Human-machine interaction in virtual reality

Paul MacNeilage, Psychology

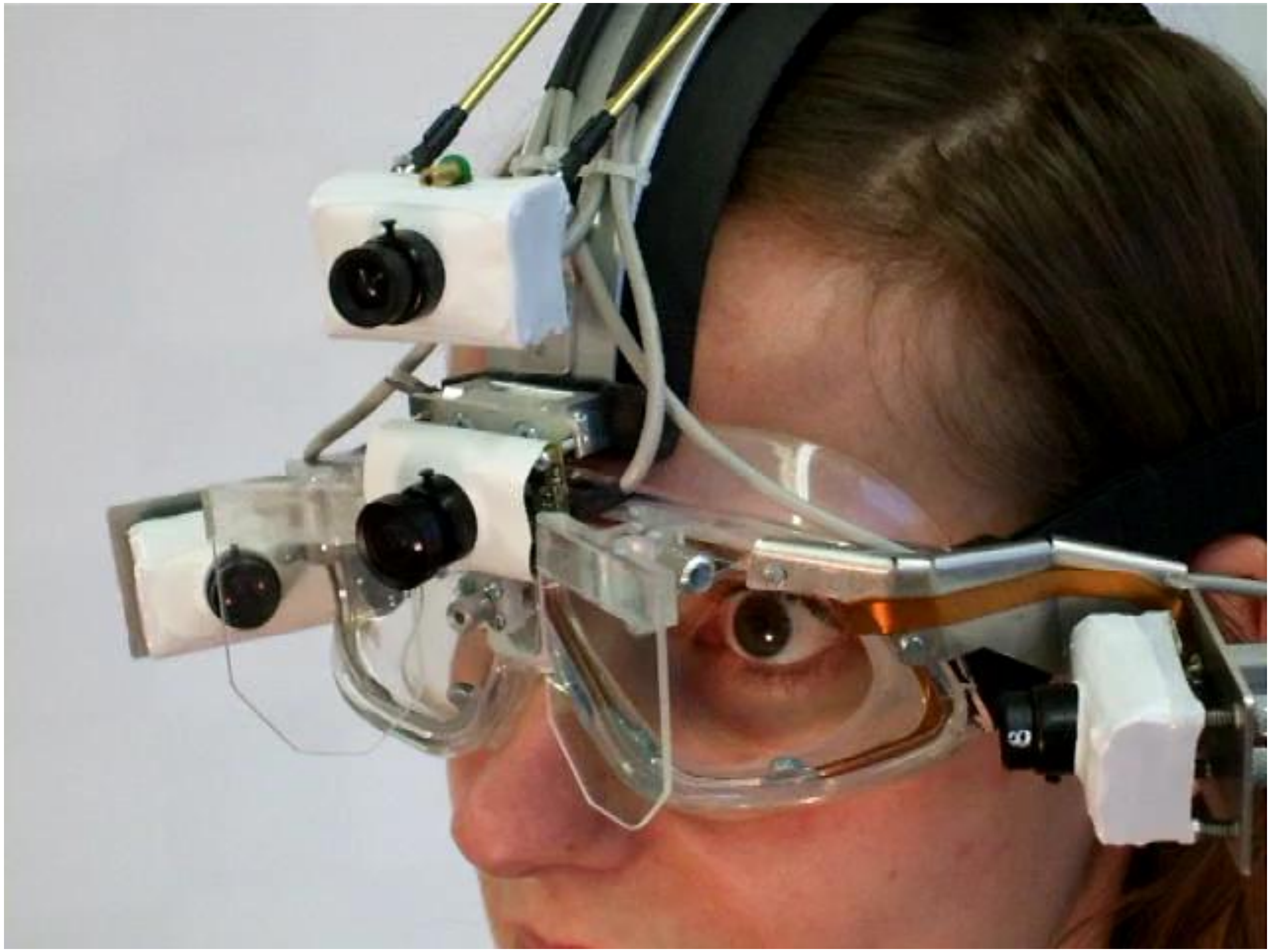
Eelke Folmer, Computer Science

Eye Movements

- Eyes are rarely still; jump ~1 per sec

Figure 5.15: The trace of scanning a face using saccades.

What the Eye Sees



Schumann, Einhäuser-Treyer, Vockeroth, Bartl, Schneider, König (2008) *JOV*

What the Eye Sees

Schumann, Einhäuser-Treyer, Vockeroth, Bartl, Schneider, König (2008) *JOV*

Visual Experience Database

- Natural co-occurrence of self-motion signals?
  - Measure it

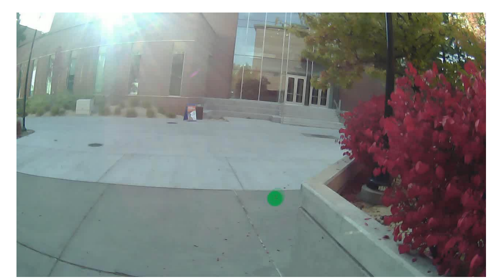
Head movement

Vestibular

Eye movement

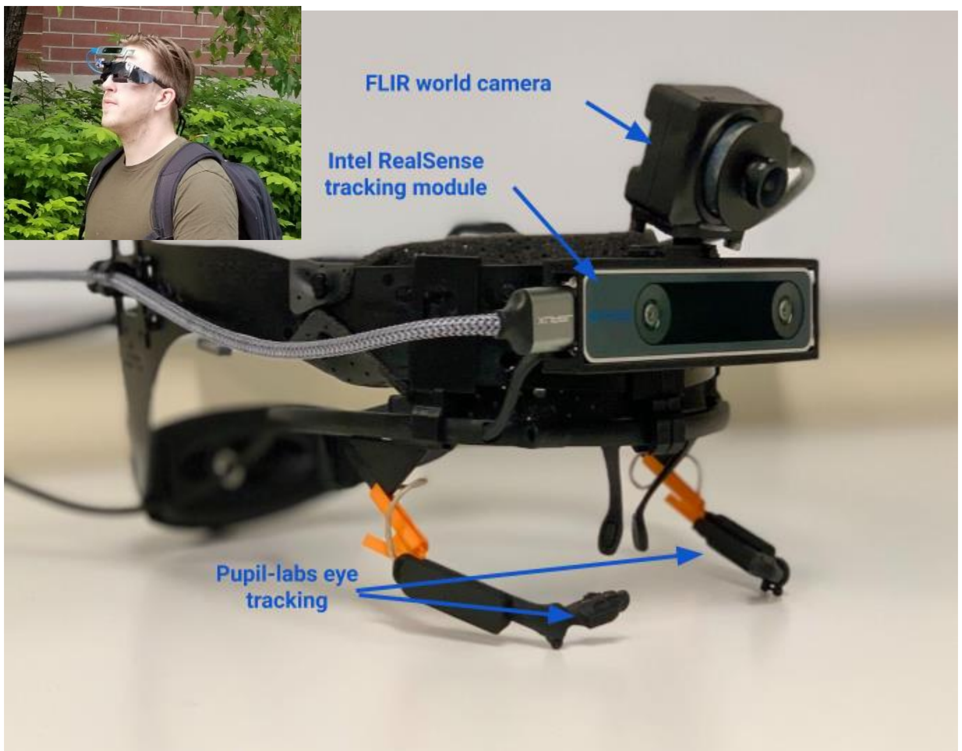
Oculomotor

Head/Eye-centered video

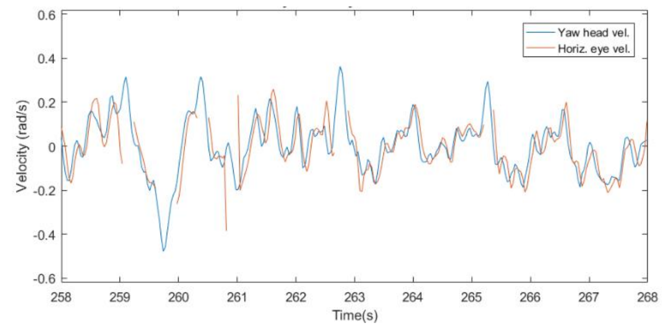


Visual

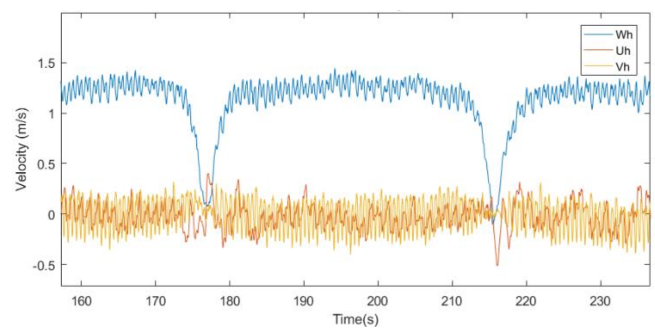
Visual Experience Database



Rotational Eye and Head Velocity



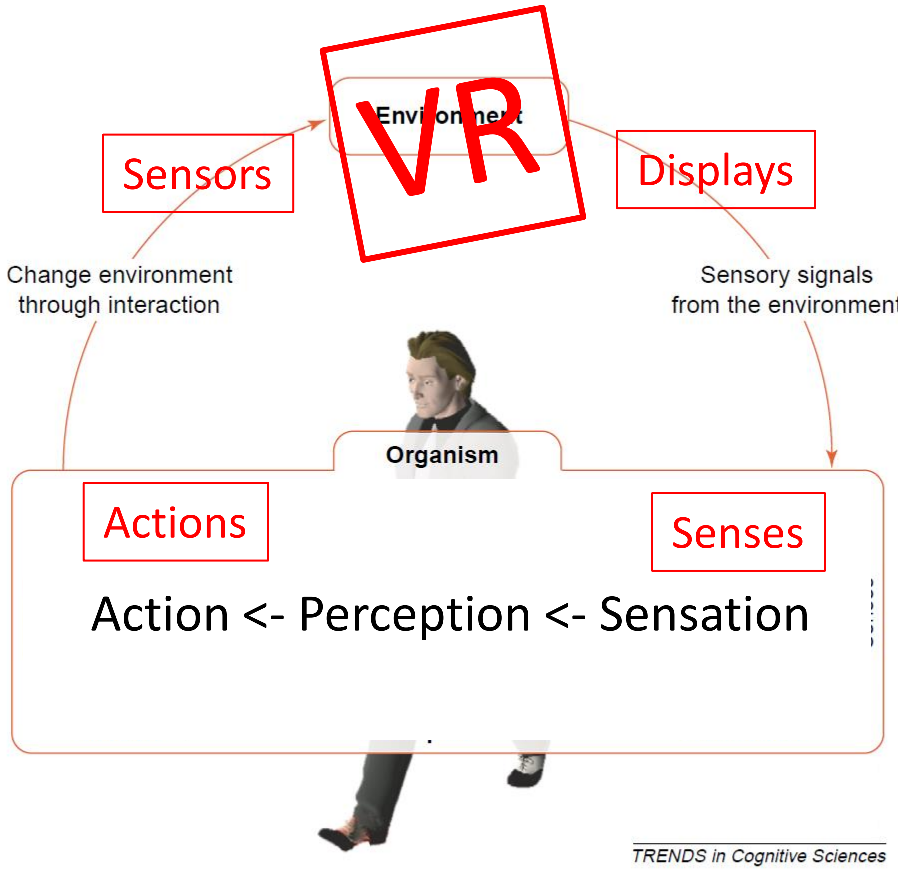
Translational Head Velocity



Visual Experience Database

- Gaze-overlaid scene video

Human-VR Loop



Eye-tracking in VR

1) HTC Vive Pro Eye
2) Fove HMD with integrated eye tracking

Virtual Reality
https://doi.org/10.1007/s10055-022-00738-z

ORIGINAL ARTICLE

Eye Tracking in Virtual Reality: a Broad Review of Applications and Challenges

Isayas Berhe Adhanom[1] · Paul MacNeilage[1] · Eelke Folmer[1]

Received: 25 August 2021 / Accepted: 30 November 2022

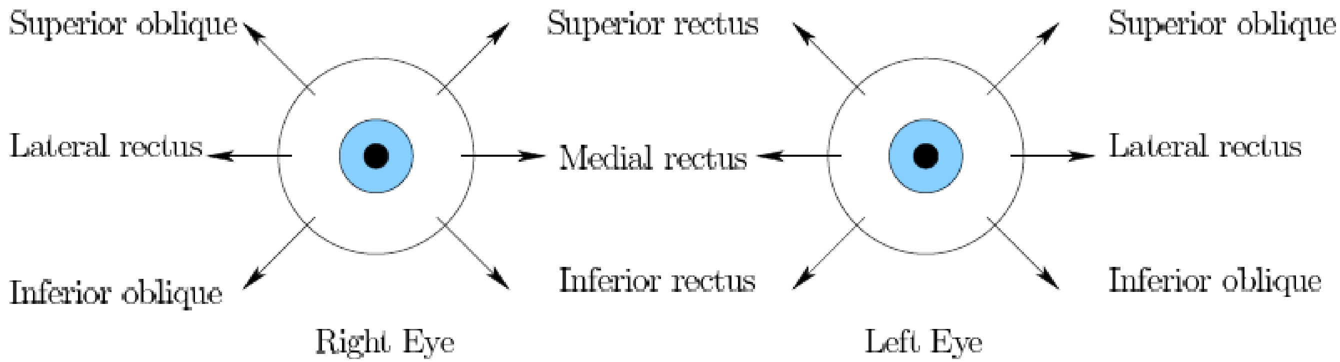
Abstract
Eye tracking is becoming increasingly available in head-mounted virtual reality displays with various headsets with integrated eye trackers already commercially available. The applications of eye tracking in virtual reality are highly diversified and span multiple disciplines. As a result, the number of peer-reviewed publications that study eye tracking applications has surged in recent years. We performed a broad review to comprehensively search academic literature databases with the aim of assessing the extent of published research dealing with applications of eye tracking in virtual reality, and highlighting challenges, limitations and areas for future research.

Keywords Eye tracking · Virtual reality

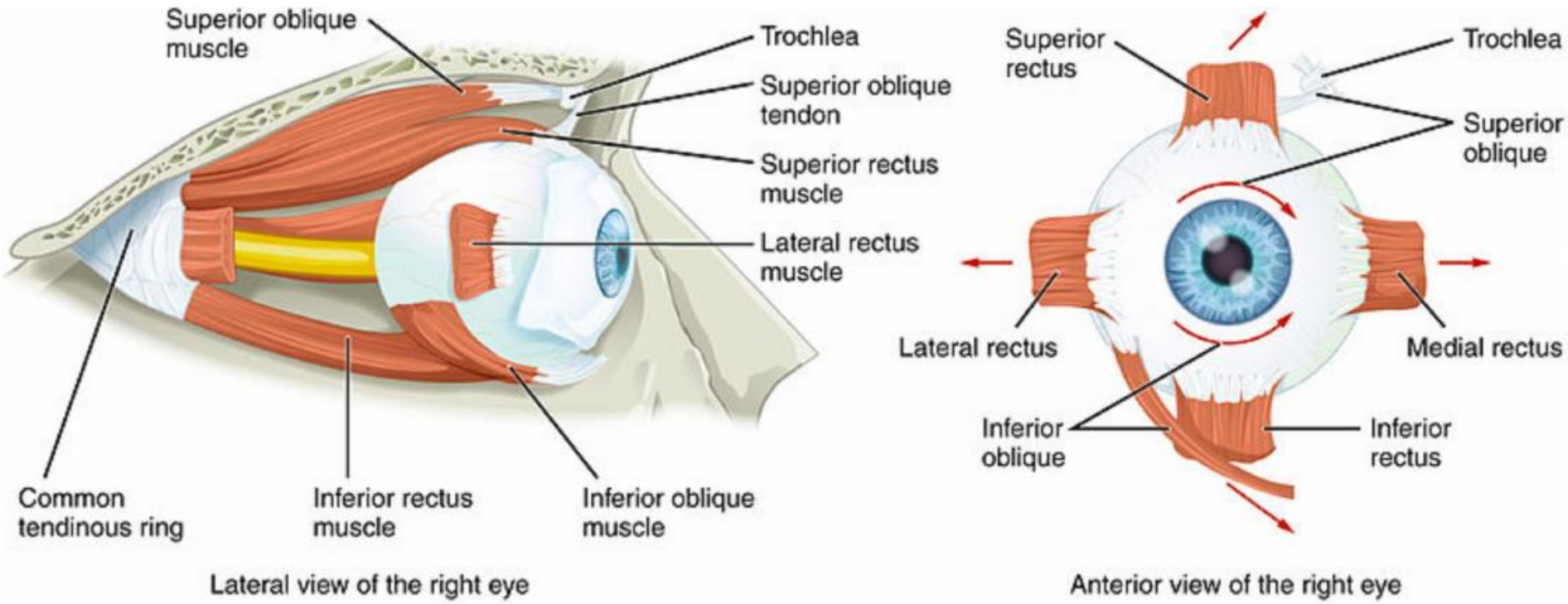
Topics Covered

- Eye muscles and neural control
- Types of eye movements:
  - Fixational
  - Saccades
  - Smooth pursuit
  - Reflexive image stabilization
- Head movements
- Implications for VR

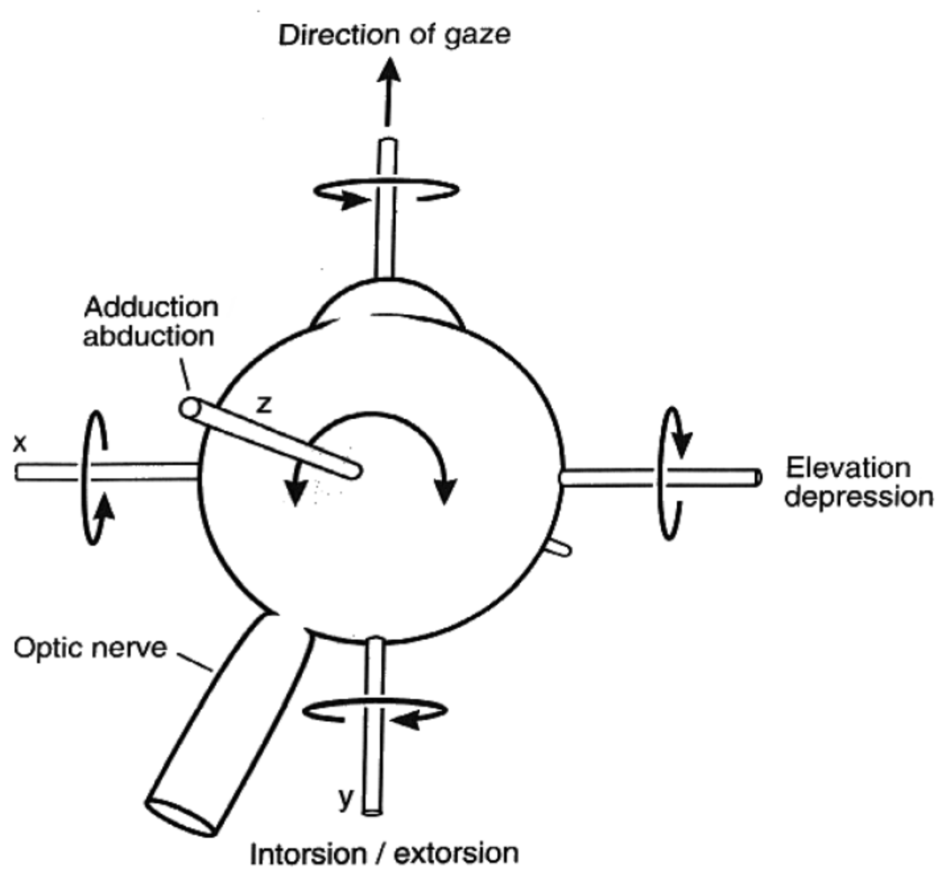
Eye Muscles & Locations



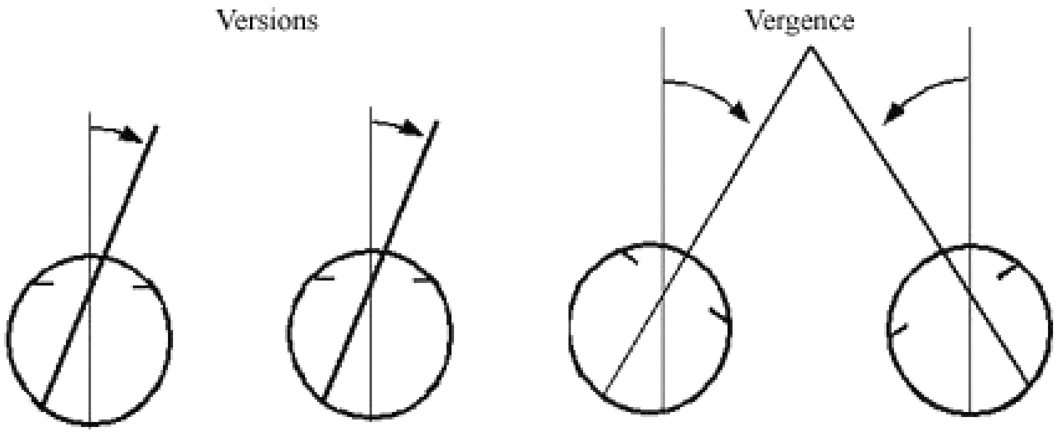
Physiology of Eye Movements



Describing 3DOF of Eye Movements



Binocular eye movements



Conjugate

Disconjugate

Eye Movement Control

<u>Supra-nuclear Neurons</u>

Voluntary control,
spatial frame of reference

<u>Pre-motor Neurons</u>

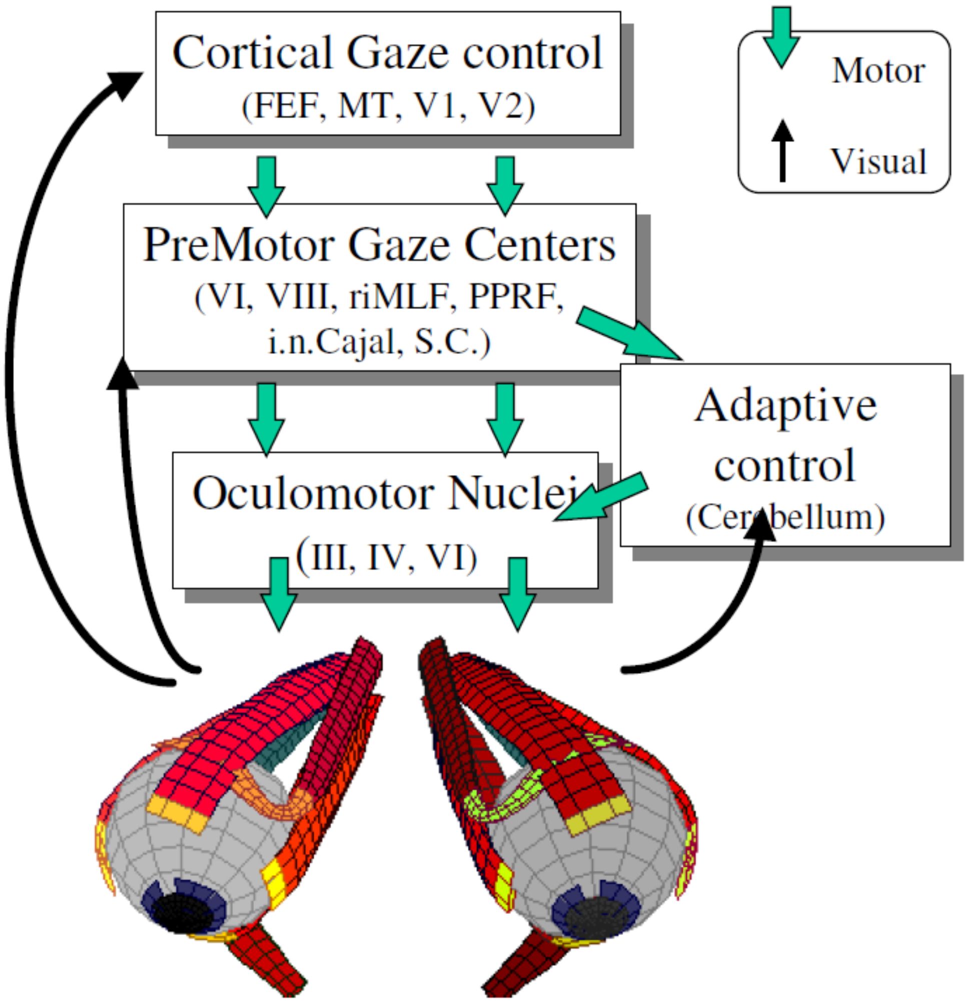
Reflex movement,
pulse generation,
integration

<u>Motor neurons</u>

Final common path,
reciprocal innervation

<u>Muscles</u>

Oculomotor plant



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- Eye muscles and neural control
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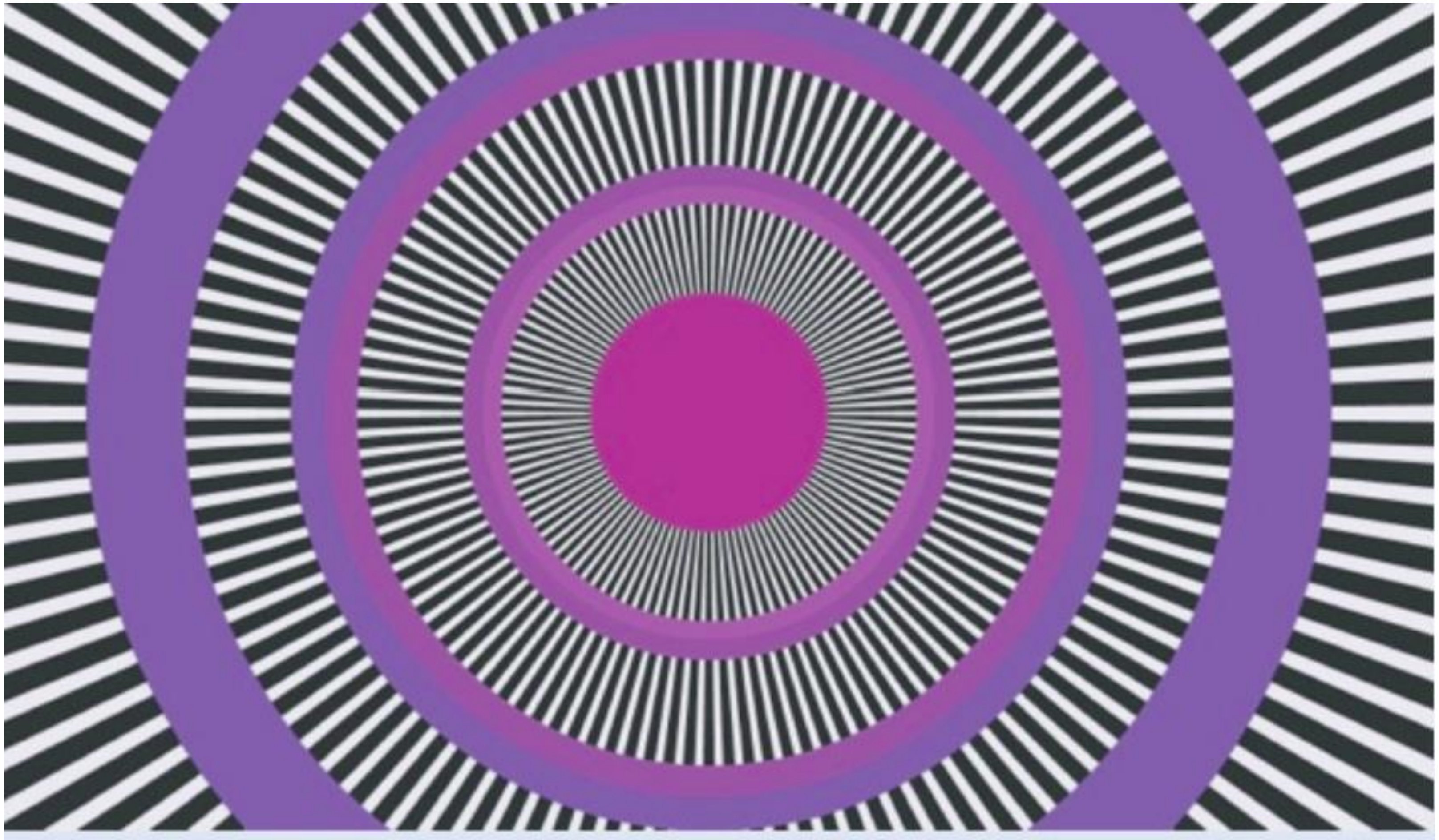
Fixational Eye Movements

- Even when you try to hold the eye completely still… it's moving!
- Microtremors and microsaccades
- Image is constantly moving over the retina
- This motion is <u>necessary</u> to counteract adaptation

- Troxler effect:
  - Stabilized images (e.g. on a contact) will fade
  - [Link](#) to lilac chaser illusion

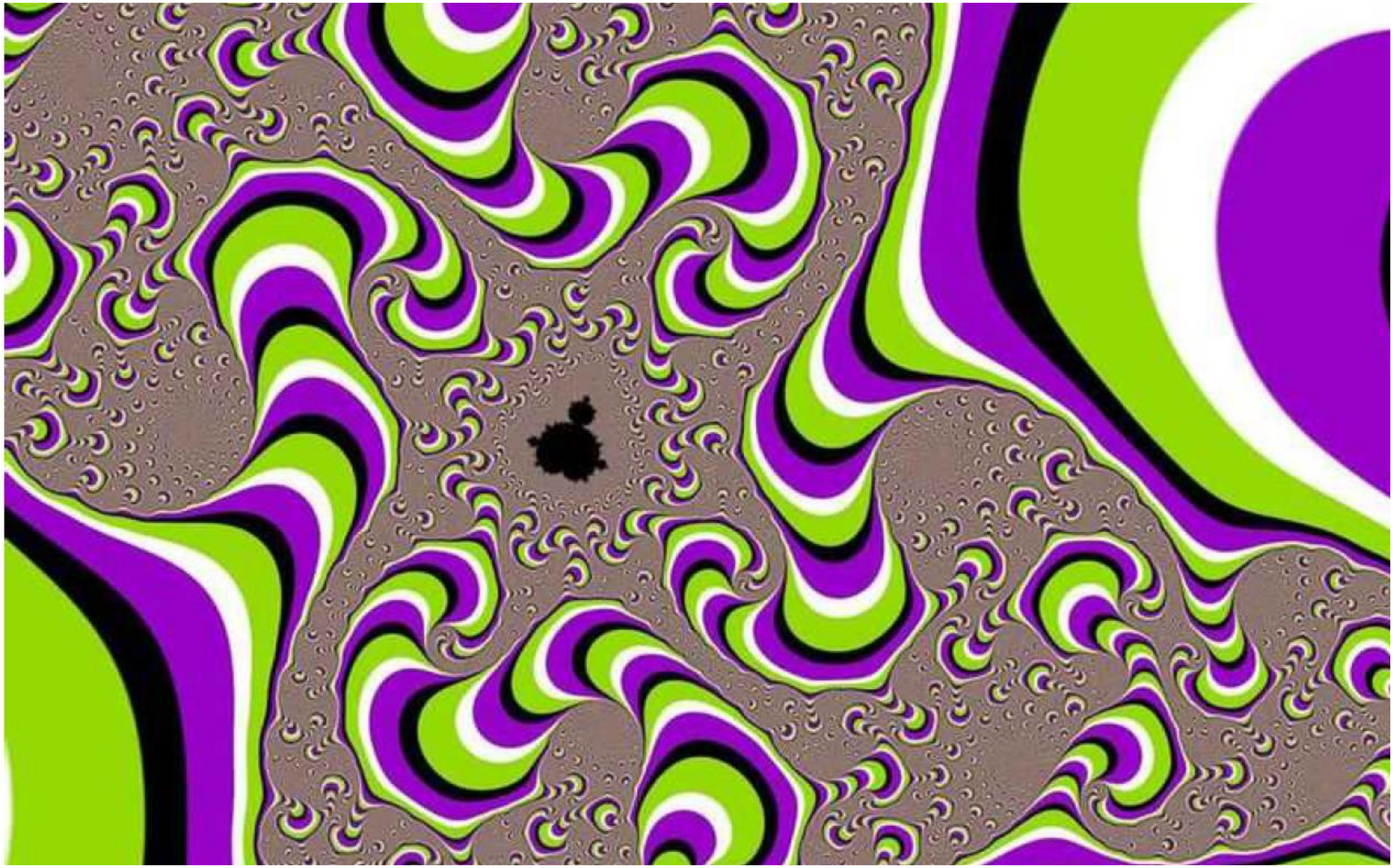
Fixational Eye Movements

- ‘Enigma’ painting



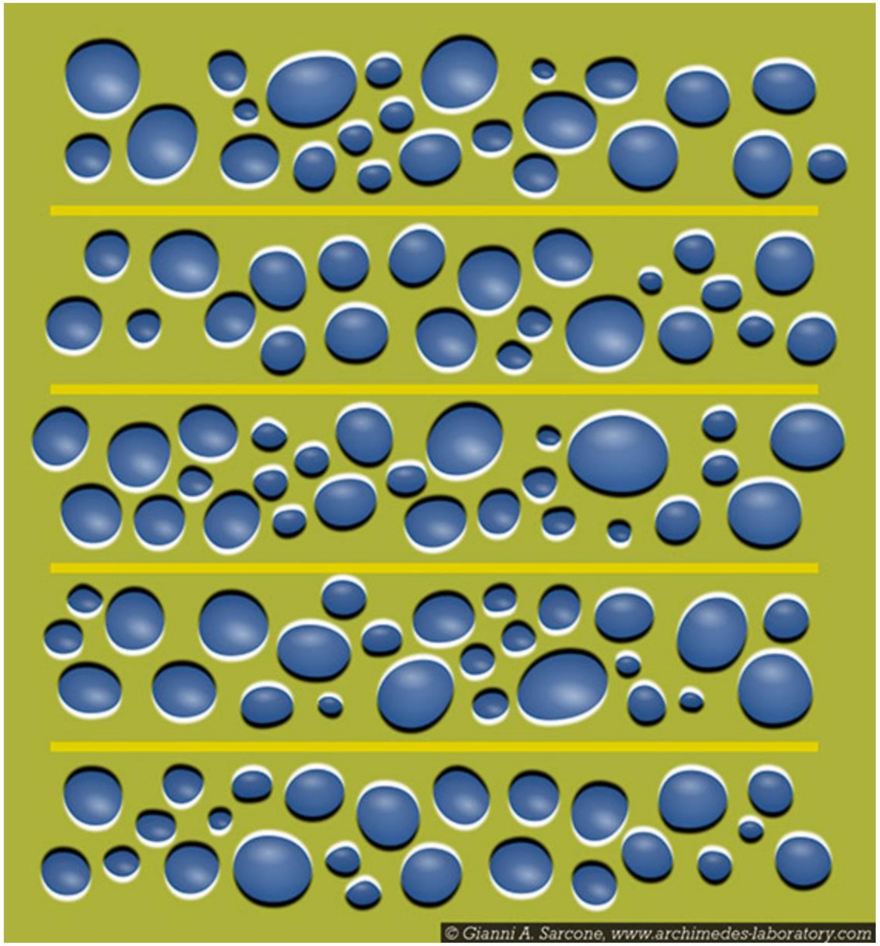
Another Eye Movement Illusion

- Peripheral drift illusions



Another Eye Movement Illusion

- Peripheral drift illusion



PNAS

RESEARCH ARTICLE | PSYCHOLOGICAL AND COGNITIVE SCIENCES

Eye drift during fixation predicts visual acuity

Ashley M. Clark[a,b], Janis Intoy[a,b], Michele Rucci[a,b,c], and Martina Poletti[a,b,c,1]

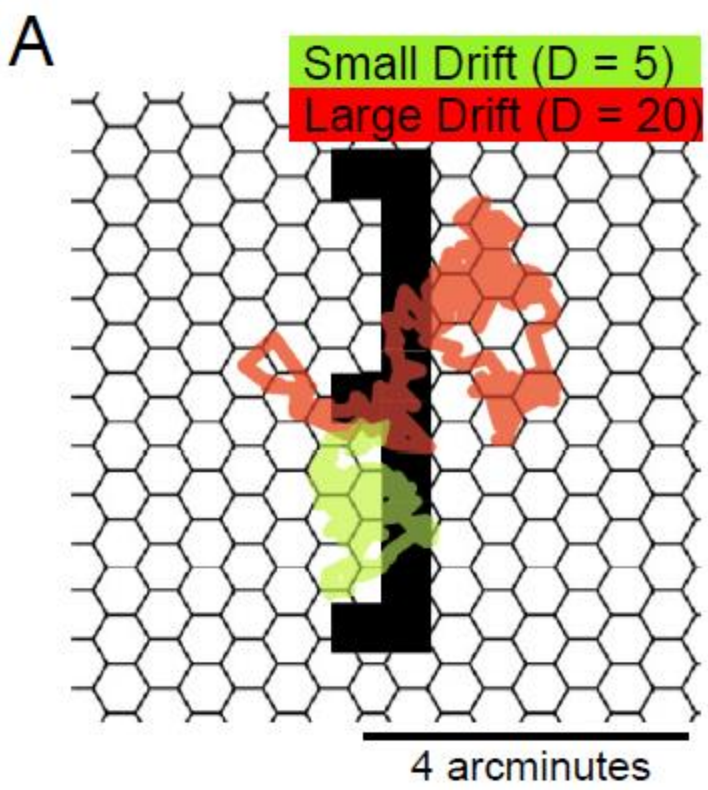
Edited by Michael Goldberg, Columbia University, New York, NY; received January 9, 2022; accepted October 25, 2022

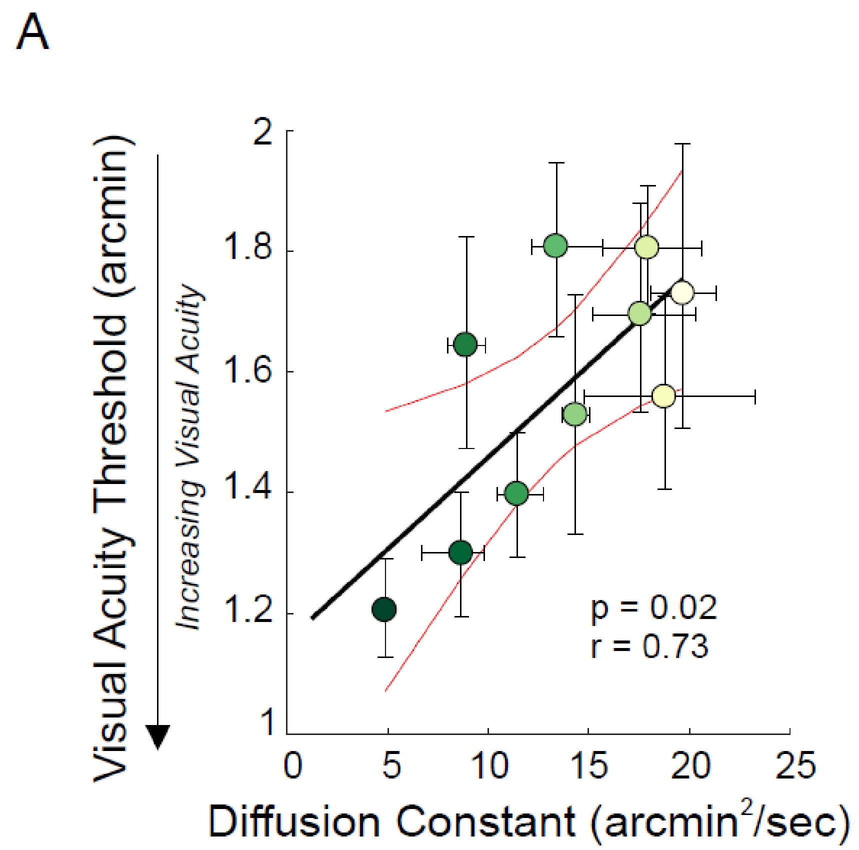
Visual acuity is commonly assumed to be determined by the eye optics and spatial sampling in the retina. Unlike a camera, however, the eyes are never stationary during the acquisition of visual information; a jittery motion known as ocular drift incessantly displaces stimuli over many photoreceptors. Previous studies have shown that acuity is impaired in the absence of retinal image motion caused by eye drift. However, the relation between individual drift characteristics and acuity remains unknown. Here, we show that a) healthy emmetropes exhibit a large variability in their amount of drift and that b) these differences profoundly affect the structure of spatiotemporal signals to the retina. We further show that c) the spectral distribution of the resulting luminance modulations strongly correlates with individual visual acuity and that d) natural intertrial fluctuations in the amount of drift modulate acuity. As a consequence, in healthy emmetropes, acuity can be predicted from the motor behavior elicited by a simple fixation task, without directly measuring it. These results shed new light on how oculomotor behavior contributes to fine spatial vision.

Significance

Healthy humans can visually resolve extremely fine patterns, in some cases with the relevant features spanning less than a single photoreceptor on the retina. This accomplishment is particularly remarkable considering that the eyes are never stationary. Ocular drift, eluding human awareness, shifts the stimulus across many photoreceptors during the

Fixational Eye Movement and Acuity





Topics Covered

- Eye muscles and neural control
- Types of eye movements:
  - Fixational
  - Saccades
  - Smooth pursuit
  - Reflexive image stabilization
- Head movements
- Implications for VR

Saccades

- Repositioning movements
  - Point high acuity fovea at regions of interest
  - Speeds up to 900 deg/s, duration 45-200 ms
  - Naturally occur several times a second (e.g. during reading)
- Transsaccadic Integration

Allows us to perceive entire environment as stable and clear

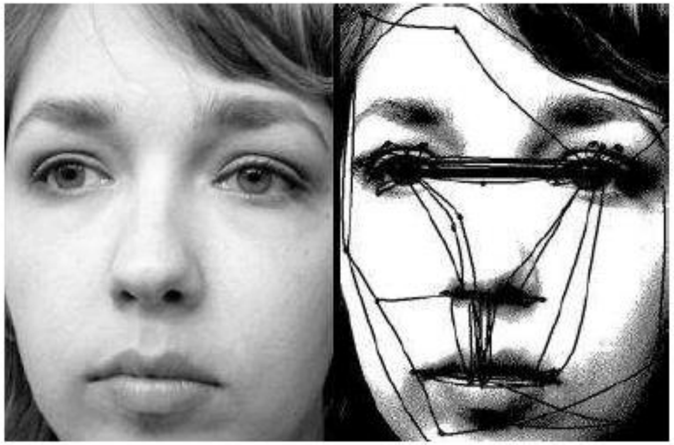
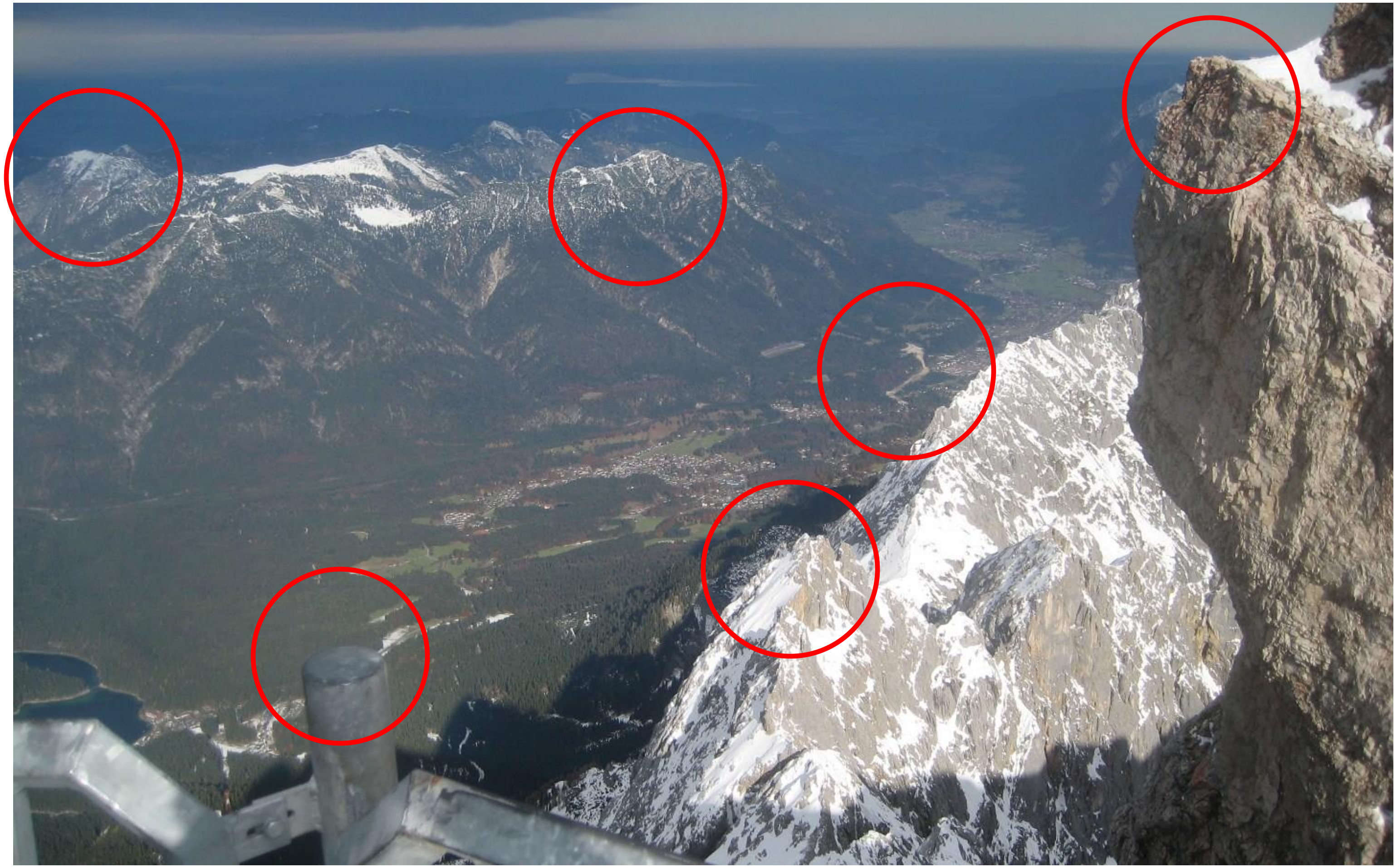
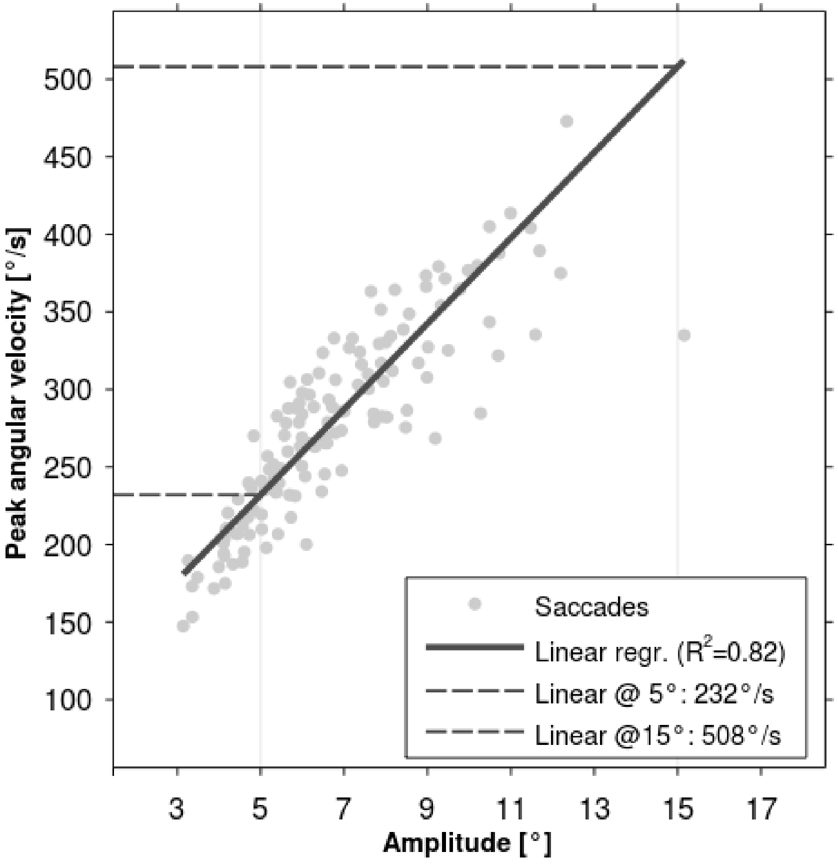


Figure 5.15: The trace of scanning a face using saccades.

Saccades



Saccadic Main Sequence



Saccadic Suppression

- Motion perception is suppressed
  - Look in the mirror, you can’t see your own eyes moving

- Used to study motor adaptation
  1. Move target during eye movement
  2. People don’t notice
  3. Saccadic eye movements adapt

Topics Covered

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  - Fixational
  - Saccades
  - Smooth pursuit
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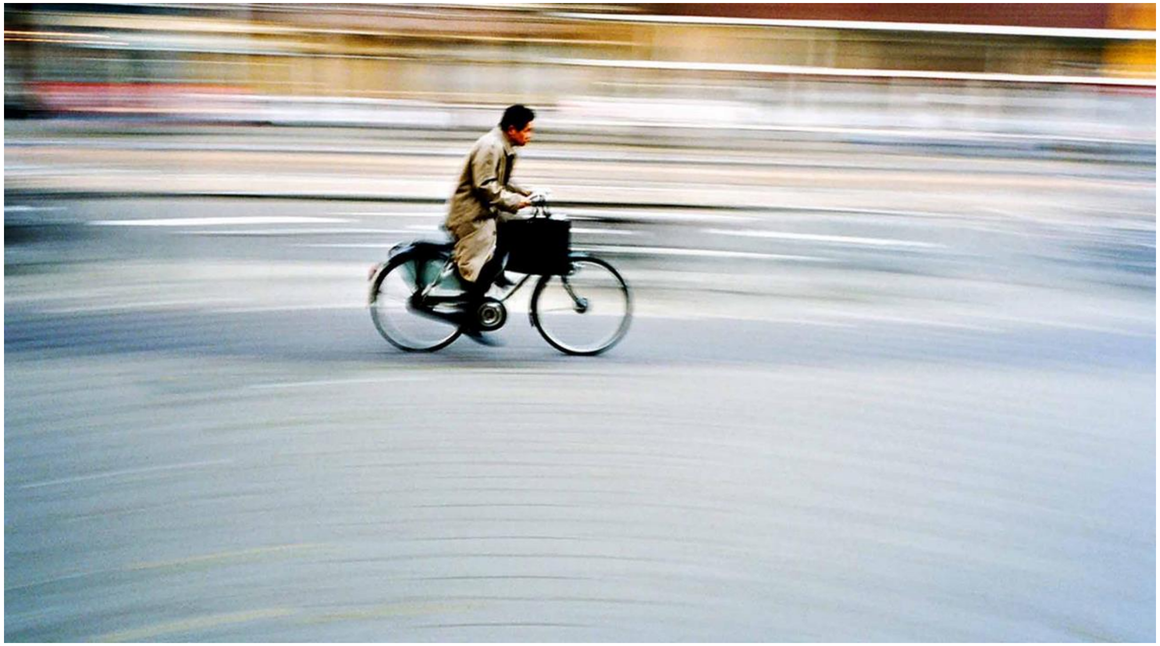
Smooth Pursuit

- Tracking of moving targets
  - Tracked object sharp
  - Background blurred by motion

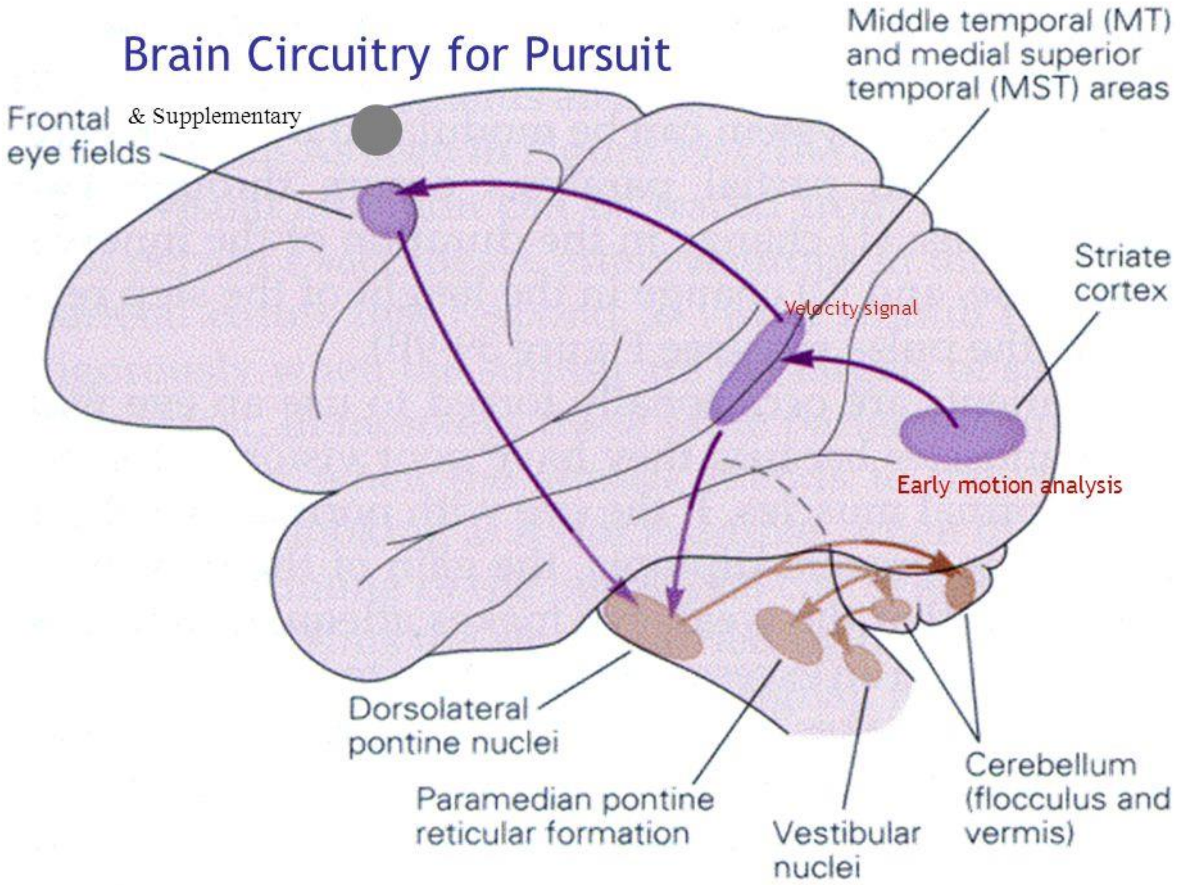


Smooth Pursuit

- Sensorimotor loop; maintained by visual feedback
  – Visual signal known as “retinal slip”

- Max. speed ~ 30 deg/s -> catch-up saccades

Smooth Pursuit



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- Eye muscles and neural control
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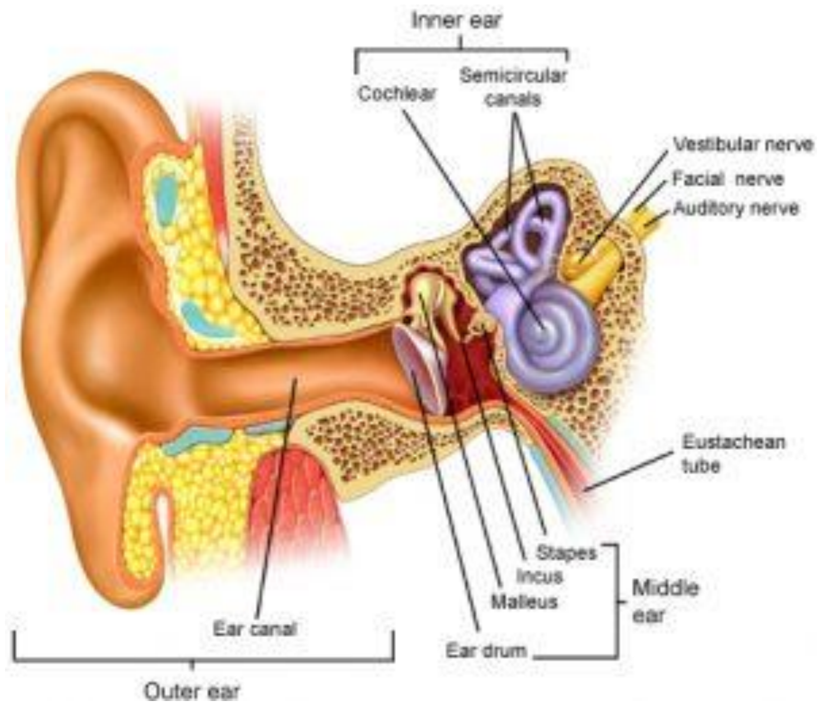
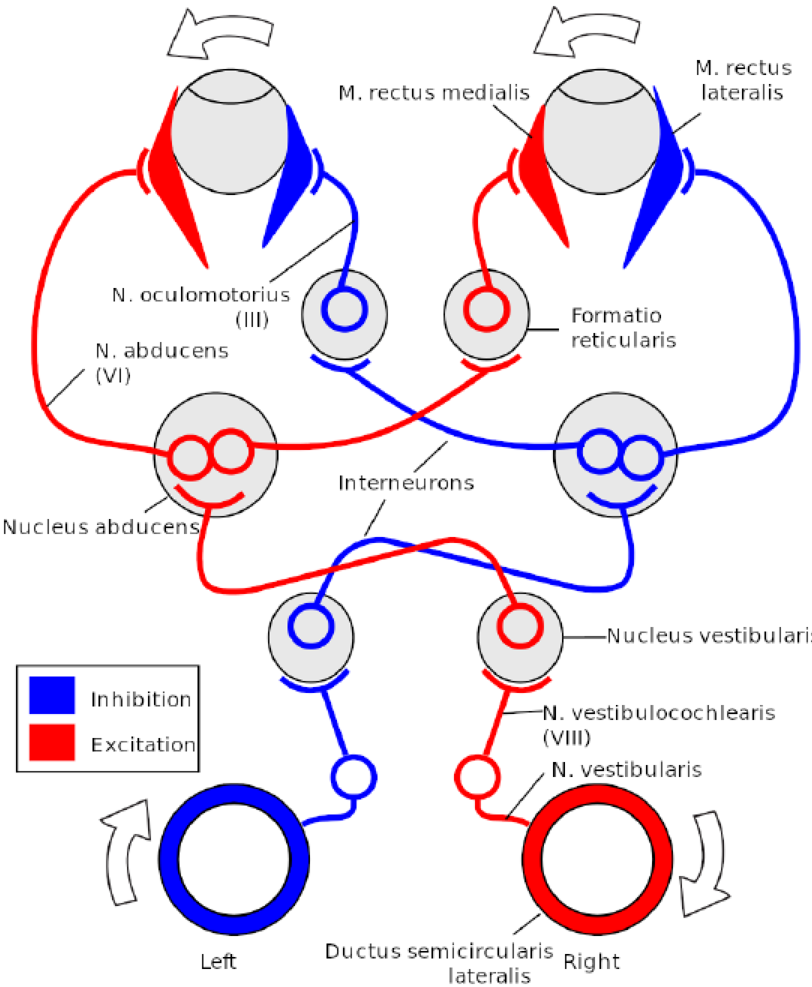
Reflexive Image Stabilization

- Vestibular System



Reflexive Image Stabilization

- Vestibulo-ocular reflex
  - 3 neurons
  - 2 synapses
  - 10 ms



Reflexive Image Stabilization

- Optokinetic reflex
  - Like pursuit followed by saccade
  - Called “slow phase” and “fast phase”

- Link to video

Topics Covered

- Eye muscles and neural control
- Types of eye movements:
  - Fixational
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  - Smooth pursuit
  - Reflexive image stabilization
- Head movements
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Head Movement

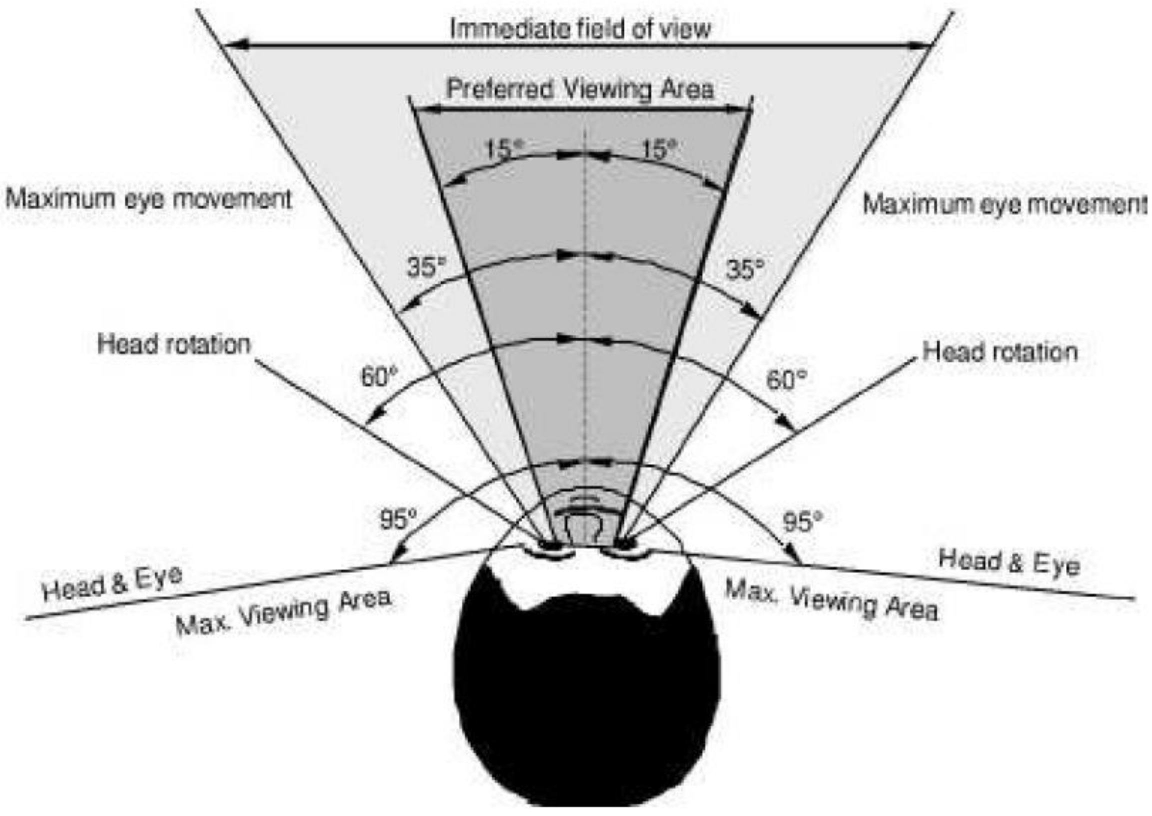
- Weighs about 10 pounds
- Constant muscle tension needed
- Types of head movements:
  - Saccades -100-200 deg/s
  - Pursuit
  - Reflexive

Reflexive Image Stabilization

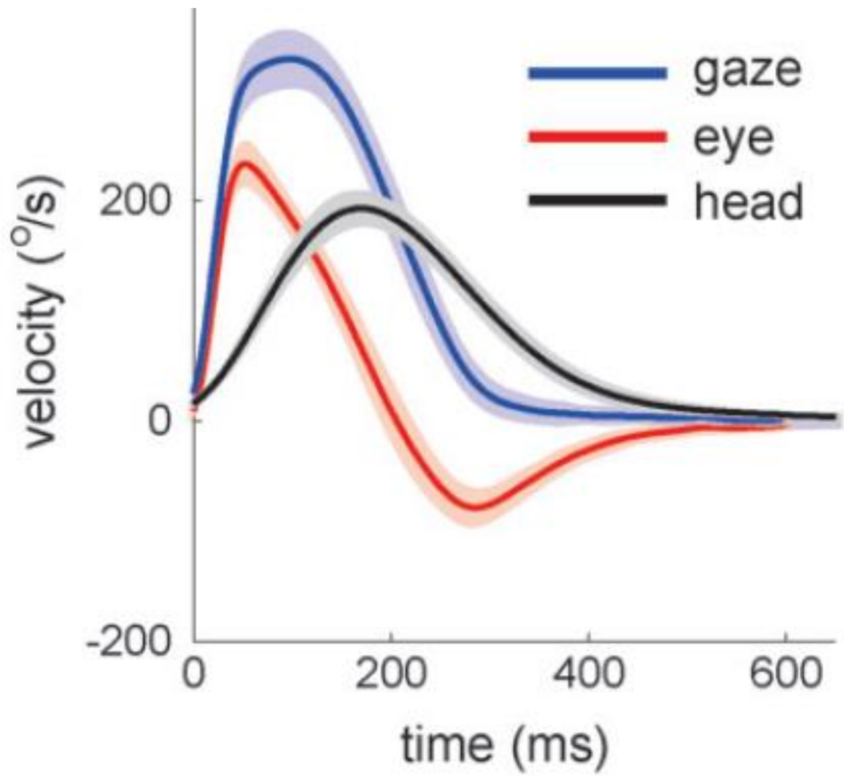
- Vestibulocollic reflex
- Link to video
- Link to video
- Link to video

Head & Eye Movement

- Naturally use both to reorient gaze



Head & Eye Movement



- Eye movement is first synergistic, then compensatory

Saglam, Glasauer, Lehnen (2014) Brain

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Implications for VR

- How fast does tracking/rendering have to be?
  - Depends on speed of head movement
    - What range of speeds do people move their heads?
    - How does wearing the headset change head movement?
  - Depends on predictability of head movement
    - Oculus patent for predictive tracking

Foveated Rendering?

- Track eye and render based on eye movements?
- Link to youtube

The Effect of a Foveated Field-of-view Restrictor on VR Sickness

Isayas Berhe Adhanom * Nathan Navarro Griffin† Paul MacNeilage‡ Eelke Folmer§

Computer Science, University of Nevada · Computer Science, University of Nevada · Psychology, University of Nevada · Computer Science, University of Nevada

Abstract

Virtual reality sickness typically results from visual-vestibular conflict. Because self-motion from optical flow is driven most strongly by motion at the periphery of the retina, reducing the user's field-of-view (FOV) during locomotion has proven to be an effective strategy to minimize visual vestibular conflict and VR sickness. Current FOV restrictor implementations reduce the user's FOV by rendering a restrictor whose center is fixed at the center of the head mounted display (HMD), which is effective when the user's eye gaze is aligned with head gaze. However, during eccentric eye gaze, users may look at the FOV restrictor itself, exposing them to peripheral optical flow which could lead to increased VR sickness. To address these limitations, we develop a foveated FOV restrictor and we explore the effect of dynamically moving the center of the FOV restrictor according to the user's eye gaze position. We conducted a user study (n=22) where each participant uses a foveated FOV restrictor and a head-fixed FOV restrictor while navigating a virtual environment. We found no statistically significant difference in VR sickness measures or noticeability between both restrictors. However, there was a significant difference in eye gaze behavior, as measured by eye gaze dispersion, with the foveated FOV restrictor allowing participants to have a wider visual scan area compared to the head-fixed FOV restrictor, which confined their eye gaze to the center of the FOV.

Keywords: Virtual Reality, VR Sickness, Field-of-view Manipulation, Eye Tracking

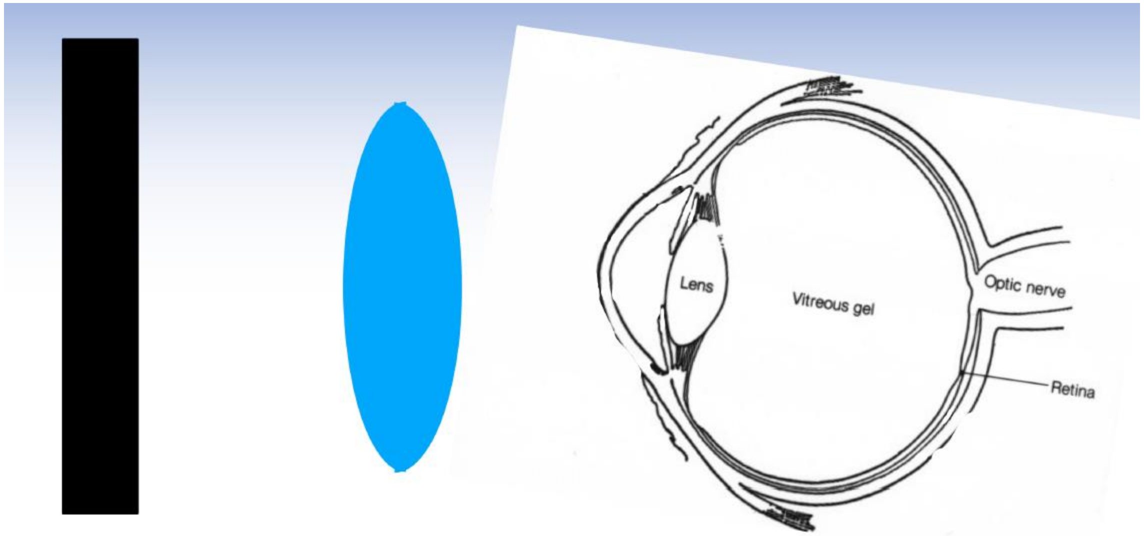
Index Terms: Human-centered computing—Virtual Reality—;—

Figure 1: FOV restriction during locomotion is a widely used strategy to mitigate visual-vestibular conflict and VR sickness. A limitation of existing implementations is that they use a viewport fixed restrictor (left). In this paper we explore the effectiveness of a foveated restrictor (right) that moves with the user's eye gaze.

dated using positional tracking, users generally don't experience VR sickness because vestibular and proprioceptive afferents from walking are generated that match the perceived optical flow. VR sickness typically occurs when there is visual self motion, but no real physical movement which leads to sensory conflict [35]. This can happen when users try to navigate VR using a game controller with steering and rate control activated using a thumbstick. Teleportation avoids optical flow generation as it instantly translates the user's

Implications for VR

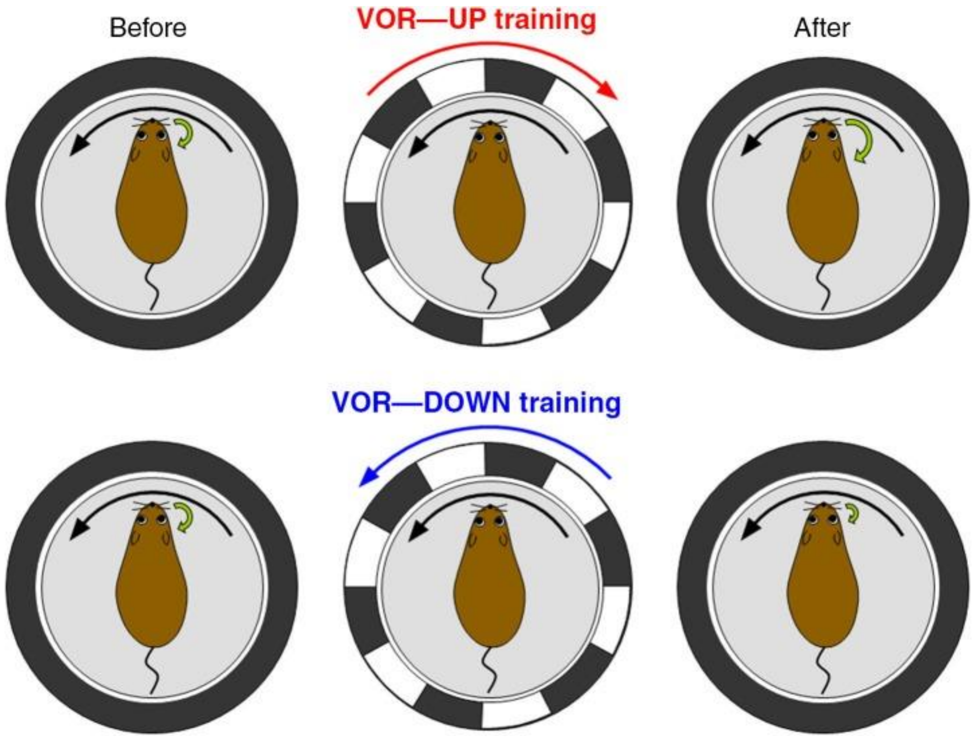
- Eye moves around behind lens
- Optical aberrations change



Display lens eye

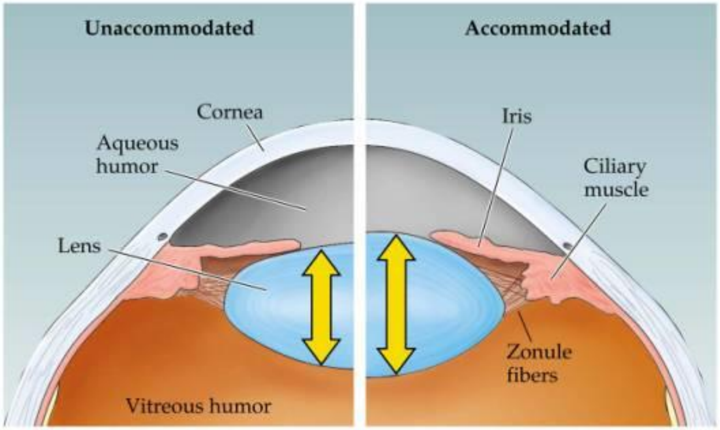
Implications for VR

- VOR gain adaptation
- Similar to wearing glasses



Accommodation

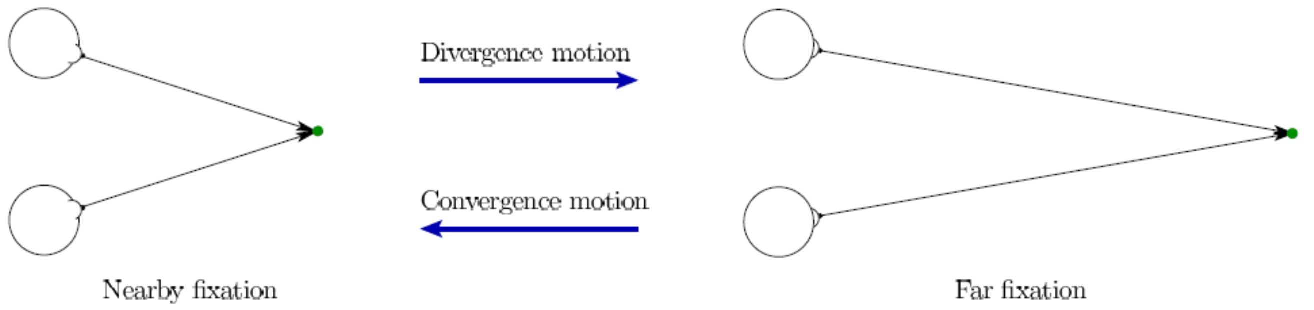
- Change focus
  - Clear near, blur far
  - Blur near, clear far



- Accommodation varies with target distance

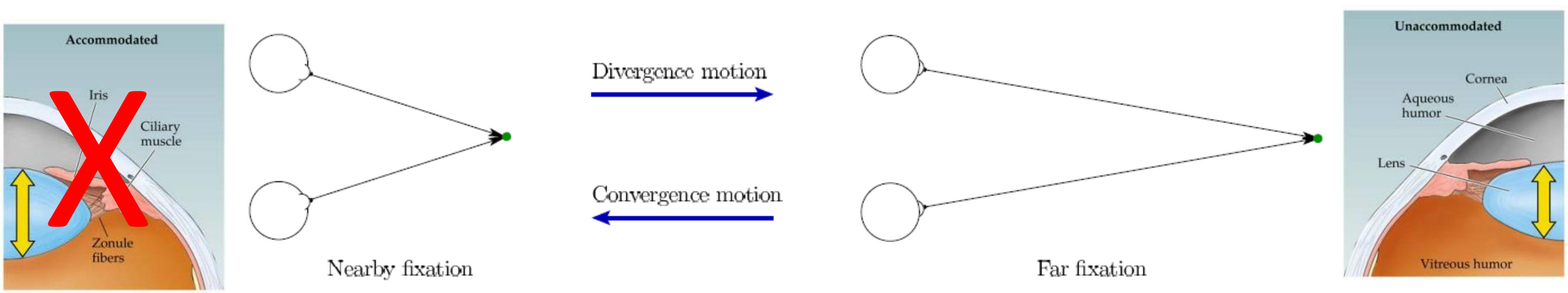
Vergence

- Vergence also varies with target distance



Vergence-accommodation Conflict

- Vergence-accommodation responses are yoked
- Looking at near objects in VR leads to vergence, but accommodation must be suppressed
  - Focal depth of the image is infinity (i.e. display depth)



Possible V-A Conflict Solutions

- Track vergence -> change focal depth
- Multifocal displays
- Lightfield displays