



Flash induced afterimage versus single spot visual object influence on visual–vestibular interaction in detection threshold for self-motion perception



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HIGHLIGHTS

- We studied the effect of visual afterimage on self-motion perception during rotation.
- Afterimage lowers the threshold for self-motion perception compared to darkness.
- Compared to a 'real' visual object fixation the threshold with afterimage is higher.
- The threshold is frequency dependent – it decreases with increase of the frequency.

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ABSTRACT

In seven healthy subjects we studied the effect of flash induced afterimage on perceptual threshold for self-motion during sinusoidal vertical axis rotation compared to rotation in darkness, and rotation with subject's gaze fixed on a 'real' visual object rotated with him. For a real object we used light-emitting diode (LED) aligned with subject's head.

A MOOG motion platform was used to generate motion. Single cycles of sinusoidal acceleration at four frequencies: 0.1, 0.2, 0.5, and 1 Hz were used as motion stimuli.

The results show that the threshold when subjects stare at an afterimage during rotation is consistently lower compared to rotation in darkness. However, compared to the threshold during rotation with a 'real' object visual fixation it is higher, significantly at frequencies 0.5 and 0.2 Hz ($p < 0.05$). The threshold is frequency dependent – it decreases with increase of the frequency ($p < 0.01$).

The probable mechanism of afterimage influence on perceptual threshold for self-motion is discussed.

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1. Introduction

Human organism uses overlap sensory systems for functioning. For instance the self-motion can be detected by the vestibular, visual, proprioceptive, and auditory sensory systems. Generally their role is to facilitate each other to allow a precise and a lower threshold perception. In some cases their interaction creates conflict; even so it results to a benefit for perception. For instance in earlier studies on self-motion perception during angular acceleration, the threshold in darkness, that is, when the vestibular system works only [1–6] has been found. When the visual system was involved by subject fixating his gaze on visual spot rotating with

him (that is, in condition of visual–vestibular interaction) a change of the threshold has been established. This is a situation of sensory conflict between the vestibular information for rotation and that from the visual system for not moving visual object with respect to the subject. In such conflict condition a decrease of the threshold has been established [3,7–11]. It was expressed mostly for lower frequencies when sinusoidal rotation was applied [1]. The lowering of the threshold is due to the "oculogyral illusion". This term was applied by Graybiel and Hupp [12] to define apparent motion of object in the visual field associated with angular acceleration of the body.

For some reactions of the human organism to external stimuli we still do not completely understand the biological meaning. For example motion sickness. It manifests with opposing effects in different individuals – lowering blood pressure in some subjects and its increase in other. The same is with the pulse rate, skin color etc [13]. Another interesting phenomenon is 'afterimage'. Its biological meaning and mechanism through which it operates is

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for now also not completely revealed. Recent study implies that formation of afterimages involves neuronal structures that access input from both eyes but that do not correspond directly to the neuronal correlates of perceptual awareness [14]. Van Boxtel et al. [15] investigated the duration of afterimages for all four combinations of high versus low attention and visible versus invisible. Interestingly they showed that selective attention and visual consciousness have opposite effects: paying attention to the grating decreases the duration of its afterimage, whereas consciously seeing the grating increases the afterimage duration. Their findings provide clear evidence for distinctive influences of selective attention and consciousness on visual perception.

With a head fixed target, perceptual thresholds for self-rotation are lower. The presence of a target improves perceptual threshold because of (i) visual suppression of the evoked vestibulo-ocular reflex (VOR), and (ii) retinal slip of the target following eye drift caused by incomplete VOR suppression [16]. The purpose of this study was to investigate the influence of another visual cue that does not imply VOR cancellation, or retinal slip. Such visual cue is afterimage.

2. Subjects and methods

2.1. Subjects

Seven healthy subjects (39 ± 12 years, 3 females and 4 males; 5 right-handed and 2 left-handed) were recruited to participate in this study. All subjects need first to complete a detailed vestibular diagnostic clinical examination to confirm a normal vestibular function before being included in the study. The vestibular screening examination consisted of Caloric electronystagmography, Hallpike testing, angular VOR evoked via rotation and posture control measures. Furthermore, a short health history questionnaire was administered; subjects were asked to indicate any known history of dizziness or vertigo, back/neck problems, cardiovascular, neurological and other physical problems. Subjects were also asked about their motion-sickness susceptibility. Informed consent was obtained from all subjects prior to participation in the study. The study was approved by the local ethics committee and has been performed in the Massachusetts Eye and Ear Infirmary building in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki.

2.2. Apparatus and motion stimuli

A MOOG motion platform (MOOG 6DOF2000E) was used to generate motion (Fig. 1). Single cycles of sinusoidal acceleration ($a(t) = A \sin(2\pi ft) = A \sin(2\pi t/T)$) were used, where A is the acceleration amplitude and f is the frequency, which is the inverse of the period (and duration) of the stimulation ($T = 1/f$). Since the motion began at zero velocity, integration of the acceleration yields an oscillatory velocity, $v(t) = AT/(2\pi) [1 - \cos(2\pi t/T)]$, and a lateral displacement $\Delta p(t) = AT/(2\pi) [t - T/(2\pi) \sin(2\pi t/T)]$. Therefore, both the peak velocity ($v_{\max} = AT/\pi$) and the total lateral displacement ($\Delta p = AT^2/2\pi$) are proportional to the peak acceleration (A). These motion profiles were chosen because they mimic the characteristics shape of natural volitional head movements, because they have been successfully utilized in the only other study quantifying perceptual yaw rotation thresholds as a function of frequency [3], and because these motion profiles contain no discontinuities in acceleration, velocity, or position.

2.3. Visual stimuli

Subjects were exposed to two different visual stimulations while sitting on a chair (Fig. 1). One with a red spot which is produced by a light emitting diode (LED) fixed 60 cm in front of them

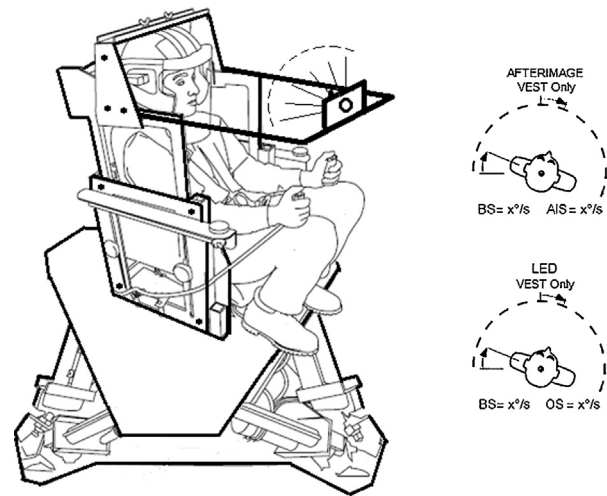


Fig. 1. Schematic presentation of the experimental set-up: Moog platform with a tested subject and visual stimuli. Schematic presentation of the used stimuli. Abbreviations: VEST – vestibular stimulus, BS – body in space, OS – object in space, AIS – afterimage in space.

aligned with midline of the subject's head. The red spot, which rotated with the chair, stayed in fixed alignment with their heads and subjects were asked to view the red spot only during motion. The brightness was just enough to be detected in darkness without illuminating the surrounding area and never changed during all the experiment. The second visual stimulation – flash induced afterimage was produced by a standard commercial xenon flash camera having a cross shaped aperture of 1 cm in height and width, fixated at the same position as LED, 60 cm in front of the subjects' eyes. To avoid any dazzle effect the flash it was covered by green plastic filter. Subjects reported that they feel comfortable with the applied attenuated flash stimulus. The afterimage was centered on the fovea. Subjects were asked to stare straight ahead without attempting to fixate the afterimage.

2.4. Experimental procedures

Subjects were seated in an upright position in a chair with a 5-point harness and rotated in darkness and under visual stimulations in yaw about an earth-vertical axis. The subject's head was held in place via an adjustable helmet, and was carefully positioned relative to the axis of rotation using external landmarks. The head was centered left to right relative to the earth-vertical rotation axis. In addition, we identified the posterior edge of the external ear canal and located the rotation axis near this landmark in the fore-aft direction. To minimize the influence of non-vestibular cues regarding motion direction, trials were performed in the dark in a light-tight room. All skin surfaces except the face were covered (long sleeves, light gloves) and a visor attached to the helmet surrounded the face. Earplugs reduced external noise by about 20 dB and the remaining auditory motion cues were masked by white noise (circa 60 dB). Tactile cues were distributed as evenly as possible using padding.

Thresholds for self-motion in darkness, with red spot visual stimulation, and with flash induced after image were measured at four different frequencies, namely at 0.1, 0.2, 0.5, and 1 Hz. Each frequency was tested in a block of contiguous trials. These four blocks of trials were separated by a short break. The order of blocks was randomized across subjects.

Subjects were rotated in yaw in three conditions randomized between the subjects: (1) in total darkness; (2) subjects were asked to fixate their gaze at the LED aligned with midline of the subject's head, rotated together with the subjects (Fig. 1); (3) subjects

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