a low cloud and goes out of sight. Shortly thereafter, the aircraft comes out of the cloud with high velocity on a downward slope straight toward the runway, and the tragedy is a fact. However unlikely this may sound, this kind of mishap has occurred. It is caused by a phenomenon called spatial disorientation and in this specific instance, the “pitch-up illusion”.

Spatial disorientation can be defined as “an erroneous sense of one’s position and motion relative to the plane of the earth’s surface.” (Gillingham, 1992, p. 1). Spatial disorientation has been divided into three basic categories: Type I (unrecognized), II (recognized) and III (incapacitating). When suffering from type I, the pilot has no sense of being disoriented. This is the most common cause of serious spatial disorientation mishaps, according to US Air Force statistics (Baker, 1998).
During type II, a pilot is sensing that something is wrong. He may feel the plane is doing one thing while the instruments give information that contradicts what his senses are telling him. Many times the pilot is able to correct this type of disorientation by reading the instruments of the plane, or by getting a view of the ground or horizon. Suffering from type III, the pilot realizes that he/she is spatially disoriented but is physically incapable of dealing with the situation. Nystagmus movements of the eyes may be so severe that it is impossible to interpret the information provided by the instruments. Also, the pilot may feel unable to move. This type of spatial disorientation, however, is relatively rare.

A pilot who suffered from type II spatial disorientation, tells this story: “Halfway to the tanker, out over the water, I began to get spatial disorientation. I was on the wing, in the soup, with no horizon and no cultural lightning (since we were over the ocean). I was just informing lead when I got a glance of the shoreline lights in my deep six. It’s amazing, but that was all I needed to recage the gyros in my brain.” (Vestal, 1998, p. 1).

To further understand how it is to encounter spatial disorientation, another pilot, who experienced type III spatial disorientation with severe nystagmus-movements of the eyes, unable to read the instruments of his plane, reported “…in my entire flying career (civilian and Desert Storm included), I have never been that scared.” (Anonymous, 2000, p. 1).

The occurrence of spatial disorientation is very costly, both monetarily and with regard to loss of human lives. Between 1990-1996, the Navy & Marine Corps suffered from 64 incidents, with a total of 88 fatalities and to an estimated cost of 956 million USD (Patterson, 2000). US Air Force (USAF) reports having a fairly constant mishap rate caused by spatial disorientation. Between 1958 and 1992 the USAF average mishap rate per 100 000 flying hours was 0.335 (Ercoline, DeVilbiss & Lyons, 1994). Also, Heinle (2001) reports that the spatial disorientation mishap rate for USAF has been on a constant level between 1971 and 2000, and that this annual cost is estimated to be 140 million USD.

In neurology and neuropsychology, spatial disorientation denotes people who have problems orienting themselves in different surroundings, or are unable to tell left from right (Ercoline & Previc, 2001). In aviation psychology, this would be referred to as geographical disorientation, an erroneous locational percept, i.e., a mistaken “sense of one’s position and motion *in* … the plane of the earth’s surface” (Gillingham, 1992, p. 1). So, simply being lost must be distinguished from being spatially disoriented in aviation psychology terms as the latter encompasses a third, vertical, dimension. A commonly used definition of spatial disorientation emphasizing this is given by Benson (1978). “Spatial disorientation is a term used to describe a variety of incidents occurring in flight where the aviator fails to sense correctly the position, motion or attitude of his aircraft or of himself within the fixed coordinate system provided by the surface of the earth and the gravitational vertical.” (Benson, 1978, p. 405).

This means, a pilot who mistakenly flies to Stockholm when heading for Gothenburg would not primarily be categorized as spatially disoriented, but as geographically disoriented. The same applies to the hiker who gets lost in the forest - however lost he may be, he still suffers from geographical disorientation, not spatial disorientation in the aviation psychologist’s use of the term. Suffering from spatial disorientation though is the pilot who does not know his whereabouts in relation to the surface of the earth, as in the introductory example of the pitch-up illusion above.

What are then the mechanisms by which spatial orientation is supported during flight?

1.2 Information about spatial orientation – the human senses

The most important systems supporting spatial orientation in humans are vision, the proprioceptive- and the vestibular mechanisms (von Hofsten & Rosander, 1997). These systems have evolved to fit the circumstances on the ground, and they work very well in this environment. However, the higher stress experienced and the different situational surroundings in the flight environment pose several challenges to these systems. In certain situations, they can provide lethally misleading information, especially if visual conditions are degraded with neither horizon nor textured ground visible. The human sensory systems were not evolved to function optimally in aircraft.

1.2.1 Vestibular system

The vestibular system has the size of about a pea, resides in the inner ear and is composed of the otoliths and the semicircular canals. They are responsible for detection of motion and gravity and are often deceived in the flight environment with varying g-forces. Thus, they may easily cause spatial disorientation.

The otoliths are composed of sacks containing hair cells attached to a gelatinous membrane. This membrane moves during linear accelerations/decelerations, and bends the hairs that register the motion and pass this information on to the brain. The otoliths react the same way if the head is tilted forward or backward. This means that the otoliths cannot distinguish backward tilt of the head from acceleration, or forward tilt of the head from deceleration (Aeromedical training for flight personnel, 2000).

Another problem with the otoliths is that they only react to changes in linear velocity. After some time in constant motion, slowing down or stopping might produce the feeling of motion in the opposite direction (von Hofsten & Rosander, 1997).

The semicircular canals are composed of three canals filled with an endolymph fluid. Each canal registers rotation in a different axis of movement (up and down, left and right turns and tilts to the left and right)[1] by the bending of a gelatinous structure called the cupula. The bending of the cupula is initiated by the endolymph fluid, which lags behind during angular accelerations. A problem with this is that if a turn is prolonged more than about 10 seconds, the fluid reaches equilibrium and stops sensing angular motion (von Hofsten & Rosander, 1997). When the turn is slowed or stopped, the equilibrium is disturbed, and the endolymph fluid lags behind in the opposite direction, thus registering movement in the opposite (wrong) angular direction (Aeromedical training for flight personnel, 2000).

1.2.2 Proprioception

The proprioceptive system registers the position of body parts relative to one another and position of the head relative to the body. It is composed of small mechanical receptors in the skin, joints and muscles. They respond to both external pressure and minor changes in position of internal organs (Aeromedical training for flight personnel, 2000). Since this pressure is dependent on the direction of the g-force, proprioception is susceptible to the same problem as the otoliths, hence the recommendation to pilots not to "…fly by the seat of your pants" (von Hofsten & Rosander, 1997, p. 5).

1.2.3 Auditory system

On earth, hearing is of importance to spatial orientation. However, in the flight environment, it does not have enough information to rely on to be efficient. The modern planes have high noise levels and the flight environment lacks audible external sound sources (Gillingham & Previc, 1993). However, as technology improves, it is experimented with 3D-sounds to utilize the auditory modality. It is doubtful if this would contribute to spatial orientation, it would rather contribute to the information of the whereabouts of other airborne objects, and thus primarily aid situational awareness.

1.2.4 Vision

During the millions of years our sensory systems evolved, the ground and its horizon were constant stimuli to us. Therefore, seeing the ground is of major importance for our orientation and action in the world. According to Gibson (1950), "a ground is necessary for bodily equilibrium and posture, for kinesthesis and locomotion, and indirectly for all behavior which depends on these adjustments." (p. 60). In the flight environment, when the visual field is devoid of ground and horizon, we can only orient ourselves by reference to substitutes in the form of instruments in the aircraft, that in various forms represent the ground and horizon.

---

[1] The corresponding terminology in aviation psychology is pitch for up and down, yaw for turns to the left and right, and finally roll for tilts/rotations to the left and right.

Of the four systems that support spatial orientation, vision is the most important and has a certain priority over the other modalities (Gillingham & Previc, 1993; Lee, 1980). By a phenomenon called vestibular suppression "…the visual image generally overrides vestibular input" (Baker, 1998, p. 2). Vision has been estimated to provide 80 percent of our orientation information (Aeromedical training for flight personnel, 2000). During flight in clear weather, when the ground and horizon are visible, accidents caused by spatial orientation are rare (von Hofsten & Rosander, 1997).

It has been argued that to understand vision, one has to place it in its ecological context (Gibson, 1950). Central to this context is motion, both of oneself and in the world. This motion constantly provides vision with dynamic information, hence it has been named the "optic flow field" (Lee, 1980).

Almost every surface has a texture, and this texture structures the light that reaches the observer. This structuring is caused by the gradients in the texture such as density and compression which have features giving rise to perception of depth, size and distance (Bruce, Green & Georgeson, 1997). According to Gibson (1950), the information that reaches the eye is reflected off surfaces in the external world. When in motion, these reflections change and this is what constitutes the flow.

The gradients of textured motion elements in the optic flow specify direction of motion. If moving straight forward for example, the optic flow expands towards you from the center of the field (see figure 1). If turning left, this pole of expansion moves from the center towards the left angle of the field. If the point of expansion moves back to the center, this indicates straight forward motion again (Gibson, 1979).

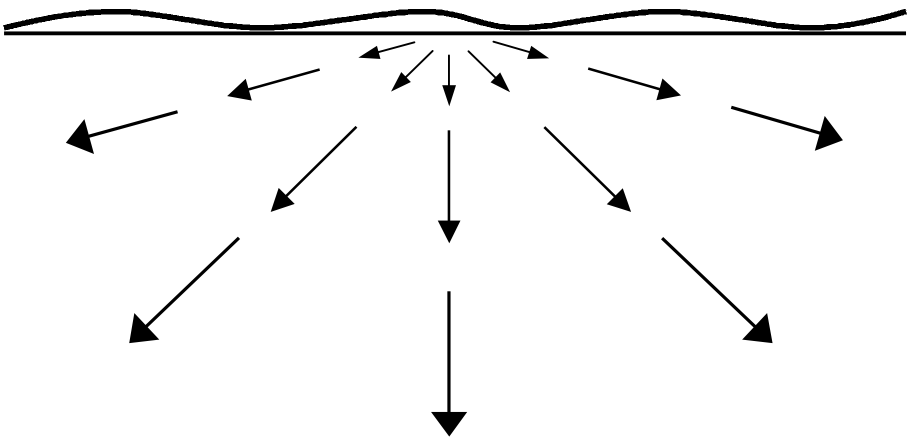

Figure 1. The direction of the expanding optic flow field when moving straight forward.

Vision can be functionally dichotomized into the focal and the ambient systems (Leibowitz, 1988; Sekuler & Blake, 1994; Gillingham & Previc, 1993). A corresponding division exists within cognitive neuropsychology and Norman (2002) suggests that, "…the focal-ambient distinction as used many years ago by Leibowitz…is quite similar, if not identical, to the ventral-dorsal distinction…" (Norman, 2002, p. 12).

The focal visual system (the ventral stream) is responsible for pattern, object and form recognition, and sensitive to details in the visual field. Attention and focusing are mostly required to utilize focal vision.

The ambient visual system (the dorsal stream) is largely responsible for spatial orientation, registration of self-motion and perception of size. It is also sensitive to the detection of movement of external objects and directs attention towards them. The ambient visual system requires little conscious attention to function (Gillingham & Previc, 1993; Leibowitz, 1988).

Both systems work simultaneously. A simple way to notice this duality of the visual system is that one can in fact read a book and walk at the same time, with no problem at all maintaining balance. This keeps the central visual field occupied, and the attention is on reading. Simultaneously, you do not fall or stumble around. Evidence from cognitive neuroscience suggests different localizations of the visual systems (Norman, 2002; Gillingham & Previc, 1993; von Hofsten & Rosander, 1997). Patients with cortical lesions can maintain visual orientation while their capability of discriminating objects is gone. Examples from the opposite exists as well, where a patient suffering from optic ataxia, cannot direct motion towards objects, but can discriminate and identify them well. (See Norman (2002) for more detailed examples on humans, monkeys and hamsters.)

Some research suggests that the focal visual system primarily gets its information from the central parts of the retina, while the ambient visual systems uses the entire retina (Norman, 2002). This would mean that the peripheral visual field is primarily responsible for ambient visual system, and that the central visual field is primarily responsible for focal vision.

Thus, vision provides the most important sensory information for spatial orientation. Ground and horizon are very important stimuli for spatial orientation. The optic flow field specifies direction of motion and the peripheral visual field is largely responsible for spatial orientation. This means that the optic flow (from ground and horizon) in the peripheral visual field should be the most important stimuli in order to maintain spatial orientation, since it is in resonance with our sensory mechanisms.

1.3 Flight situation – g-forces and illusions causing spatial disorientation

In the flight situation, the g-force is the cause of many illusions since it tends to mislead the proprioceptive and the vestibular systems. Problems arise when the perceived g-force is not directed vertically in relation to the body (as it normally is on earth). During accelerations and decelerations, the perceived verticality of the gravitational vertical shifts in relation to the aircraft (backward during accelerations and forward during decelerations). This gives the pilot a sensation of being tilted in relation to the ground, when the course of flight actually is horizontal (von Hofsten & Rosander, 1997). During accelerations of very high sustained g-forces, other effects are induced such as loss of peripheral vision, problem of moving limbs or even unconsciousness (Aeromedical training for flight personnel, 2000).

A pilot is susceptible to numerous illusions during flight. (For a comprehensive review of these illusions causing spatial disorientation, see Gillingham & Previc, 1993.) Below a few are mentioned to illustrate the problem of spatial disorientation. All of them occur predominantly during poor visual conditions (darkness, cloudiness, rain etc). These illusions are not limited to high performance aircraft, they also occur in low performance aircraft and during low g-forces as well (Gillingham & Previc, 1993).

1.3.1 False horizon illusions

Certain conditions during flight may produce illusory horizons. It may be the line of the city light at night, sloping cloud decks or distant rain showers. Sloping terrain without textured surface may also produce illusory percepts of the horizon. If acted on, this information may lead a pilot to fly the plane on a course leading to collision (Gillingham & Previc 1993; Aeromedical training for flight personnel, 2000).

1.3.2 The leans

The most common vestibular illusion is the leans (Gillingham & Previc, 1993; Leibowitz, 1988). If rotational movement of the plane is slow, it might go below the threshold of the vestibular organs and pass unnoticed and lead to an erroneous sensation of angular displacement. This often occurs after a slow turn after which the pilot may feel that the plane is parallel to the ground, while the plane is in fact still banked. If the pilot straightens the plane quickly, an erroneous sensation of rotation in the other direction can be induced, leading to further spatial confusion. However, in sight of the ground, the illusion vanishes instantly (Leibowitz, 1988). Short of external cues such as a view of the ground, the erroneous sensation may endure up to one hour (von Hofsten & Rosander, 1997).

1.3.3 Pitch-up illusion

This illusion often occurs during take off. The otoliths rely on the g-force to be vertical, and this is not the case during acceleration, deceleration and numerous other instances during flight. As a consequence, the acceleration during take-off induces a sensation of a pitch-up attitude of the plane. When the pilot leaves ground and pitches the plane, the combined effect of the illusory and real pitch may evoke the sensation of a peak-high attitude, or in extreme cases, even being tilted backwards. If the pilot attempts to compensate for this erroneous sensation, an immediate mishap can occur.

The pitch-up illusion is most likely to occur during poor visibility conditions, such as darkness. When the ground is clearly visible, the pitch-up illusion does not become a problem (von Hofsten & Rosander, 1997; Leibowitz, 1988).

1.3.4 Graveyard spin

If a pilot enters a spin, the fluid in the semicircular canals reaches equilibrium after a few seconds, and the pilot loses his/her sensation of turning. After pulling out of the turn, the semicircular canals register this as new motion in the opposite direction, and, with no help from visual stimuli, the pilot may act on this information and reenter the original turn. At this moment the pilot is sensing straight movement when he is in fact spinning and loosing altitude. Unless the course is corrected from its path towards the ground, it can end on impact (Gillingham & Previc, 1993; Aeromedical training for flight personnel, 2000).

1.4 Flight instruments – traditional "counter measures"

In the cockpit of today, several instruments represent the ground and horizon. When spatial orientation is dependent on only these instruments, this is called instrument meteorological conditions. How these instruments are designed and where they are placed, vary from aircraft to aircraft. Common important instruments are the horizontal gyro and the altimeter. The horizontal gyro represents the horizon, and moves with the aircraft to always provide information of the status in the roll and pitch axes (see figure 2) of the aircraft. The altimeter is a clock-like device that indicates altitude above ground. Also, a head up display (HUD) is standard in fighter aircraft of today. There are many different modes available depending on the model of the aircraft, but standard spatial information is the displaying of horizontal, attitude and jaw information. HUDs require the use of the central visual field.

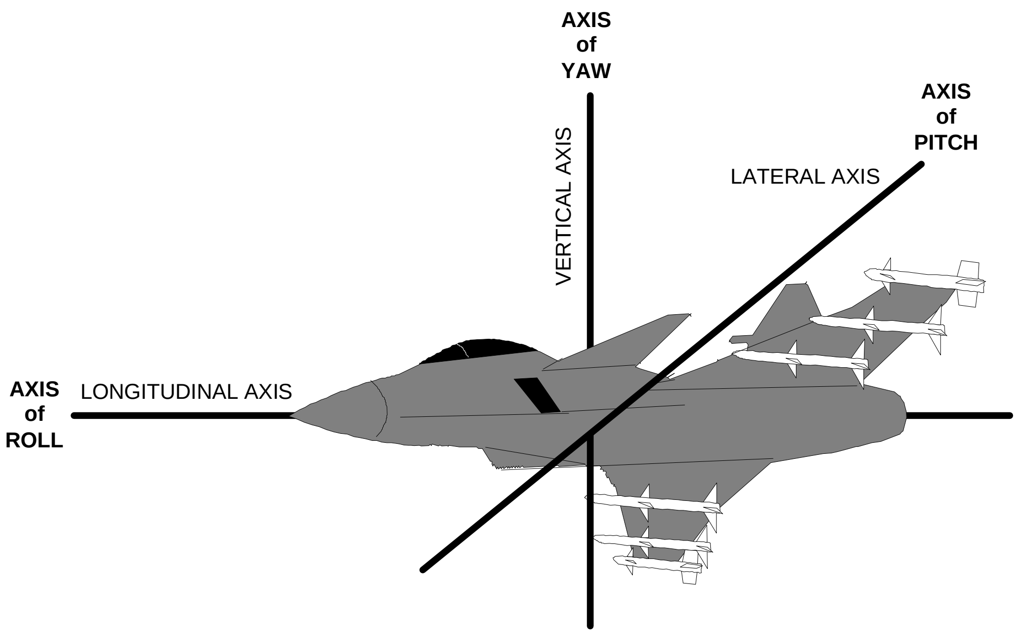

Figure 2. The directions of the different axes in which the aircraft can move. Rotations around the longitudinal axis correspond to roll movements (tilts), rotations around the vertical axis correspond to yaw movements (turns), and rotations around the lateral axis correspond to pitch movements (attitude changes).

1.4.1 Instrument cross-checking

To counter spatial disorientation, pilots are instructed to always consult the instruments and to disregard the information from the senses when in conflict with the instrument information. Cross check procedures are learned to establish safe routines. Pilots are also educated as to when spatial disorientation is likely to occur in order to pay extra close attention during these occasions. Pilots are also instructed about "stressors" that make them especially vulnerable to spatial disorientation, such as fatigue, alcohol, having an absent mind, time-stress, and low levels of blood sugar (Aeromedical training for flight personnel, 2000).

Pilots are frequently encouraged to trust their instruments and to maintain safe cross checking procedures (Leibowitz, 1988; Marlowe, 1985; Baker, 1998). However, attention can be diverted from these procedures by warning lights, radio traffic, target scanning and so forth. Breakdown in the crosscheck procedures is a common cause of spatial disorientation (Davenport, 2000). Leibowitz (1988) describes the situation for a typical passenger plane, which shortly after the model had been launched into commercial use, was involved in unusually many accidents during landing (due to pilots not keeping a close track of the altimeter). "During approach and landing, pilots must carefully monitor the velocity of the aircraft, adjust the power settings of the engines, steer the aircraft in a three-dimensional space, respond to instructions from the ground controller, and be alert to other aircraft in line with the see-and-avoid principle. Given these multiple responsibilities, it is understandable that pilots may assign a lower priority or even fail to check the altimeter if they feel confident that visual estimates of altitude are accurate." (Leibowitz, 1988, p. 98).

1.4.2 A common assumption for countermeasures

A common assumption when developing spatial disorientation countermeasures is to work with different layouts of cockpit instruments. Wickens and Hollands (2000) follow this tradition when suggesting different ways to present banking of the aircraft. However, these instruments *all require the use of the central visual field*, and are therefore dependent on focused attention. This means that they will always have to compete with other attention demanding tasks in the cockpit.

It can be assumed that the sensory mechanisms discussed above are the same while airborne as on the ground. The sensory system is the same, it is just put in another context, one in which humans were not evolved to function. In this environment, as noted above, auditory information has little significance and both proprioception and the vestibular systems are easily deceived. The major source for spatial information is vision, and in particular, peripheral vision. This is why the traditional way of approaching the problem of spatial disorientation (by information presented in the central visual field) does not resonate with how our spatial orientation system works. Information might instead be presented to the peripheral visual field, which normally seems most responsible for spatial orientation. This would better resonate with the perceptual system and its mechanism for spatial orientation, and in addition, would therefore not be as attention consuming. Also, a display in the peripheral field might not require learning due to its congruence with our normal way of orienting ourselves (Leibowitz, 1988). von Hofsten & Rosander (1997) therefore recommend a visual aid (helmet mounted display, HMD) with peripheral visual information containing a horizon and a textured ground surface to counteract spatial disorientation.

1.5 Earlier empirical findings and the aims of this study

The Swedish Defence Research Agency (FOI), Uppsala University and Saab AB cooperate in investigating such an alternative within the Swedish National Aviation Research Program (NFFP). As part of this program, Eriksson and von Hofsten (2002) performed a set of experiments with the aim of developing design guidelines for a visual display that later on may be further evaluated in a flight simulator with varying g-forces.

In the experiments, three computer screens displayed an optic flow from a textured surface with a horizon. The displays of this flow were varied in velocity, size of peripheral visual field and size of omissions in the central visual field. The participants in the experiments stood in an erect stance, heel to toe and with their hands folded across their chest. The task during the investigations was to maintain posture and balance while presented with the different display configurations of the stimuli.

As noted earlier, central to our visual perception is visual motion. A visual flow may induce the perception of self-motion in the beholder of the flow and there are three different aspects of induced self-motion:
1) Vection, where the subject experiences forward, backward or rotating motion, depending on direction of the optic flow. An example of this is the "rotating room" at amusement parks, where one sits in a stationary seat, when the surrounding walls, floor and roof start rotating. This induces the feeling of self-rotation. Most advanced flight simulators rely on vection (Gillingham & Previc, 1993).
2) Heading is when the subject perceives direction of self-motion in the optic flow that induces the sensation.
3) Postural control: When presented with optic flow, postural sway responses have been detected in several studies summarized by Bruce, Green and Georgeson (1997). This effect may have been experienced by the reader if he/she has visited advanced simulators such as Cosmonova in Stockholm. It is no coincidence that the audience is sitting down during the presentations.

In the experiments performed by Eriksson and von Hofsten (2002), postural control (compensatory postural adjustment) was measured instead of vection or heading, because it more directly involves the vestibular system and proprioception.

Based on the arguments above, Eriksson and von Hofsten (2002) chose a ground and a horizon as stimuli that in motion provide optic flow and enable both horizon and ground to work as a frame of reference.

Instead of using an environment with varying g-forces and a stable horizon and ground, a stable g-force was used while varying the horizon and ground. Since the g-force is stable, the vestibular and the proprioceptive systems are given correct information. The visual information on the other hand, is being manipulated. Therefore, a fundamental assumption is that if participants show problems in maintaining balance, this effect could be ascribed to an effective visual presentation generating vestibular suppression. Following this assumption, information from these experiments may generate design guidelines as to how to efficiently model visual stimuli in more advanced experimental settings.

Eriksson and von Hofsten (2002) have so far conducted three experiments. The first experiment studied the effects of a number of variables such as texture, velocity (of flow), banking, changes in pitch, and the size of omission in the central visual field. The main purpose of this experiment was to investigate whether the experimental situation as such could affect posture (wagging motion sideways or for- and backwards) as coupled with variations in the visual display characteristics together with banking or rolling. The results of the study showed that postural instability was effectively evoked by the experimental situation. And the larger the central omission, the less the postural instability became. The strongest postural instability effects occurred during combinations of banking and rolling and evoked primarily lateral imbalance, i.e., wagging sideways. No effect was found due to variations in texture.

In the second study, the number of variables manipulated was decreased. Postural instability effects of varying the velocity of the visual flow, and omissions of the central visual field were primarily investigated. The black and white texture was used due to the results of the first experiments and because it provides a good contrast to mediate motion information. The results showed that up to 20˚x20˚ of the central visual field could be removed without decreasing the postural instability when compared to a full central view presentation. It was also shown that velocity forward (expanding flowfield) induced larger instability than no velocity forward (no expanding flowfield).

The third experiment primarily investigated postural instability effects during omissions of both the central and peripheral visual fields. It was shown that a decrease in the horizontal dimension of the peripheral visual field to 105˚ could be done, without decreasing the evoked postural instability when compared to the full-view presentation of 150˚. However, the results of central omissions from the second experiment were not replicated. Both 20˚x20˚ and 30˚x30˚ showed decreased effects on balance compared to the full-view.

Because of the contradictory findings with regard to central omissions, the effects on postural responses with 20˚x20˚ and 30˚x30˚ omissions need to be further investigated. Also, a horizon-line is to be presented in the “omitted” visual field, in line with the standard fighter aircraft cockpits of today, with head-up displays (HUDs) containing such spatial information. A horizon-line in the central visual field is an information component in helmet-mounted displays (HMDs). Therefore, such a mode of presentation is of interest to investigate because it approaches already implemented display interfaces. The horizon line adds spatial information to the stimuli, so it may support the visual information more, by leading to more postural imbalance. Further, the effects of flow velocity will also be studied in the following experiment.

1.5.1 The experiment in this study

Above in the introduction, we have seen that the optic flow is important to our spatial orientation, as is the ground and the horizon. In regard to the functionality of the visual system, the peripheral visual field seems primarily responsible for spatial orientation. Therefore, it is to be explored how balance is affected when presenting an optic flow from ground and horizon in the peripheral visual field. Effects on balance when manipulating the size, centrally and peripherally, of the visual field are also to be explored. To relate the experiment closer to the fighter cockpit of today, the effects of a horizon-line in the central visual field during central omissions, are also to be examined. From theory, it can be assumed that optic flow will be more effective than no optic flow, and that some degree of the central visual field can be omitted without decreasing the effects on balance compared to a full view, especially if complemented with additional spatial information in the form of a horizon-line. From the earlier experiments by Eriksson and von Hofsten (2002), it is also expected that some of the peripheral information can be cropped horizontally, without decreasing effects on balance.

2. Experiment

The experiment presented here is based on earlier experiments by Eriksson and von Hofsten (2002). To further investigate important display characteristics, the experiment was designed to again investigate the earlier effects of visual flow velocity. Also, due to the mixed findings in the earlier experiments, it was of interest as to how another group of participants would react to omissions in the central field in combination with omissions in the peripheral visual field. In addition, the conditions of the central visual field omissions were also studied with a horizon-line added in the omitted area. The rationale for examining this characteristic is that it provides added spatial information and that head up display (HUD) functionality, already implemented in fighter aircraft of today, presents variations of this kind of information. Because of the added spatial information, the horizon-line may lead to larger effects in postural response.

2.1 Method

2.1.1 Participants

16 undergraduate students (7 females and 9 males) participated. The mean age was 24.6 with a range from 21 to 32 years. All participants had normal or corrected-to-normal vision and were unaware of the purpose of the study and had not been acquainted with the stimuli presented. They had not participated in the experiments by Eriksson and von Hofsten (2002). As payment, participants received a voucher to a cinema of their choice. E-mailing lists of Linköping University were used to send out requests to students, most of whom attending the cognitive science program.

2.1.2 Apparatus

Four Dell PCs were interconnected through a hub in a network (100Mb/s). The main computer, responsible for controlling the 3 stimuli computers and the registering of head tracker data, was a Dell Precision 620 with MS Windows NT4 platform. The three stimuli computers used Dell P110 21” monitors. 1 of the 3 computers was a Dell Dimension XPSB933 with a Geoforce Ultra 2 display adapter. The other 2 computers were Dell Dimension 8100 with Geoforce 3 display adapters.

The three computer monitors were placed on top of a height adjustable bench.

The stimuli computers used a 1280x960 pixels resolution with a refresh rate of 75Hz. All 4 computers used the software Vega for 3D graphics together with FOI-produced complementary software.

To measure head movements, a head tracker of brand Intersense IS-600 Mark 2 Plus was used. Following the refresh rate of the computer monitors, head tracker data were taken 75 times per second.

2.1.3 Design and Stimuli

A 3x3x5 factorial within-subjects design was used. The independent variables were:

1) velocity – three conditions: zero forward velocity (beginning), high forward velocity, followed by zero forward velocity (end).
2) width of horizontal visual field – three conditions: 153° (full-view), 108° and 45° central view. (See Figures 3 and 4.) The degrees in degrees of visual angle.

3) omission of central visual field – five conditions: 0°, 20°x34°, 30°x34°, 20°x34° with a horizon line, and 30°x34° with a horizon line. (See Figures 3 and 4.) The degrees in degrees of visual angle.

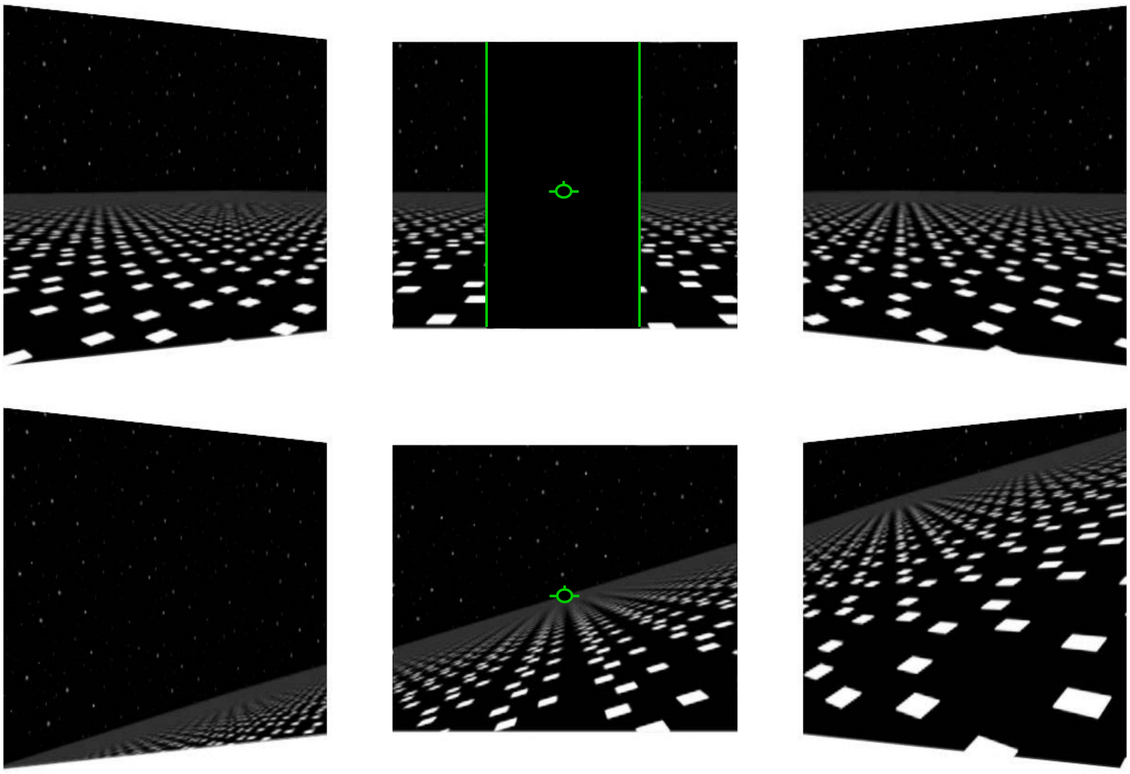

Figure 3. The top configuration shows the stimuli with full peripheral presentation and 20° (horizontally) central omission. In the centre is the aircraft-like symbol without horizon-line. The lower configuration shows the stimuli with full horizontal presentation and thus no central omission. This configuration also shows the 20° roll position.

The central field was varied in 5 ways. Either 20° or 30° were removed, or the full central view was kept intact (0° removed). During the removals of the 20° and 30°, a horizon-line was also introduced in the cropped area, i.e., the horizon-line modes were nested into each respective removal mode. For each block with a cropped central view, 4 rolls were conducted with horizon line, and 4 rolls were conducted without horizon line. To balance the order of presentation of the horizon line, randomization determined whether the first person would begin with or without horizon-line in the different configurations, and for the second person, this order was reversed.

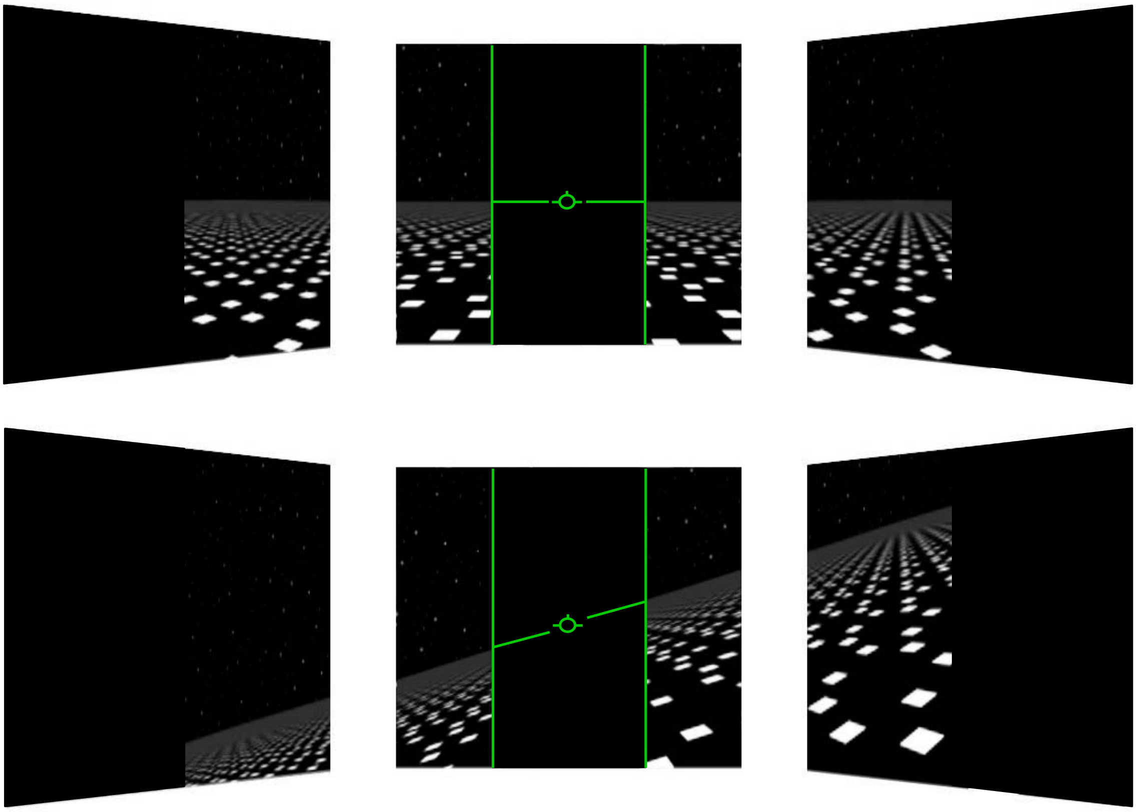

Figure 4. The top configuration shows the stimuli with cropped peripheral presentation horizontally to 108°, and 20° central omission horizontally with a horizon-line. The lower screens of the figure shows the same configuration in a 20° roll position.

The experiment was divided into 9 different blocks. The blocks consisted of variations of the peripheral visual field horizontally (as specified above), and variations in the size of omission of the central visual field (as specified above). This gave 9 (3x3) configurations/blocks since the horizon-line modes were nested together with the 20° and 30° central omission modes.

Each block was composed of three trials (the trials with the central cropping had the horizontal line trials nested within them). In each block, the three different trials varied velocity as mentioned above (zero velocity forward, velocity forward, zero velocity forward). Roll movements in the stimuli were done 4 times, 2 left and 2 right during each block. The order of these rolls was randomized for each subject.

The 9 different display configurations (blocks) were randomized for all subjects. A configuration consisting of only a horizon-line 30° wide was presented before and after each experimental session. Thus, this configuration contained no textured ground, just a rotating horizon-line. Each of these presentations included 4 rolls (2 left and 2 right) and were controls used to establish reference measures.

The monitors were 45˚ (horizontally) x 34˚ (vertically). The frames of the monitors gave rise to a 2x9˚ border between the active parts of the screens (see Figure 4). Thus, the width of the full view display configuration was 153˚ of the horizontal visual field and the vertical visual angle was covered to 34˚.

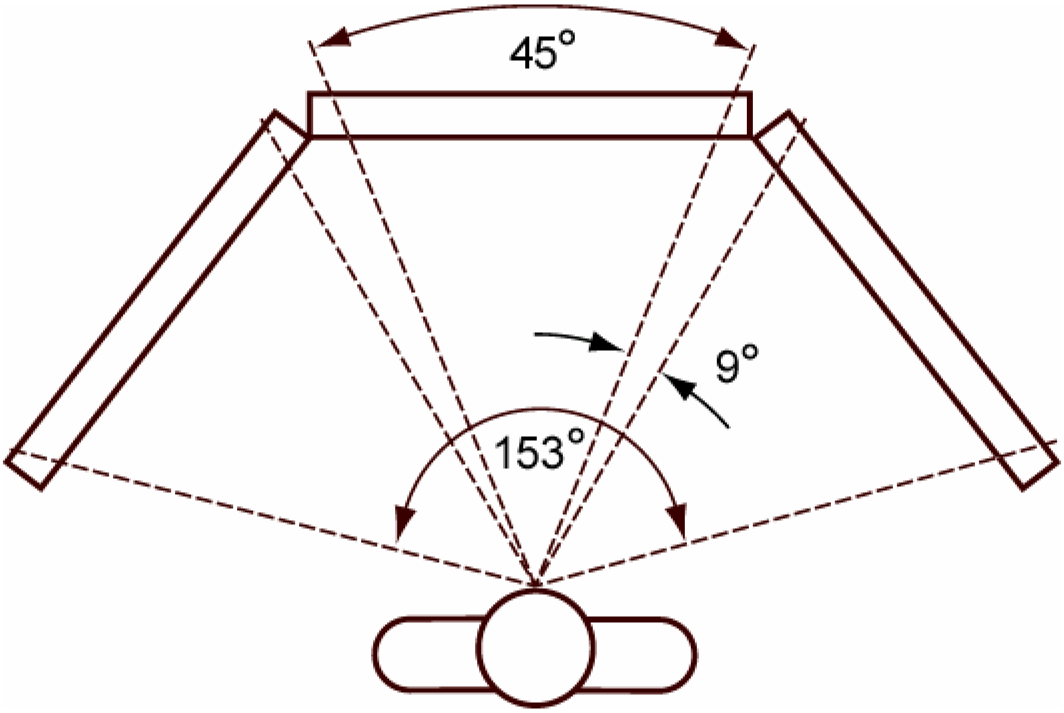

Figure 5. A top view showing the visual fields covered by the display surfaces of the computer monitors relative to the observer position.

The stimuli consisted of white texture elements on a black background (a textured ground surface and a starry sky). In motion, this generated an optic flow pattern. The depth of the texture in the displays was 10 000 units. A texture square was composed of 25x25 units, and every square contained three white texture elements. This gives a virtual world of 400 texture squares (10000/25) and thus 1200 white texture elements (400x3). The geometrical viewer perspective of the virtual world was given from a height of 20 units above ground.

The velocity forward was 200 units/second, i.e., 8 texture squares (24 white texture elements). The velocity of the rolls was 25˚/second, thus a 20˚ roll took 0,8 seconds.

In the centre of the stimuli was an aircraft-like symbol that remained stationary throughout the experiment. The height of the symbol was 1.19˚ and the width 1.66˚.

The horizon line had a height of 0.0035˚.

The color of the aircraft-like symbol, horizon line and the vertical lines of the omissions in the central display, were all in a green color similar to the standard in the Gripen aircraft (JAS 39).

2.1.4 Postural instability measures

The dependent variable was postural instability, measured by head movement (see Figure 6). During translation in x and y-axis, the whole upper body is swaying.

1) head translation in x-axis, measured in centimeters (cm). (movement back and forth)
2) head translation in y-axis, measured in centimeters (cm). (movement sideways)
3) head rotation around x-axis, measured in degrees. (tilting the head sideways)

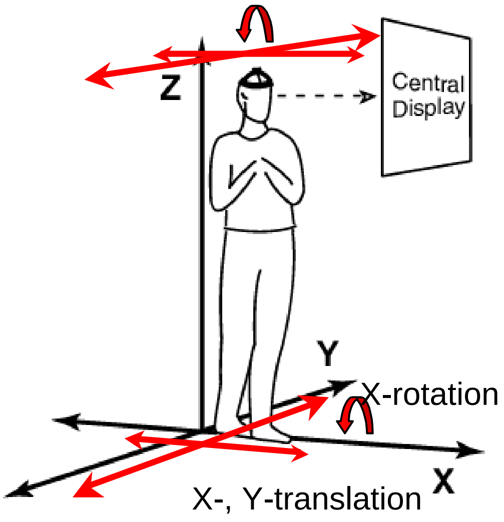

Figure 6. The different axes of measurements.

Repeated measures (75 per second) were conducted in x-axis, y-axis and rotation around x-axis. The measures were computed from the registered changes from start of roll to back to horizontal (each roll sequence) using the calculations below. (It is simply the values from the conducted measurements divided by the number of measurepoints.)

Translation in x-axis:

$$\left(\frac{1}{\text{n measure points}}\right)\sum_{i=1}^{\text{n measure points}} |x_i|$$

Translation in y-axis:

$$\left(\frac{1}{\text{n measure points}}\right)\sum_{i=1}^{\text{n measure points}} |y_i|$$

Rotation around x-axis:

$$\left(\frac{1}{\text{n measure points}}\right)\sum_{i=1}^{\text{n measure points}} |xrot_i|$$

Using these calculations, four values were obtained per individual, since there were 4 rolls during each configuration. An average value of these four was then obtained. This average value of all experimental conditions and for all participants were then analyzed with ANOVA for each of the three measures of postural instability using Statistica.

2.1.5 Procedure

An initial briefing was given to the participant, informing about the structure of the experiment, and instructed that the main task was to focus on the middle of the central screen and to maintain posture as good as possible. The participants was asked to remove their shoes and to stand in the "Sharpened Romberg Stance", upright heel-to-toe, with knees straight, both hands folded across their chest and with their weight centered between their feet.

The headtracker, mounted on top of a helmet, was placed on the head of the participant. The helmet was then adjusted to properly fit the head of the participant, to ensure its constant position to the head.

Measurements were made to assure that the participant was at a distance of 78.5 cm from the middle display to the corner of the eye, in order for the three computer monitors to cover 153 degrees of the participant's visual field. The height of the displays was adjusted in order to place the central mark and the horizon at eye level.

Nine different display configurations (blocks) were presented, complemented by two control display configurations. The control configurations lasted 40.5 seconds (4 rolls x 4.5 seconds + time between the rolls 5 x 4.5 seconds). The full central view configurations lasted 121.5 seconds (3 x 40.5), and the configurations with central omissions 243 (3 x 81) seconds.

During presentations, the lights were out, and possible light sources had been masked to minimize visual references primarily from the floor. Between each presentation, lights were turned on and participants could stand "at ease" for 120 seconds before the next block was presented. When the participant had been repositioned back to the Romberg stance, measurements were conducted again, and instructions to keep concentrated on maintaining posture while focusing on the central mark of the displays were repeated.

After the final presentation, the participants were given time to read a brief summary explaining the purpose of the experiment. When they were finished reading the summary, participants could ask questions and discuss the experiment. Finally, each participant received a voucher to a cinema of their choice.

The estimated average time for the whole procedure including the closing discussion, was 1 hour and 15 minutes.

2.2 Results and conclusions

The purpose of the experiment was to examine the effects of the variations in the display configurations on postural control. The obtained data was analyzed using ANOVA. Possible interaction effects were further analyzed by Tukey's HSD post-hoc test. The values from x- and y-translation are head movements in centimeters. The values of x-rotation are movements in degrees.

The ANOVA for individual means of translation in the x-axis showed no significant effects as shown in Table 1. This means that no effect on posture back and forth was observed during the trials.

Table 1. ANOVA of the individual means of translation in x-axis.

Source	df	MS	df error	MS error	F	*p*	*p* corr.[1]
Peripheral	2	.015066	30	.010585	1.42	.257	.255
Central	4	.009900	60	.007796	1.27	.292	.288
Flow-velocity	2	.001200	30	.000803	1.49	.241	.244
Peripheral by Central	8	.003661	120	.008222	.44	.892	.624
Peripheral by Flow-velocity	4	.000557	60	.000798	.70	.596	.486
Central by Flow-velocity	8	.001152	120	.000643	1.79	.085	.197
Peripheral by Central by Flow-velocity	16	.000501	240	.000672	.74	.745	.449

[1] Greenhouse-Geisser correction of *p*-value due to increased risk for Type I error (45 conditions for each subject).

The ANOVA for individual means on translation in the y-axis showed a significant main effect of flow velocity, $F(2,30) = 63.57$, $p < .00000001$. Significant interaction effects were found between peripheral mode and flow velocity, $F(4,60) = 7.22$, $p < 0.001$, and between central mode and flow velocity, $F(8,120) = 3.71$, $p < 0.01$. See Table 2. Figure 7 and 8 illustrate the significant 2-way interaction effects.

A Tukey HSD-test showed that the main effect of flow velocity depended on higher means of y-translation with forward velocity than with the zero velocity conditions at start ($p<.001$) and at end ($p<.001$). This main effect needs to be interpreted in the light of the interaction effects shown below.

Table 2. ANOVA of the individual means of translation in y-axis.

Source	df	MS	df error	MS error	F	*p*	*p* corr.[1]
Peripheral	2	.000001	30	.000008	.14	.866	.836
Central	4	.000005	60	.000005	.99	.422	.415
Flow-velocity	2	.000437	30	.000007	63.57	.00000000002	.000000003 *
Peripheral by Central	8	.000001	120	.000004	.33	.953	.840
Peripheral by Flow-velocity	4	.000023	60	.000003	7.22	.00008	.0004 **
Central by Flow-velocity	8	.000012	120	.000003	3.71	.0007	.004 ***
Peripheral by Central by Flow-velocity	16	.000003	240	.000003	1.06	.395	.393

[1] Greenhouse-Geisser correction of *p*-value due to increased risk for Type I error (45 conditions for each subject).
* Power = 1.00 at α= .05. ** Power = .98 at α= .05. *** Power = .93 at α= .05.

The Tukey HSD-test of the interaction effect peripheral by flow velocity, showed that high forward velocity generated greater translation in the y-dimension for each of the different peripheral view modes (153°, 108° and 45°), as shown in Figure 7. For 153°, there was greater y-translation with high forward velocity (mean = 0.84 cm) compared to the conditions of no velocity forward at the beginning (mean = 0.51 cm, *p*<.001) and at end (mean = 0.54 cm, *p*<.001). For 108° (mean = 0.78 cm), the

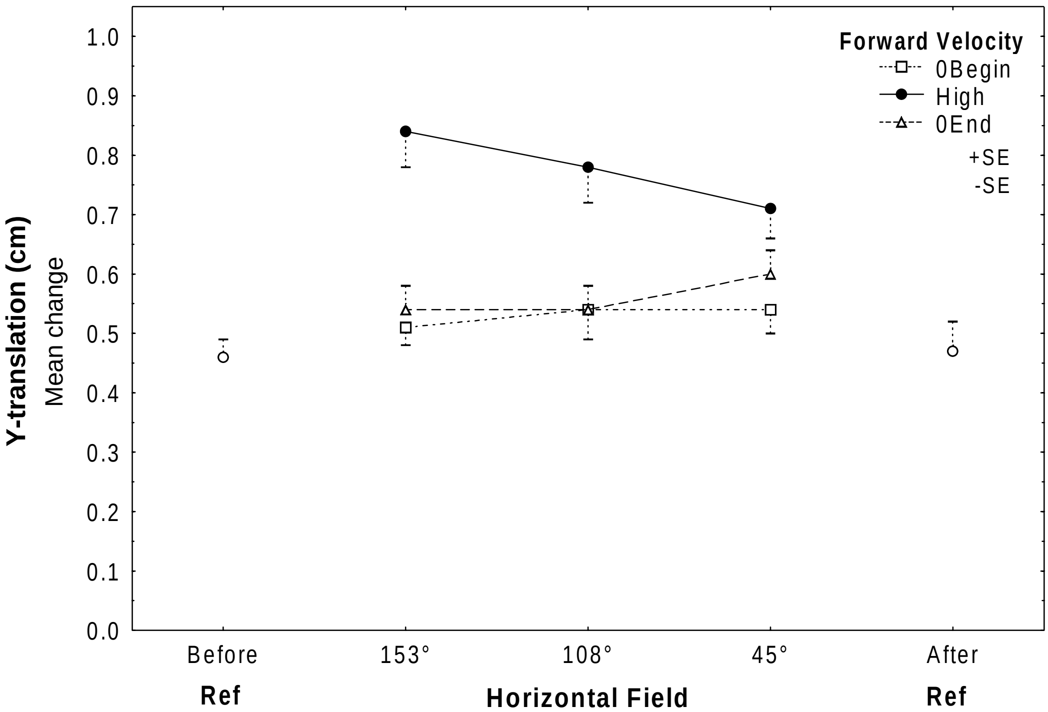

Figure 7. The interaction between peripheral mode and flow velocity, with the group means of Y-translation at different sizes of the horizontal field for each forward velocity. Also shown are the group means of the reference measures (Ref) taken before and after each experimental session. Means are shown with either +SE or –SE.

difference was equivalent for no velocity at beginning (mean = 0.54 cm, *p*<.001) and for no velocity at end (mean = 0.54 cm, *p*<.001). The 45° mode (mean = 0.71 cm), also exhibited equivalent differences for no velocity at beginning (mean = 0.54 cm, *p*<.001) and for no velocity at end (mean = 0.60 cm, *p*<.01). Further, at forward velocity the full view (153°) showed more y-translation than the 45° view (mean = 0.71 cm, *p*<.001), but not more than the 108° view (mean = 0.78 cm, n.s.).

Furthermore, during all central modes (0°, 20°, 20°H, 30°, 30°H), velocity forward showed more y-translation than the no velocity configurations before and after (see Figure 8). For the full view (no omission), forward velocity (mean = 0.89 cm) imposed greater translation than the no velocity conditions at beginning (0.53 cm, *p*<.001) and at end (mean = 0.51 cm, *p*<.001). For the 20° omissions, forward velocity (0.72 cm) imposed greater translation compared to no velocity at beginning (mean = 0.49 cm *p*<.001) and at end (mean = 0.58 cm *p*<.001). The equivalent relationship for 20° with horizon-line showed the following, forward velocity had a mean translation of 0.77 cm, no velocity at beginning a mean of 0.55 cm (*p*<.001) and no velocity at end 0.53 cm (*p*<.001). As for the 30° mode, forward velocity (mean = 0.77 cm) showed greater impact than no velocity at beginning (mean = 0.56 cm, *p*<.001) and at end (mean = 0.51 cm, *p*<.001). Finally, with the 30° condition with added horizon-line, forward velocity (mean = 0.74 cm) also exhibited greater translation than no velocity at beginning (mean = 0.51 cm, *p*<.001) and at end (mean = 0.60 cm, *p*<.025).

Finally, at forward velocity the full central view (no omission) showed more translation than 20° omission (mean = 0.72 cm, *p*<.01) and 30° omission with

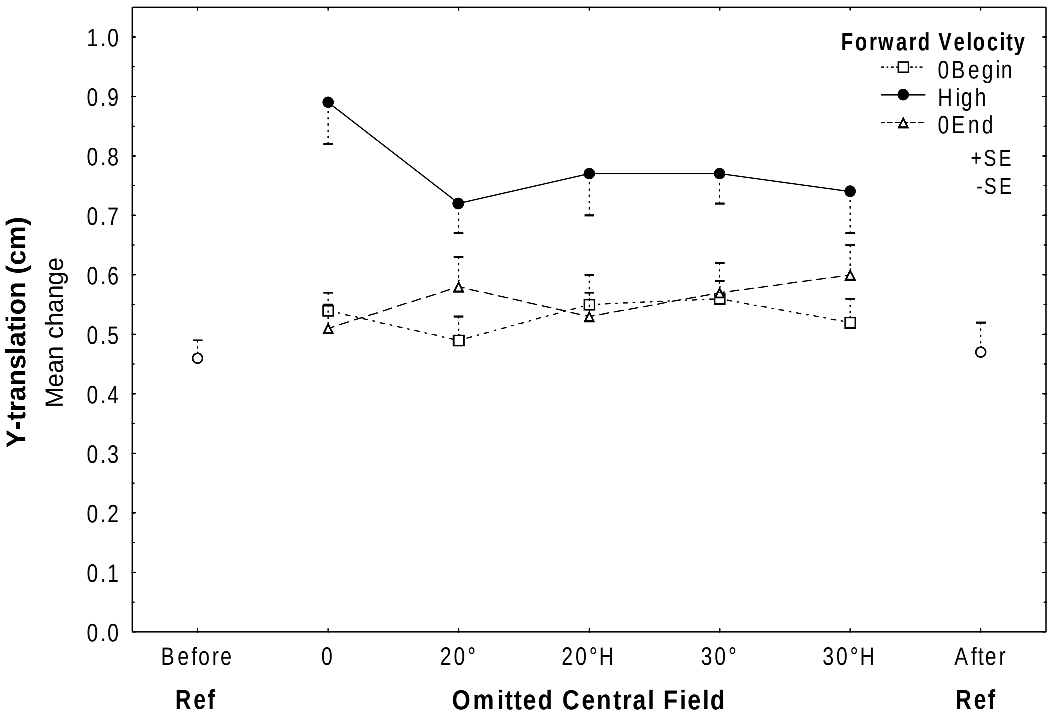

Figure 8. The interaction between central mode and flow velocity, with the group means of Y-translation at the different conditions of omitted central field for each forward velocity. Also shown are the group means of the reference measures (Ref) taken before and after each experimental session. Means are shown with either +SE or –SE. The denoted omitted central fields of 0, 20°, 20°H, 30°, and 30°H correspond to no omission (central full-view), 20°x34°, 20°x34° with horizon-line, 30°x34°, and 30°x34° with horizon-line, respectively.

horizon-line (mean = 0.74 cm, $p<.025$), but not more than the 20° omission with horizon-line (mean = 0.77 cm, n.s.) or the 30° omission without horizon-line (mean = 0.77 cm, n.s.).

The ANOVA for individual means on rotation around the x-axis (lateral head tilt) showed a significant main effect of flow velocity, F(2,30) = 16.71, $p<.0001$ and a significant interaction effect of central mode and flow velocity, F(8,120) = 4.43, $p<.01$. See Table 3. A Tukey HSD-test showed that the main effect of flow velocity depended on higher lateral tilt during forward velocity than during the zero velocity conditions at beginning ($p<.001$) and at end ($p<.001$). This main effect needs to interpreted in the light of the interaction effects shown below.

Table 3. ANOVA of the individual means of rotation around x-axis.

Source	df	MS	df error	MS error	F	*p*	*p* corr.[1]
Peripheral	2	.039779	30	.027721	1.44	.254	.255
Central	4	.014799	60	.013386	1.11	.362	.358
Flow-velocity	2	.359850	30	.021534	16.71	.00001	.00003 *
Peripheral by Central	8	.010945	120	.007443	1.47	.175	.229
Peripheral by Flow-velocity	4	.013986	60	.009974	1.40	.244	.261
Central by Flow-velocity	8	.050255	120	.011342	4.43	.0001	.003 **
Peripheral by Central by Flow-velocity	16	.014542	240	.010438	1.39	.146	.235

[1] Greenhouse-Geisser correction of *p*-value due to increased risk for Type I error (45 conditions for each subject).
* Power = .998 at $\alpha = .05$. ** Power = .93 at $\alpha = .05$.

The Tukey HSD-test showed that full central view and 20° central omission with horizon-line had higher effects on x-rotation during velocity forward than during the zero velocity conditions (see Figure 9). The full view mode showed a mean of 0.42°, no velocity at beginning a mean of 0.33° ($p<.01$) and no velocity at end a mean of 0.29° ($p<.01$). The corresponding relation for the 20° central omission with horizon-line were for velocity forward 0.38°, zero velocity at beginning 0.26° ($p<.01$) and at end 0.29° ($p<.01$). Comparing the full central view mode to the other modes at forward velocity showed no significant difference with the 20° central omission with added horizon-line (mean= 0.38°, n.s.) and with the 30° central omission without horizon-line (mean = 0.35°, n.s.), respectively. However, significant decreases were shown in comparison with the 20° omission (mean of 0.33°, $p<.01$) and the 30° omission with added horizon-line (0.34°, $p<.025$).

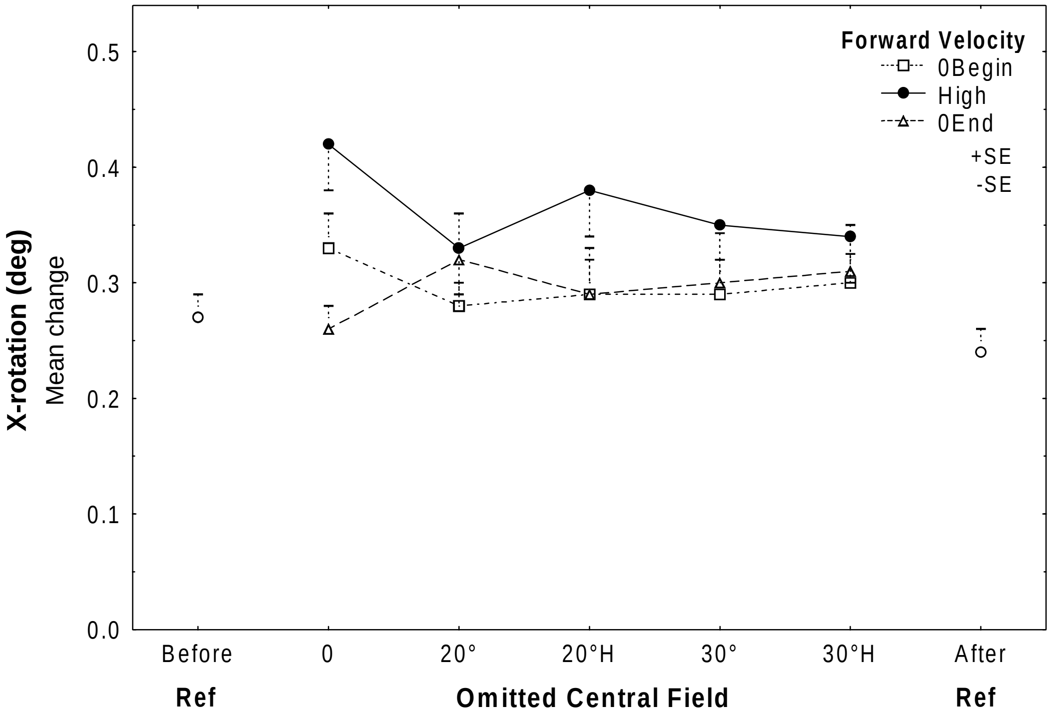

Figure 9. The interaction between central mode and flow velocity, with the group means of X-rotation at the different conditions of omitted central field for each forward velocity. Also shown are the group means of the reference measures (Ref) taken before and after each experimental session. Means are shown with either +SE or –SE.

2.2.1 Summary of the results

Altogether, the statistical analyses show no significant effects for x-translation. However, in y-translation a forward visual flow clearly affects balance. As seen in Figure 7, it does not matter what (horizontal) size the peripheral visual field has, for each of the different modes (153°, 108°, 45°), we have a significant effect of the forward visual flow. This is also manifest in all the different central modes (full central view, 20° and 30° omissions with and without added horizon-line) - during each and every one of them, a forward visual flow significantly increases postural instability.

Decreasing the peripheral view from 153° to 108° showed no significant decrease in postural response. However, decreasing to a 45° view did show such a decrease. That is, the postural effects seem to decrease if the peripheral visual field is cropped too much.

Furthermore, omitting 20° from the central view and adding a horizon-line, or omitting 30° showed no significant decrease in postural response in relation to full central view (no omissions). However, omitting 20° without adding a horizon-line, or omitting 30° with a horizon-line added, a significant decrease in postural response was shown in the participants.

Head tilt (x-rotation) did not show the effect of forward velocity as clearly as y-translation. As seen in Figure 9, the full central view and 20° omission with added horizon-line showed significantly larger rotations during forward velocity. None of the other modes showed significant changes during forward velocity. Comparing the different views to each other at forward velocity yielded results equivalent to y-translation, i.e. 20° with horizon-line and 30° without horizon-line did not show significant decreases, but the other views did.

3. Discussion

As noted in the results section, the translation in y-axis in the experiment show that adding a visual flow leads to greater postural instability. This effect is observed whether we have a full central view, remove 20˚ with or without a horizon line added, or remove 30˚ with or without horizon line added. For all these conditions, the visual flow increases postural instability significantly. The same goes for the peripheral croppings (horizontally). For 153˚, 108˚ and 45˚, the visual flow increases the postural instability effects. Hence, the visual flow proved to be important visual information in suppressing vestibular and proprioceptive information.

It also seems like we can crop the peripheral visual field from 153˚ to 108˚ without decreases in postural responses (in y-translation). If the peripheral visual field is cropped down to 45˚ however, a significant decrease in postural response was observed.

The results from the manipulations of the central visual field are not as clear as the manipulations of velocity or peripheral visual field. If omitting 20˚ of the central visual field, a significant decrease in postural response was observed in relation to the full central mode. However, with an added horizon line, no decrease was found in relation to full central view. This indicates that the horizon line provides some important spatial information. When omitting 30˚ of the central visual field, no significant decrease was shown in postural responses compared to full central view. However, if a horizon line is added, a significant decrease becomes manifest (in relation to the full central view). This result is less clear, and therefore harder to interpret.

Why x-rotation did not show clearer effects of forward visual flow might be an effect of the erect “Sharpened Romberg Stance”, which makes swaying the whole body more natural than just tilting the head. Also, it may be the case that participants, with the instructions to remain in upright posture fresh in mind, held the head more stiffly than they might have done without the instruction. A different result of x-rotation may have been generated in a situation with the participants sitting down, a situation that could be more natural to that postural response.

Translation in x-axis did not show any significant effects from the displayed visual information. This was not a surprise, since the stimuli do not present changes in the pitch axis, only changes in the roll axis (laterally). The attitude in the stimuli remained constant.

Interpreting the results in the light of the introduction, it seems indeed as spatial orientation is dependent on an optic flow, because that is the clearest effect shown in the experiment. The postural sway responses obtained can be ascribed to the phenomenon of vestibular suppression, since the g-force was constant during the experiment, while the visual information was manipulated. With regard to the different functions of the visual field, it seems as the spatial orientation functionality of the ambient system functions well with a certain loss of peripheral information horizontally. If the omission goes beyond a certain degree, however, the effectivity of the system is impaired. The ambient visual system also seems to function with a certain loss of information centrally, if some clue of spatial information is given in the omitted field. As with the peripheral information, if the central visual field is cropped too much, the ambient visual system's spatial orientation functionality decreases. Another possible interpretation of this effect could be that the focal visual system is involved in spatial orientation to a certain degree.

During the experimental situation, it was at no time assured that the participants kept his/her gaze at the central mark of the stimuli. Instructions to do so were given before each configuration was presented but it was not controlled that the participants complied. A possible way to go about this in another experiment would be to use stimuli with some information presented in the central visual field, and some task for the participant to execute. Another way to go about this would be to use a gaze controller to keep track of the eye movements of the participant.

A factor which may increase the postural response in the participants, would be to increase the degrees for the rolls, and to complement them with turn (yaw) movements.

Relating this experiment to the research conducted by Eriksson and von Hofsten (2002), the importance of a forward visual flow has once again been established. In their experiments, it was shown that the peripheral visual field could be cropped to 105˚ horizontally without significantly decreasing postural sway effects, and this experiment suggested a similar relationship at 108˚. Taking into account the contradictory findings Eriksson and von Hofsten (2002) had with regard to omissions in the central visual field, the results of this experiments give some support for the effectiveness of a 20˚ omission complemented by a horizon-line. But as noted above in the discussion, this result is not unambiguous.

Given the results of this experiment, a few implications are generated as how to design a visual display to counter spatial disorientation in the flight situation. The postural instability effects observed are interpreted as vestibular suppression, since the presented visual information overrode the vestibular and proprioceptive information. To achieve this, a visual flow is of large importance. It seems that we can crop the periphery of this flow to 108˚ (horizontally) without decreasing its effectiveness. When drawing conclusions about the central view, one has to bear in mind that existing technology displays a horizon-line in the HUD. Therefore, using the view with 20˚ omitted and complemented by a horizon-line, would both be in line with the results of this study and the technology in use today. Not to crop the central visual field at all is not an option, as a pilot must be able to access other information than an optic flow. Also, if comparing all the centrally omitted modes to the full view-mode, there is a clear tendency in decreasing effects on balance. However, the effect of the visual flow still makes the configuration more effective than no visual flow. So, in order to be realistic implementation-wise, we have to accept a decreasing effect in relation to full view, because the pilot must have access to a central visual field without an artificial flow.

To have an artificial optic flow as constant stimuli would be tiring. While using this optic flow, however, with 20˚ of the visual field available to other information, the major part of the visual field is still covered, something one can suspect a pilot would not like at all times especially not when meeting other hostile aircraft. HMD- and HUD-technology will have different modes, of which one could be a "spatial disorientation avoidance mode”. It would be able to have this turned on either by the pilot, during situations SD is likely to occur, or to have it turned on automatically during certain situations. Typical situations when SD is likely to occur are during take off, landing, conditions with poor visibility (fog, mist, rain, darkness) and when flying close to the ground at night.

It could be argued that attempts to support the pilot with information in the peripheral visual field would be of no use, as this narrows during very high g-forces. However, spatial disorientation occurs during situations with lower g-forces. During extremely high g-forces, a grayout first occurs, one loses the ability to see color. Then the peripheral visual system is affected in an intermittent manner, it just doesn’t disappear flat-out. Exposure to g-forces of this magnitude cannot be sustained for more than a few seconds, otherwise unconsciousness will occur, and then no spatial disorientation countermeasures can be of help whatsoever (except fully automated takeover procedures performed by the aircraft system).

To further investigate the properties of display characteristics to support spatial orientation, it is necessary to see how postural stability is affected when the participants have tasks to perform. It could be motor tasks or cognitive tasks somewhat relevant to the flight situation, and it would prevent them from focusing on maintaining posture.

Experimental situations with varying g-forces would be a critical test for our assumption that the vestibular suppression achieved in these experimental situations would transfer over to a situation closer to the reality of flying. When performing such experiments, the results in this study can serve as guidelines for how to design the visual support in this situation.

4. Acknowledgements

This work has been carried out at FOI, Division of Command and Control Systems, Departement of Man-System Interaction, Linköping.

First, I would like to thank Lars Eriksson and FOI, for offering me to be a part of their project, the office room to work in and the monthly salary. Special thanks to Lars for being a never ending source of information, and always being willing to discuss spatial disorientation and all related subjects with me. My gratitude also goes to Peter Andersson as well, who spent a lot of overtime work to get the experimental equipment up and running – and maintaining them during the time of the experiments.

I would also like to thank Paul Hemeren of Skövde University College, for both his extensive comments on my drafts as advisor, and for accepting me the last semester of the program as principal for the cognitive science program.

Lastly, thanks to the MSI-coffee machine at FOI, for brewing numerous cups a day and thus enabling my caffeine-level to remain at a constant high level during office hours this spring.

5. References

Anonymous, (2000). Wanna Shake? *Flying Safety*. Accessed March 1st, 2002, at: http://www.spatiald.wpafb.af.mil/news_view.asp?cid=7

Baker, M. (1998). A Primer on Spatial Disorientation. *Flying Safety*. Accessed March 1st, 2002, at: http://www.spatiald.wpafb.af.mil/news_view.asp?cid=4

Benson, A. J. (1978). Spatial Orientation – General Aspects. In G. Dehnin, G. R. Sharp & J. Ernsting (Eds.), *Aviation Medicine* Vol 1 (p 405-433). London: Tri-Med Books Ltd.

Bruce, V., Green, P. & Georgeson, M. (1997). *Visual Perception*. East Sussex: Psychology Press.

Davenport, C. (2000). Spatial Disorientation. *Flying Safety*. Accessed March 1st, 2002, at: http://www.spatiald.wpafb.af.mil/news_view.asp?cid=37

Eriksson, L. & von Hofsten, C. (2002). *Effects of Distribution of Peripheral Visual Flow on Percieved Spatial Orientation*. Manuscript in preparation.

Ercoline, W. & Previc. F. (2001). Spatial Disorientation, Geographic Disorientation. Loss of Situational Awareness, and Controlled Flight Into Terrain. *Human Systems IAC Gateway*, Vol XII no 3, 1-2. Accessed January 31st, 2002 at: http://iac.dtic.mil/hsiac/gateway/gw_xii_3.pdf

Ercoline, W., DeVilbiss, C. & Lyons, T. (1994). Trends in USAF Spatial Disorientation Accidents – 1958-1992. In R. Lewandowski.; W. Stephens & L. Haworth. (Eds) *Helmet- and Head-Mounted Displays and Symbology Design Requirements*. (p. 257-260). Proceedings of SPIE Volume: 2218.

Gibson, J. (1950). *The perception of the visual world*. Boston: Houghton Mifflin Company.

Gibson, J. (1979). The *Ecological Approach to Visual Perception*. Boston: Houghton Mifflin Company.

Gillingham, K. (1992). The Spatial Disorientation Problem in the United States Air Force. *Journal of Vestibular Research*, 2, 297-306.

Gillingham, K. & Previc, F. (1993) *Spatial Orientation in Flight*. Technical Report AL-TR-1993-0022, Armstrong Laboratory, Crew Systems Directorate, Crew Technology Division, Brooks Air Force Base, Texas, USA. (Can also be accessed at: http://www.spatiald.wpafb.af.mil/overview.asp)

Heinle, T. (2001). Spatial Disorientation Research. *Human Systems IAC Gateway*, Vol XII no 3, 1-2. Accessed January 31st, 2002 at: http://iac.dtic.mil/hsiac/gateway/gw_xii_3.pdf von Hofsten, C. & Rosander, K. (1997). *Spatial desorientering i flygsituationen*. HFA Report 1997-04, Linköping University, Departement of Mechanical Engineering.

Lee, D. (1980). The optic flow field: the foundation of vision. *Philosophic Transactions of the Royal Society of London, B 290*, 169-179.

Leibowitz, H.. (1988). The human senses in flight. In: E. Wiener. & D. Nagel. (Eds.), *Human factors in aviation* (pp. 83-110). London: Academic Press.

Marlowe, M. (1985). Spatial Disorientation Instrument Cross-Check: Your Achilles Heel. *Flying Safety*. Accessed February 10th, 2002, at: http://www.spatiald.wpafb.af.mil/news_view.asp?cid=52

Norman, J. (2002). Two Visual Systems and Two Theories of Perception: An attempt to Reconcile the Constructivist and Ecological Approaches. *Behavioral and Brain Sciences*, *24(6)*. Unedited final draft accessed April 14th, 2002, at: http://www.bbsonline.org/documents/a/00/00/05/11/bbs00000511-00/index.html

Patterson, F. (2000) *Conflict Between the Human Sensory System and Cockpit Design Standards.* Presented at Spatial Disorientation Symposium, 2000, San Antonio, USA. Accessed March 1st, 2002, at: http://www.spatiald.wpafb.af.mil/Mechanisms%20Studies/patterson.pdf

Sekuler, R. & Blake, R. (1994). *Perception*. Singapore: McGraw-Hill.

Vestal, M. (1998). First Time for Everything. *Flying Safety*, 1998. Retrived Accessed February 27th, 2002, from Spatial Disorientation Countermeasures Website at: http://www.spatiald.wpafb.af.mil/

Wickens, C. D. & Hollands, J. G. (2000). *Engineering psychology and human performance*. Upper Saddle River, NJ: Prentice Hall.

Aeromedical training for flight personnel. (2000). Accessed February 1st, 2002, from General Dennis J. Reimer Training and Doctrine Digital Library at: http://www.adtdl.army.mil/cgi-bin/atdl.dll/fm/3-04.301/toc.htm