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# **Some recent studies on spatial perception in Helmet-Mounted Displays**

## **Contributions récentes aux études sur la perception de l'espace dans les visuels de casque**

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## **ABSTRACT**

One challenging human factors issue in Helmet-Mounted Displays is the alteration of perceived distance. Distances judgments in virtual environments and Helmet-Mounted Displays are generally underestimated compared to the real world. Indeed, visual stimulation in Helmet-Mounted Displays presents some discrepancy with natural visual stimulation. After a brief review of the literature pertaining to the representation of space in Helmet-Mounted Displays, we explore two potential factors for the altered distance perception: the increased interocular separation (also called hyperstereopsis) and the reduction of the field of view. Some laboratory and training ground data are reported. This research has direct impact on the design and use of Helmet-Mounted Displays in order to ensure flight safety.

**Keywords:** Helmet-Mounted Displays, field of view, hyperstereopsis, distance perception, human factors

## **RESUME**

Les nouveaux équipements de tête de type viseur / visuel de casque présentent une information visuelle sur des optiques transparentes du casque du pilote, en superposition de l'environnement. Les contraintes optiques ne permettent de restituer que partiellement les conditions naturelles de vision. Notamment, la perception des distances est modifiée. Après une brève revue de la littérature concernant la perception de l'espace dans les visuels de casque, deux facteurs potentiels de sous-estimation des distances sont explorés : le sur-écartement des capteurs et la réduction du champ de vision. Les résultats présentés proviennent d'études de laboratoire mais également d'études de terrain. Le projet de recherche vise à analyser les conséquences perceptuelles et opérationnelles des différentes contraintes et l'adaptation de l'observateur à l'usage de ces dispositifs optiques afin de définir les conditions d'emploi optimales pour la sécurité du vol.

**Mots-clés :** Visuels de casque, champ de vision, sur-écartement des capteurs, hyperstéréopsie, perception des distances, facteurs humains

## INTRODUCTION

Head-and Helmet-Mounted Displays (HMDs) are being developed and marketed in a growing number of applications (military, medical and commercial e.g. in manufacturing and in entertainment). Visual displays may be either monocular (one single image source presented to only one eye), biocular (one single image source presented to both eyes) or binocular (each eye is presented a different image source). The advantages of binocular stereoscopic displays are linked to their ability to simulate three-dimensional (3D) objects or visual scenes. A number of studies have looked at the human factors involved in binocular stereoscopic displays<sup>(1, 2)</sup>. The present paper deals with space perception through such visual displays: although these displays provide an effective simulation of the visual world, they do not replicate it.

Multiple and redundant visual cues for the perception of the three-dimensional space perception are available when exploring a natural scene. Visual cues for 3D space perception may be monocular and/or binocular. Some are quite independent from visual signal processing and directly depend on the optical parameters of the eye. Other visual cues for 3D space perception demand a visual processing of the light signal.

Under normal conditions, the integration of those information leads to a single, coherent, three-dimensional and a nearly metric perception of space<sup>(3)</sup>. In virtual environments, egocentric distances (i.e. perceived distance of an object relative to the observer) tend to be underestimated when compared to the same distance judgments in the real world. This underestimation may reach 47% of the true distance<sup>(4, 5)</sup>, thereby impacting the ability for a user to interact in the virtual world as in the real one.

In a stereoscopic visual display, most but not all the relevant visual cues to 3D space perception are present in accordance with the technology used. Some hypotheses concerning factors affecting distance perception are discussed in the following section.

## LITTERATURE DATA

Clear, binocular single vision of an object requires the accommodation system to bring the object into focus and the vergence system to locate the image of the object on the fovea of each eye (figure 1A). A stereoscopic display specifies the distance and depth of objects by the relative positions (i.e. disparity) of the left and right images presented on a flat screen (figure 1B). The image projection on the screen determines the accommodation (i.e. focusing).

One possible candidate to the explanation of distance underestimation is the difference between the physical accommodation (focal) distance to the projection plane and the accommodation that would be required for a fixation onto the object in the real world (figure 1B). The different required accommodative response may influence the perceived distance of the object. There is in fact some debate about the effective role of the accommodative cue in distance perception. Mon-Williams & Tresilian suggested that accommodation may give only ordinal information for distance<sup>(6)</sup>. Moreover, among the literature, only few subjects showed a strong correlation between their accommodative response and their distance estimation<sup>(7)</sup>, thus suggesting that accommodation can provide a minority of subjects with ordinal distance information<sup>(6)</sup>.

Another factor could be the dissociation between accommodation and convergence<sup>(8)</sup>. Under normal viewing condition, accommodative and convergence demands are congruent and depend on the object distance (figures 1A and 2A). As an object approaches, it requires progressively more accommodation and vergence. Indeed, a physiological coupling between accommodation and convergence provides accurate accommodative and vergence responses to the target<sup>(9)</sup>. In HMDs, the accommodative demand is a constant and is determined by the projection plane, whilst the convergence demand varies with the distance of the observed target (figures 1B and 2B). This mismatch increases as the object is located farther from the projection plane. Many studies have shown that the accommodation and vergence cues together play an important role in egocentric distance perception, at least in a reduced cue environment<sup>(10, 11)</sup>.

Another particular demand may be placed on the vergence system. In some recent helmet-mounted night vision devices (“See-through” HMDs, such as the Tiger pilots’ TopOwl™, see figure 3), image intensifier tubes are located on both sides of the helmet. Such lateral placement of the sensors optically increases the interpupillary distance (IPD), see figure 4. Horizontal binocular disparities and the required vergence to fuse on close objects are increased. This can cause the distance to a viewed object to appear shorter and the object to appear closer. These aspects will be discussed below.

The image quality could be another candidate. Low-contrast or dim displays may cause vergence to drift toward a rest position (called dark vergence) and then cause distance to be misperceived<sup>(12)</sup>. However, recent studies showed that image quality is not a critical factor in distance judgment<sup>(13)</sup>, but rather may degrade the sense of presence.

Another parameter that may impact distance perception in virtual environments is the size of the field of view. Actually, the projection technologies (HMD or projection screen) restrict the visual field to a central part of the human natural visual field (which is approximately 200° Horizontal by 120° Vertical). The observation of a virtual image may be considered as the observation of a scene through a window reducing the number of objects that can be simultaneously seen in the scene, and thus limiting the chance of a correct understanding of the environment<sup>(14)</sup>. Despite the fact that the size of the field of view has been reported to play a crucial role on the space perception in real environment<sup>(15-17)</sup>, its effective role in virtual environment needs to be clarified.

## **FIELD OF VIEW (FOV)**

The experiments reported in this section<sup>(18)</sup> deal with egocentric distances in the personal space (<1 m)<sup>(3)</sup>, which are especially relevant to many virtual environments applications.

Among the relevant cues partially represented in a virtual environment is the size of the visual field. Some experiments reported that the truncation of the visual field

causes compression of perceived distance – people estimate objects closer than they actually are<sup>(19)</sup>, and/or decreases precision<sup>(20)</sup>. The missing part of space could provide additional data for the task of distance estimation to objects in the environment. In the real world, it has been shown that the overlap of peripheral and fovea information is necessary for veridical perception to occur and that restricting the FOV would interfere with both perception and visuomotor performance<sup>(15)</sup>. For example, the constriction of the visual field significantly increased the time taken to complete a driving course, reduced the ability to detect and correctly identify road signs, avoid obstacles and to manoeuvre through limited space while driving<sup>(21)</sup>.

The purpose of the first experiment reported here was to test the influence of the size of the FOV on the accuracy of distance estimates in a static simulated rich environment. The results showed that when the ratio between the angular size of the target and the angular size of the FOV is below a threshold around the third ( $1/3$ ) of the image, whatever the size of the FOV, egocentric distance judgments tend to be underestimated. We can suppose that narrowing the FOV corresponds to a suppression of peripheral environmental information (i.e. contextual cues). Conversely, when the information on the environment surrounding the object is sufficient, the egocentric distance estimations are more accurate.

In another experiment, subjects underwent the same experiment (with reduced FOV) but were allowed to move their head in order to explore the whole scene. The results showed that when a subject increases his “dynamic FOV” by turning his/her head, the egocentric distance estimation becomes normal again, even if the “static” FOV is narrow. It shows that the movements of the observer give sufficient information to the brain to allow a distance scale reconstruction. This result is important because it proves that the essential FOV for egocentric distance perception is the “dynamic FOV” and not the “static” FOV. The brain seems to integrate in time the extension of the FOV and to use the “dynamic FOV” as the new dimension of the image. The more the subject can move, the wider the dimension of the image will be and the more accurate the egocentric distance estimation will be.

In summary, the experiments reported here demonstrate that for a static observer, the reduction of the available FOV leads to an underestimation of egocentric distance to nearby objects. The more the FOV is limited, the more the distances are underestimated. Such underestimation disappears when the participants are allowed to perform head movements. We also suggest that the important parameter is not the size of the FOV itself, but rather another related parameter: the ratio of the angular size of the target compared to the angular size of the static FOV.

## **LATERAL SENSORS PLACEMENT AND HYPERSTEREOPSIS**

Both binocular disparities and convergence are sensitive to the placement of the image intensifier tubes in a stereoscopic display and could be modified in See-through (i.e. type II) HMDs. As an example, the sensors of Tiger pilots' TopOwl™ are separated by more than four times the standard interpupillary distance (which is 63 mm on average), as seen in figure 4. Increasing the inter-sensors separation (a phenomenon called hyperstereopsis) is a candidate factor for distance perception alteration.

In fact, sensors placement was found to influence the pilots' estimation of distance. Data on hyperstereopsis come from laboratory studies as well as from flight testing and pilot training survey. Results reported here involve both egocentric (i.e. from the observer to an object) and relative (i.e. between two objects) distance perception. The range of distances explored extends from short to large distances, covering a large range of flight operations.

Laboratory studies were performed in order to investigate the initial effects of hyperstereopsis and resulting short-term adaptation. A compression of near visual space was obtained during exposure to a three-fold increased IPD in a reduced cues environment<sup>(22)</sup>. Partial adaptation occurred after a ten-minute exposure, with large inter-individual differences.

A simulation study used videotapes recorded during helicopter flights with varying the layout of a couple of cameras, modifying the inter-camera separation and the

convergence state of their optical axis<sup>(23)</sup>. Distance perception was evaluated using a double distance paradigm (which is a validated distance estimation method in natural outdoor settings<sup>(24)</sup>). Results showed a relative underestimation of the first plane (egocentric distance to the marker) compared to the further plane (relative distance between the marker and the target) for short and mid distances (295 m for distance and 60 ft for height). The estimations were significantly dependent on the spatial arrangement of the cameras. Results also individualized a clear subjects' preference for the reproduction of the three dimensions of the over flown terrain at low altitude. This condition was obtained with an increased inter-camera separation (240 mm) and convergence of the optical axis of the video cameras (convergence at 20 m). These observation conditions enhanced relative distance perception due to magnified crossed and uncrossed lateral binocular disparities.

It seems unlikely that increased convergence would be efficient at the distances investigated. Nevertheless, lateral retinal disparities may provide information up to 264 m<sup>(25)</sup>. We could suppose that the range of distances where binocular disparity acts as a cue for relative distance perception increases with greater inter-sensors separation.

French developmental testing for the earlier configuration of the TopOwl™ HMD was conducted on a two-year period from 1995 to 1997. The study reported “a systematic underestimation of distances and heights, (with) pilots feeling closer and lower than they really were”<sup>(26)</sup>. Pilots also reported to have “returned to nominal performance” after 5 to 10 hours of flight.

A prospective study following Tiger Helicopter pilots' training showed double height estimation errors with a tendency for the pilot to stand farther from the target<sup>(27)</sup>. Such effect occurred for heights smaller than 66 ft. Pilots also underestimated double distances (< 60 m). Several pilots cited landing as the most delicate situation encountered. Some other studies highlighted terrain slopes as an aggravating factor<sup>(28)</sup>. More than half of the pilots experienced sensory illusions during the first flight. The most common sensory illusion was faulty height judgment or “sitting in a hole” feeling when the aircraft was on the ground. Other mentioned visual illusions

were objects appearing nearer than they actually were and micropsia (smaller size objects), see details in figure 4.

Experienced visual illusions are a complex outcome of hyperstereopsis. They could be related to increased binocular disparity and increased convergence, depending on viewing distance. Experienced illusions could also depend on the presence of other cues for distance, or the motion of the observer.

To conclude this section, laboratory and field studies have revealed both a real impact of increased inter-sensors separation on distance perception and the possibility for adaptation to such an optical constraint. Hyperstereopsis is a near- to mid-range effect and thus a potential issue for landing, especially on sloped grounds, and low altitude operations.

## **CONCLUSION**

One challenging human factors issue when using HMDs is the distortion of distance (egocentric and relative). A small FOV reduces the number of elements that can be simultaneously seen and thus limits the chances of a correct understanding of the environment. Hyperstereopsis may modify distance, depth and size of near objects and may generate complex sensory illusions.

Such human factors issues may impact flight safety. Fortunately, humans are capable of a certain amount of adaptation. Further studies are needed to explore the nature of the adaptive component, the amount of adaptation (complete vs partial), the time course of the adaptive phenomenon, the inter-individual differences, and the limits of the tolerance to such constraints. The findings of the studies will have direct application for the design and use of HMDs.

It must be noted that the perceptual issues related to lateral sensors placement in some stereoscopic displays do not question the relevancy of stereopsis. The addition of stereopsis allows the pilot to directly visualize the spatial relationships among objects and resolve any ambiguity in monocular visual cues without complex cognitive processing.

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The laboratory experiments reported in the section “Lateral sensors placement and hyperstereopsis” were performed on the “Plateforme Mouvement et Handicap” IFNL (Lyon Bron, France). The survey of Tiger pilots training was conducted at the Ecole Franco-Allemande (EFA), Base Ecole Général Lejay, Le Luc-en-Provence, France.

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## FIGURES

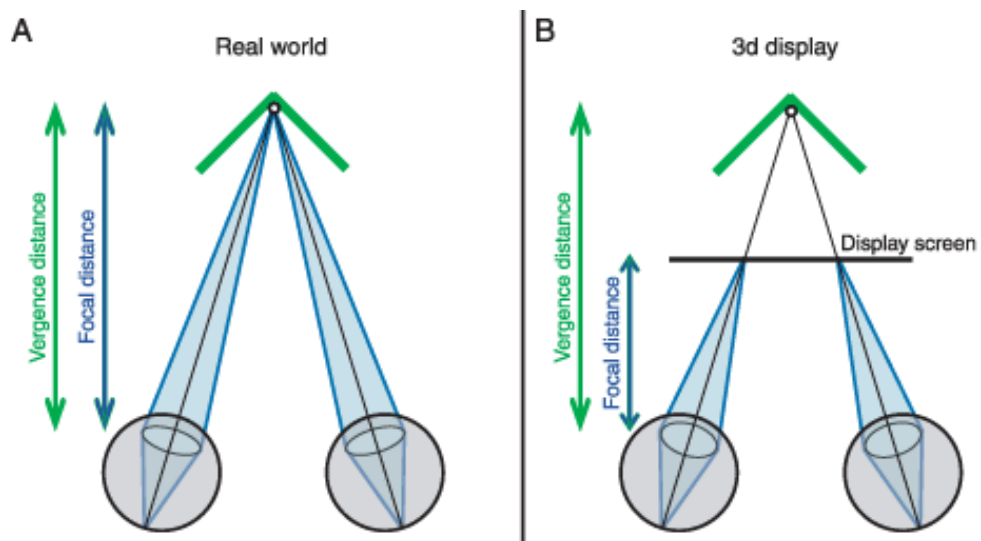


FIG. 1

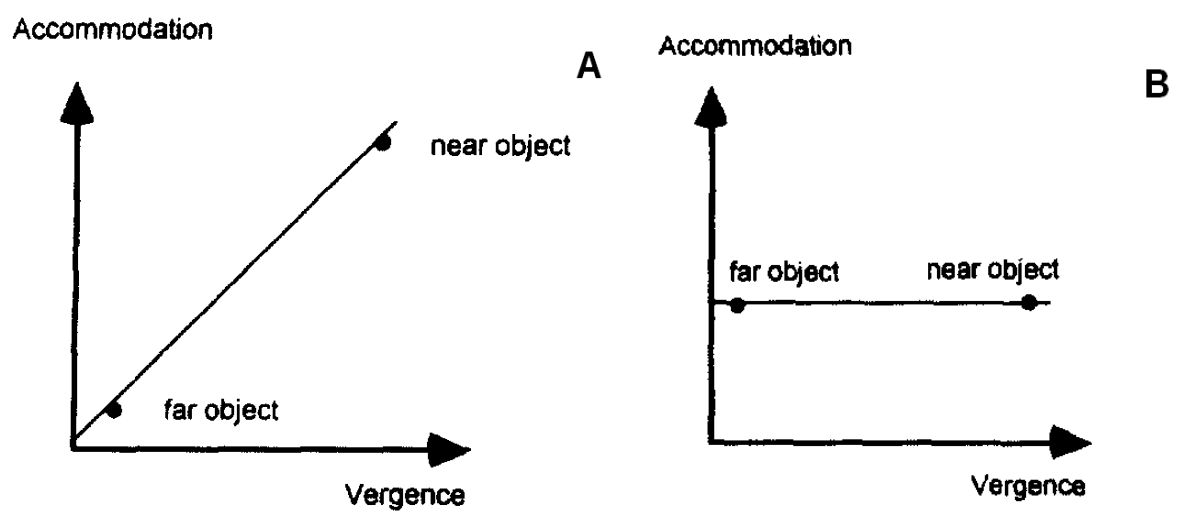


FIG. 2



FIG. 3

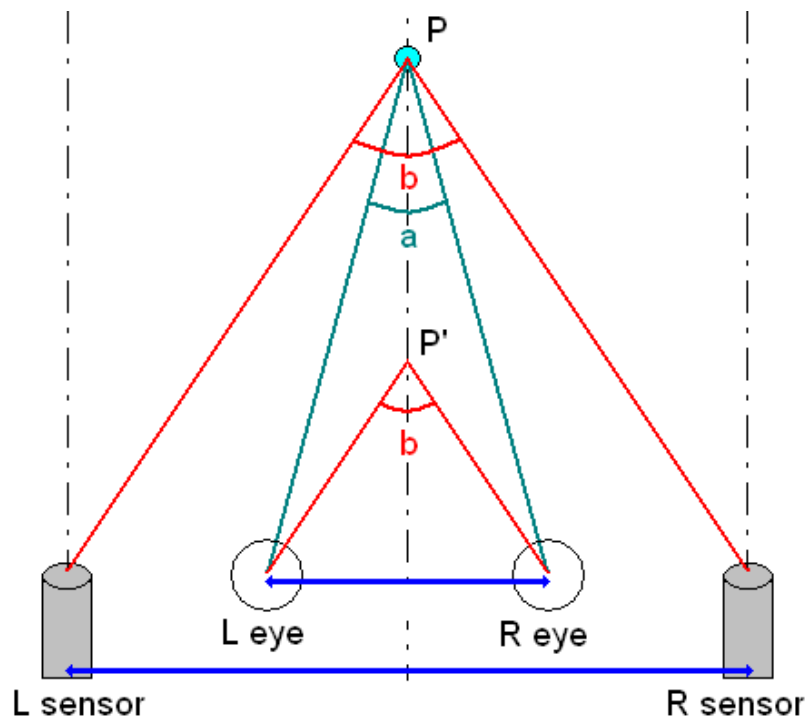


FIG. 4

## **Figures title and captions**

### **Fig. 1: vergence and accommodation (focal) distance with real stimuli and stimuli presented on stereoscopic displays.**

(A) In the real world, vergence distance and accommodation (or focal) distance are congruent.

(B) In a stereoscopic or 3D display, the accommodation (or focal) distance is the distance to the display plane/screen. There is a difference between the physical accommodation (focal) distance to the projection screen of the display and the accommodation required to fixate the object in the real world. Moreover, the observer has to accommodate to the display screen but to converge on different depth planes.

### **Fig. 2: the relationship between accommodation and vergence stimuli**

(A) In normal viewing.

(B) In HMDs.

### **Fig. 3: the TopOwl™ Helmet.**

Including night vision capabilities in visual displays requires sensors such as image intensifier tubes. “See-through” systems project imagery from intensifiers mounted on the sides of the helmet onto the helmet semi-transparent visor. The pilot is able to see both sensor images and direct vision of the outside scene through the semi-transparent visor.

### **Fig. 4: distance perception with See-through HMDs and resulting visual illusions.**

The distance between the two image intensifier tubes (IPD') is equivalent to more than 4x the subject's normal IPD. An observer fixating the target point P must converge at the point P'. The convergence angle thus increases from  $b$  to  $a$ . The target point P is then perceived to be located at the point P'.

The physical size (on the retina) is not modified by the increased IPD. However, as the object is seen closer for the same retinal size, it gives the observer the impression of being smaller (a phenomenon called micropsia).

The hyperstereopsis effect decreases with increasing observation distance, as the impact of convergence decreases with distance. When a pilot is sitting in the cockpit on the ground, he may perceive that ground level outside the cockpit is at chest level. The pilot can summarize the perception as “sitting in a hole”. However, distant objects may look natural.