Motion perception under involuntary eye vibration

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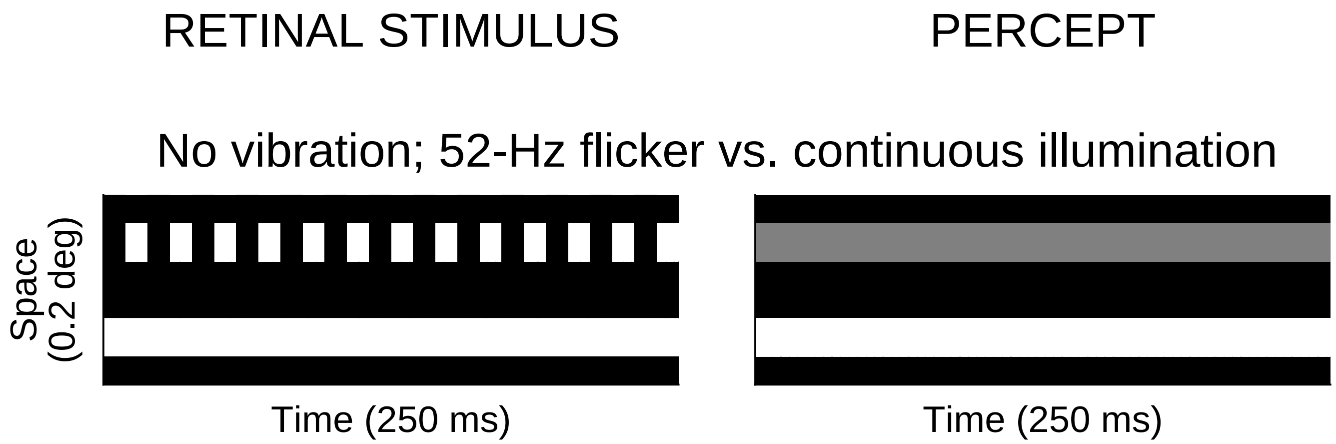
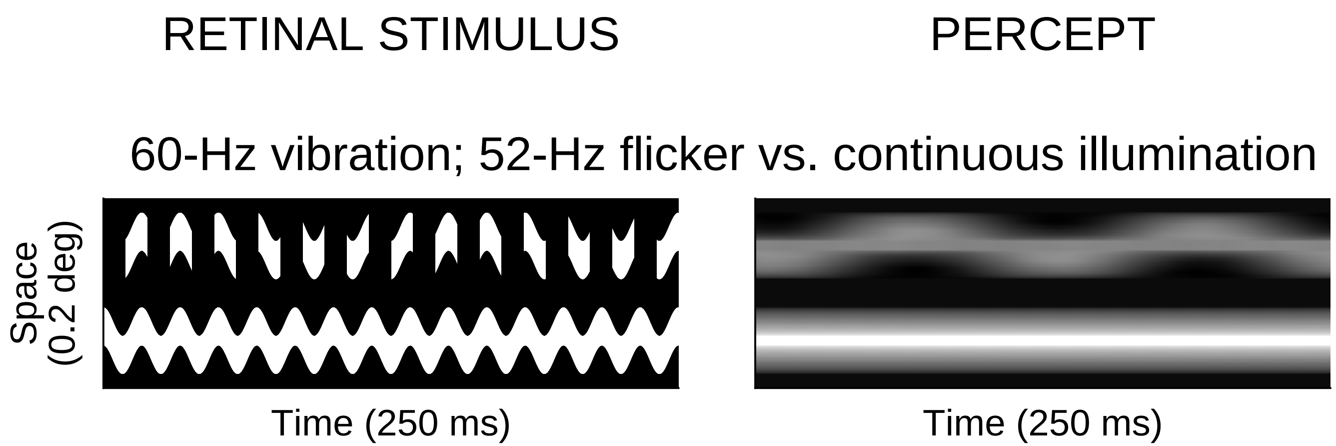
1. Abstract

Retinal motion caused by voluntary eye movements is rarely misinterpreted as object motion, as if the visual system discounted the contribution of voluntary eye movements to retinal motion. Yet, involuntary eye movements caused by mechanical eye vibration is often interpreted as object motion unless the vibration has high frequency, in which case only image blur may be noticed. In these latter conditions, however, a light flickering above the fusion limit is vividly perceived to undergo oscillatory motion over its static surround. We determined the conditions of this phenomenon, showing that the perceived frequency of illusory oscillation equals the difference between flicker frequency and the frequency of vibration of the eyes. This outcome is explained as a result of the low-pass temporal frequency characteristic of vision, which further predicts that the same effect should occur if the flickering light is vibrated and observed with static eyes. This prediction was corroborated empirically. We also determined the minimal amplitude of oscillation required to perceive motion as a function of postural stability and the presence of static references, finding an amplitude threshold of 1 arcmin with postural stability in dim-light conditions which increases to 2 arcmin with postural instability in the dark.

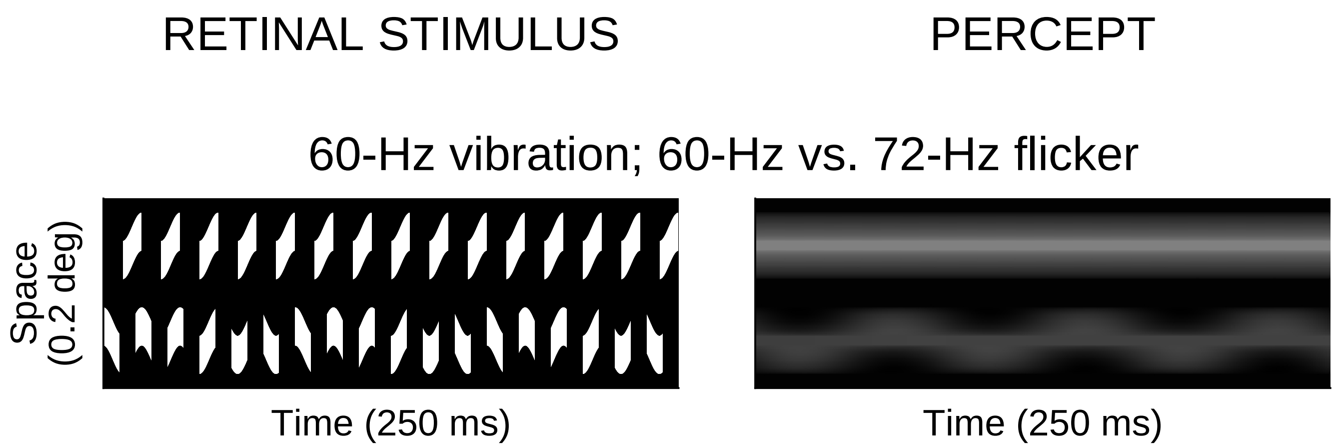
2. Illusory motion resulting from light flicker and eye vibration



Without eye vibration, a light source flickering above the fusion limit (52 Hz; top left) is perceived as continuous illumination (top right), although dimmer than a non-flickering light source (bottom).



When the eyes vibrate at 60 Hz, the light sources are effectively swept back and forth over the retina. Temporal lowpass filtering in the visual system makes the flickering stimulus appear perceptually as undergoing 8-Hz oscillatory motion (2 cycles over the 250-ms span displayed in the top right), whereas the same process makes the continuous light source appear blurred but motionless (bottom right).



The perceived frequency of illusory oscillation should depend on the difference between flicker frequency and the frequency of eye vibration. When both frequencies are identical (top), no illusory oscillation should occur; when they differ by 12 Hz (bottom), the illusory motion should have that frequency (3 cycles over the 250-ms span displayed in the figure).

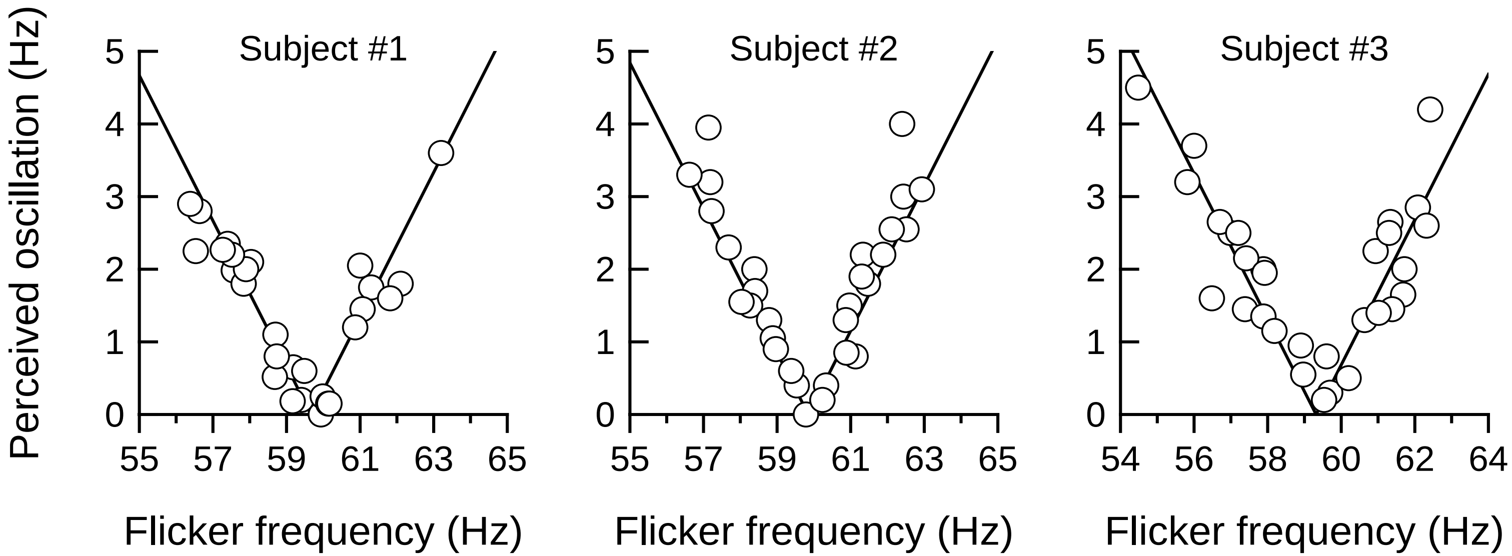
Massager used in our experiments

Other People's Money, 1991: Danny De Vito experiences the motion illusion as he watches his computer while brushing his teeth

3. Experiment 1

If the illusory oscillation is caused by temporal filtering, its temporal frequency should be the absolute value of the difference between the frequency of flicker and the frequency of eye vibration.

The prediction was confirmed in an experiment that measured perceived frequency of oscillation as a function of flicker frequency:



Methods

Apparatus and stimuli

Head vibration was produced with a commercial percussion massager. The stimulus consisted of two adjacent light sources: a sharp-edged circular LED (4.5 mm in diameter) and a reflected laser beam (3.5 mm in diameter). The LED was made to flicker with a square waveform, and its frequency is the independent variable in the present experiment. The beam of a 640-nm laser pointer came reflected from a front-surface mirror galvanometer that was set to oscillate vertically with a triangular waveform. The frequency of oscillatory motion of the laser beam—adjusted by the subject until it matched the illusory oscillation of the LED—is the dependent variable in this experiment.

Procedure

Subjects sat 1 m from the visual display and pushed the body of the massager up against their lower jaw. The subjects had their jaws locked so that vibration was transmitted up to the cranium and on to the eyes, which thus vibrated vertically. Differences in pressure of the massager against the lower jaw as well as differences in locking pressure of the jaws affected the amplitude of vertical eye vibration but did not alter its frequency as measured with a cancellation method (García-Pérez & Peli 2002).

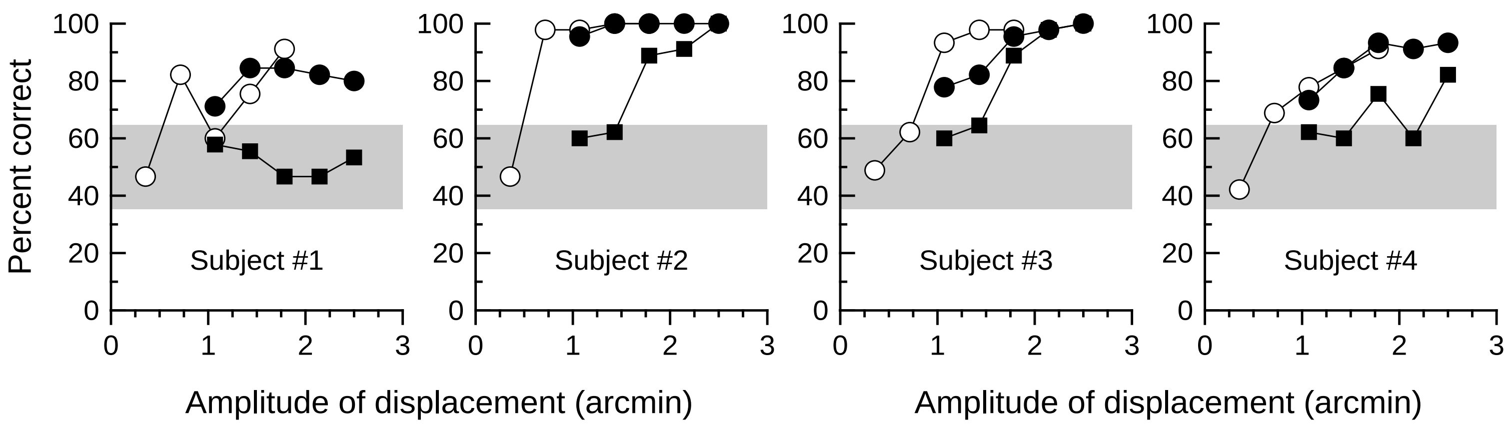
The experiment was carried out in a single session of 30 trials. The room was lit with incandescent light. On each trial, the flicker frequency of the LED was set at a random value within 4 Hz from a rough estimate of the frequency of eye vibration obtained at the beginning of the session with a cancellation method (García-Pérez & Peli 2002). The subject then adjusted the frequency of oscillation of the laser beam until it appeared to match the illusory rate of oscillation of the LED. Subjects were allowed to adjust the amplitude of oscillation of the laser beam at any time if this helped them carry out the task more comfortably. Each trial produced a pair of values: the flicker frequency of the LED (independent variable) and the matching frequency of oscillation of the laser beam (dependent variable).

4. Experiment 2

The motion illusion was used to determine the minimal displacement (amplitude of eye vibration) that is necessary to perceive motion. The vibration was applied to the stimulus and the study was carried out under three lighting/postural conditions:

1. postural stability in the light (thus with static visual references; ○ in the figure below)
2. postural stability in the dark (without visual but with proprioceptive references; ● in the figure)
3. postural **in**stability in the dark (without visual or proprioceptive references; ■ in the figure)

Threshold increased with decreasing references (whether visual or proprioceptive):



Methods

Apparatus and stimuli

A 633-nm He-Ne laser beam was used which rendered an elongated shape (2.5×5 arcmin at the viewing distance of 5.5 m) on the projection plane. The laser beam passed through an acousto-optical modulator driven to produce square-wave flicker of adjustable frequency. The flickering beam was reflected on a front-surface mirror galvanometer that was set in sinusoidal oscillation at 55 Hz. The amplitude of the oscillation of the beam along its long axis is the independent variable in this experiment.

Procedure

There were three conditions. In one, subjects sat and the room was lit with a DC source so as to allow visible fixed references within the field of view; in another, subjects sat similarly but the room was in complete darkness; in the third one, subjects were also in complete darkness and stood on only one foot to produce postural instability. A session consisted of 15 trials at each of 5 amplitudes of oscillation, order randomized. Three separate sessions were run for each of the three postural/lighting conditions for a total of 45 trials per amplitude per condition. Each trial, whose beginning was signaled by an audible beep, presented a temporal 2AFC task in which the acousto-optical modulator was set to flicker at 60 Hz in one of the intervals (chosen at random with equiprobability) and at 600 Hz in the other. Presentation duration in each of the intervals was 2 s, with an interleaved blank lasting 1 s. One of the intervals thus resulted in the laser beam actually appearing to undergo sinusoidal oscillation at a detectable 5 Hz while the other resulted in an undetectable oscillation at 545 Hz which simply appeared perceptually as continuous illumination without motion. The subject’s task was to indicate in which of the two intervals the beam had oscillated.

5. Discussion

— Flicker that is not detectable with static eyes gives rise to the perception of illusory motion when the eyes vibrate. This is a simple consequence of the lowpass temporal-frequency characteristic of vision.

— The displacement threshold for motion perception in complete darkness with postural instability is ~2 arcmin; with postural stability in the light (with nearby static visual references), the displacement threshold decreases to ~1 arcmin. Previous estimates of the displacement threshold in the light varied across studies from ~0.2 arcmin (Tyler & Torres 1972; Westheimer 1979; Nakayama & Tyler 1981) to ~1 arcmin (Levi et al. 1984); previous estimates of the displacement threshold in the dark were always lower than 2 arcmin, but none of those estimates were obtained in complete darkness.

6. References and other relevant papers

Bolger C, Bojanic S, Sheahan NF, Coakley D, Malone JF (1999) Dominant frequency content of ocular microtremor from normal subjects. Vision Res 39:1911–1915

Coats AC, McCrary JA (1979) Voluntary nystagmus masquerading as Tullio’s phenomenon. Arch Otolaryngol 105:288–289

Dennis JP (1965) Some effects of vibration upon visual performance. J Appl Psychol 49:245–252

Eastman PC (1969) Effect of humming on vision. Nature 222:164

García-Pérez MA, Peli E (2001) Intrasaccadic perception. J Neurosci 21:7313–7322

García-Pérez MA, Peli E (2002) Simple non-invasive measurement of rapid eye vibration. J Sound Vib, in press

Griffin MJ, Lewis CH (1978) A review of the effects of vibration on visual acuity and continuous manual control, part I: Visual acuity. J Sound Vib 56:383-413

Harazin B, Louda L, Pawlas K, Jandak Z (1996) Influence of whole-body vertical vibration on vision performance. J Low Freq Noise Vib 15:17–24

Lange KO, Coermann RR (1962) Visual acuity under vibration. Human Factors 4:291–300

Legge GE, Campbell FW (1981) Displacement detection in human vision. Vision Res 21:205–213

Levi DM, Klein SA, Aitsebaomo P (1984) Detection and discrimination of the direction of motion in central and peripheral vision of normal and amblyopic observers. Vision Res 24:789–800

Levinson JZ (1968) Flicker fusion phenomena. Science 160:21–28

MacKay DM (1958) Perceptual stability of a stroboscopically lit visual field containing self-luminous objects. Nature 181:507–508

Moseley MJ, Griffin MJ (1987) Whole-body vibration and visual performance: An examination of spatial filtering and time-dependency. Ergonomics 30:613–626

Nakayama K, Tyler CW (1981) Psychophysical isolation of movement sensitivity by removal of familiar position cues. Vision Res 21:427–433

Peli E, García-Pérez MA (2000) Motion perception under vibration. Invest Ophth Vis Sci 41:S792.

Rushton WAH (1967) Effect of humming on vision. Nature 216:1173–1175

Tyler CW, Torres J (1972) Frequency response characteristics for sinusoidal movement in the fovea and periphery. Percept Psychophys 12:232–236

Velay JL, Allin F, Bouquerel A (1997) Motor and perceptual responses to horizontal and vertical eye vibration in humans. Vision Res 37:2631–2638

Wells AM, Evans CR (1968) Effect of humming on the visibility of a stabilized retinal image. Nature 217:1168–1169

Westheimer G (1979) The spatial sense of the eye. Invest Ophth Vis Sci 18:893–912