Abstract

A difficult challenge faced by the visual system is attaining a stable view of the world despite constant eye movements and object motion. Temporal low-pass filtering can suppress and eliminate the effects of rapid retinal image motion, and it can be a major component of the mechanism for image stabilization (at the cost of some image blur). Sampling a high temporal-frequency signal, at a rate close to the signal frequency, creates frequency domain replicas that are aliased into the low-frequency range. Sampling a visual temporally-varying stimulus may make it visible under conditions of eye vibrations.

We studied the effect of sampling on the stability of perception with eye oscillation at a rate of about 60 Hz. Despite the substantial amplitude of the oscillations (0.1to 0.25 deg), the world appears stable. However, if

the field of view includes an intermittent display such as a computer CRT or the LED digits of a digital clock, then the intermittent part of the display appears to oscillate vigorously within its stable surround. The frequency of the perceived oscillation was measured and found to be the difference between the vibration frequency of the eye and the flicker rate of the display.

When the same intermittent display is observed in absolute darkness, or when it fills the entire visual field, the perceived oscillation disappears. Similar results were obtained when the oscillation was applied to the display instead of the eye.

These observations are consistent with the notion of a simple lowpass filtering for the elimination of the effects of rapid retinal image motion. They indicate a lack of absolute position reference for low magnitude (though substantially super-threshold) motion.

Image Appearance under Eye Vibration

Continuous Illumination:

Other People's Money, 1991: Danny DeVito watching his computer while brushing his teeth

- This activity causes substantial oscillation of the eyes.
- Oscillations of more than 6 min-arc. at about 60 Hz.
- Yet, the world appears stable.
- A slight blur can be noted with careful observation.

Low-pass filtering by the limited bandwidth of the visual system may explain this. 60Hz is simply too fast for the visual system.

The toothbrush vibrates at 67 Hz in the air, and drops to 50 to 55 Hz in the mouth depending on pressure etc. (Measured with a stroboscope)

Graph of eye movements recorded with the Scleral Coil device while using the Braun Electric toothbrush.

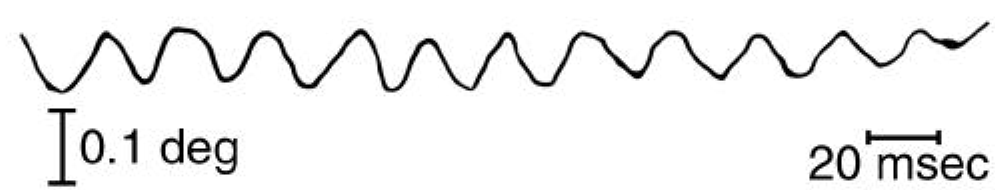
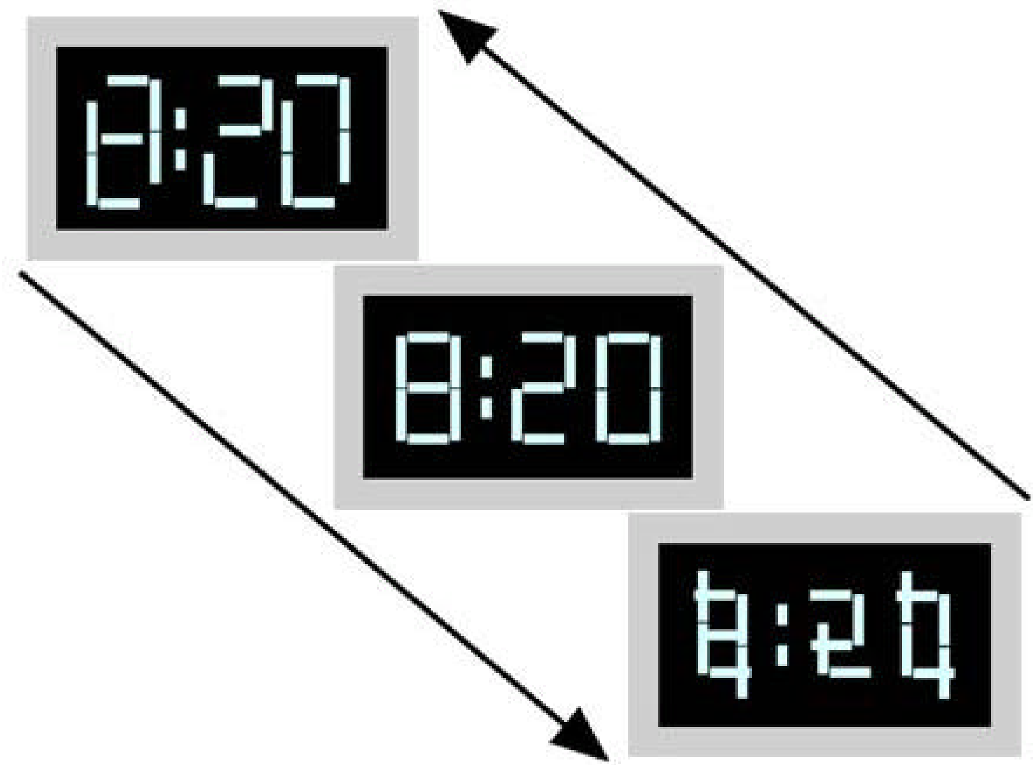


Image Appearance under Eye Vibration

Intermittent Illumination:

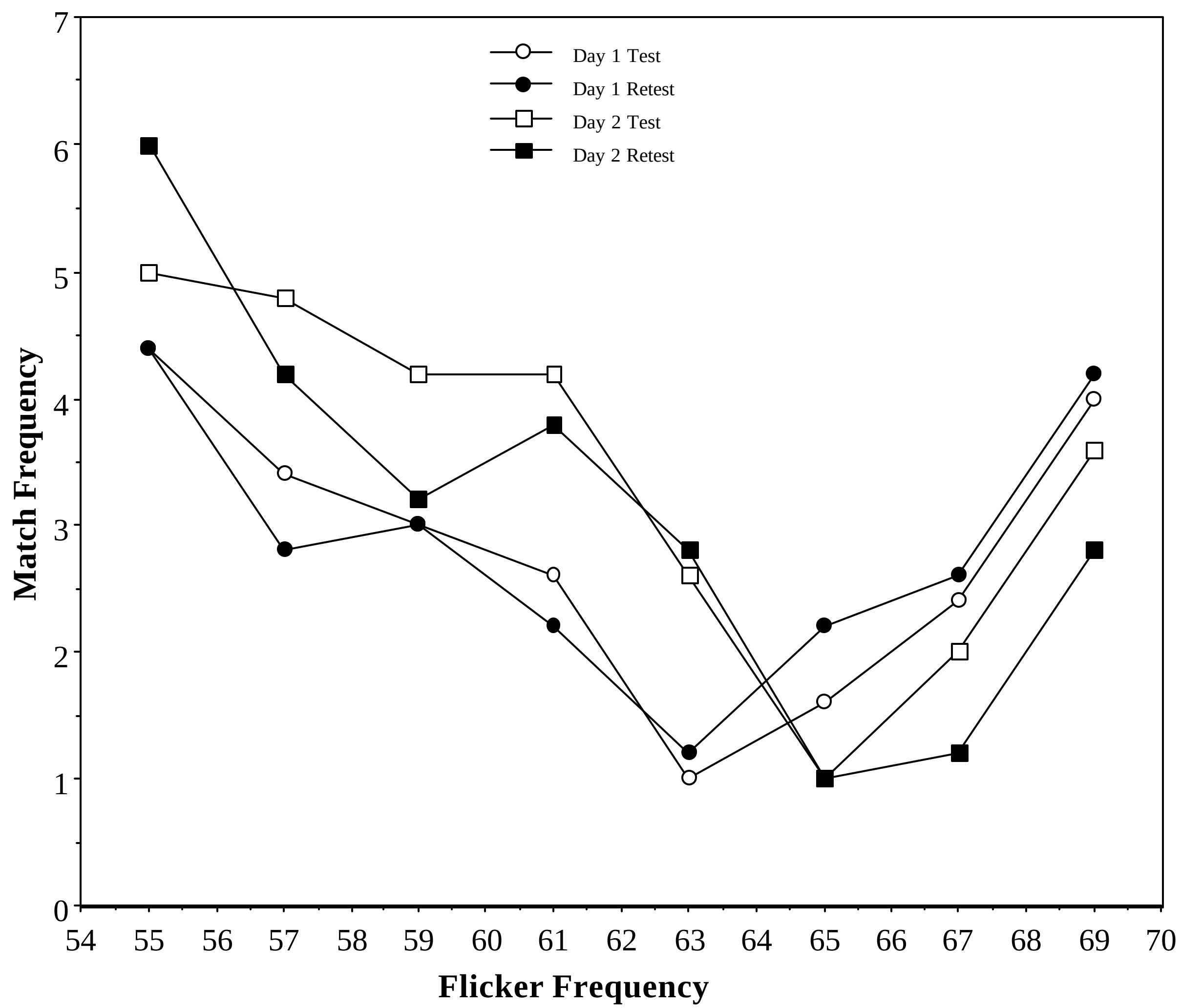
When objects illuminated with flickering light (at frequencies above the CFF – 60 Hz for the clock LEDs) are viewed with vibrating eye they appear to move back and forth at a slow rate (a few Hz).



Similar effects noted when looking at a CRT screen (TV or Computer) while the eye is vibrating.

Frequency Matching Experiment

- Experimenter adjusted the frequency of oscillation of two LED segments illuminated continuously and viewed next to a 60 Hz LED while using the toothbrush.
- The test LED digit had all segments flickering in-phase, unlike the clock LEDs.
- The frequency changed day-to-day due to changes in toothbrush pressure.



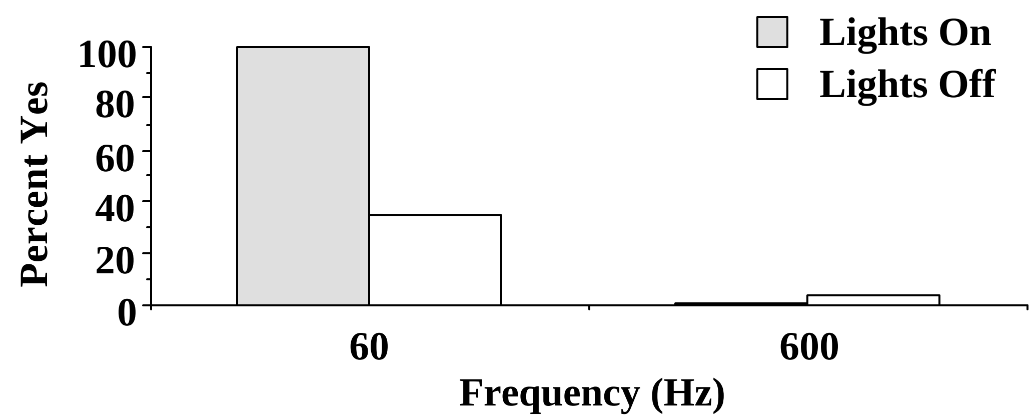
The movement observed is an oscillation at the difference frequency,

|flicker frequency-vibration frequency|

Movement Disappears in the Dark

When the flickering LED is observed in the dark (while vibrating the eye) the movement stops.

Subject was asked to judge if the single LED digit moves (Yes/No). Room illumination varied randomly from light to dark and flicker frequency from 60Hz to 600Hz (at the latter no movement is anticipated).



Subjects could not detect the flicker at either 60 or 600Hz.
Subjects verified on each trial that the eye vibration was present by looking at a LED clock.
The clock’s LED appears to move even in the dark because different LED segments are illuminated at different times resulting in relative movements between the segments. The test LED digits had all its segments flicker in phase.
On careful observation of the clock in the dark one set of segments is stable and the others are moving relative to it. The stable segment flips from time to time.

Movement Disappears when the Whole World is Flickering

A room illuminated only with a stroboscope at 60Hz does not seem to move when the eye is vibrating at a similar frequency.

Moving out of the room into a continuously illuminated space but still looking into the room through a partially opened door, the room appears to move (at the difference frequency) with eye vibration.

Is it simply a matter of retinal stimulus?

Does the phenomenon have any bearing on the questions of extra retinal information?

Yes and No

Yes –

- We can get similar effects by moving only the display without vibrating the eye
- Projecting a laser beam on a wall with an oscillating mirror (55 Hz)

  When laser is continuously on, the beam is stationary though blurred

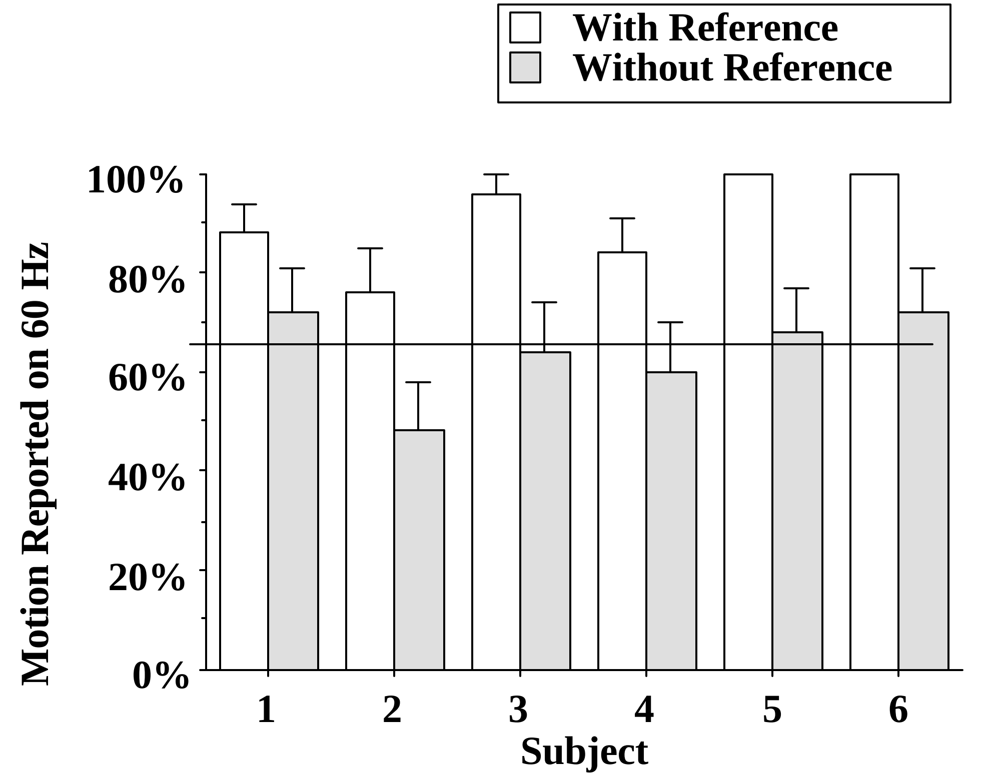
  When the beam is flickered (60 Hz) using AO modulator, the stimulus looks like a 5 Hz oscillatory motion of a spot

No –

- In complete darkness the movement stops or is significantly reduced in magnitude
- Adding a reference in the dark (a second continuous laser line) restores movement

In a 2AFC task, subjects had to judge if motion was seen on a 60 Hz or 600 Hz flicker condition, with and without a reference (a second continuously illuminated laser line)
The graph shows percent of times movement was reported on the 60 Hz Interval.

$$error\ bar = \sqrt{\frac{p(1-p)}{N}}$$



Performance is better when the head is stable on the chair headrest
In normally lit room motion quality is superior to that in the small reference condition

Similar Effect with Stroboscope

Illuminating the room with stroboscope at 60Hz
and looking at the room through the oscillating mirror (55Hz)
– no movement is noted.

When incandescent light is added to room illumination, objects that reflect the stroboscope light better appear to move, while the rest of the room (controlled by continuous illumination) remains stable.

Conclusions

- Lowpass filtering accounts for lack of perception of fast movements

- The reason for the limited blur in natural environment is the difference between the blur of Edge and Bar – Bar's blur is more noticeable

- The perception of small magnitude movement (<0.25 deg) requires a reference. Without such reference the visual system discounts the movement as resulting from self-motion

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