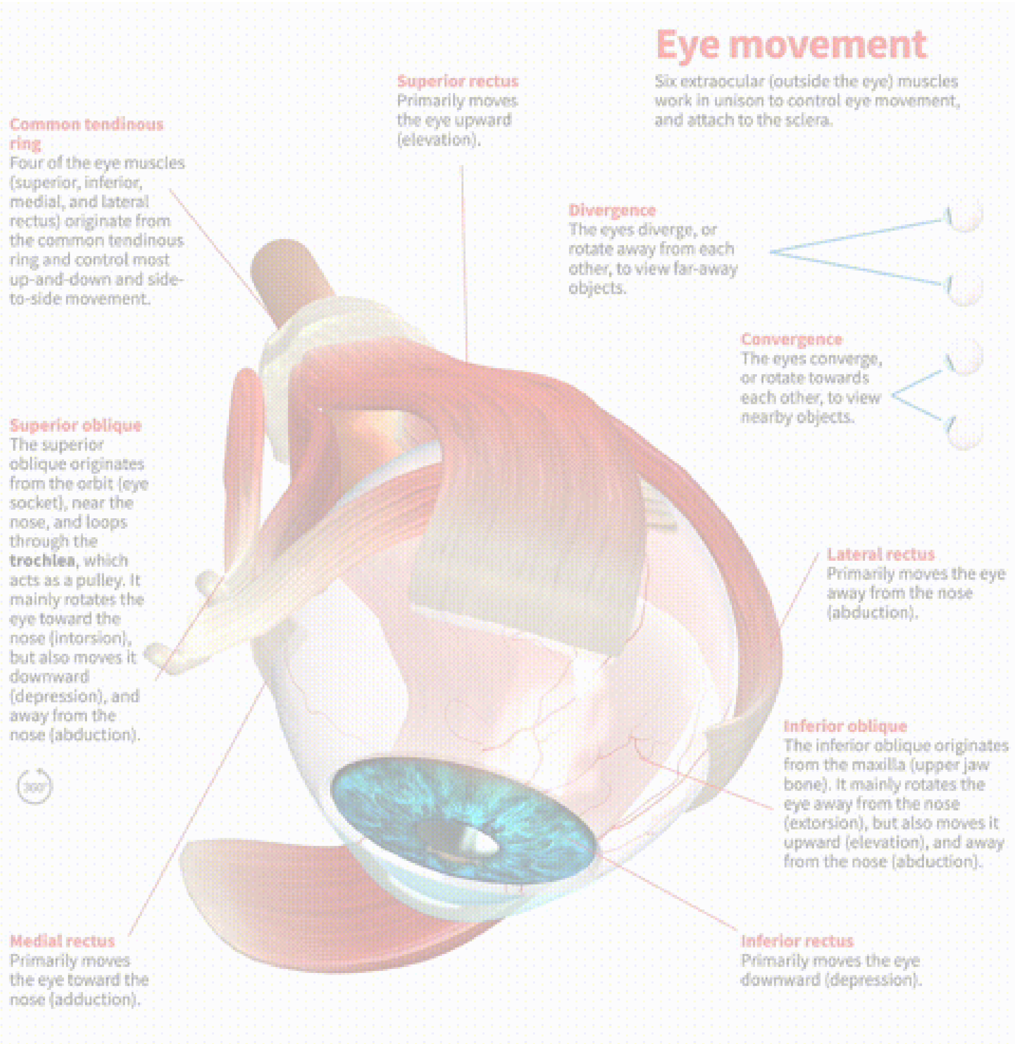
Sissejuhatus psühhofüsioloogia rakendustesse

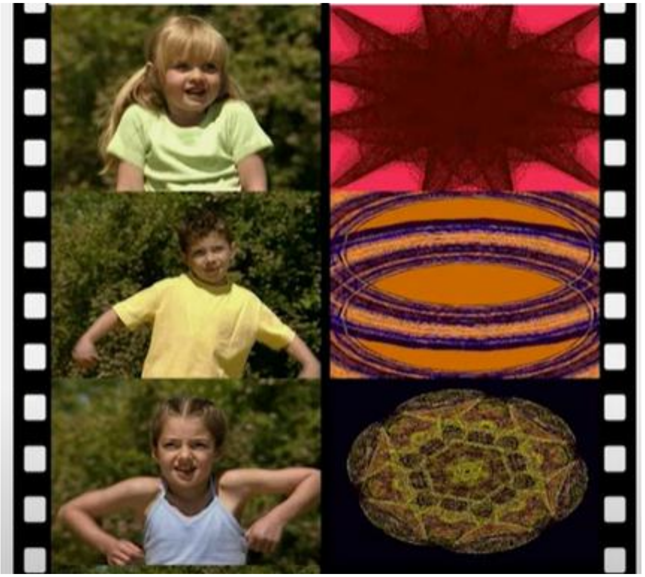
SILMALIIGUTUSED

Richard Naar

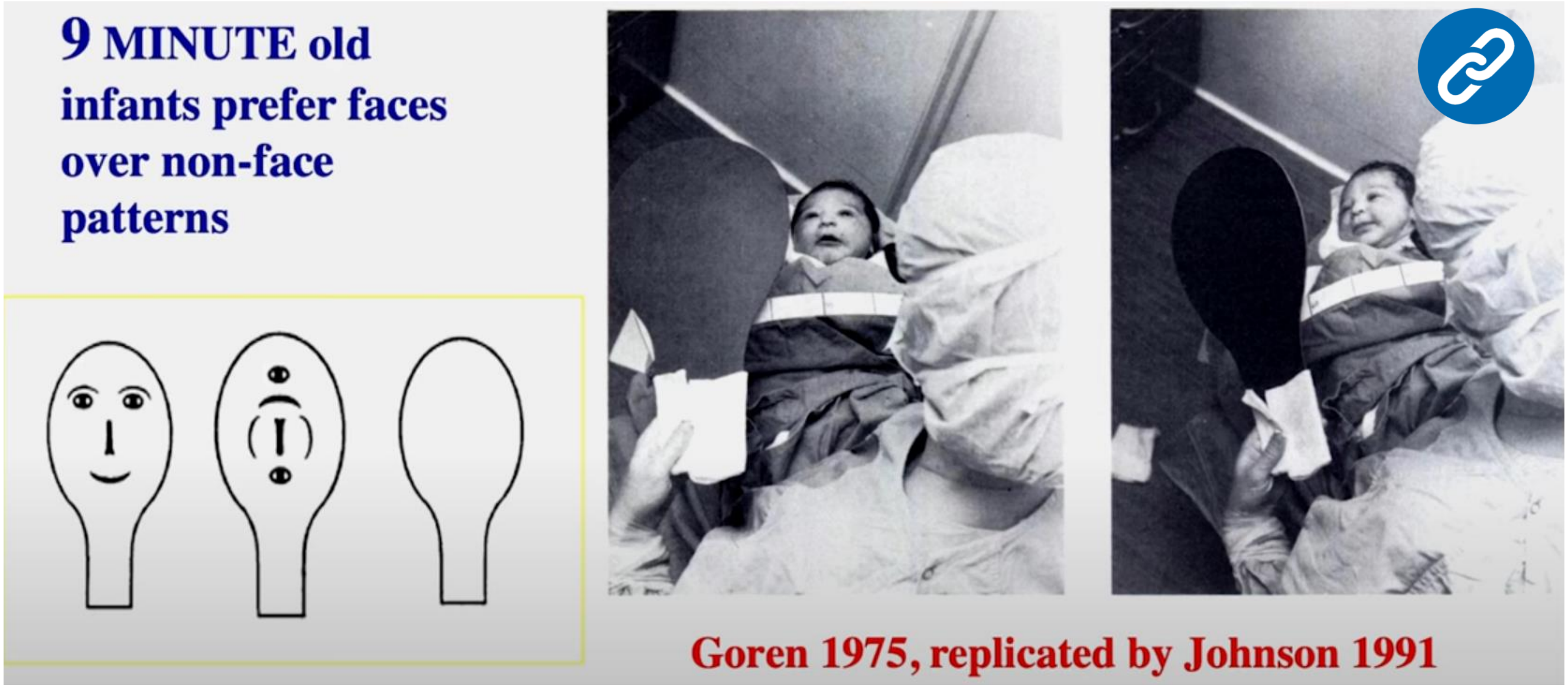


Kursuse arendamist toetas Haridus- ja noorteameti IT-akadeemia

Eye-Tracking: The Future of Diagnostics, Prognostics, and Treatment Planning in Autism



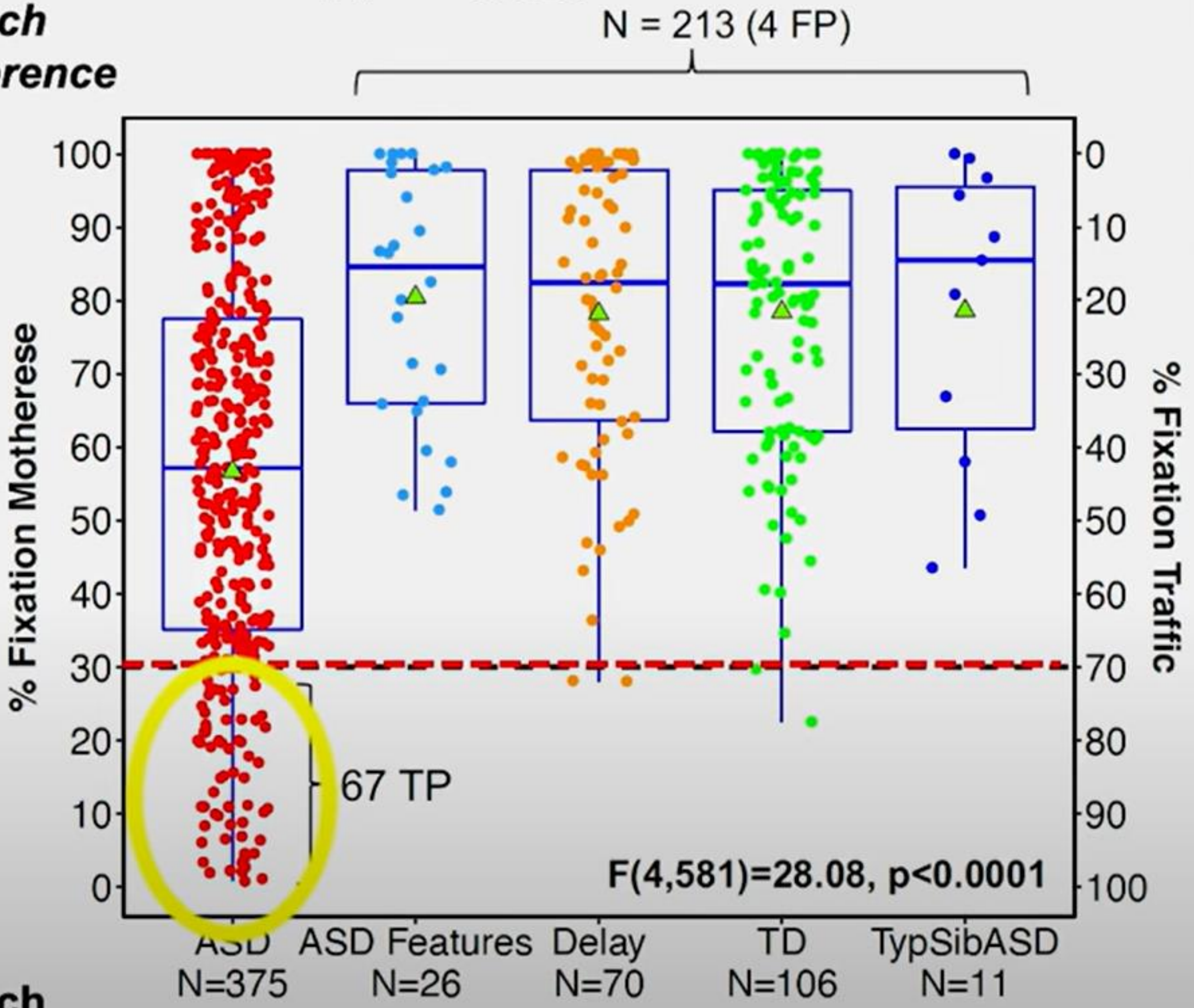
Eye-Tracking: The Future of Diagnostics, Prognostics, and Treatment Planning in Autism



Motherese Speech vs Highway Traffic Sounds

High Speech Preference

N = 588



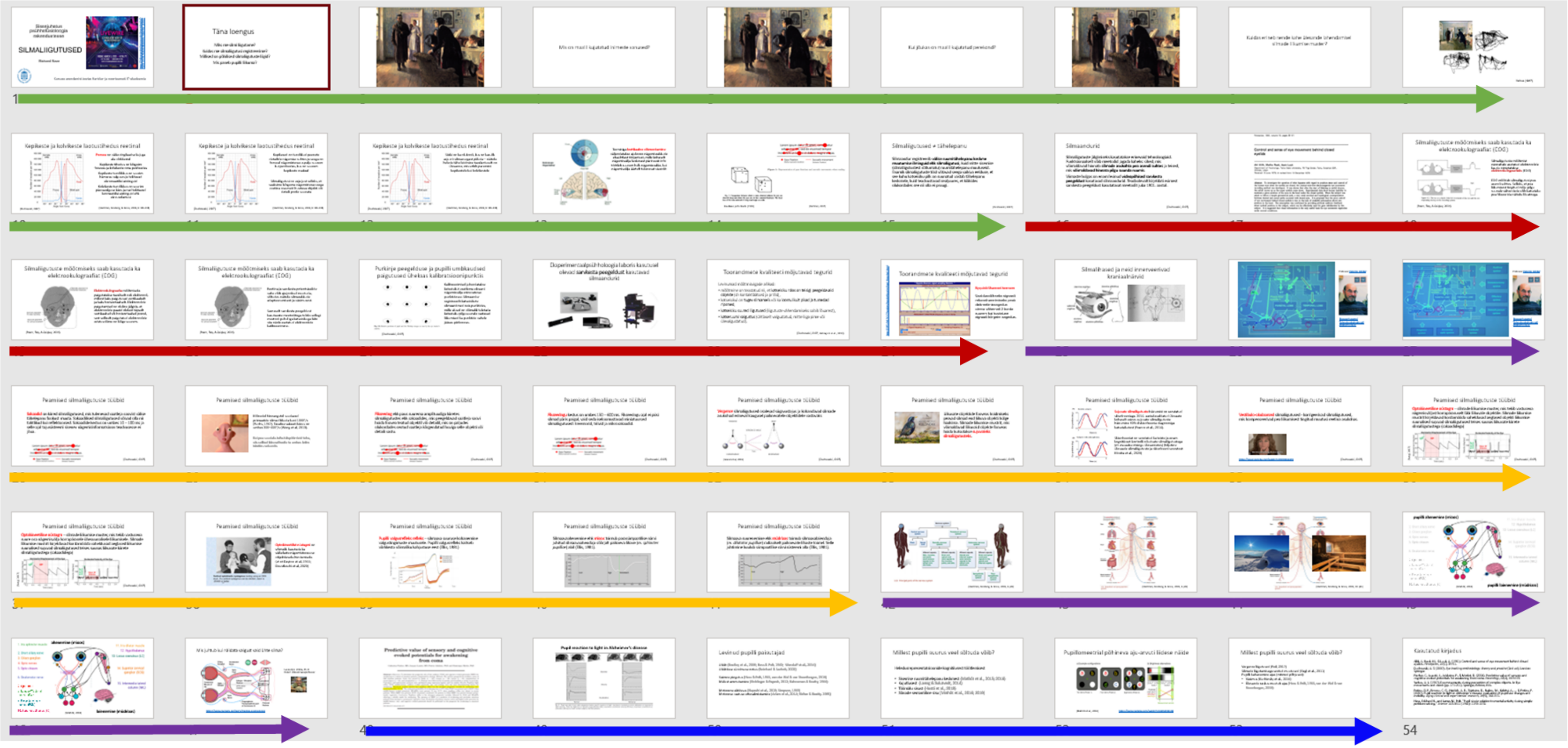
Low Speech Preference

AUC = .70
p = .0001
CI = .64-.77

Sens = 18%
Spec = 98%
PPV = 94%
NPV = 40%

Pierce et al., 2023, *JAMA Network Open*

Täna loengus



Miks liigutame?

Kuidas mõõdame?

Kuidas liigutame?

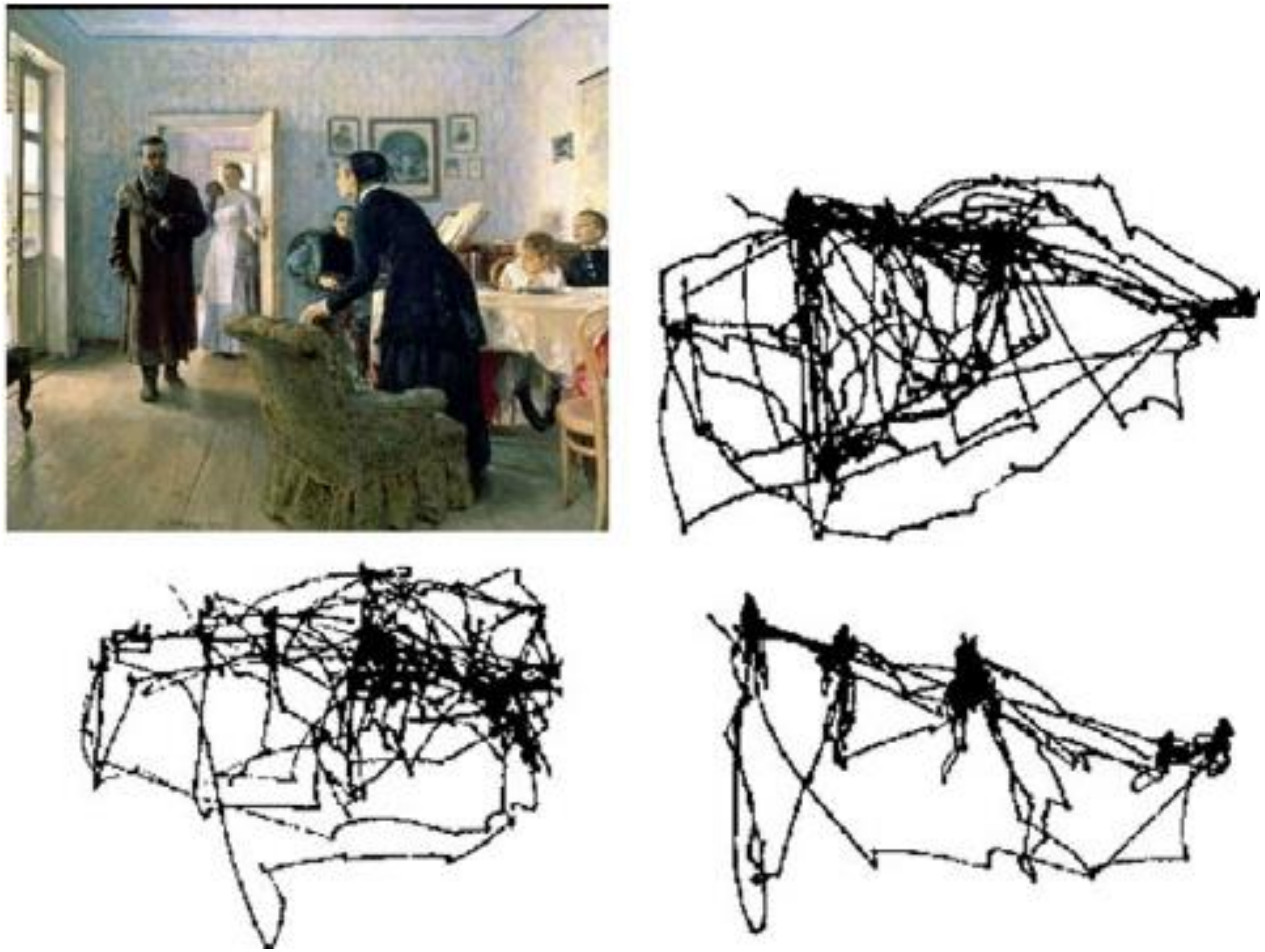
Mis on liigutamise füsioloogia?

Mis paneb pupilli liikuma?

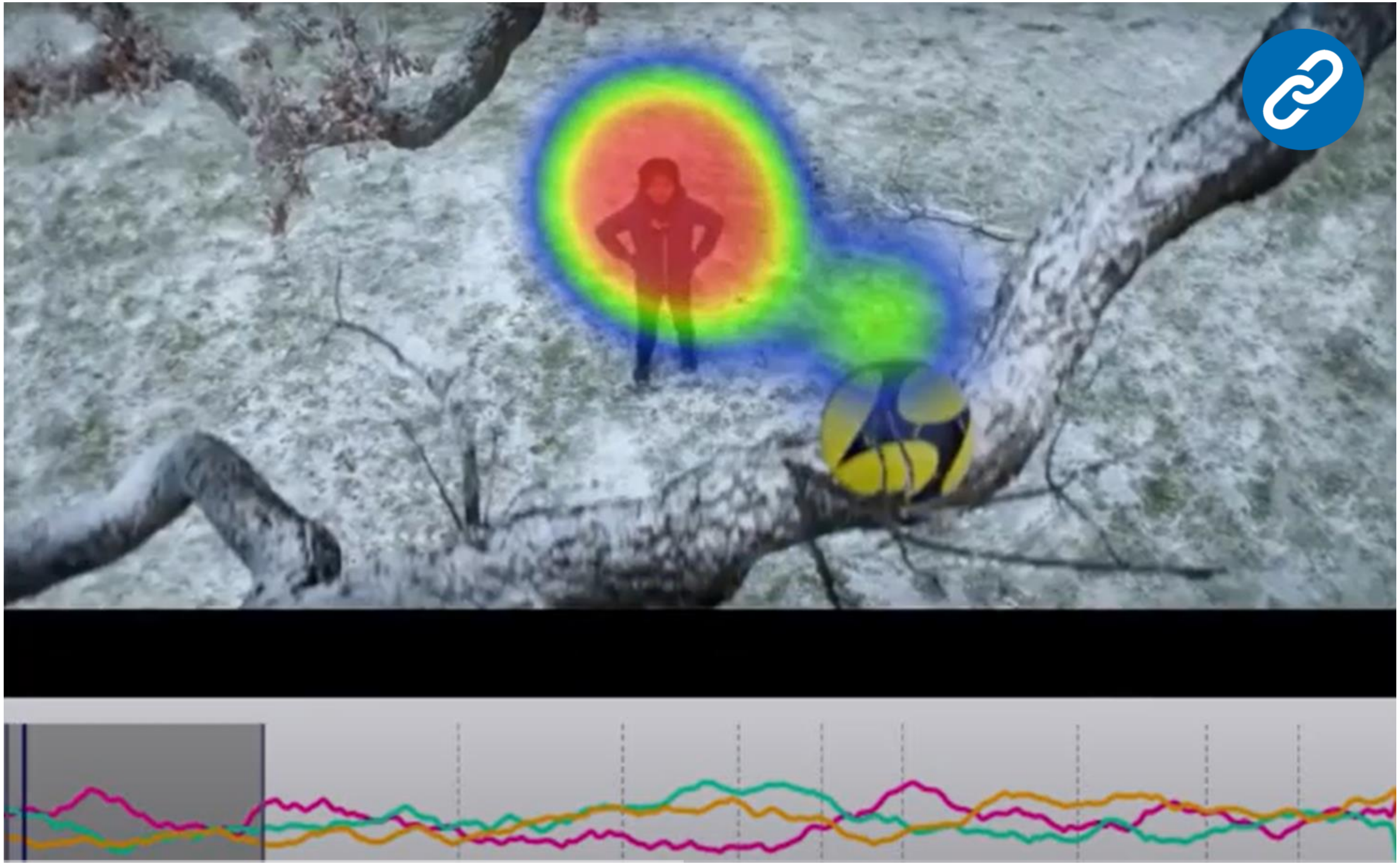
Mis on maalil kujutatud inimeste vanused?

Kui jõukas on maalil kujutatud perekond?

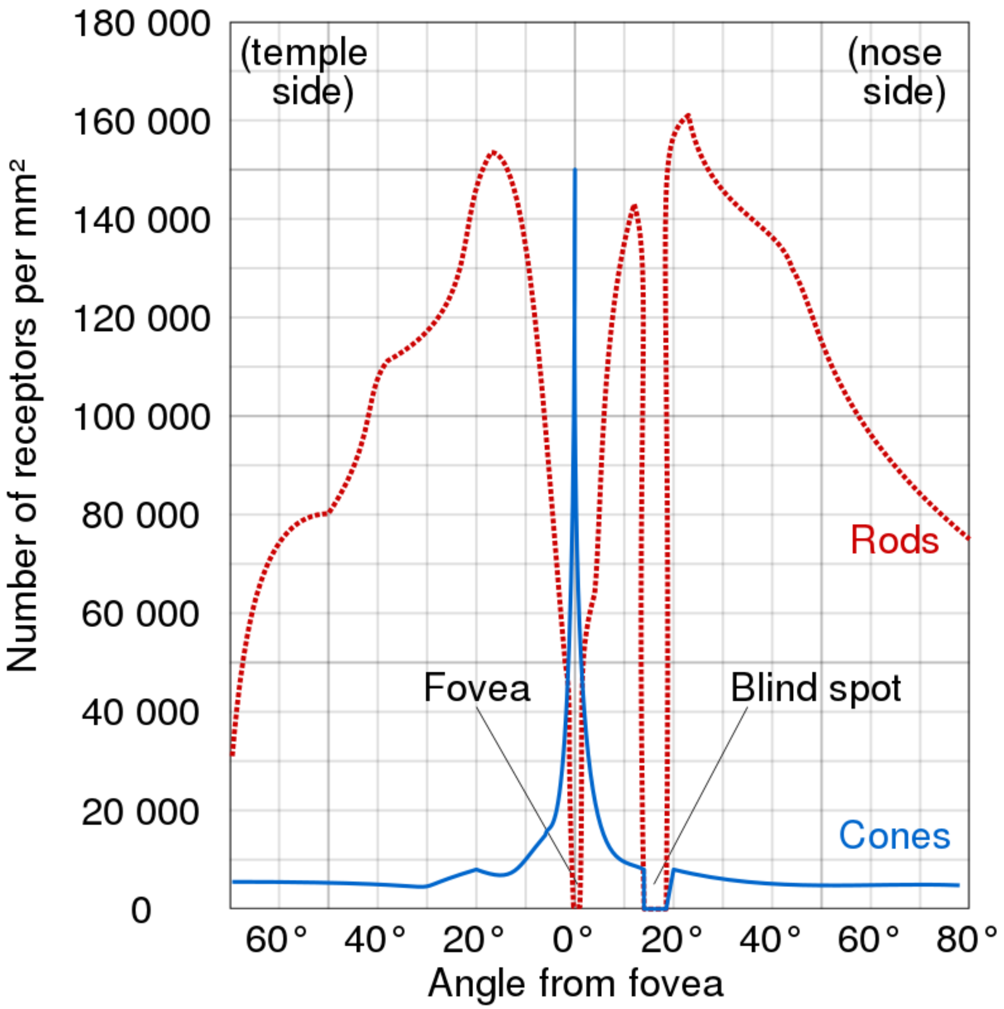
Kuidas erineb nende kahe ülesande lahendamisel silmade liikumise muster?



Yarbus (1967)



Miks me silmi liigutame?



(Duchowski, 2007)

Foovea on väike ringilaadse kujuga ala võrkkestal

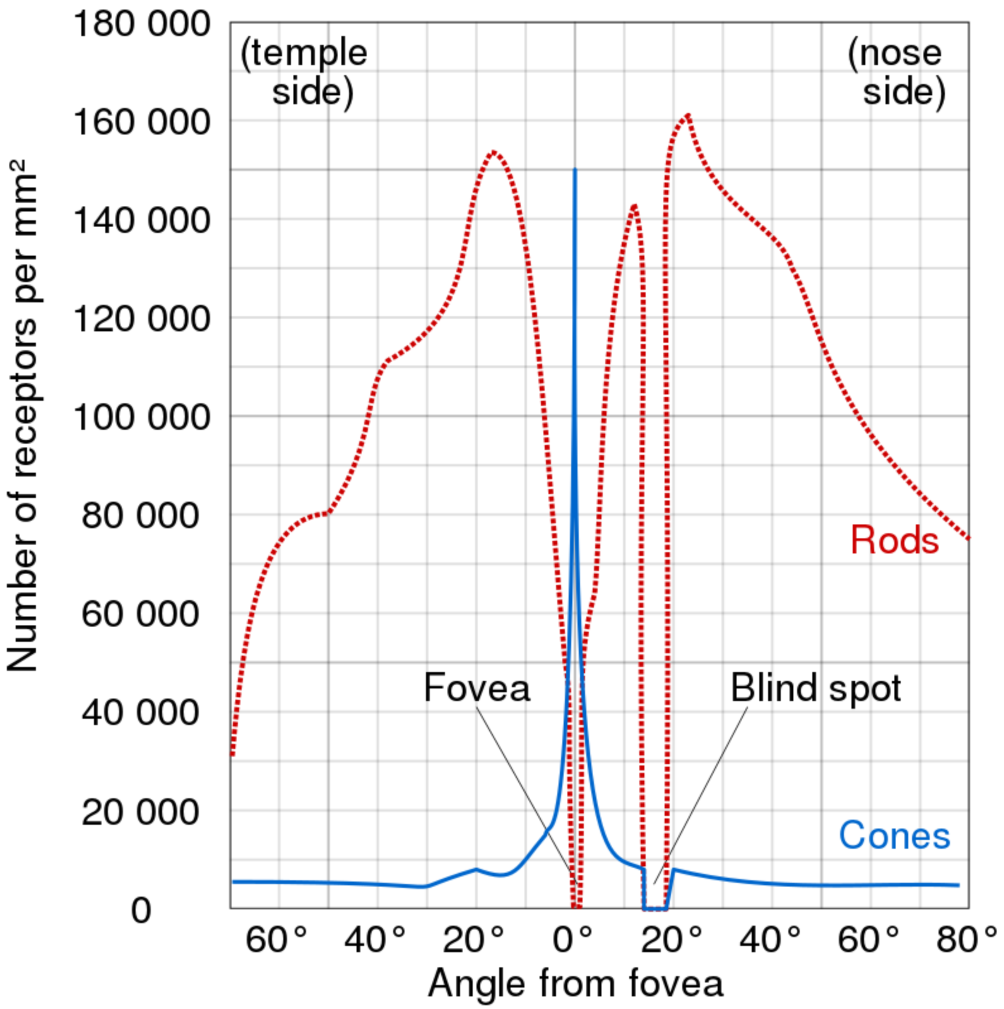
Kolvikeste tihedus on kõrgeim fooveas ja kepikeste oma võrkkesta välisservades

Kepikeste tundlikkus on suurim hämaras valguses ja nad tekitavad akromaatilisi aistinguid

Kolvikeste tundlikkus on suurim päevavalguse käes ja nad tekitavad kromaatilisi aistinguid ehk värvuselamusi

(Gleitman, Reisberg, & Gross, 2003, lk 196-198)

Miks me silmi liigutame?



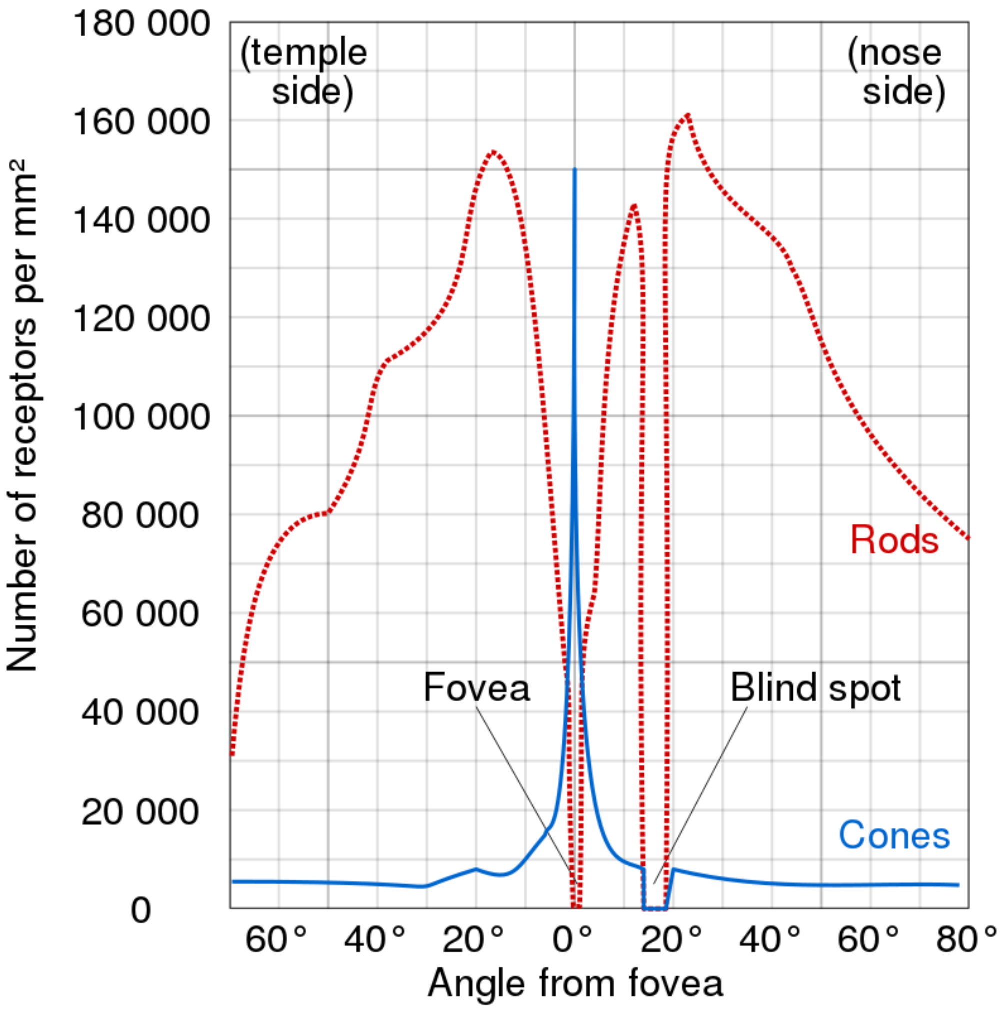
(Duchowski, 2007)

Kolvikesed on tundlikud peenete detailide nägemise suhtes ja seega on fooveal nägemisteravus palju suurem kui võrkkesta välisservades, kus kolvikeste osakaal on palju madalam

Silmaliigutusi on vaja just selleks, et saaksime kõrgema nägemisteravusega reetina osa meid huvitava objekti või detaili poole suunata

(Gleitman, Reisberg, & Gross, 2003, lk 196-198)

Miks me silmi liigutame?

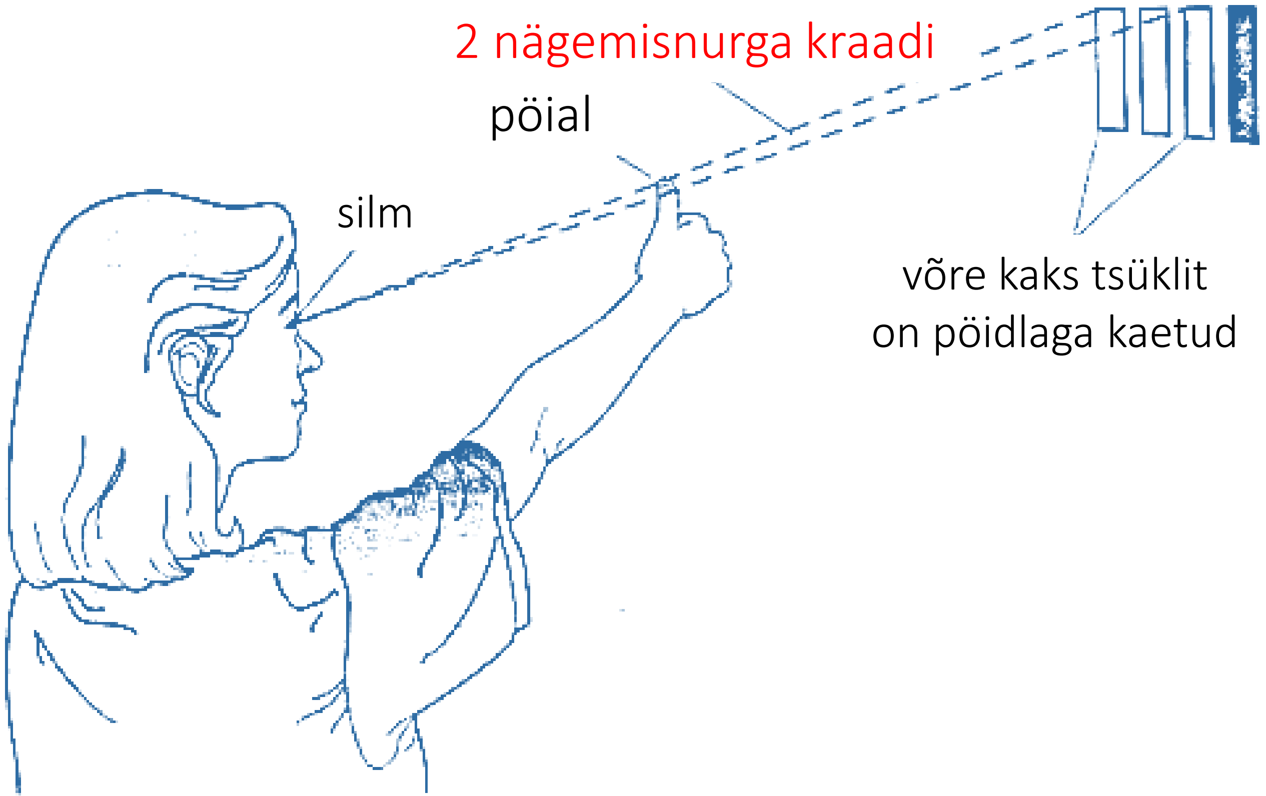


(Duchowski, 2007)

Siiski on ka olukordi, kus on kasulik asju nö silmanurgast piiluda – näiteks heleda tähe leidmine taevalaotuselt on ülesanne, mis sobib paremini kepikestele kui kolvikestele

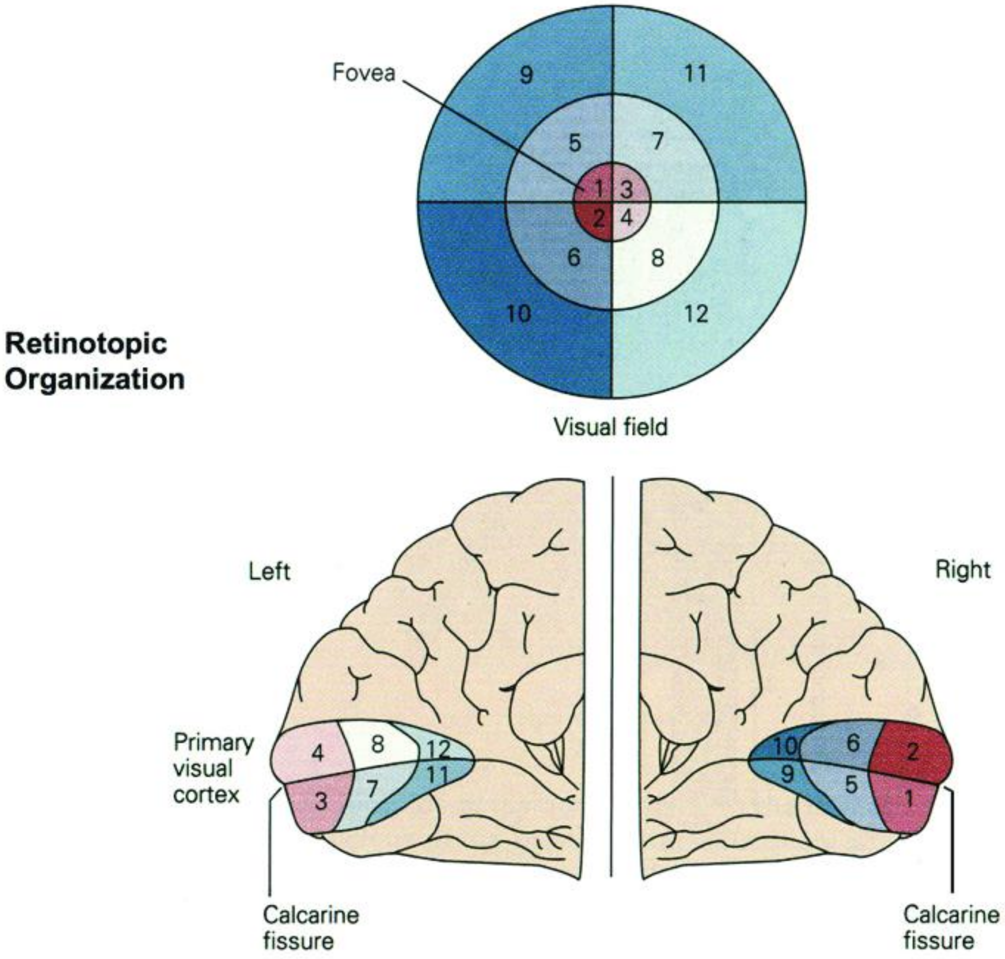
(Gleitman, Reisberg, & Gross, 2003, lk 196-198)

Miks me silmi liigutame?



(O'Shea, R. P, 1991).

Miks me silmi liigutame?



Terminiga kortikaalne võimendamine (suurendus) väljendatakse ajukoore nägemisrakkude ebaühtlast tööjaotust, mille kohaselt nägemisvälja keskosast pärinevat info töötleb suurem hulk nägemisrakke, kui nägemisvälja äärtelt tulenevat sisendit

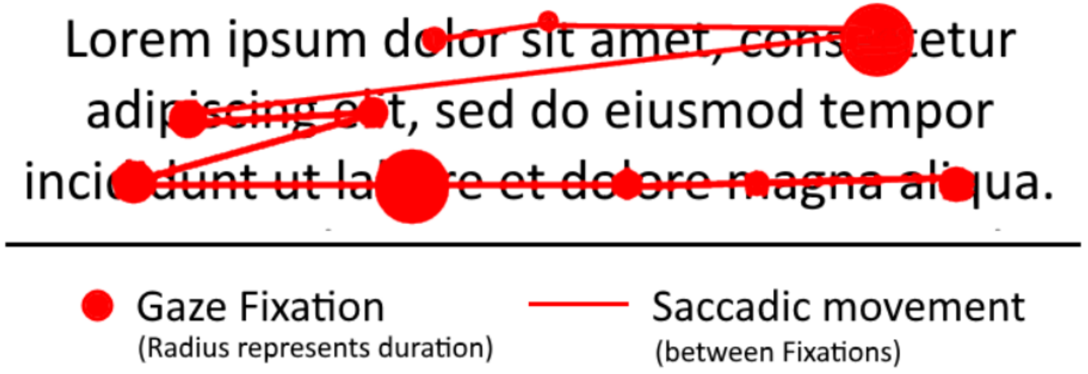


Figure 1: Representation of gaze fixations and saccadic movements when reading.

(Ramirez, 2017)

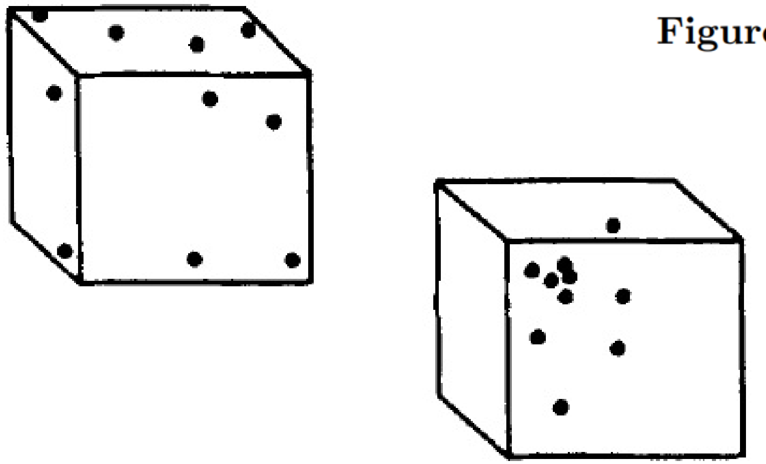


Fig. 1. Comparison between where a naive observer believes his eyes are directed (top) and where the eyes are, in fact, oriented (bottom). The front face of the cube subtends 2.5 deg visual angle on a side.

Kaufman ja Richards (1969)

Silmaliigutused ≠ tähelepanu

Silmaandur registreerib **välise ruumitähelepanu keskme muutumise ilminguid ehk silmaliigutusi**, kuid mitte sisemise (silmaliigutustest sõltumatu) ruumitähelepanu muutuseid. Enamik silmaliigutuste töid võtavad seega vaikiva eelduse, et see kuhu katseisiku pilk on suunatud vastab tähelepanu keskmele, kuid teadvustavad sealjuures, et kõikides olukordades see nii olla ei pruugi.

(Duchowski, 2007)

Kuidas me silmaliigutusi mõõdame?

Silmaliigutuste jälgimiseks kasutatakse erinevaid tehnoloogiaid. Funktsionaalselt võib meetodid jagada kaheks: ühed, mis võimaldavad hinnata **silmade asukohta pea asendi suhtes** ja teised, mis **võimaldavad hinnata pilgu suunda ruumis**.

Viimaste hulgas on enam levinud **videopõhised sarvkesta peegeldust** kasutavad silmaandurid. Teadaolevalt kirjeldati esimest sarvkesta peegeldust kasutatavat meetodit juba 1901. aastal.

(Duchowski, 2007)

Perception, 1981, volume 10, pages 39-51

Control and sense of eye movement behind closed eyelids

Jüri Allik, Marika Rauk, Aavo Luuk
Department of Psychology, Tartu State University, 78 Tiigi Street, Tartu, Estonian SSR, 202400, USSR
Received 13 June 1979, in revised form 10 December 1979

Abstract. To investigate the question of what happens with regard to position sense and control of the human eyes when the eyelids are closed, the contact-wire-free electromagnetic eye movement recording method was developed. It was shown that after the start of blinking or eyelid closure, the eyball moves up as the upper eyelids come down. Experimental data show human inability to maintain a given position of the eyes in the head under the closed eyelids. When the subject was asked to follow a simple geometrical path, a very weak metrical and topological correspondence between desired and actual paths occurred with closed eyes. It is proposed that the poor control of eye movements behind closed eyelids is due to the lack of available information about eye position in the head. The assumption was confirmed by providing artificial auditory feedback about eyeball position to the subject, which can be effectively used for gaze stabilization by the subject. It is suggested that visual information is the only useful basis for eye movement regulation under normal conditions.

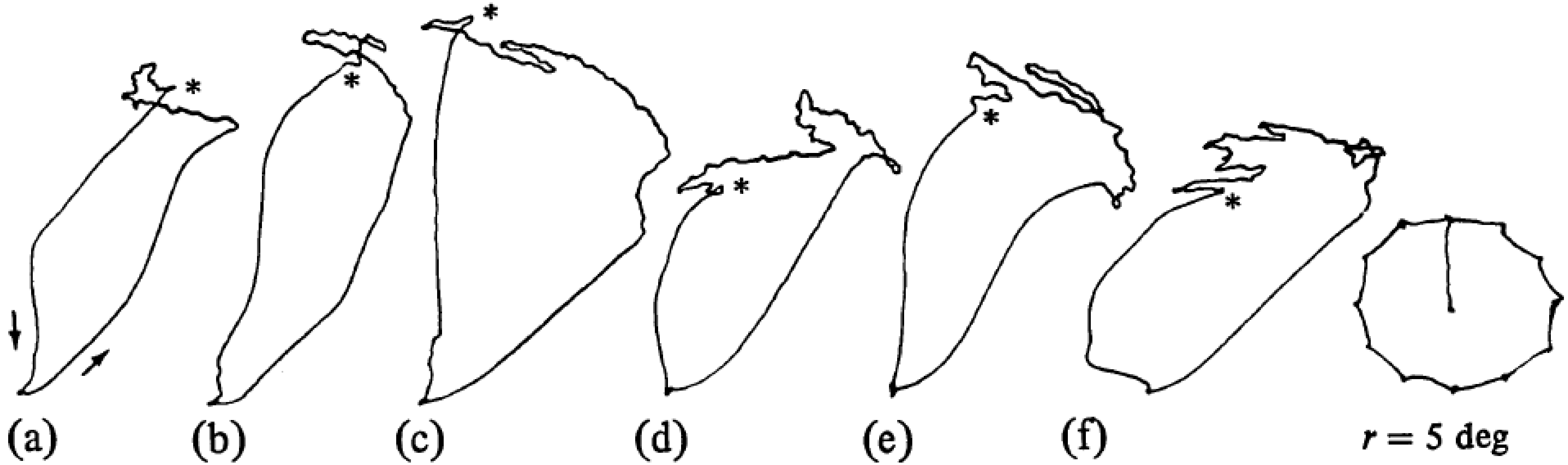
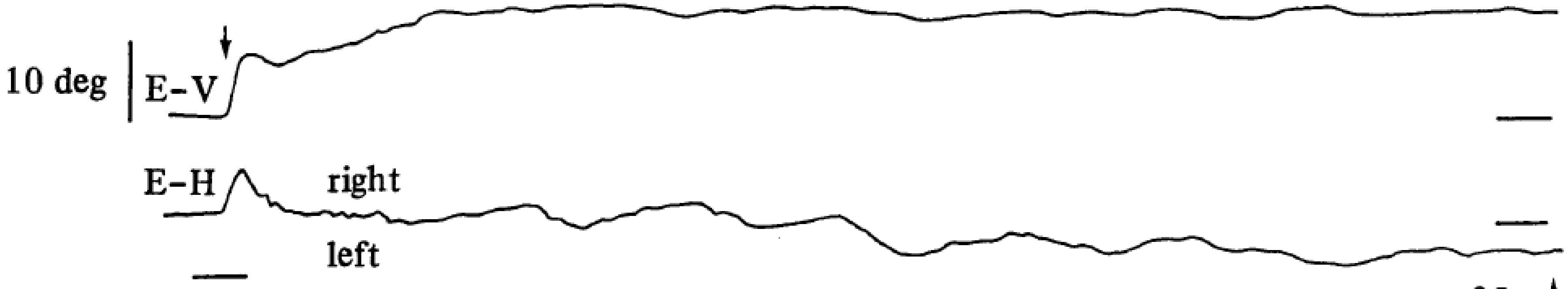
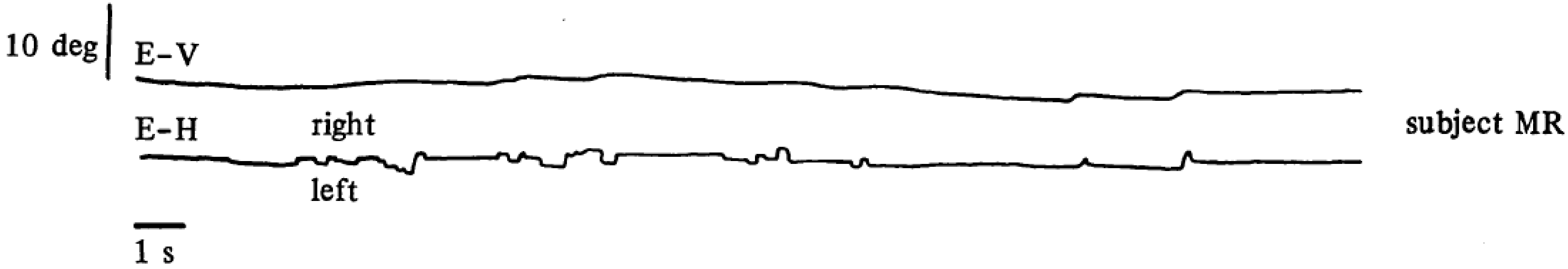


Figure 6. Six sequential trials of subject MR in an attempt to maintain a prior fixation position after eyelid closure. The short arrows indicate the direction of the eye movement paths. The eyelids were closed for about 20 s. The drawing with the eyes of the calibration circle is shown (r = 5 deg). The asterisk shows the approximate time at which the lids opened.


10 deg
E-V
E-H
right
left
1 s
25 s

(b)


10 deg
E-V
E-H
right
left
1 s
subject MR

Silmaliigutuste mõõtmiseks saab kasutada ka elektrookulograafiat (EOG)

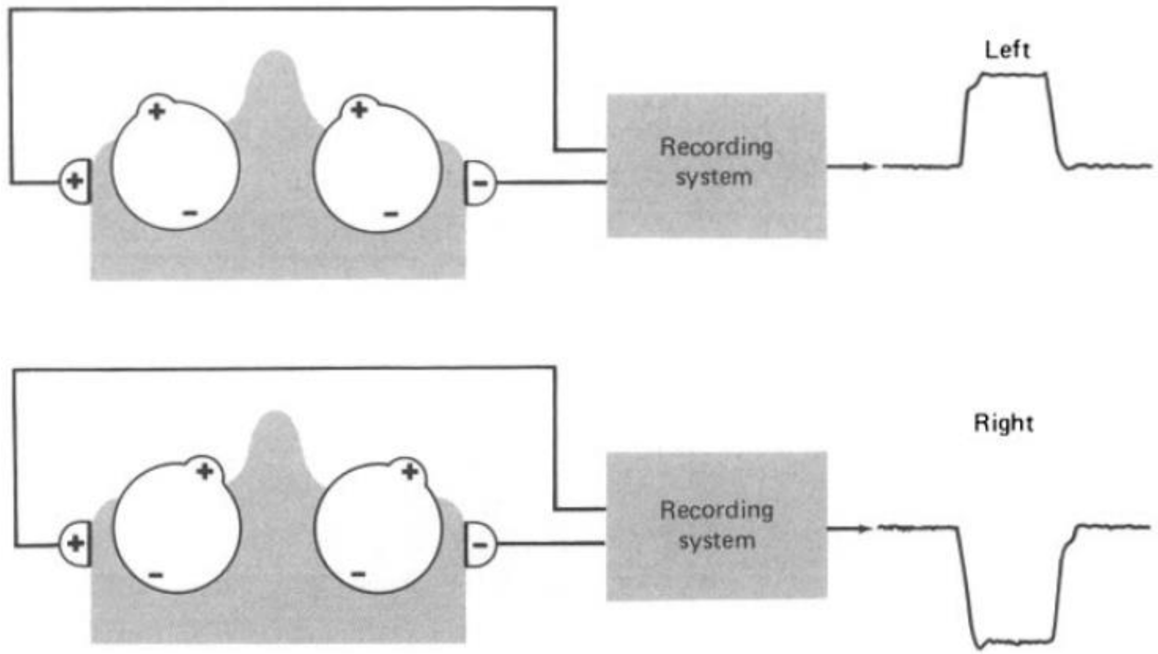


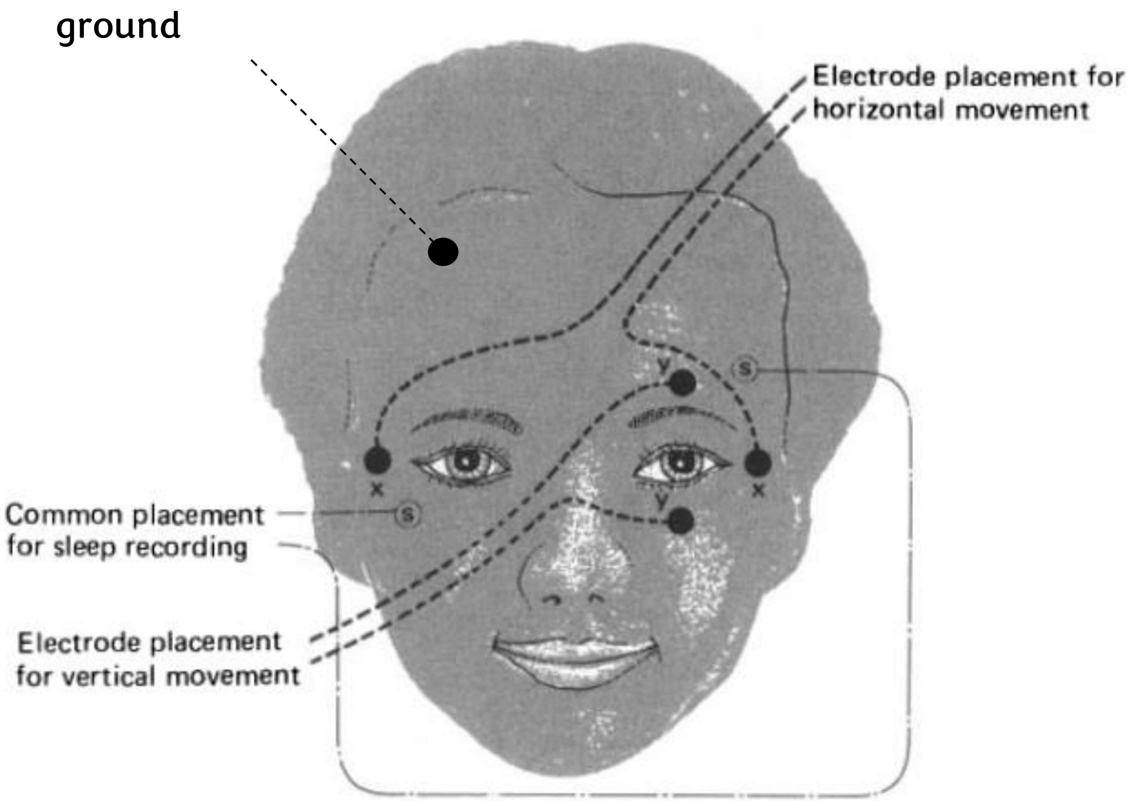
Figure 9.2. The eye as a dipole. Note the movement of the eye and the corresponding tracing on the recording system.

(Stern, Ray, & Quigley, 2001)

Silmaliigutuste mõõtmist näonahale asetatud elektroodide kaudu nimetatakse elektrookulograafiaks (EOG)

EOG mõõdab silmaliigutusi pea asendi suhtes. Selleks, et pea liikumisest tingitud mõju pilgu suunale vähendada võib katseisiku pea fikseerida näiteks lõuatoega.

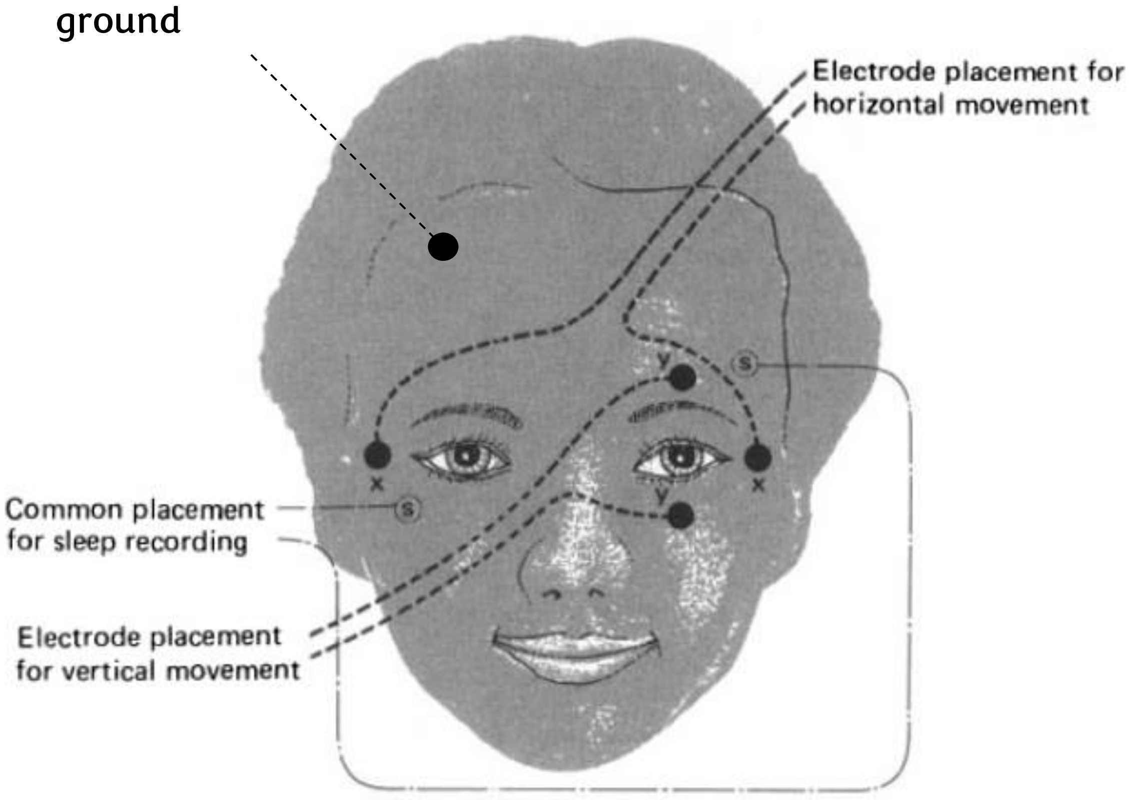
Silmaliigututuste mõõtmiseks saab kasutada ka elektrookulograafiat (EOG)



(Stern, Ray, & Quigley, 2001)

Elektrookulograafia mõõtmiseks paigutatakse tavaliselt neli elektroodi, millest kaks paigutuvad vertikaalselt ja kaks horisontaalselt. Elektroodide paigutamisel on oluline jälgida, et elektroodide paarid oleksid täpselt vertikaalsel või horisontaalsel joonel, sest selliselt paigutatud elektroodide eristusvõime on kõige suurem.

Silmaliigutuste mõõtmiseks saab kasutada ka elektrookulograafiat (EOG)



(Stern, Ray, & Quigley, 2001)

Reetina ja sarvkesta potentsiaalide vahe võib aja jooksul muutuda, sõltudes näiteks silmarakkude adapteerumisest ja väsimusest.

Sarnaselt sarvkesta peegeldust kasutavate meetoditega tuleks sellegi meetodi puhul iga katseisikuga läbi viia näole asetatud elektroodide kalibreerimine.

Purkinje peegelduse ja pupilli umbkaudsed paigutused üheksas kalibratsioonipunktis

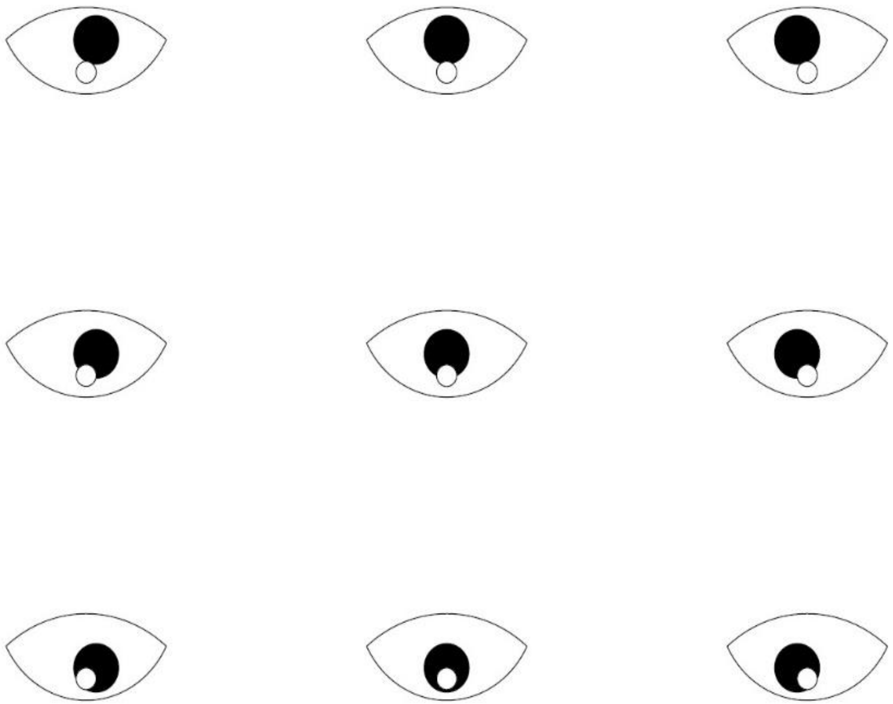


Fig. 5.8. Relative positions of pupil and first Purkinje images as seen by the eye tracker's camera.

(Duchowski, 2007)

Kalibreerimisel juhendatakse katseisikut vaatlema ekraani nägemisvälja erinevatesse punktidesse. Silmaandur registreerib katseisikute silmaandmed neis punktides, mille alusel on võimalik tuletada katseisiku pilgusuunale vastavad liikumised ka punktide vahele jäävas piirkonnas.


CPU 2.5
45 FPS

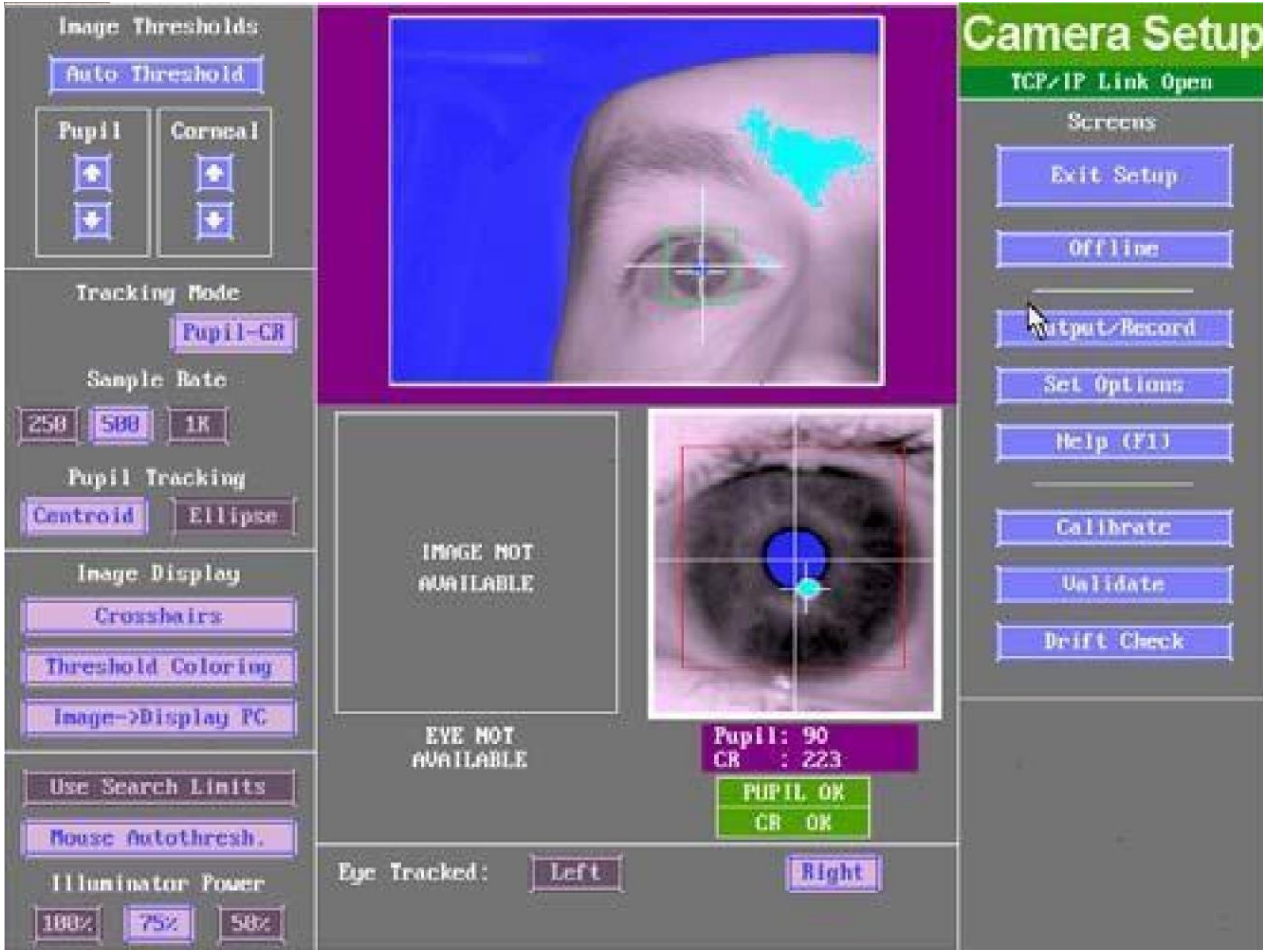


Image Thresholds
Auto Threshold
Pupil
Corneal
Tracking Mode
Pupil-CR
Sample Rate
250
500
1K
Pupil Tracking
Centroid
Ellipse
Image Display
Crosshairs
Threshold Coloring
Image->Display PC
Use Search Limits
Mouse Autothresh.
Illuminator Power
100%
75%
50%
IMAGE NOT AVAILABLE
EYE NOT AVAILABLE
Pupil: 90
CR : 223
PUPIL OK
CR OK
Eye Tracked:
Left
Right
Camera Setup
TCP/IP Link Open
Screens
Exit Setup
Offline
Output/Record
Set Options
Help (F1)
Calibrate
Validate
Drift Check

Eksperimentaalpsühholoogia laboris kasutusel olevad **sarvkesta peegeldust** kasutavad silmaandurid

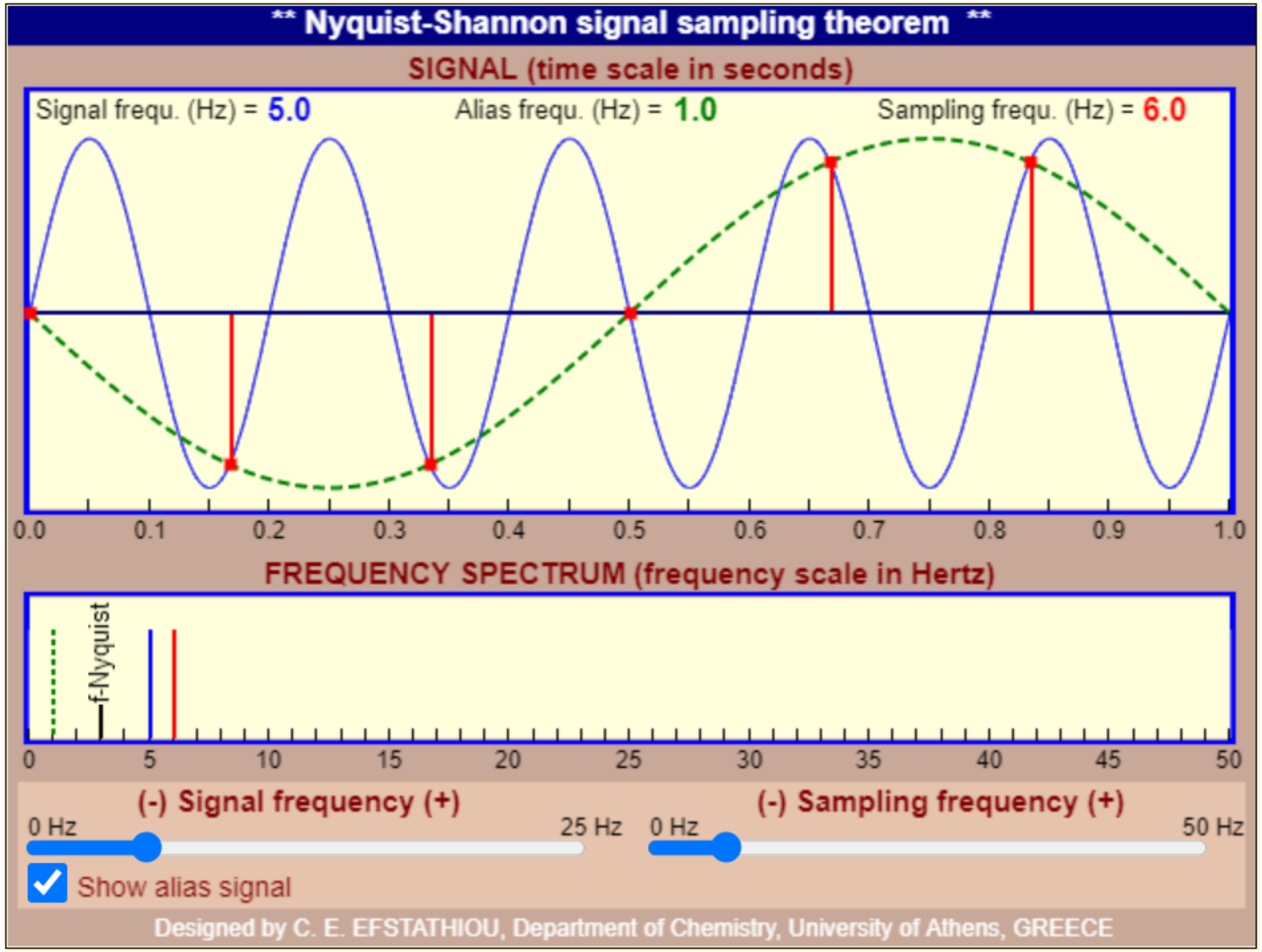
Toorandmete kvaliteeti mõjutavad tegurid

Levinumad mõõtmisvigade allikad:

- mõõtmine on teostatud nii, et **katseisiku näos on teisigi peegeldavaid objekte** (sh kontaktläätsed ja prillid);
- katseisikul on **tugev silmameik** või ka **loomulikult pikad ja tumedad ripsmed;**
- **katseisiku suured liigutused** (liigutuste vähendamiseks sobib lõuarest)**;**
- **katseruumi valgustus** (ühtlaselt valgustatud, mitte liiga pime või ülevalgustatud)**.**

(Duchowski, 2007; Holmqvist et al., 2012)

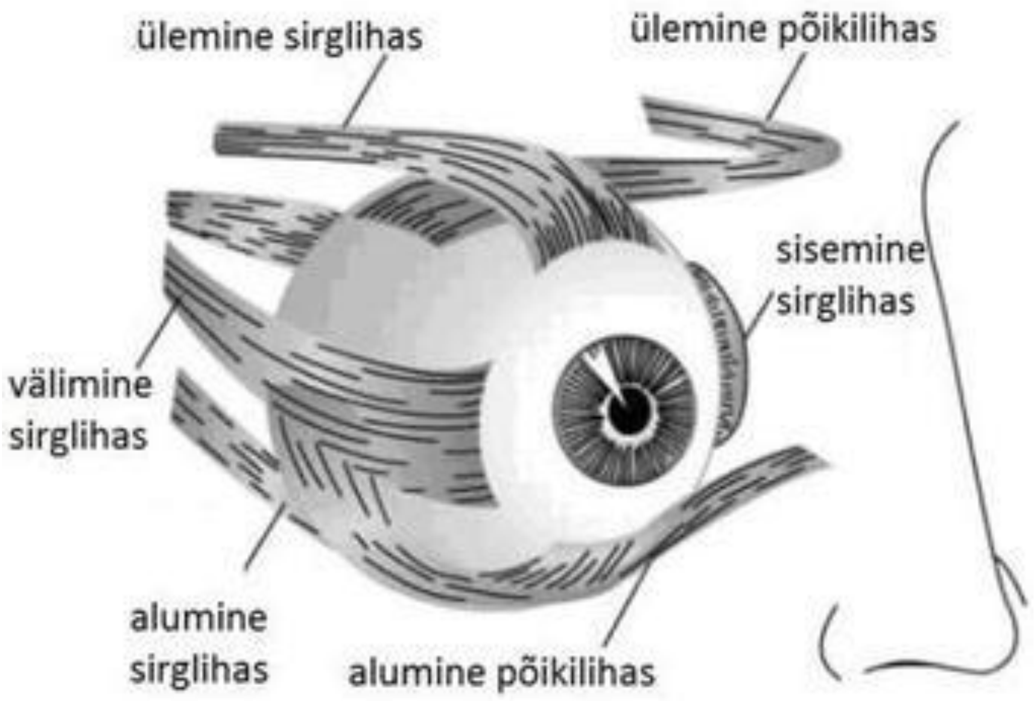
Toorandmete kvaliteeti mõjutavad tegurid

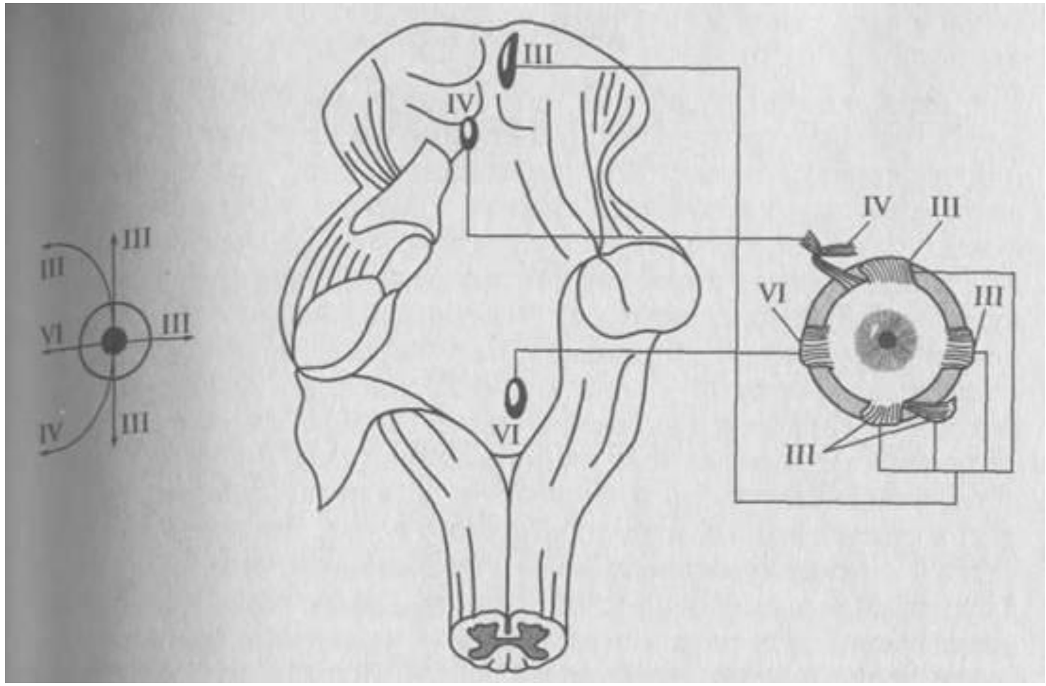


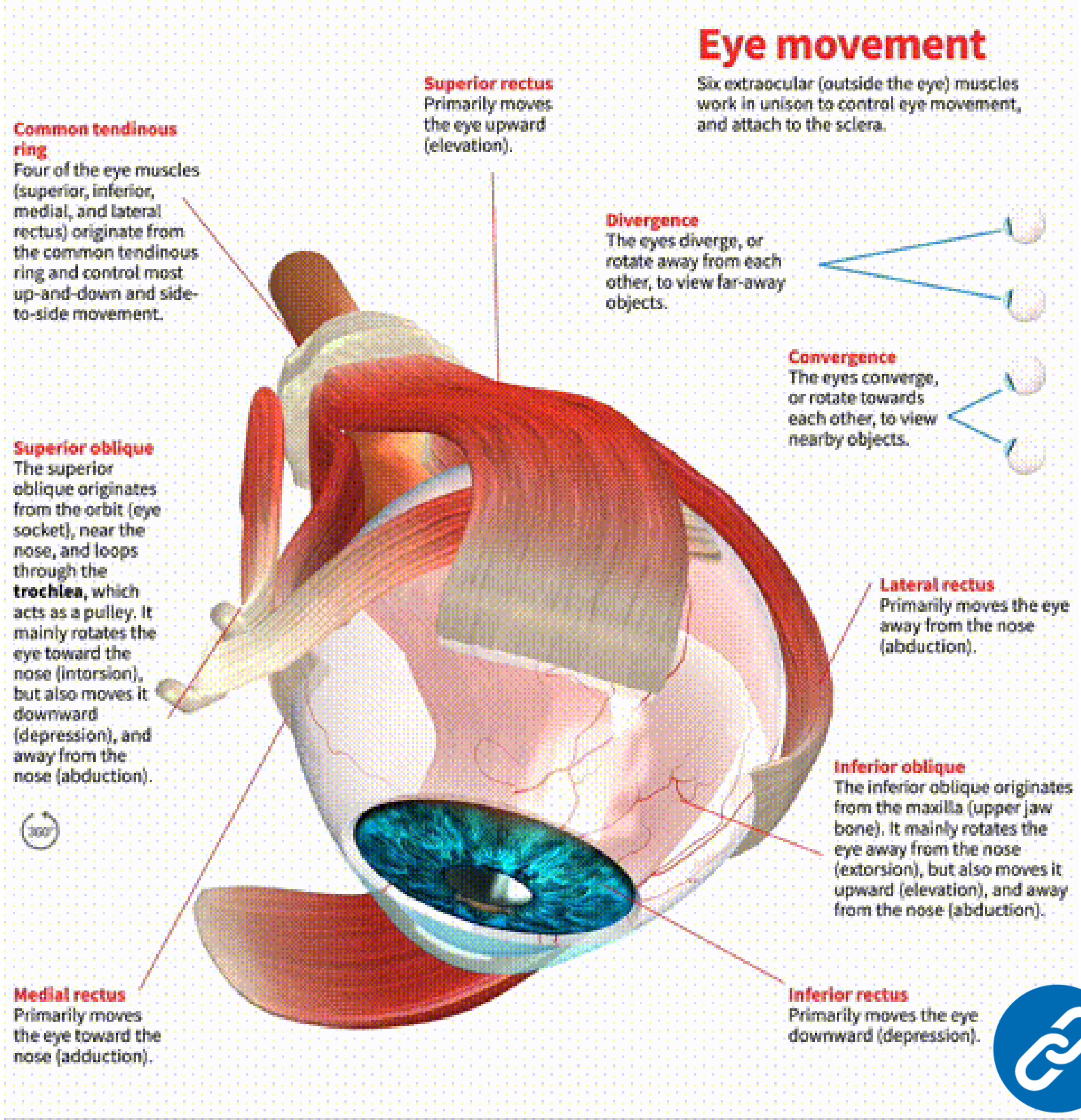
Nyquisti-Shannoni teoreem

Usaldusväärseks signaali rekonstrueerimiseks peab diskreetimissagedus olema vähemalt 2 korda suurem kui huvialuse signaali kõrgeim sagedus.

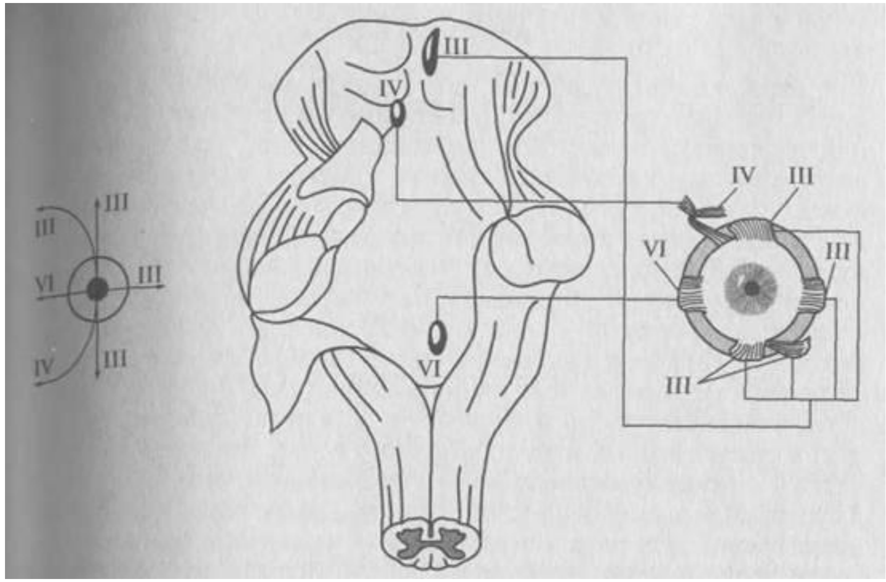
Silmalihased ja neid innerveerivad kraniaalnärvid



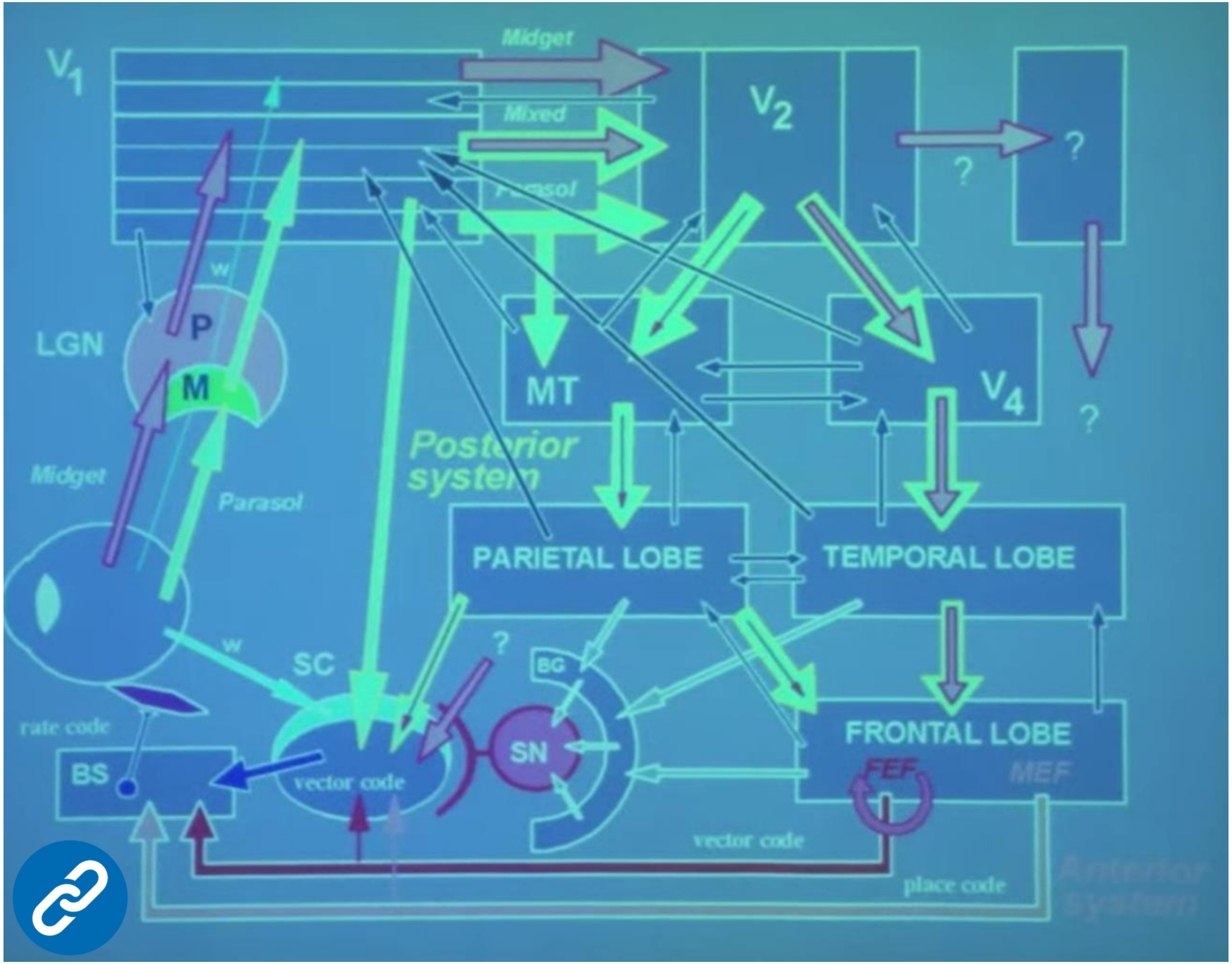




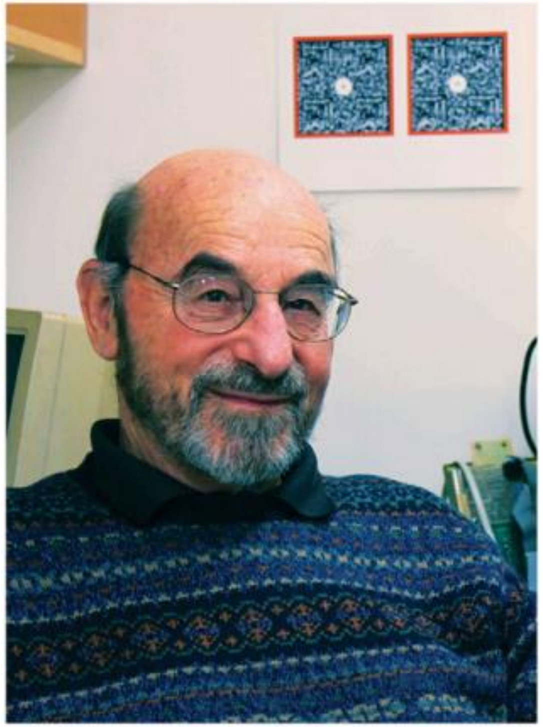
Eye movement
Six extraocular (outside the eye) muscles work in unison to control eye movement, and attach to the sclera.
Superior rectus
Primarily moves the eye upward (elevation).
Common tendinous ring
Four of the eye muscles (superior, inferior, medial, and lateral rectus) originate from the common tendinous ring and control most up-and-down and side-to-side movement.
Divergence
The eyes diverge, or rotate away from each other, to view far-away objects.
Convergence
The eyes converge, or rotate towards each other, to view nearby objects.
Superior oblique
The superior oblique originates from the orbit (eye socket), near the nose, and loops through the trochlea, which acts as a pulley. It mainly rotates the eye toward the nose (intorsion), but also moves it downward (depression), and away from the nose (abduction).
Lateral rectus
Primarily moves the eye away from the nose (abduction).
Inferior oblique
The inferior oblique originates from the maxilla (upper jaw bone). It mainly rotates the eye away from the nose (extorsion), but also moves it upward (elevation), and away from the nose (abduction).
Medial rectus
Primarily moves the eye toward the nose (adduction).
Inferior rectus
Primarily moves the eye downward (depression).



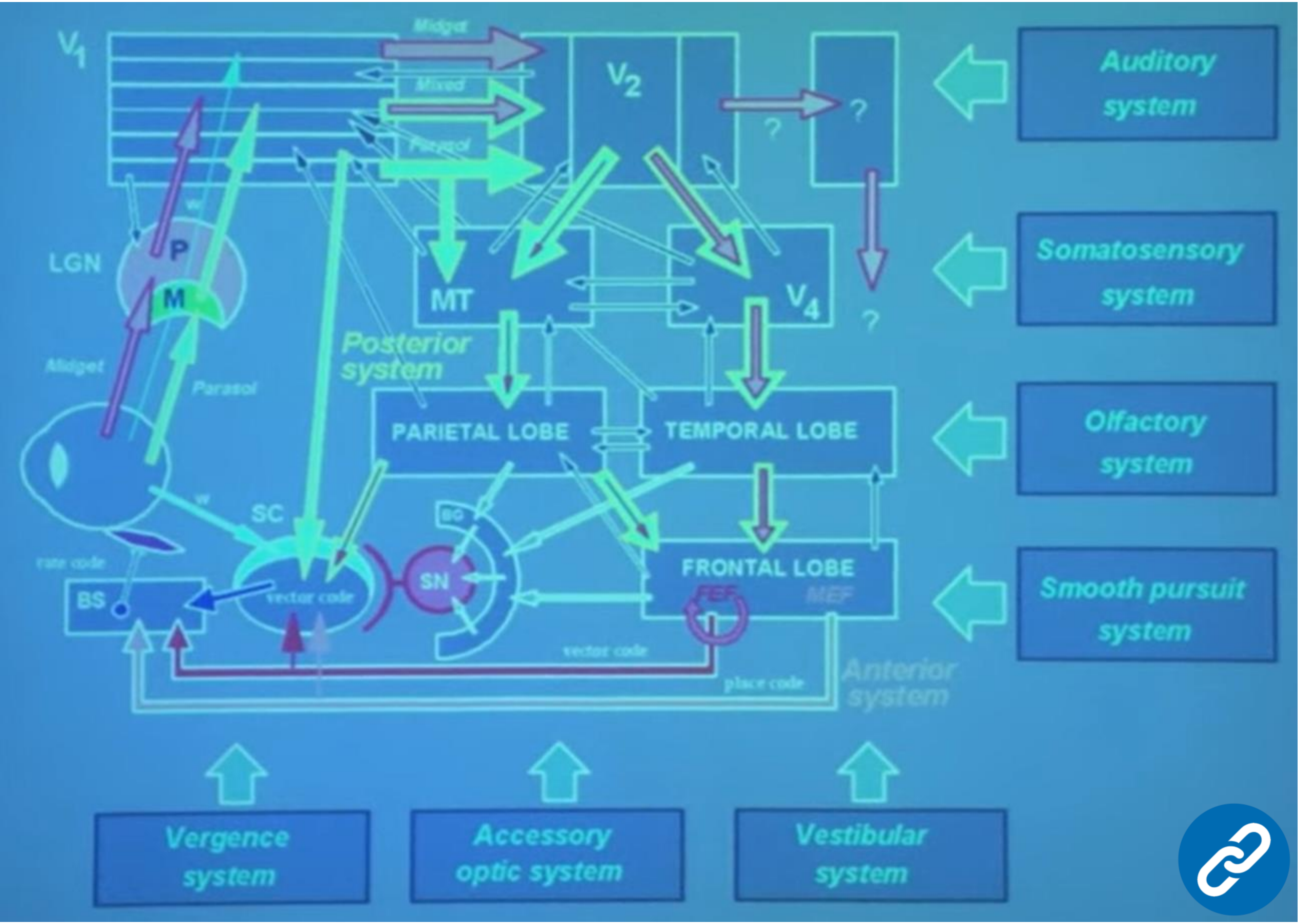
III
IV
VI



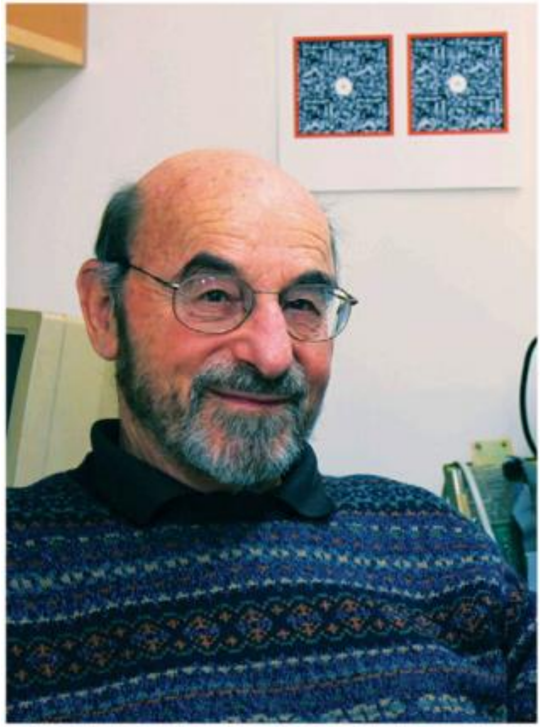
Professor [Peter H. Schiller]()



[Massachusettsi Tehnoloogiainstituudi avatud kursus]()



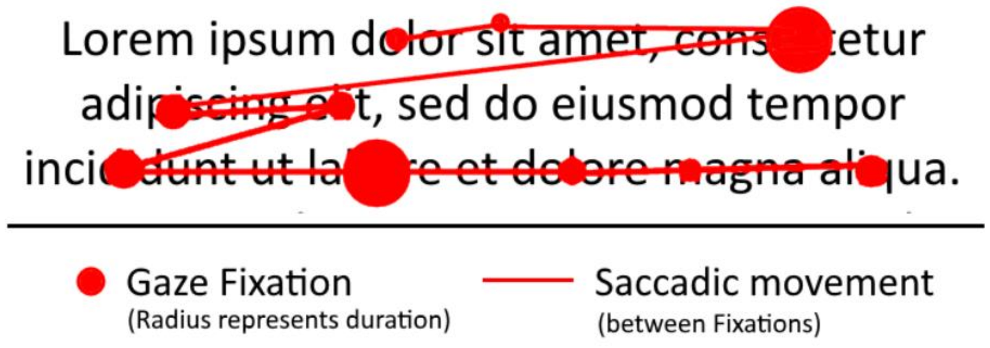
Professor [Peter H. Schiller]



[Massachusettsi Tehnoloogiainstituudi avatud kursus]

Peamised silmaliigutuste tüübid

Sakaadid on kiired silmaliigutused, mis tulenevad vaatleja soovist välise tähelepanu fookust muuta. Sakaadilised silmaliigutused võivad olla nii tahtlikud kui reflektoorsed. Sakaadide kestus on umbes 10 – 100 ms ja selle ajal tajusüsteemi sisenev nägemisinformatsioon teadvusesse ei jõua.



(Duchowski, 2007)

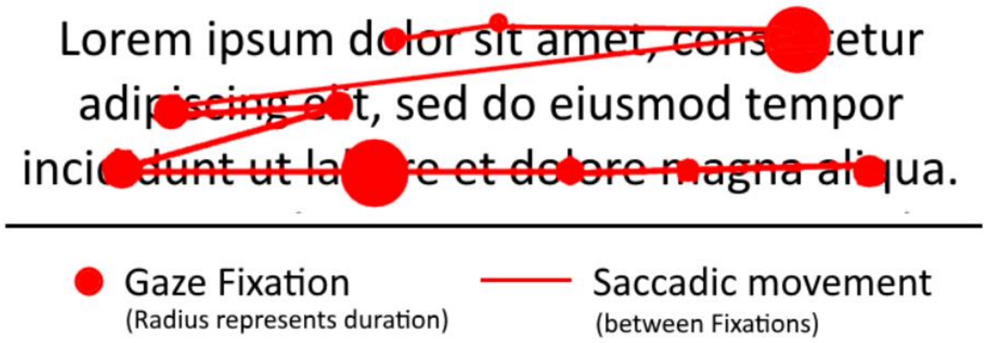
Peamised silmaliigutuste tüübid

Mõnedel hinnangutel suudavad primaatide silmad liikuda kuni 1000°/s (Fuchs, 1967). Tavalise sakaadi kiirus on umbes 300–400°/s (Wong et al, 2013).

Kui pea suudaks teha täispöördeid, siis sellisel kiirusel teeks ta umbes kolm täistiiru sekundis

Peamised silmaliigutuste tüübid

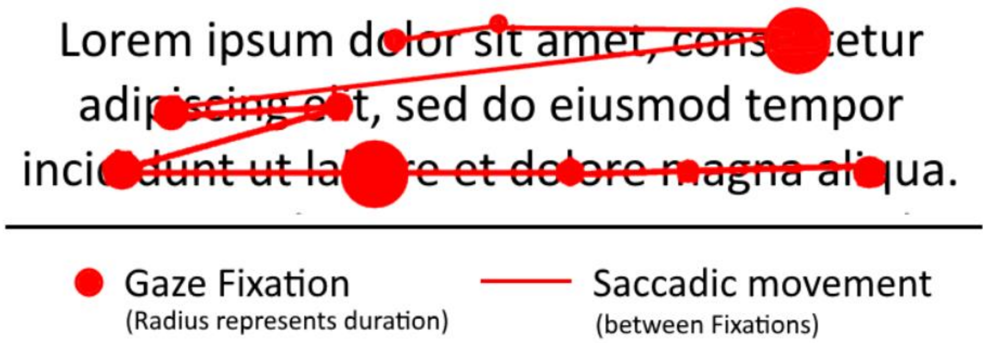
Fikseering ehk paus suurema amplituudiga kiiretes silmaliigutustes ehk sakaadides, mis peegeldavad vaatleja soovi hoida foovea teatud objektil või detailil, mis on paljudes olukordades seotud vaatleja kõrgendatud huviga selle objekti või detaili vastu.



(Duchowski, 2007)

Peamised silmaliigutuste tüübid

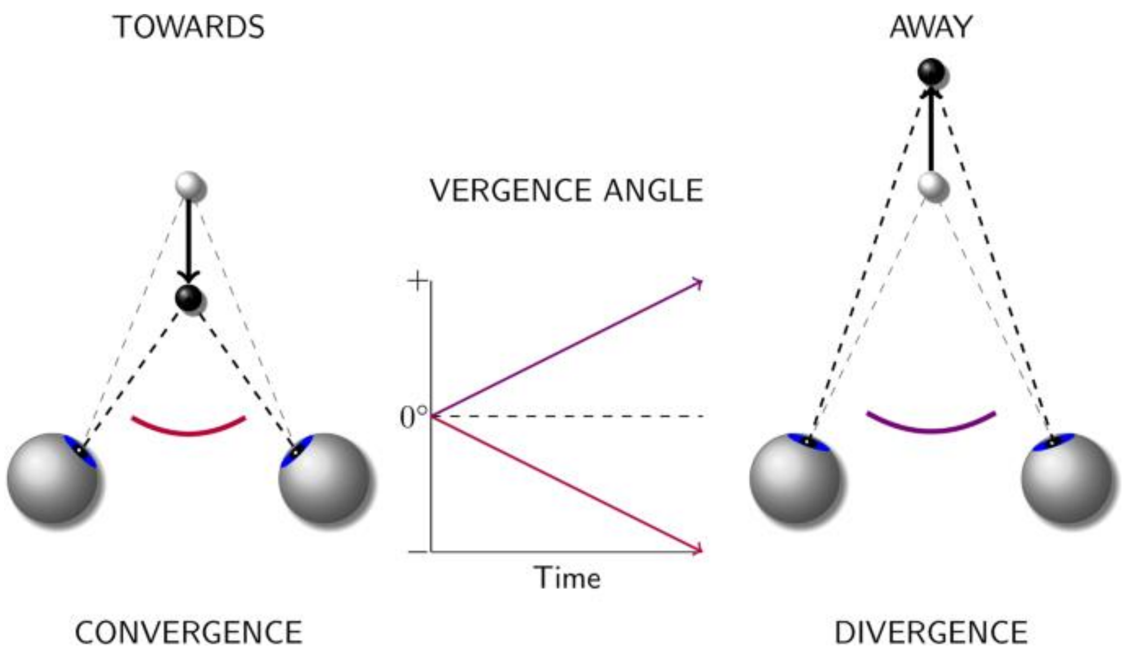
Fikseeringu kestus on umbes 150 – 600 ms. Fikseeringu ajal ei püsi silmad päris paigal, vaid seda iseloomustavad miniatuursed silmaliigutused: treemorid, triivid ja mikrosakaadid.



(Duchowski, 2007)

Peamised silmaliigutuste tüübid

Vergence silmaliigutused osalevad sügavustajus ja kohandavad silmade asukohad erineval kaugusel paiknevatele objektidele vastavaks



(Giesel et al, 2019)

(Duchowski, 2007)

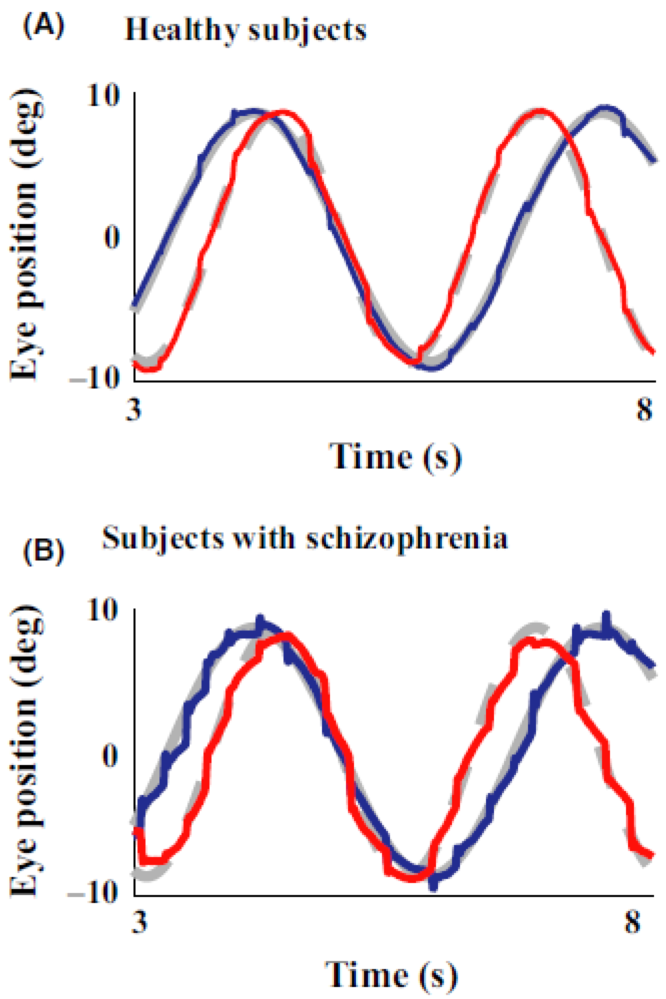
Peamised silmaliigutuste tüübid

Kägu (aasta lind 2024)

Liikuvate objektide fooveas hoidmiseks peavad silmad end liikuva objekti külge haakima. Silmade liikumise mustrit, mis võimaldavad liikuvaid objekte fooveas hoida kutsutakse sujuvateks silmaliigutusteks.

(Duchowski, 2007)

Peamised silmaliigutuste tüübid



Sujuvate silmaliigutuste häirumist on seostatud skisofreeniaga. 2014. aastal avaldatud ülevaate kohaselt esines sujuvate silmaliigutuste häirumine 80%-il skisofreenia diagnoosiga katseisikutest (Franco et al., 2014).

Skisofreeniat on seostatud ka teiste ja enam kognitiivset kontrolli nõudvate silmaliigutustega (nt visuaalse otsingu ülesannetes) (hiljutine ülevaade silmaliigutuste ja skisofreenia seostest: Morita et al., 2020)

Peamised silmaliigutuste tüübid

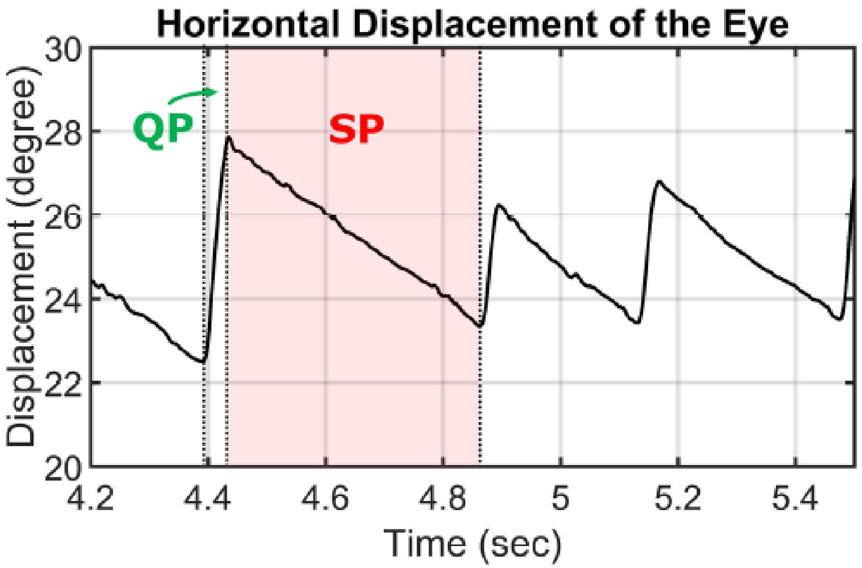
Vestibulo-okulaarsed silmaliigutused - korrigeerivad silmaliigutused, mis kompenseerivad pea liikumisest tingitud muutusi reetina asukohas.

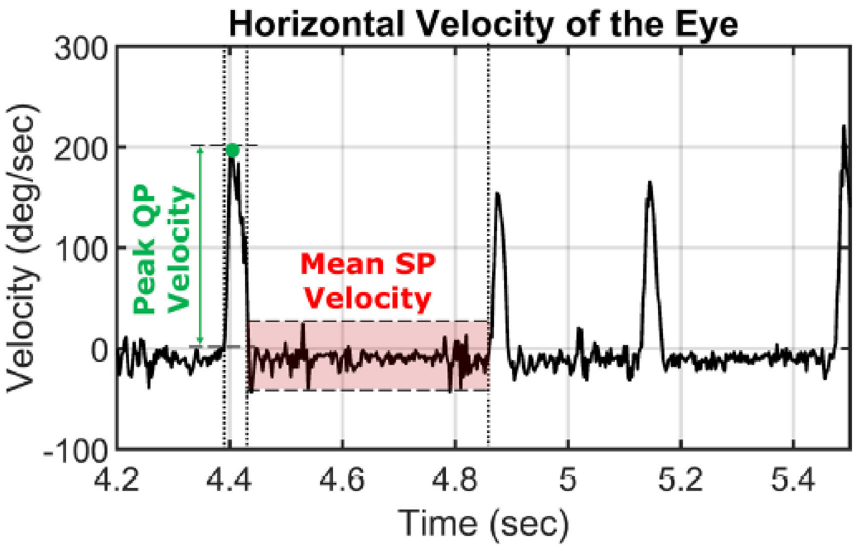
(Duchowski, 2007)

Peamised silmaliigutuste tüübid

Optokineetiline nüstagm – silmade liikumise muster, mis tekib vastusena suure osa nägemisvälja korrapärasele liikumisele. Silmade liikumise mustrit kirjeldavad kordamööda vahelduvad aeglased liikumise suunalised sujuvad silmaliigutused teises suunas liikuvate kiirete silmaliigutustega (sakaadidega)

(Sangi, 2017)





(Duchowski, 2007)

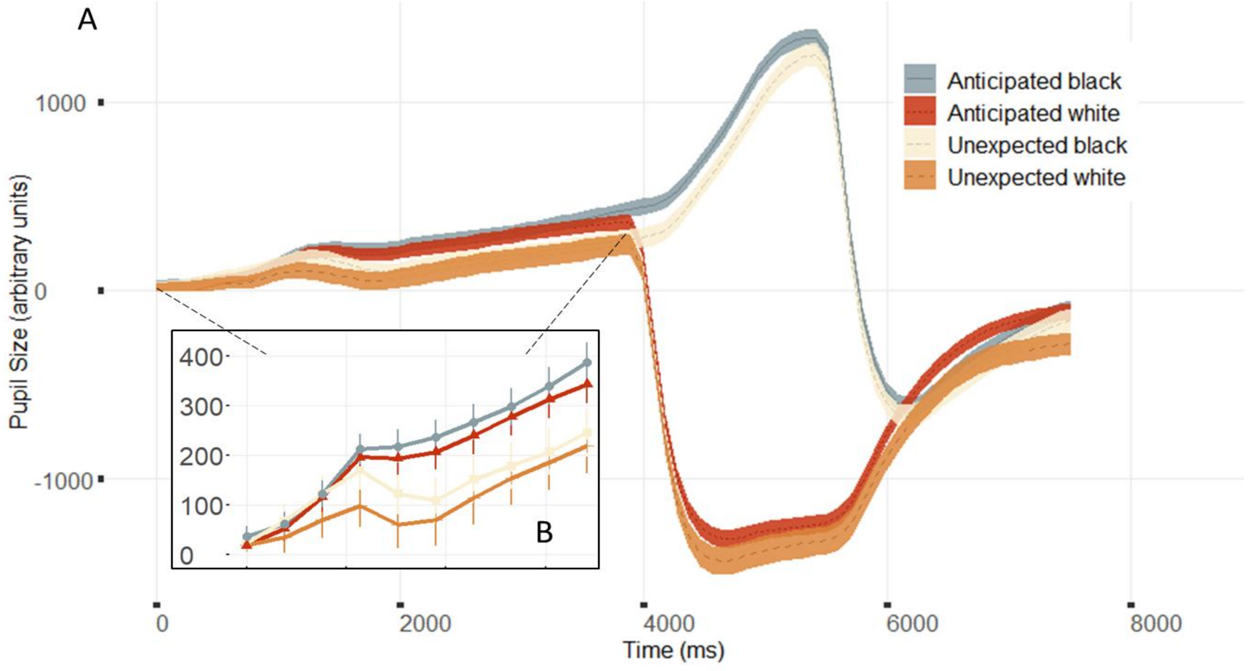
Peamised silmaliigutuste tüübid

Vertical optokinetic nystagmus testing using an OKN drum. If a vertical nystagmus can be elicited, vision is .20/400 or better
17

Optokineetilist nüstagmi on võimalik kasutada ka väikelaste nägemisteravuse objektiivseks hindamiseks (vt nt Dayton et al, 1964; Doustkouhi et al, 2020)

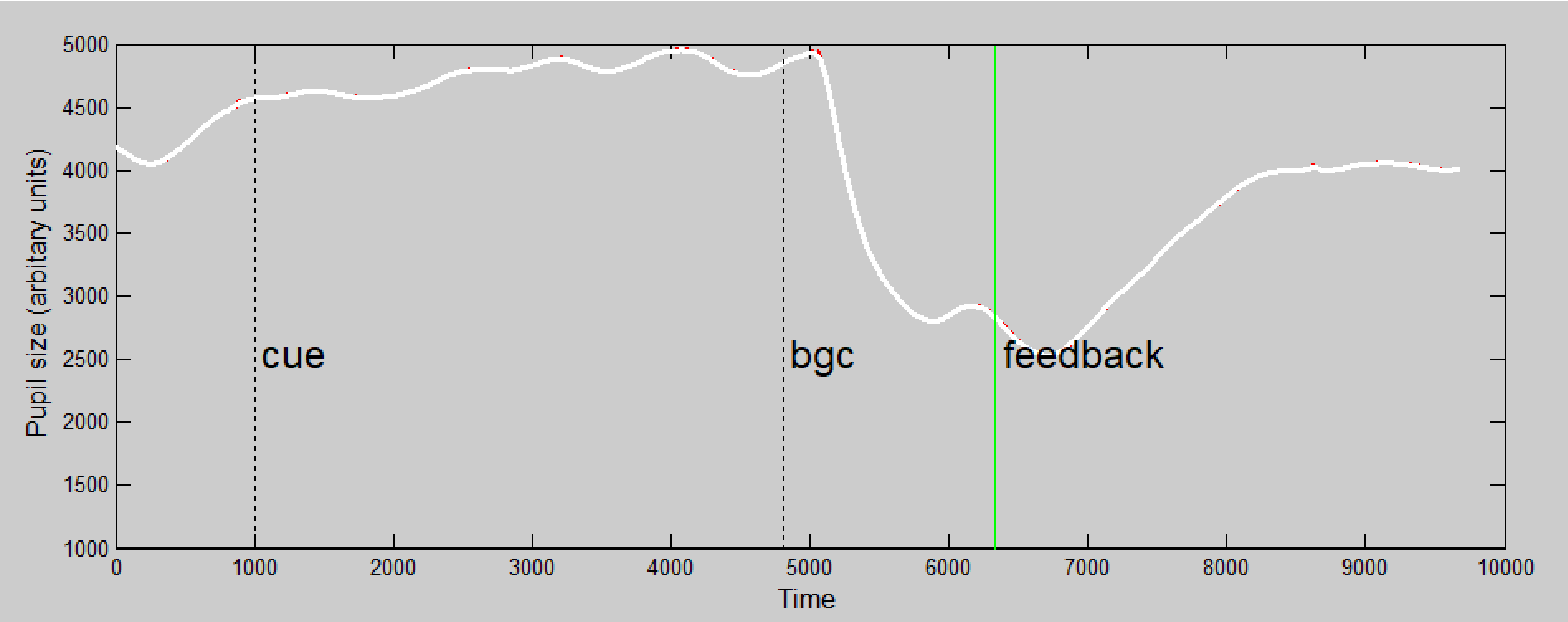
Peamised silmaliigutuste tüübid

Pupilli valgusrefleks – silmaava suuruse kohanemine valgustingimuste muutusele. Pupilli valgusrefleks kaitseb võrkkesta võimaliku kahjustuse eest (Ellis, 1981)



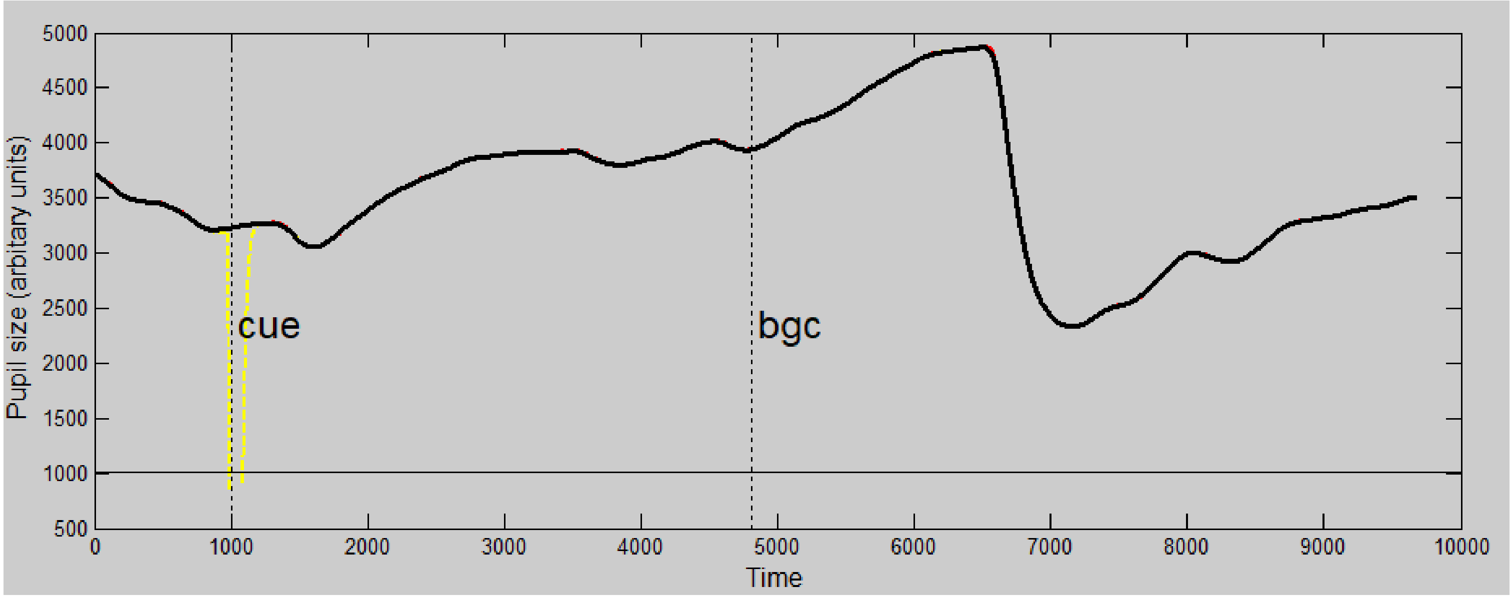
Peamised silmaliigutuste tüübid

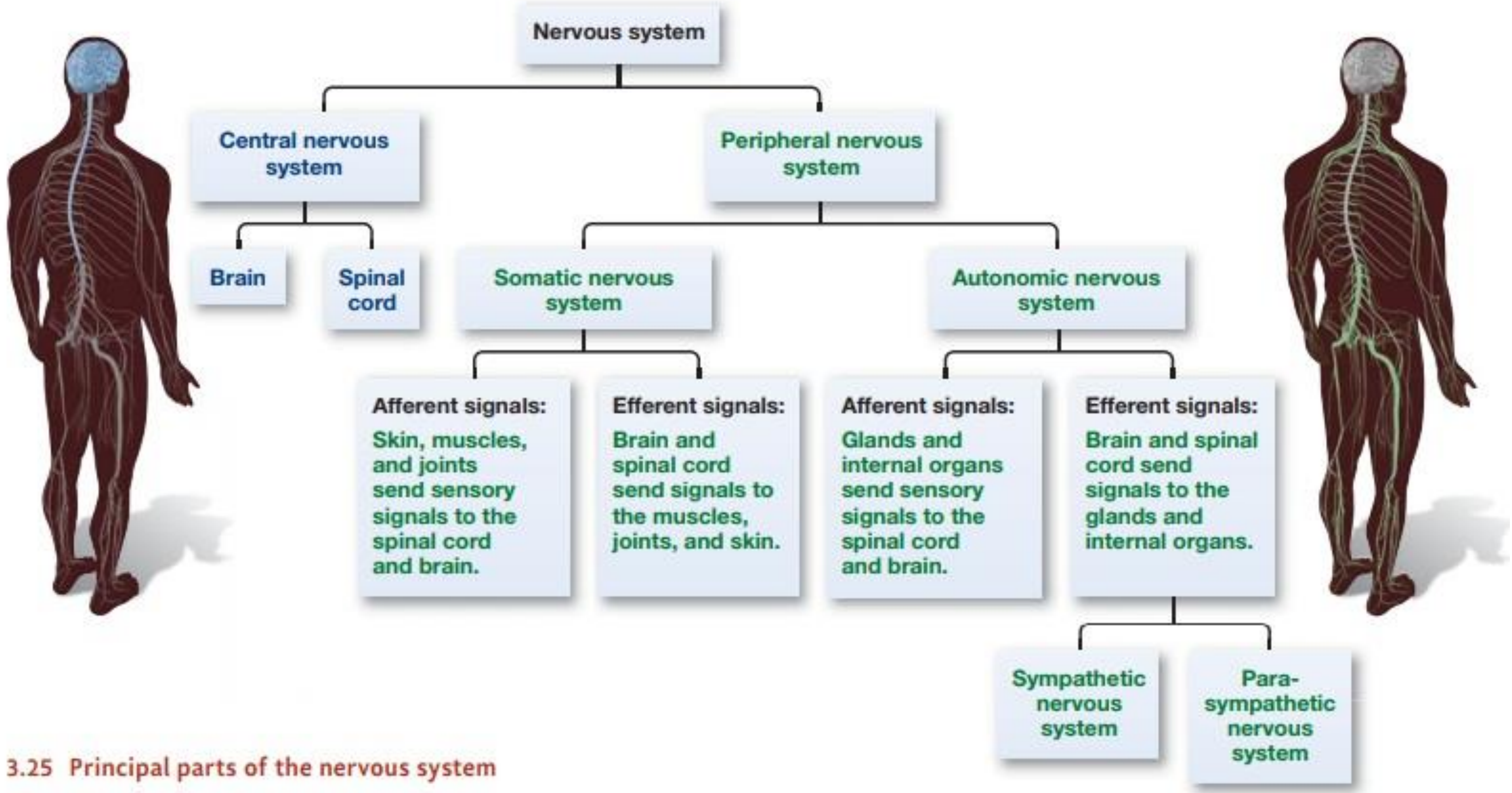
Silmaavaahenemine ehk mioos toimub parasümpaatilise närvi juhitud silmaavaahendaja sõõrjalt paikneva lihase (*m. sphincter pupillae*) abil (Ellis, 1981).



Peamised silmaliigutuste tüübid

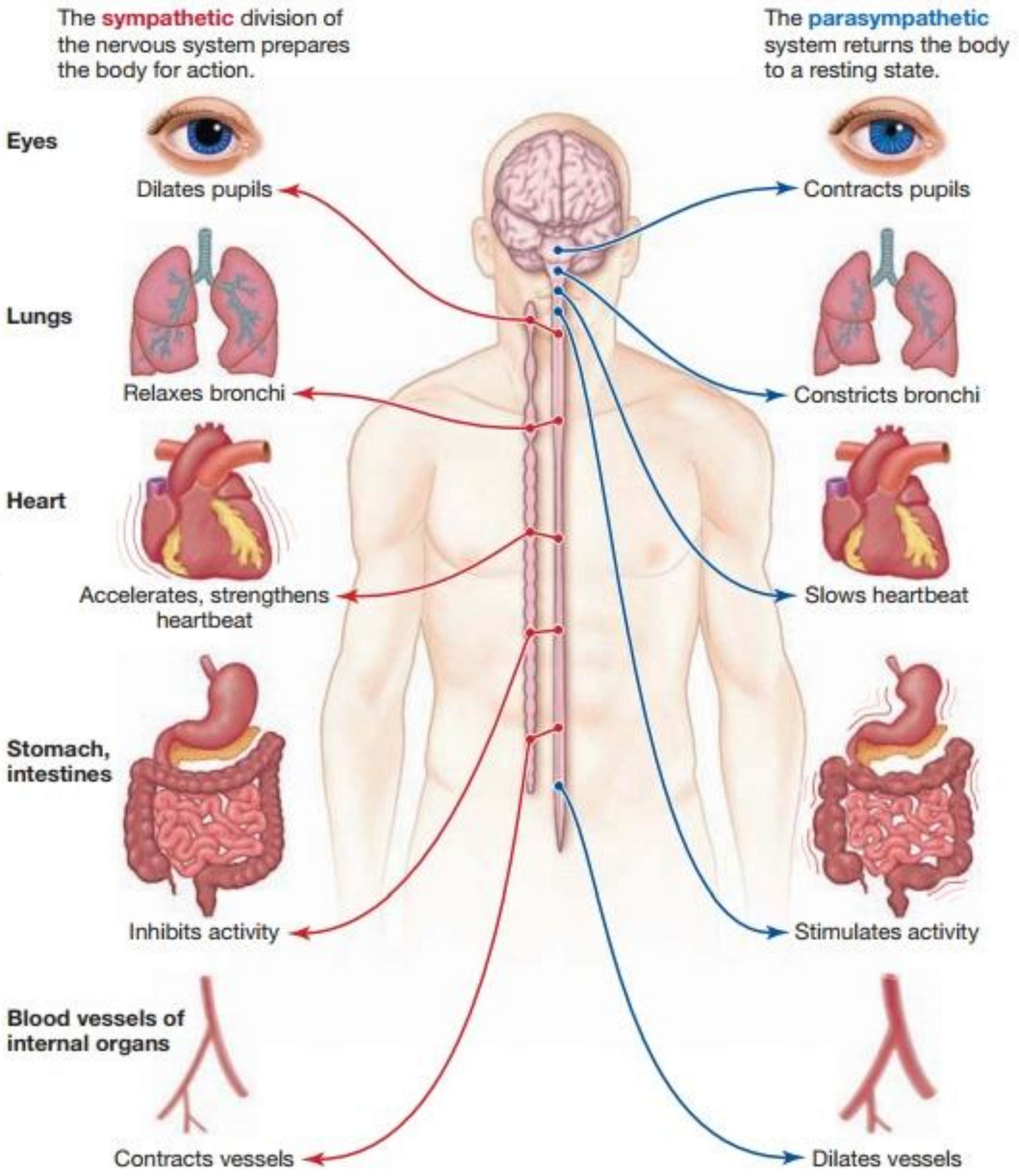
Silmaava suurenemine ehk müdriaas toimub silmaavalaiendaja (*m. dilatator pupillae*) radiaalselt paiknevate lihaste toimel. Selle juhtimine kuulub sümpaatilise närvisüsteemi alla (Ellis, 1981).





3.25 Principal parts of the nervous system

(Gleitman, Reisberg, & Gross, 2003, 3. ptk)

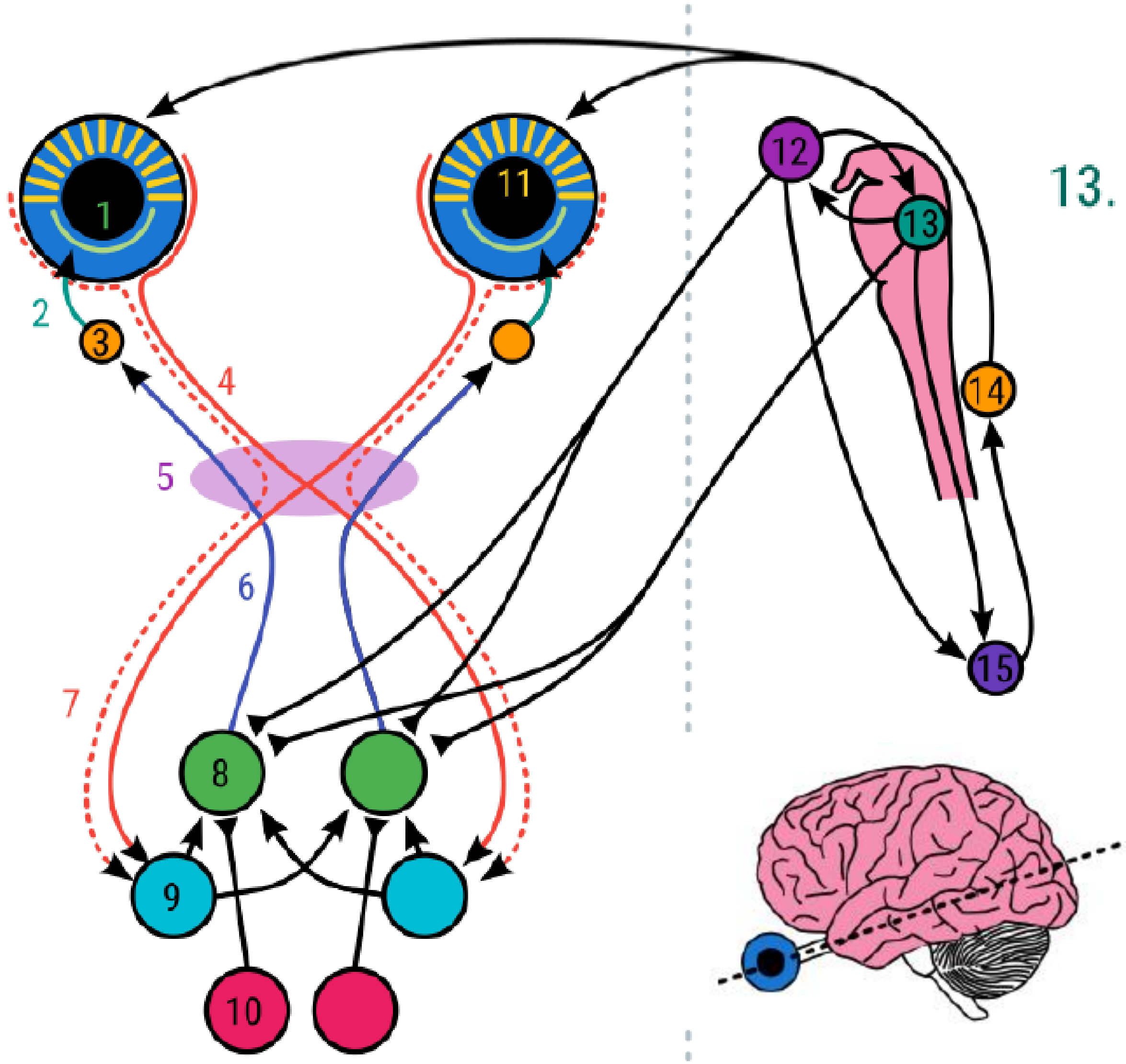


3.26 Sympathetic and parasympathetic systems

(Gleitman, Reisberg, & Gross, 2003, 3. ptk)

ahenemine (mioos)

1. Iris sphincter muscle
2. Short ciliary nerve
3. Ciliary ganglion
4. Optic nerves
5. Optic chiasm
6. Oculomotor nerve
7. Optic tract
8. Edinger-Westphal nucleus (EWN)
9. Pretectal olivary nucleus (PON)
10. Superior colliculus (SC)



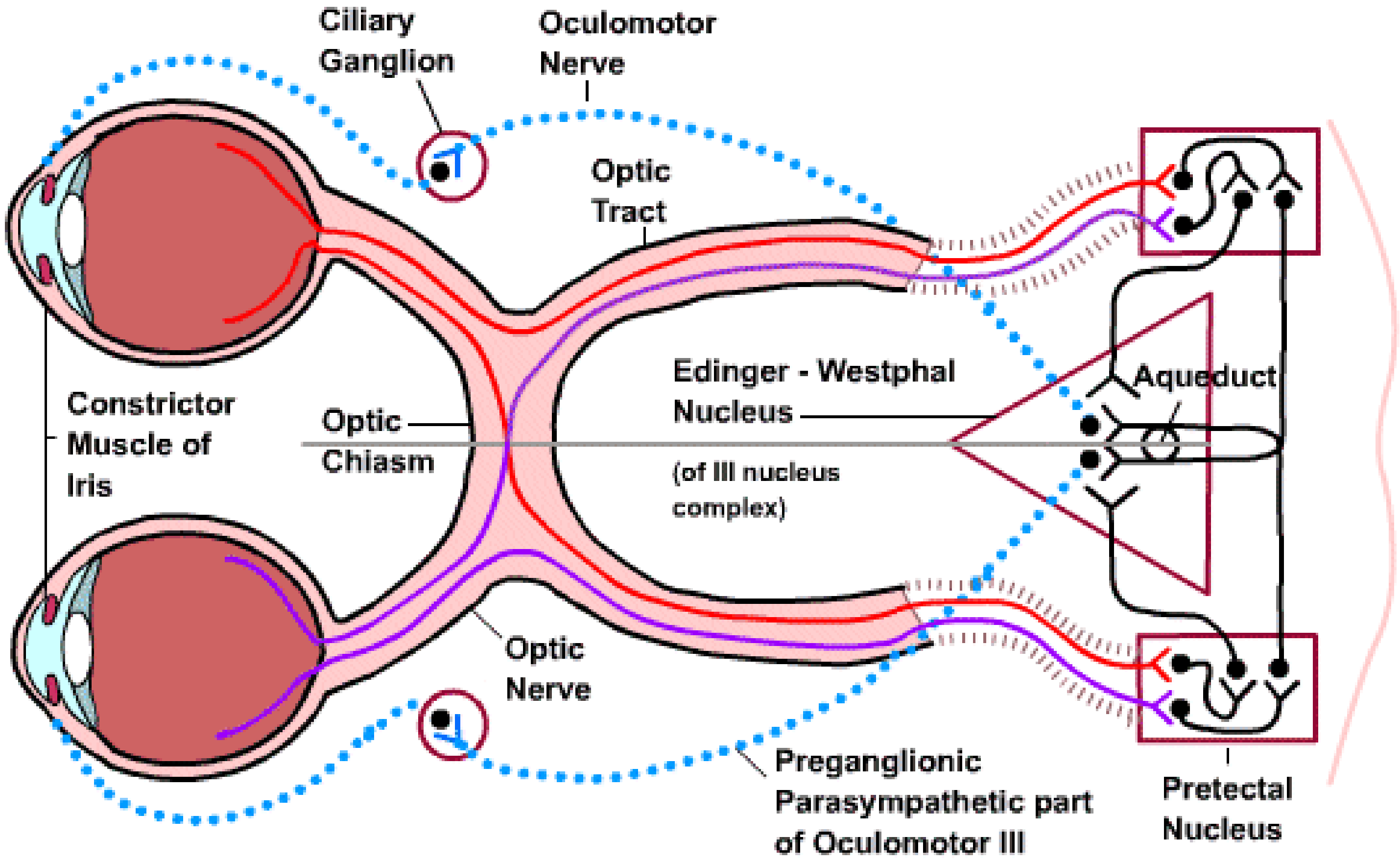
(Mathôt, 2018)

11. Iris dilator muscle
12. Hypothalamus
13. Locus coeruleus (LC)
14. Superior cervical ganglion (SCG)
15. Intermedio-lateral column (IML)

laienemine (müdriaas)

Mis juhtub kui näidata valgust vaid ühte silma?

This is a representation of parasympathetic pathways in the pupillary light reflex.



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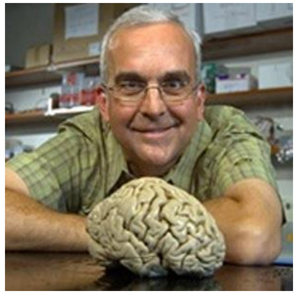


Predictive value of sensory and cognitive evoked potentials for awakening from coma

Catherine Fischer, MD; Jacques Luauté, MD; Patrice Adeleine, PhD; and Dominique Morlet, PhD

Abstract—*Objectives:* To determine the prognostic role of late auditory (N100) and cognitive evoked potentials (MMN) for awakening in a cohort of comatose patients categorized by etiology. *Methods:* The authors prospectively studied a series of 346 comatose patients. Coma was caused by stroke (n = 125), trauma (n = 96), anoxia (n = 64), complications of neurosurgery (n = 54), and encephalitis (n = 7). Patients were followed for 12 months and classified as awake or unawake. Univariate and multivariate analyses were performed using regression logistic and Cox models. *Results:* Pupillary light reflex, N100, middle-latency auditory evoked potentials, age, and etiology were the most discriminating factors for awakening. Statistical analysis showed that pupillary reflex was the strongest prognostic variable for awakening (estimated probability 79.7%). The estimated probability of awakening rose to 87% when N100 was present and to 89.9% when middle-latency evoked potentials (MLAEPs) were present. It was 13.7% when pupillary reflex was absent in anoxic patients. When MMN was present, 88.6% of patients awakened. No patient in whom MMN was present became permanently vegetative. *Conclusion:* Pupillary reflex is the strongest prognostic variable, followed by N100 and MLAEPs allowing a reliable model for awakening. The presence of MMN is a predictor of awakening and precludes comatose patients from moving to a permanent vegetative state. Evaluation of primary sensory cortex and higher-order processes by middle-latency-, late, and cognitive evoked potentials should be performed in the prognosis for awakening in comatose patients.

NEUROLOGY 2004;63:669–673

Pupil reaction to light in Alzheimer's disease

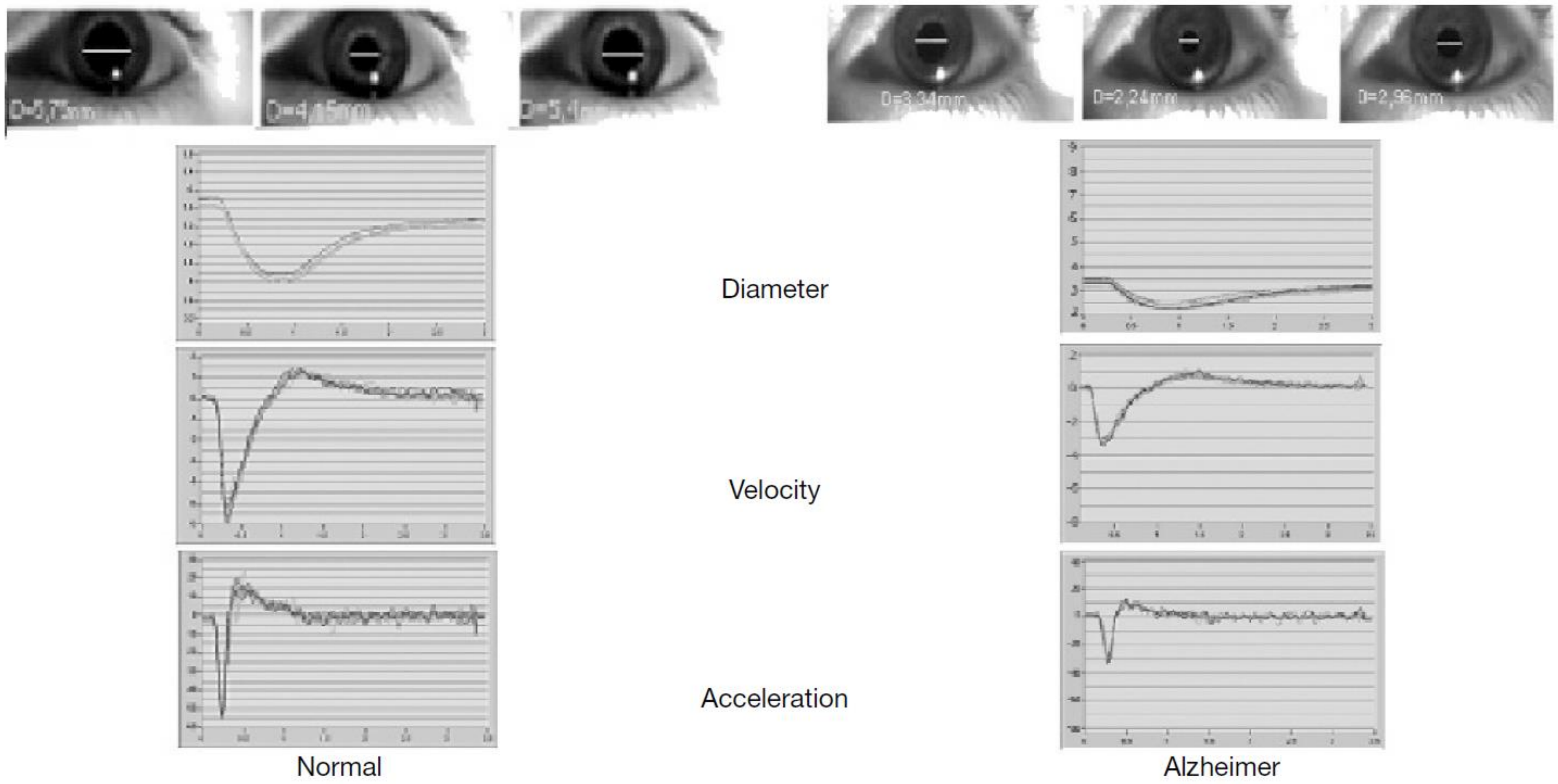


Fig. 2 - *Pupil size after 2-min dark adaptation before pupil's reaction to light, maximum constriction and re-dilatation as response to light stimulus. Note the difference in baseline pupil diameter (D1), maximum constriction velocity (VCmax), maximum constriction acceleration (ACmax) in both normal subjects and AD patients.*


reflex
0:01 / 0:57

Levinud pupilli paisutajad

Afekt (Bradley et al., 2008; Hess & Polt, 1960; Wenzlaff et al., 2016)
Afektiivse sündmuse ootus (Reinhard & Lachnit, 2002)

Vaimne pingutus (Hess & Polt, 1964, van der Wel & van Steenbergen, 2018)
Mälust ammutamine (Goldinger & Papesh, 2012; Kahneman & Beatty, 1966)

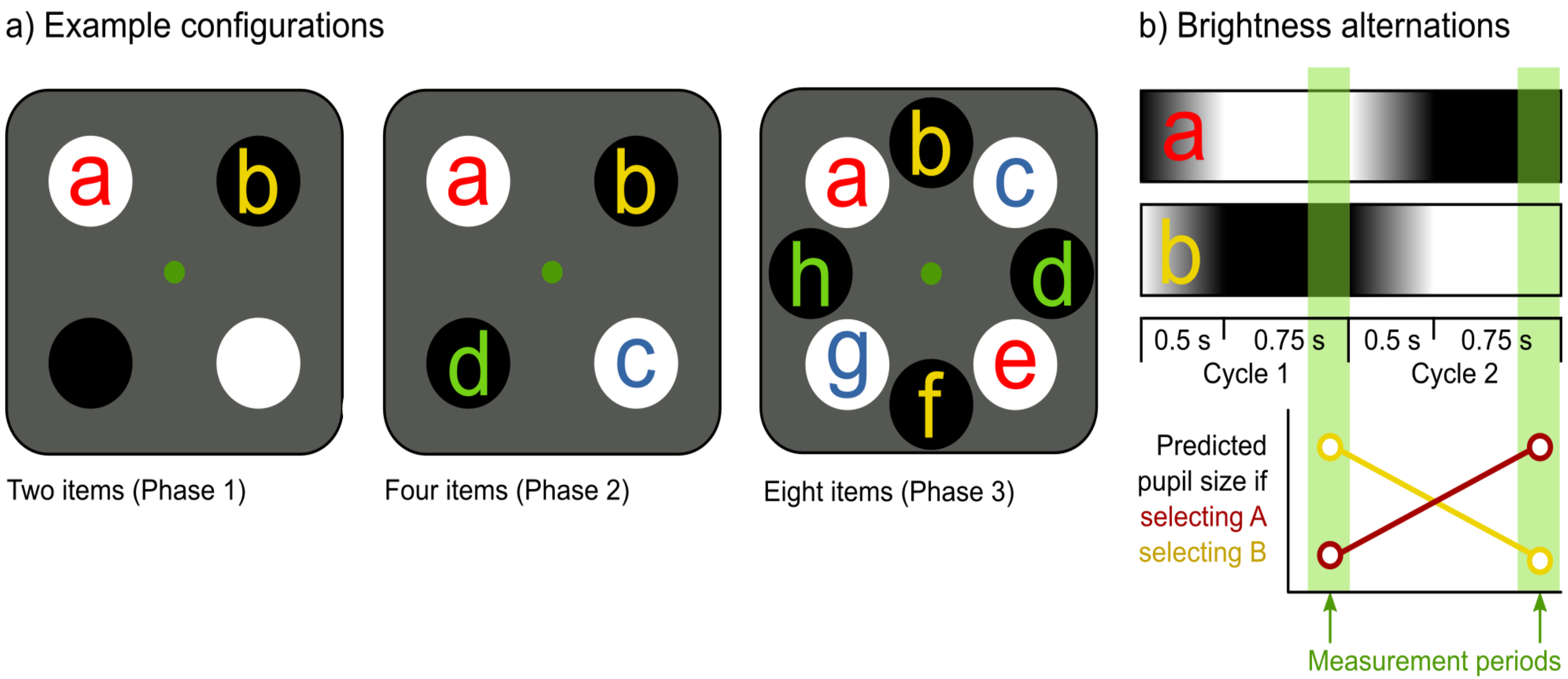
Motoorne aktiivsus (Hayashi et al., 2010; Simpson, 1969)
Motoorse vastuse ettevalmistamine (Adam et al., 2014; Richer & Beatty, 1985)

Millest pupilli suurus veel sõltuda võib?

Heledusrepresentatsioonide kognitiivsest töötlemisest

Sisemise ruumitähelepanu keskmest (Binda et al., 2013; Mathôt et al., 2013; Naber et al., 2013)
Kujutlusest (Laeng & Sulutvedt, 2014)
Töömälu sisust (Hustá et al., 2018)
Sõnade semantiline sisu (Mathôt et al., 2016; 2019)

Pupillomeetrial põhineva aju-arvuti liidese näide



(Mathôt et al., 2016)

Millest pupilli suurus veel sõltuda võib?

Vergence liigutused (Feil, 2017)
Silmade liigutamisega seotud muutused (Gagl et al., 2011)
Pupilli kahanemine ajas (mitmed põhjused):
- Väsimus (Kuchinsky et al., 2016)
- Ülesande raskus muutub ajas (Hess & Polt, 1964, van der Wel & van Steenbergen, 2018)

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Tänan tähelepanu eest!

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