

Sissejuhatus
psühhofüsioloogia
rakendustesse

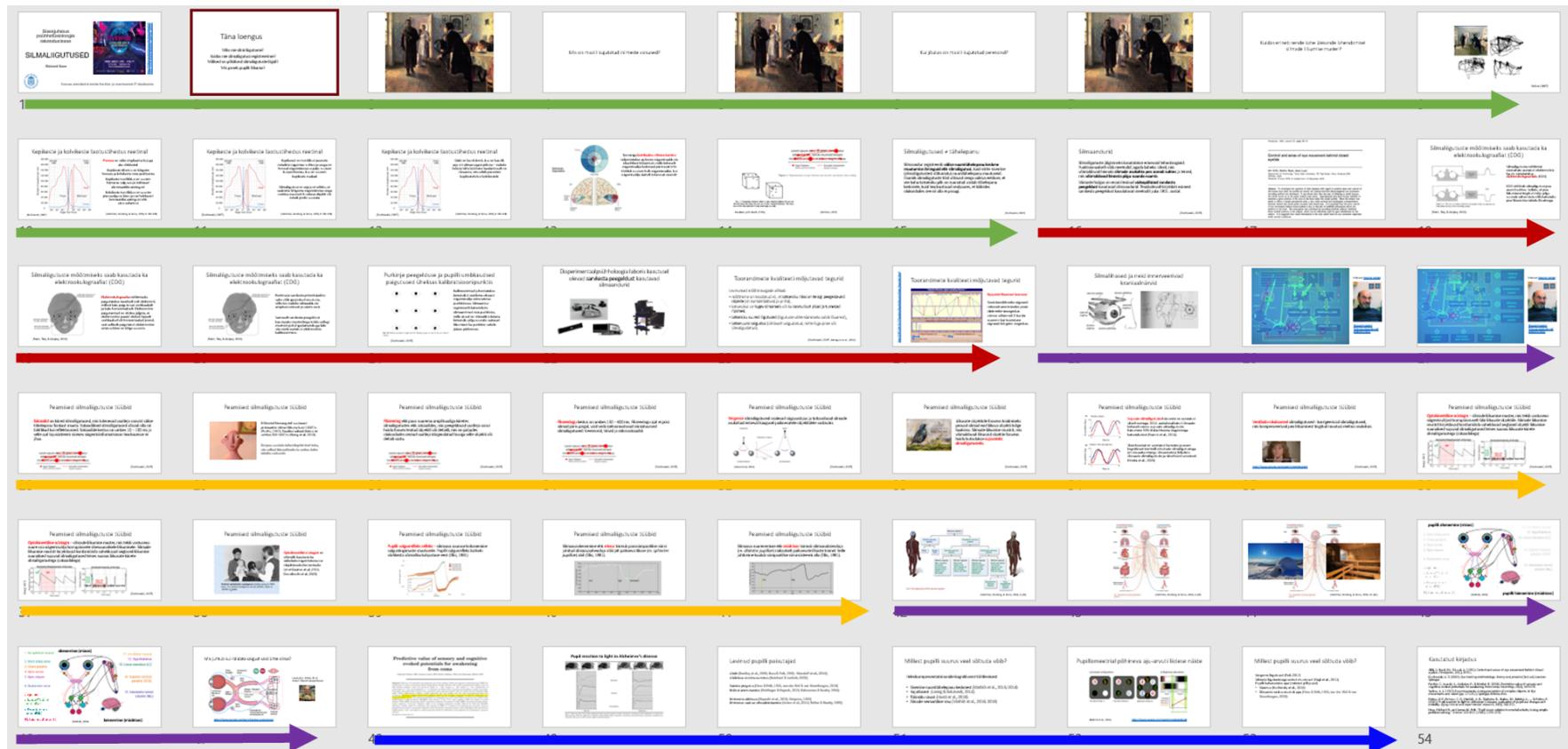
SILMALIIGUTUSED

Richard Naar



Kursuse arendamist toetas Haridus- ja noorteameti IT-akadeemia

Täna loengus



Miks
liigutame?

Kuidas
mõõdame?

Kuidas
liigutame?

Mis on liigutamise
füsioloogia?

Mis paneb
pupilli liikuma?



Mis on maalil kujutatud inimeste vanused?



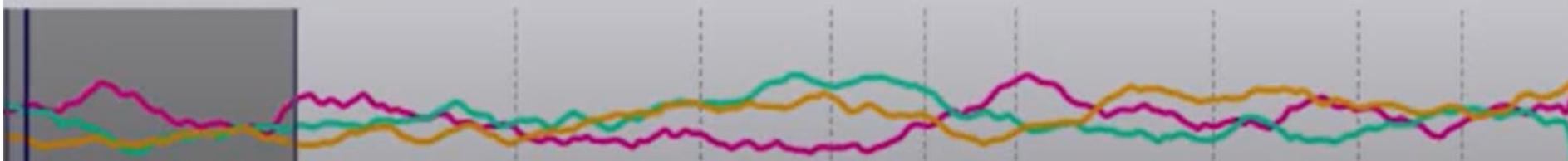
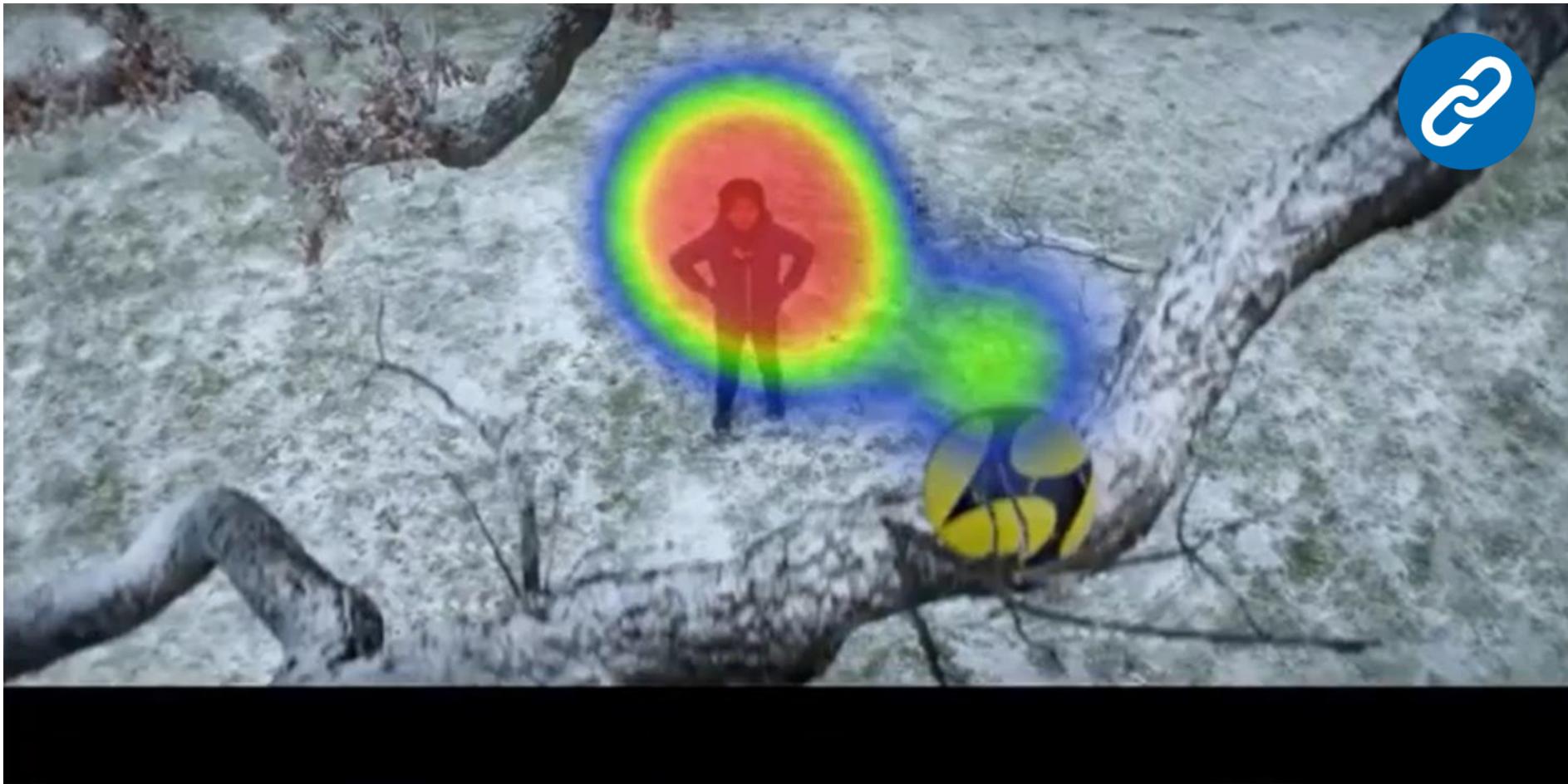
Kui jõukas on maalil kujutatud perekond?



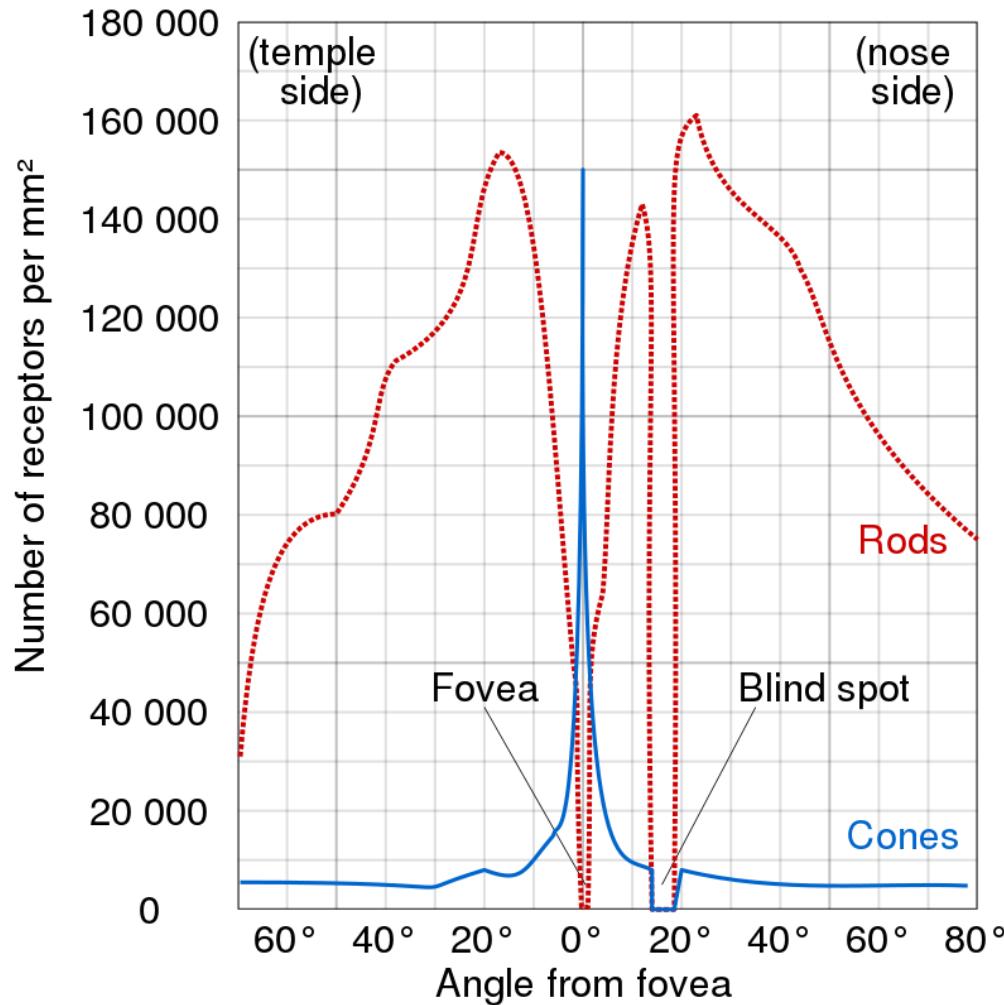
Kuidas erineb nende kahe ülesande lahendamisel
silmade liikumise muster?



Yarbus (1967)



Miks me silmi liigutame?



(Duchowski, 2007)

Foovea on väike ringilaadse kujuga
ala võrkkestal

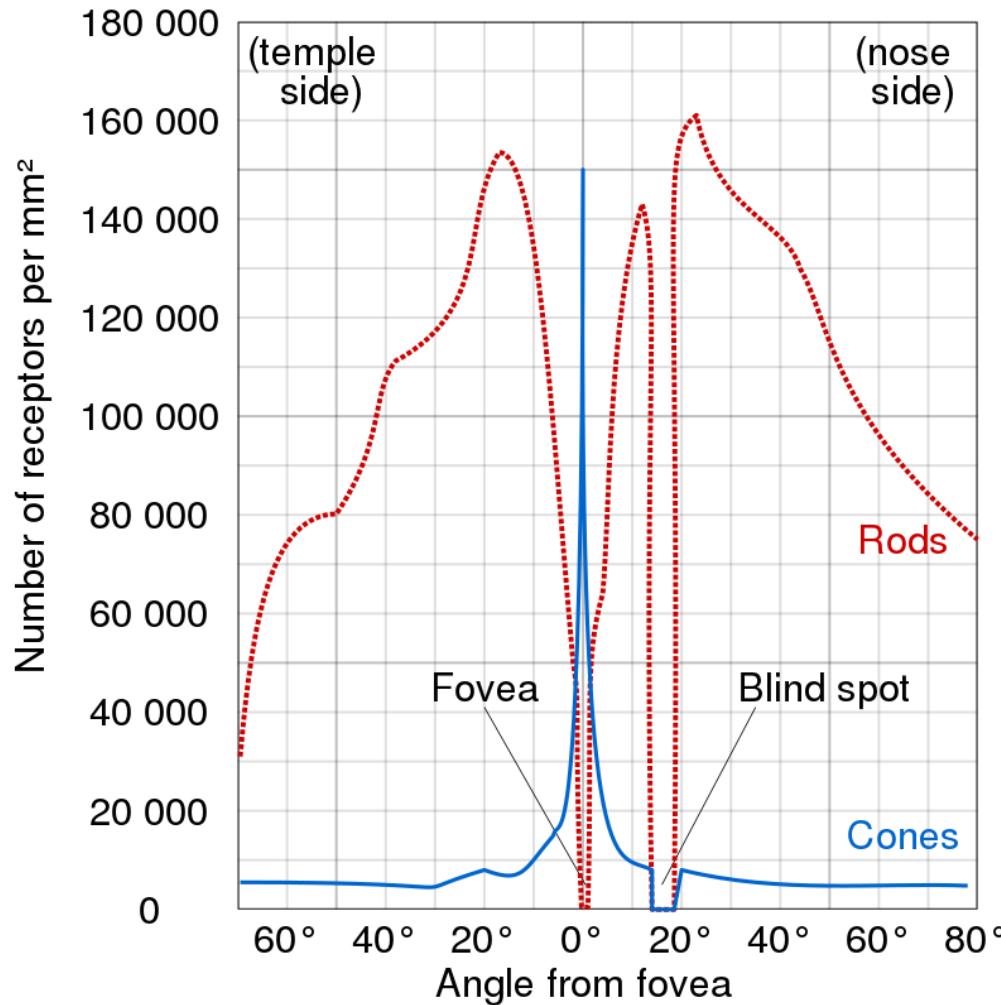
Kolvikeste tihedus on kõrgeim
fooveas ja kepikeste oma võrkesta
väliservades

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?



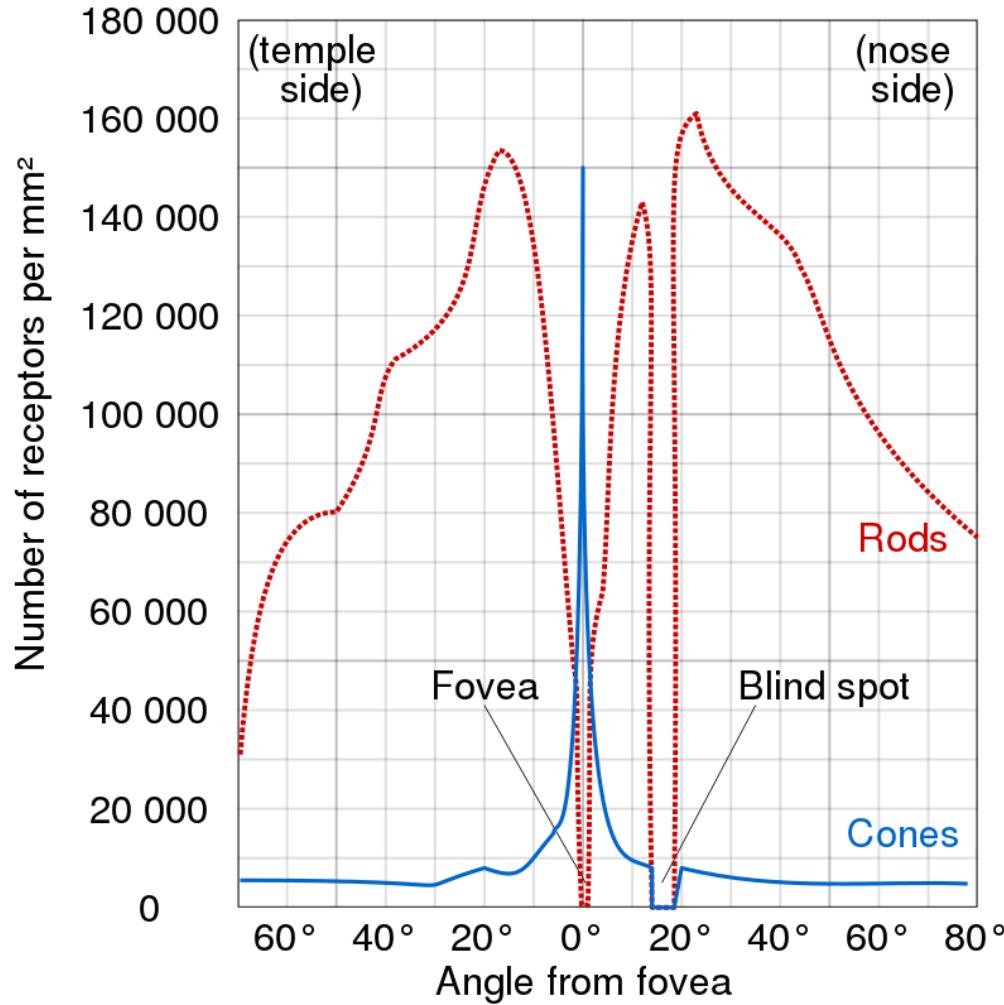
(Duchowski, 2007)

Kolvikesed on tundlikud peenete detailide nägemise suhtes ja seega on fooveal nägemisteravus palju suurem kui võrkesta väliservades, 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?

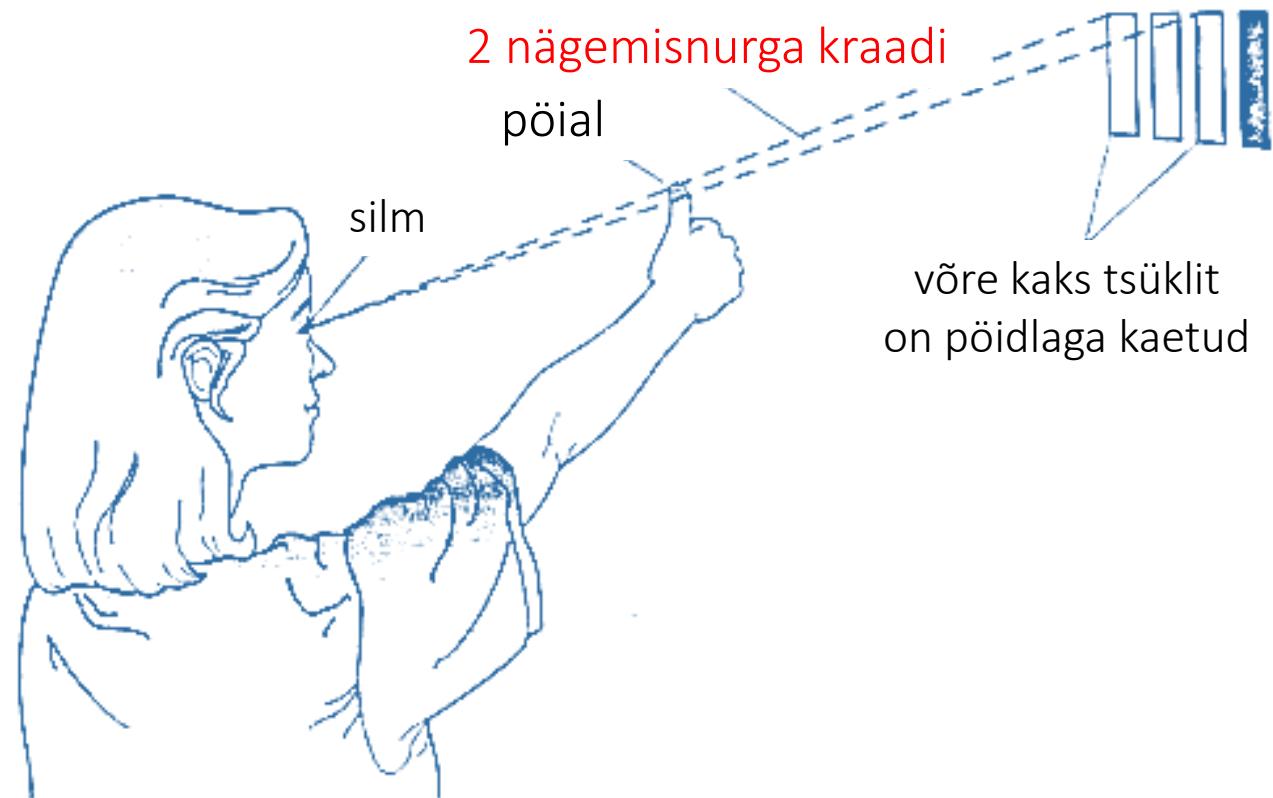


(Duchowski, 2007)

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

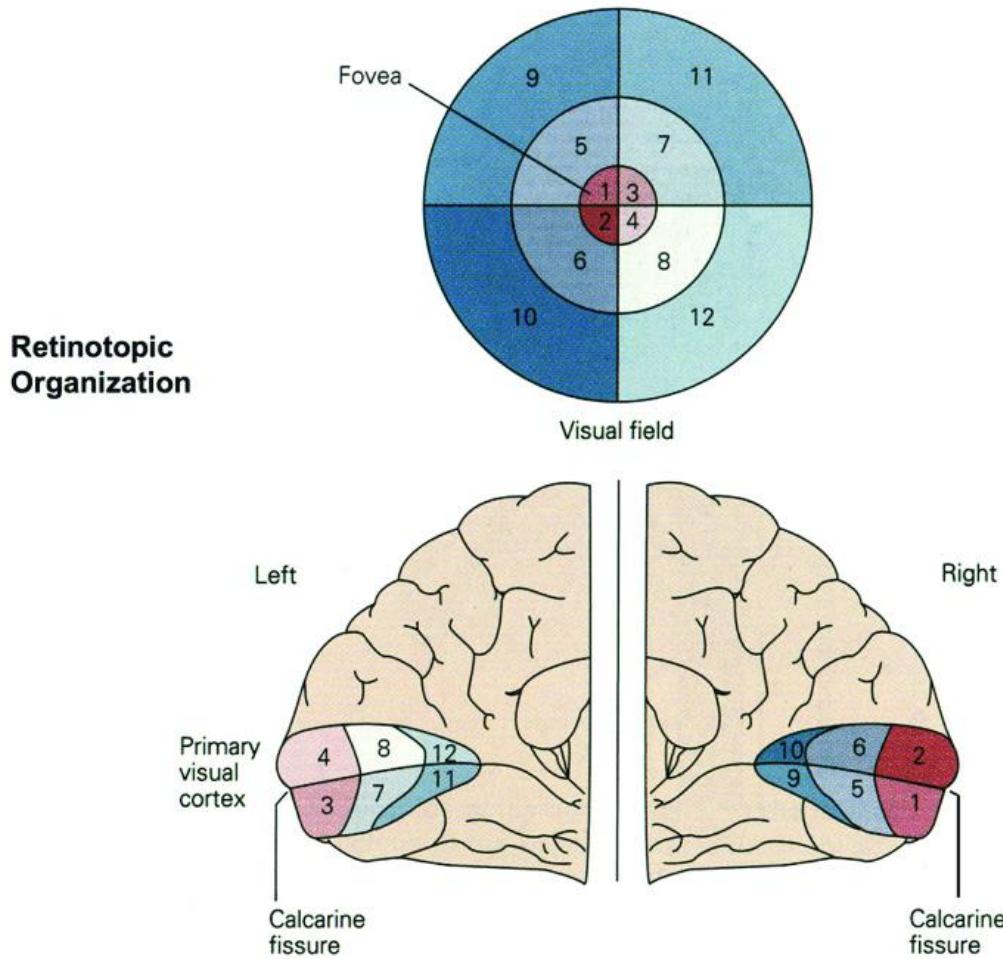
(Gleitman, Reisberg, & Gross, 2003, lk 196-198)

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 pärinevad info töötleb suurem hulk nägemisrakke, kui nägemisvälja äärtelt tulenevat sisendit

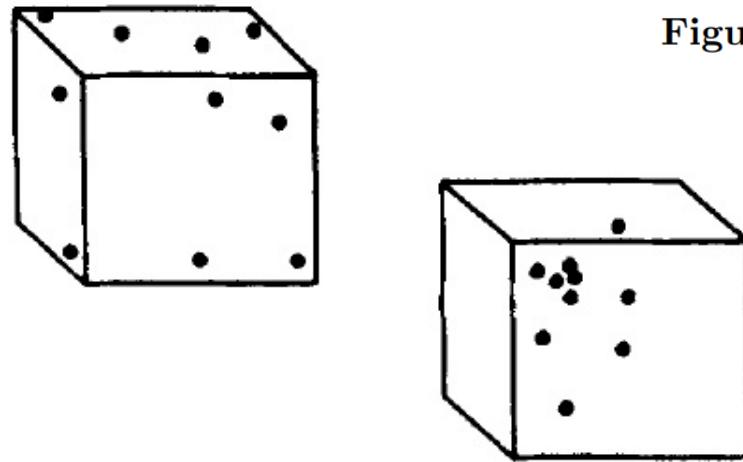


Fig. 1. Comparison between where a naive observer believes his eyes are directed (top) and where the eyes are, in fact, oriented (bottom). The front face of the cube subtends 2.5 deg visual angle on a side.

Kaufman ja Richards (1969)

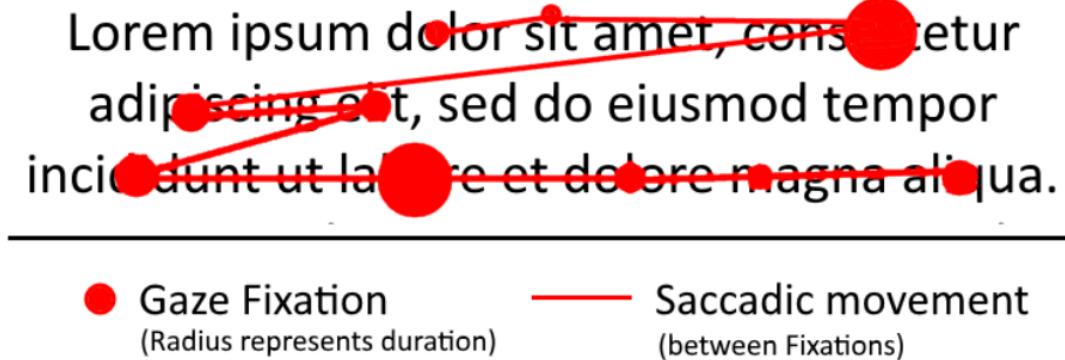


Figure 1: Representation of gaze fixations and saccadic movements when reading.

(Ramirez, 2017)

Silmaliigutused ≠ tähelepanu

Silmaandur registreerib **välise ruumitähelapanu keskme muutumise ilminguid ehk silmaliigutusi**, kuid mitte sisemise (silmaliigutustest sõltumatu) ruumitähelapanu 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.

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.

Control and sense of eye movement behind closed eyelids

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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 eyeball 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.

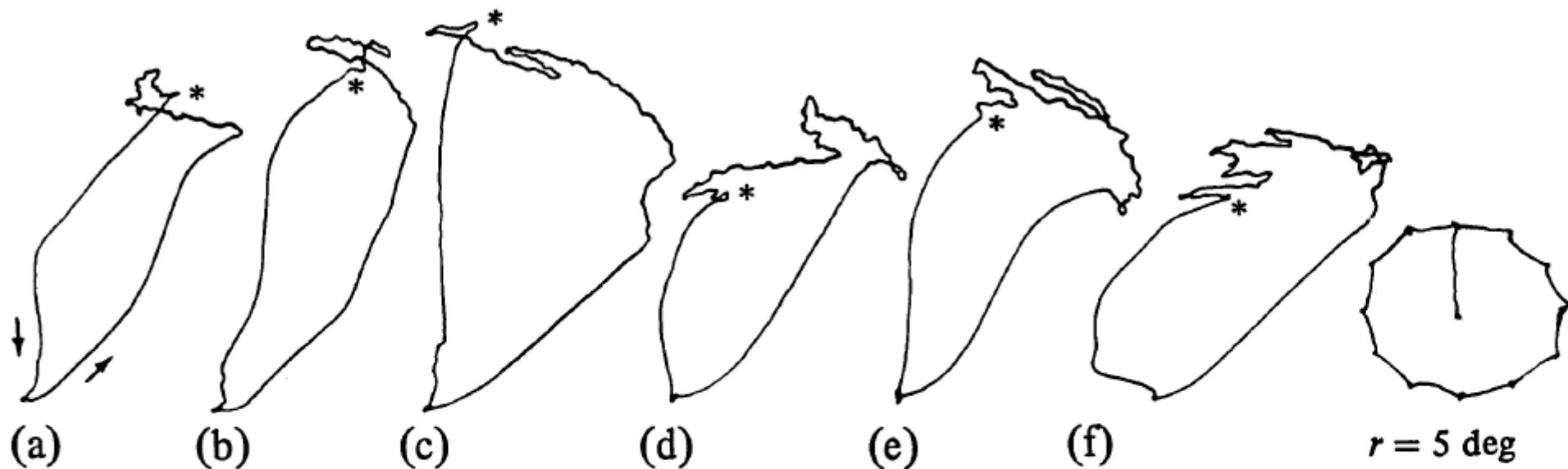
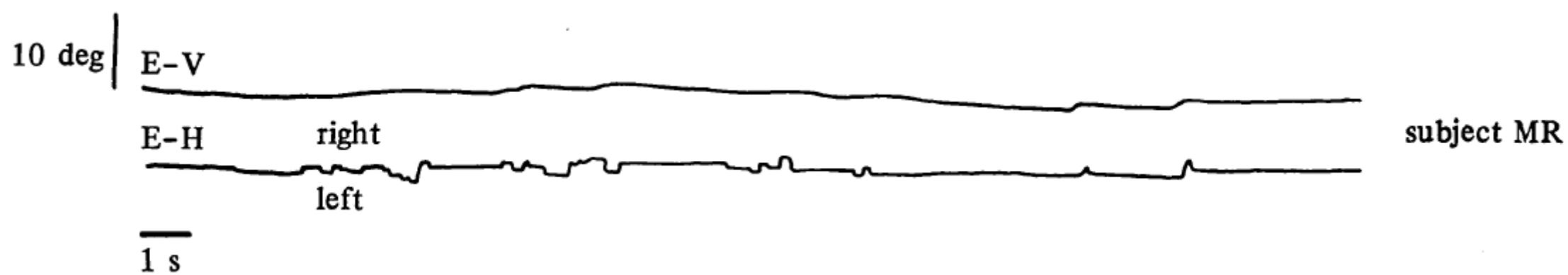
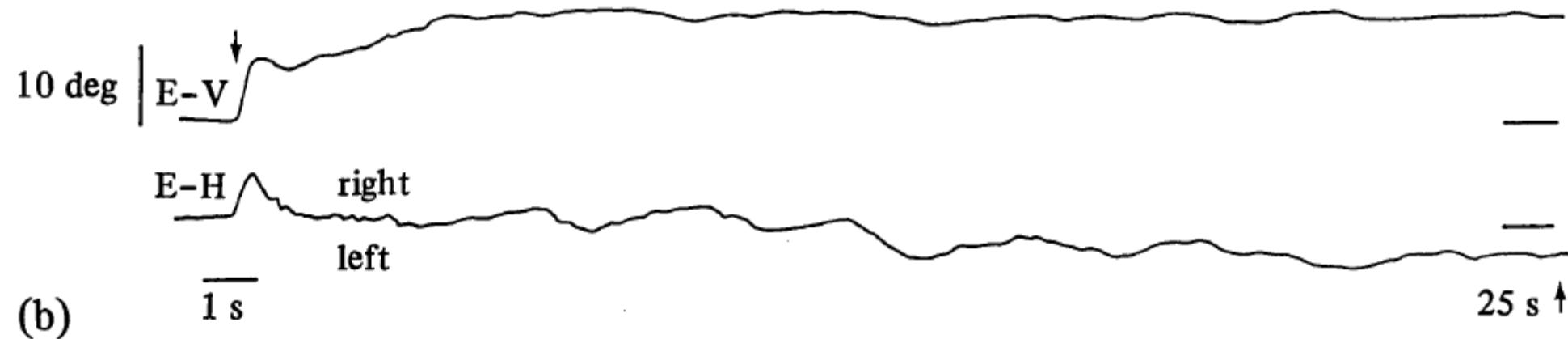
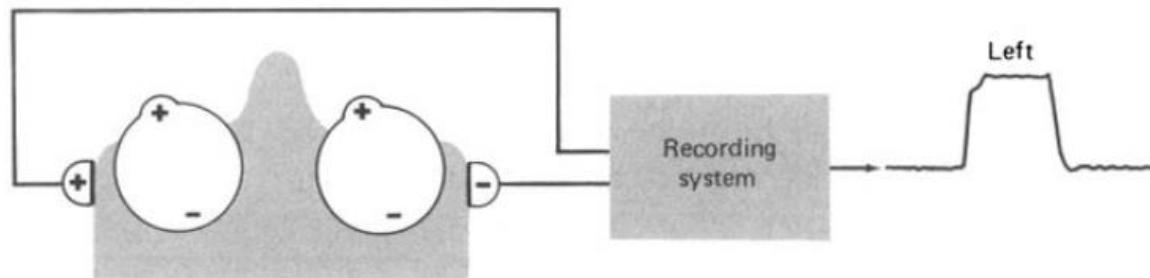


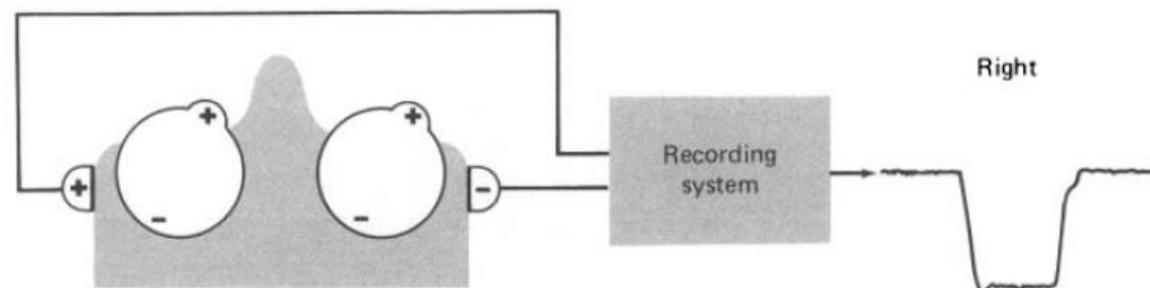
Figure 6. Six sequential trials of subject MR in an attempt to maintain a prior fixation position after eyelid closure. The short arrows indicate the direction of the eye movement paths. The eyelids were closed for about 20 s. The drawing with the eyes of the calibration circle is shown ($r = 5 \text{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



Silmaliigutuste mõõtmiseks saab kasutada ka elektrookulograafiat (EOG)



Silmaliigutuste mõõtmist näonahale asetatud elektroodide kaudu nimetatakse **elektrookulograafiaks** (EOG)

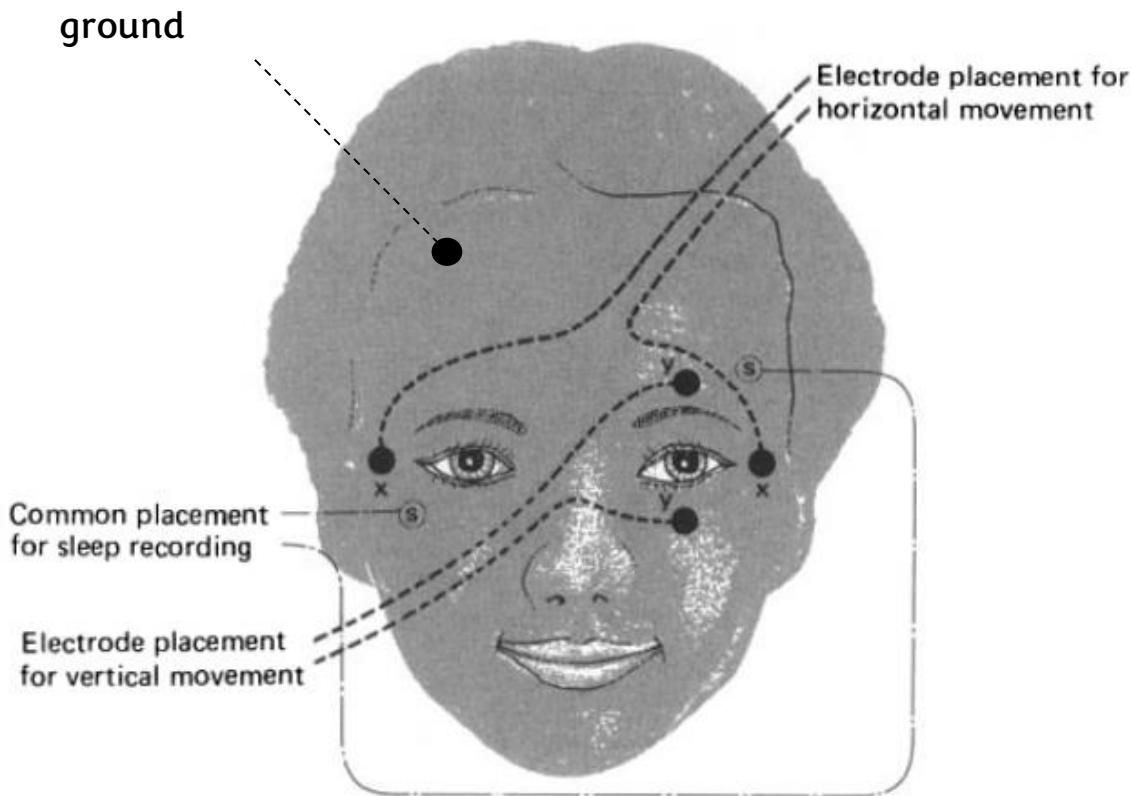


EOG mõõdab silmaliigutusi pea asendi suhtes. Selleks, et pea liikumisest tingitud mõju pilgu suunale vähendada võib katseisiku pea fikseerida näiteks lõuatoega.

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

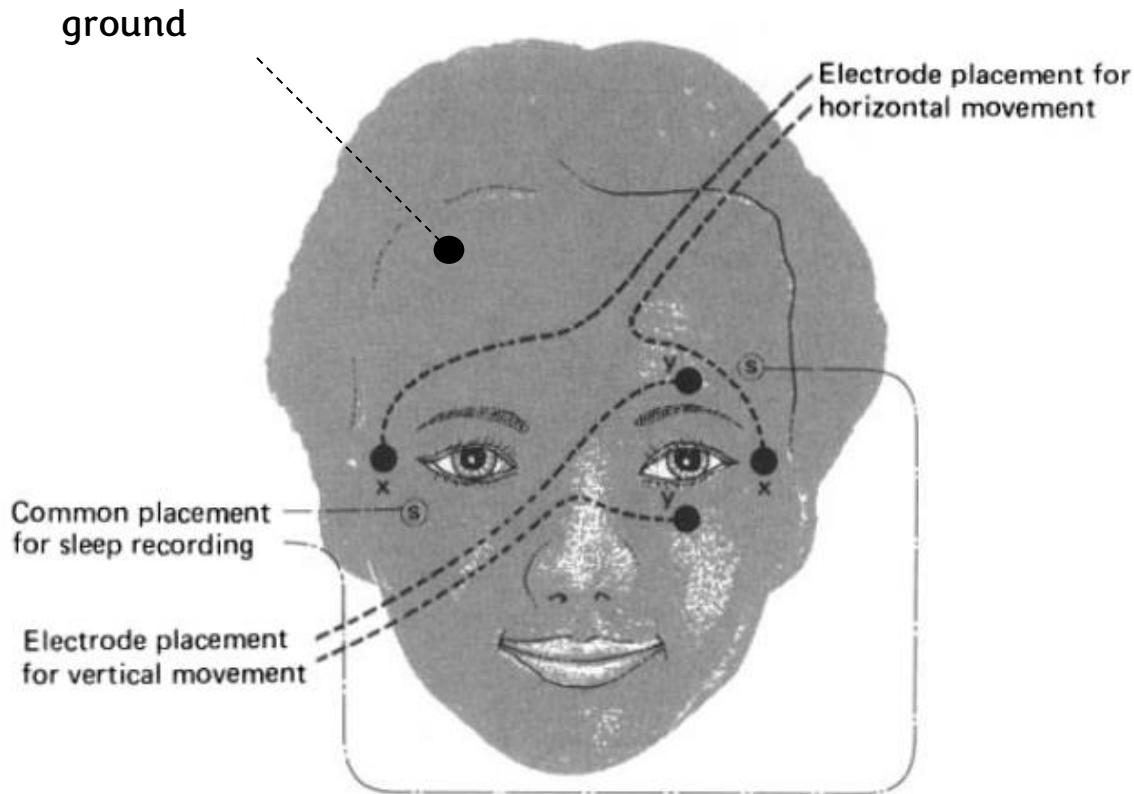
(Stern, Ray, & Quigley, 2001)

Silmaliigutuste mõõtmiseks saab kasutada ka elektrookulograafiat (EOG)



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)

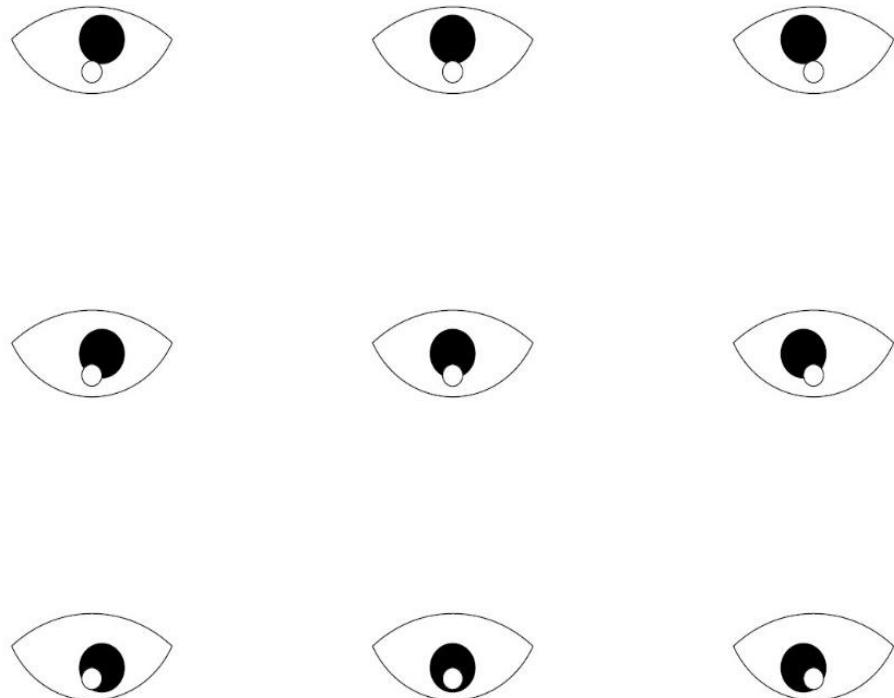


Reetina ja sarvkesta potentsiaalide vahe võib aja jooksul muutuda, sõltudes näiteks silmarakkude adapteerumisest ja väsimusest.

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

(Stern, Ray, & Quigley, 2001)

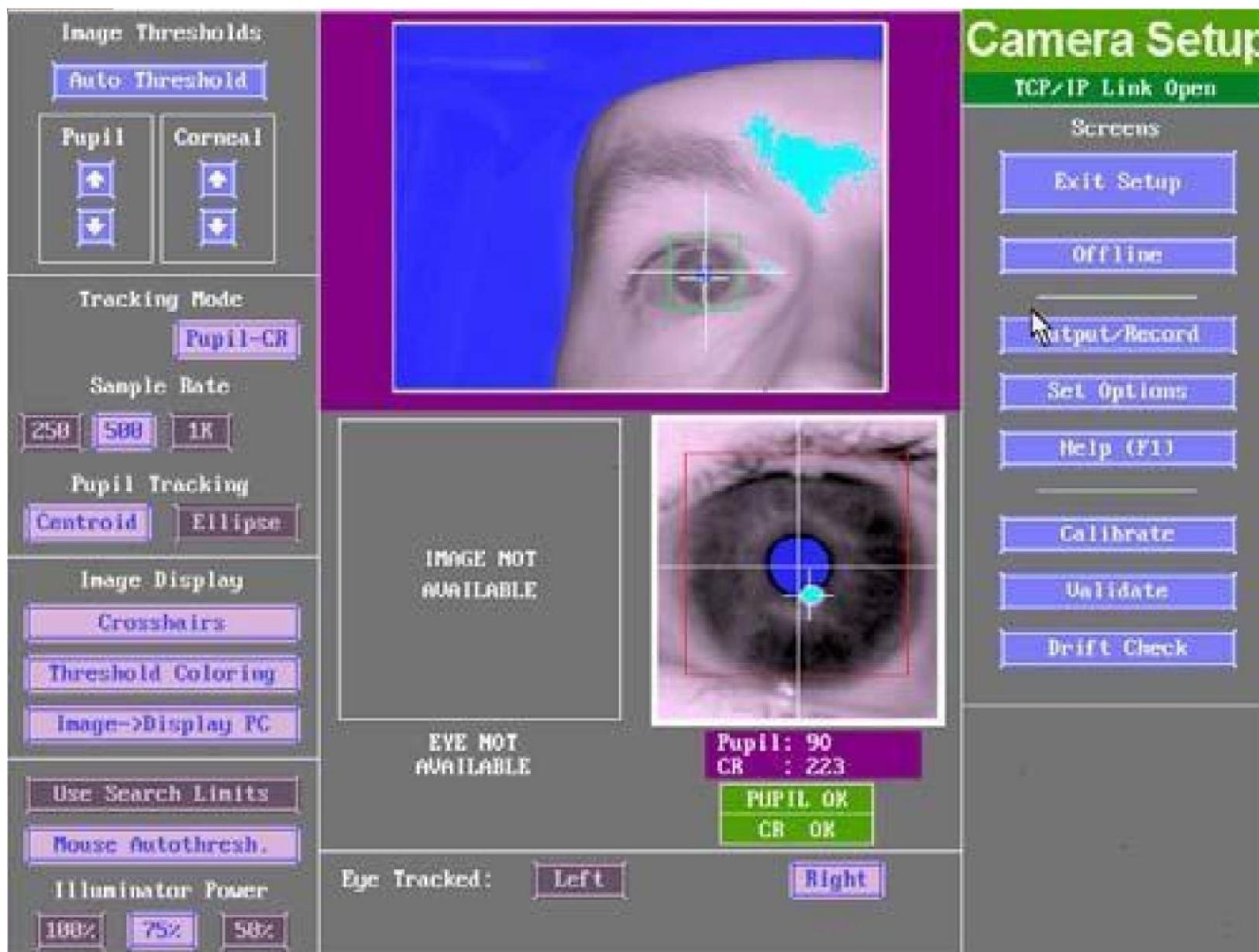
Purkinje peegelduse ja pupilli umbkaudsed paigutused üheksas kalibratsioonipunktis



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 vahel jäävas piirkonnas.

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

(Duchowski, 2007)



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



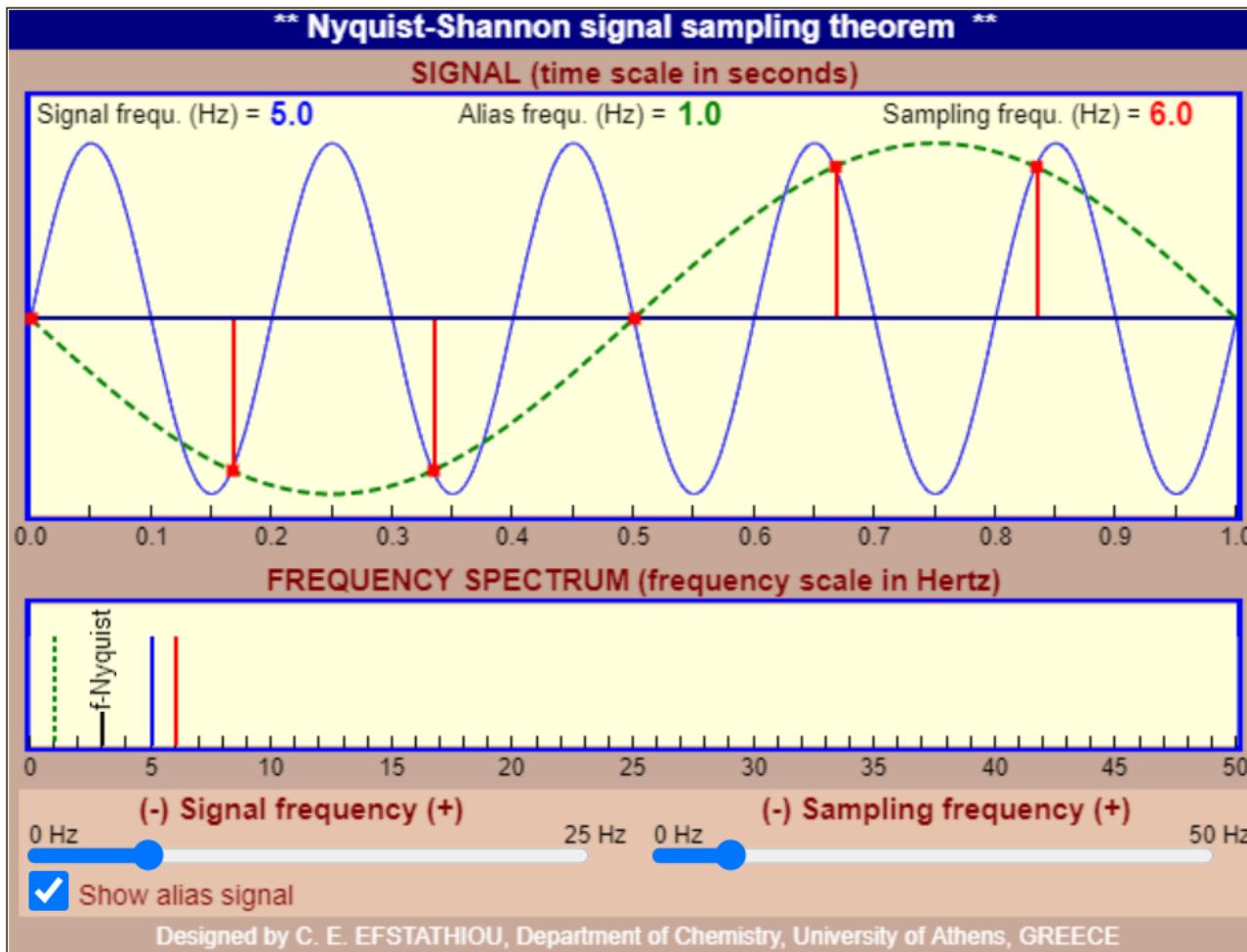
Toorandmete kvaliteeti mõjutavad tegurid

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)

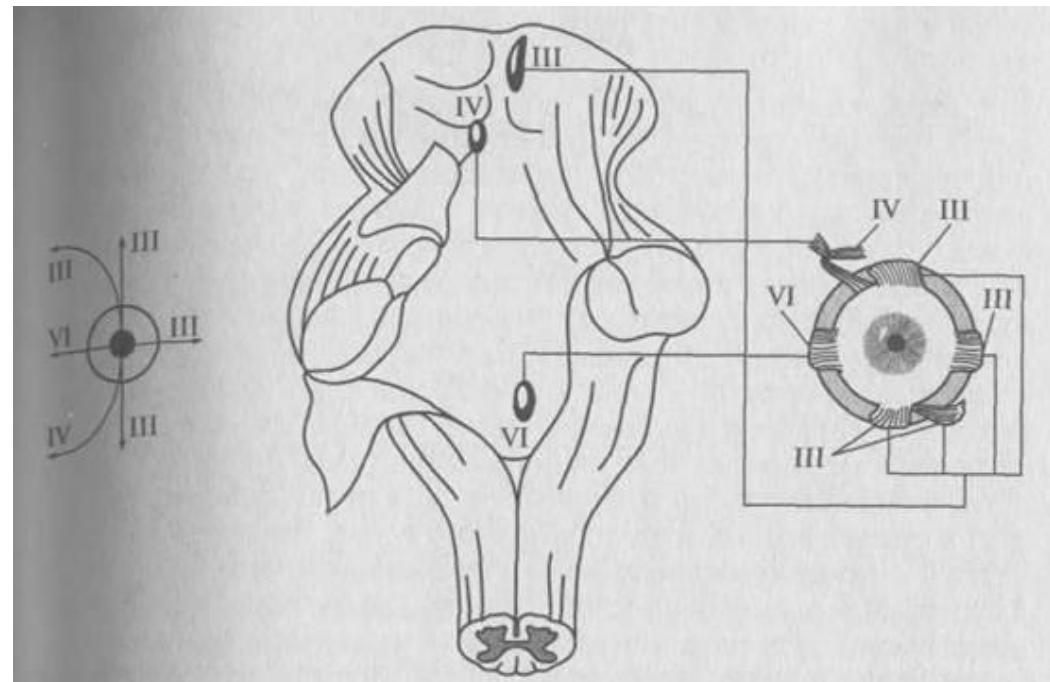
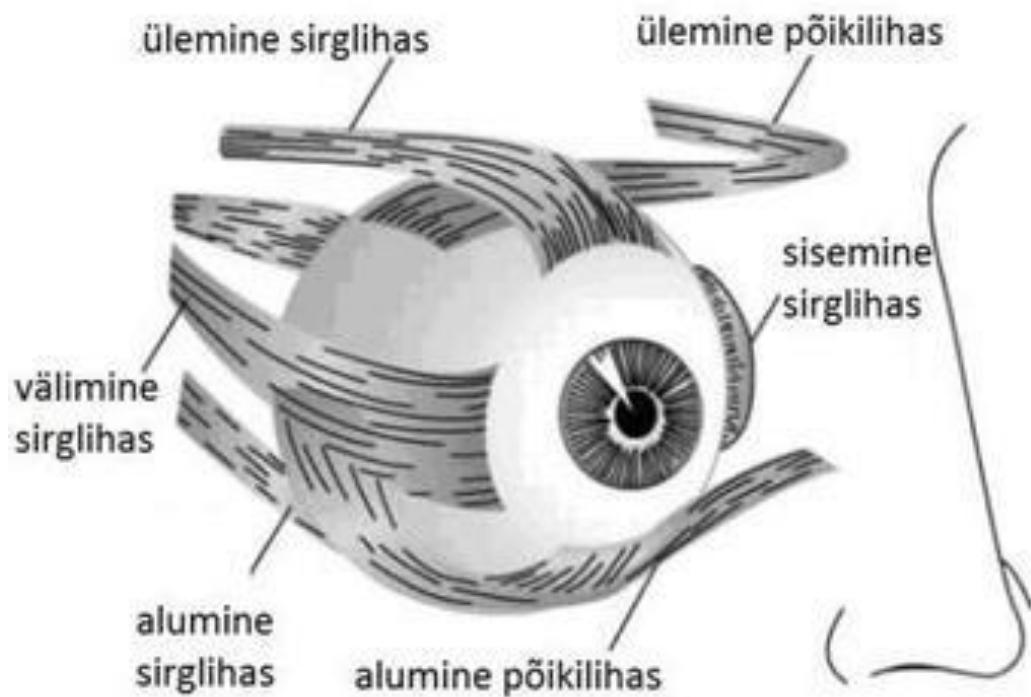
Toorandmete kvaliteeti mõjutavad tegurid

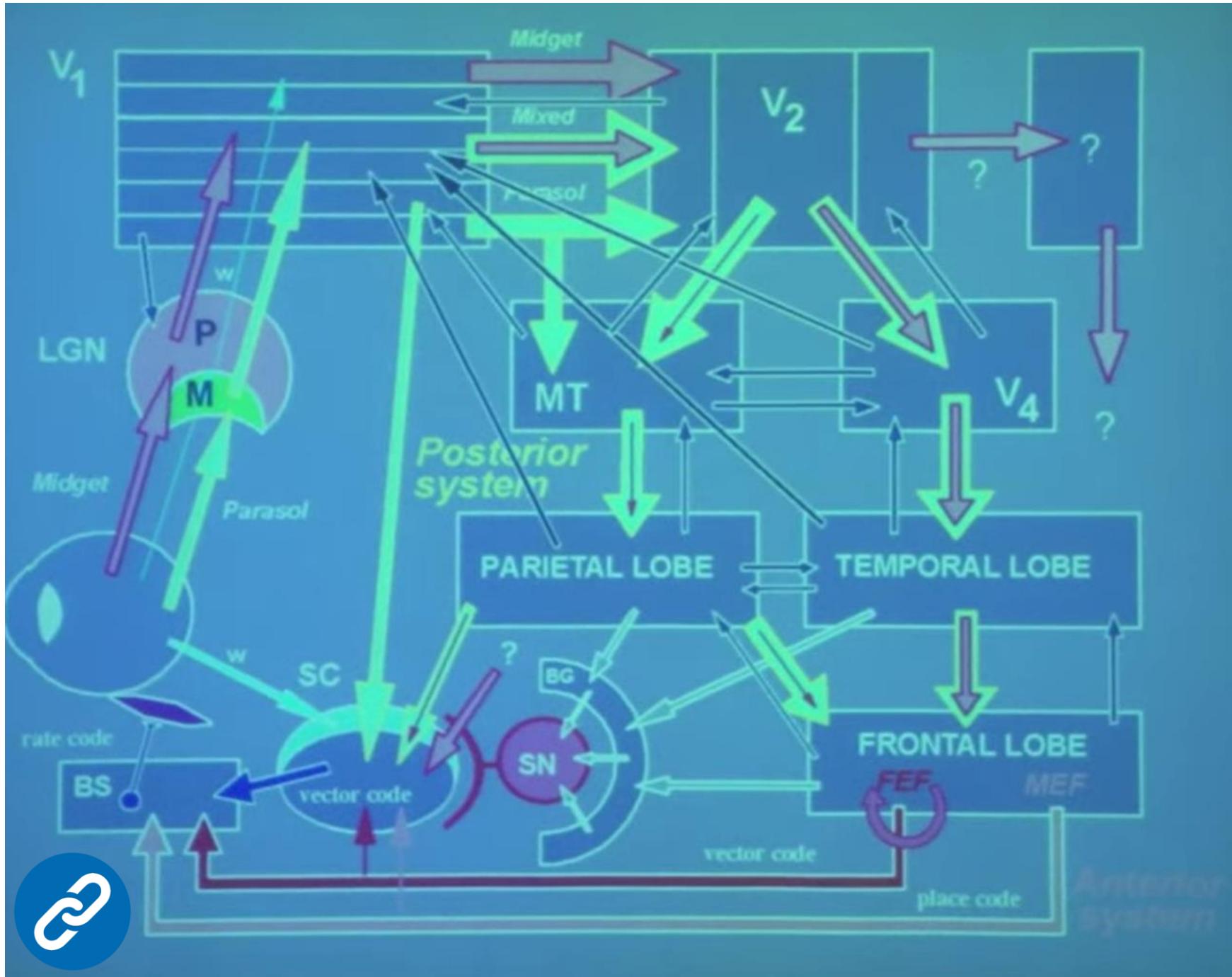


Nyquisti-Shannon teoreem

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

Silmalihased ja neid innerveerivad kraniaalnärvid

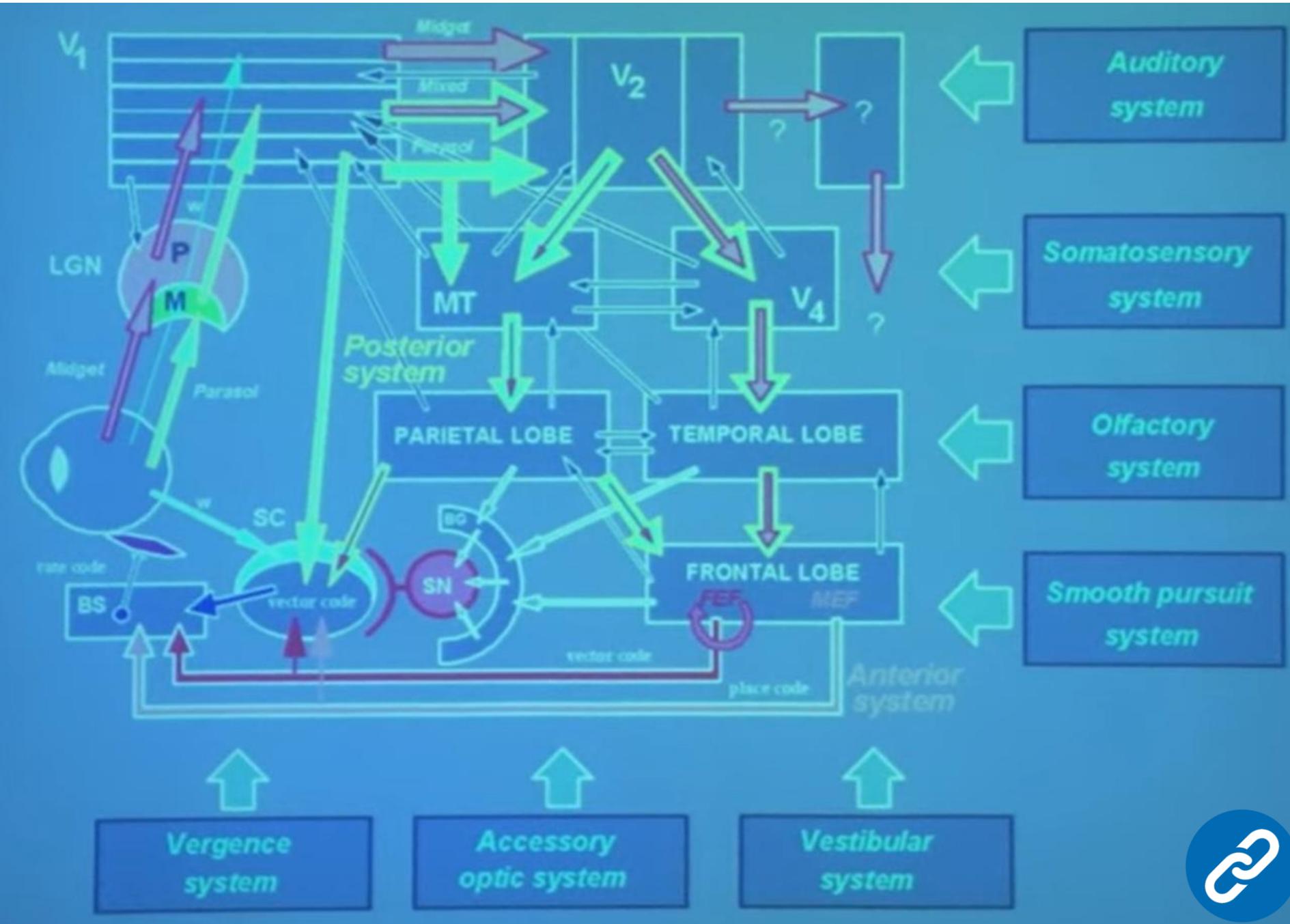




Professor [Peter H. Schiller](#)



[Massachusetts
Tehnoloogia instituudi
avatud kursus](#)



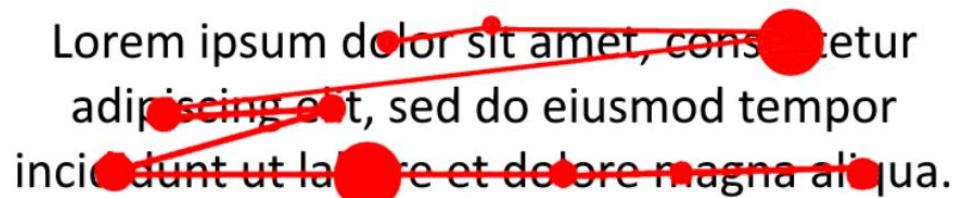
Professor [Peter H. Schiller](#)



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Peamised silmaliigutuste tüübид

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



● Gaze Fixation

(Radius represents duration)

— Saccadic movement

(between Fixations)

(Duchowski, 2007)

Peamised silmaliigutuste tüübид



Mõnedel hinnangutel suudavad primaatide silmad liikuda kuni $1000^{\circ}/\text{s}$ (Fuchs, 1967). Tavalise sakaadi kiirus on umbes $300-400^{\circ}/\text{s}$ (Wong et al, 2013).

Kui pea suudaks teha täispöördeid, siis sellisel kiiruse sel 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.

The diagram shows a horizontal line of Latin text: "Lorem ipsum dolor sit amet, consectetur adipisciing et, sed do eiusmod tempor incididunt ut labore et dolore magna aliqua." Red dots, representing gaze fixations, are placed at various points along the text. Red lines connect these dots, representing saccadic movements between fixations. The size of the red dots varies, indicating the duration of each fixation. The text is in a monospace font.

Lorem ipsum dolor sit amet, consectetur
adipisciing et, sed do eiusmod tempor
incididunt ut labore et dolore magna aliqua.

● Gaze Fixation

(Radius represents duration)

— Saccadic movement

(between Fixations)

(Duchowski, 2007)

Peamised silmaliigutuste tüübidi

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

Lorem ipsum dolor sit amet, consectetur
adipiscing elit, sed do eiusmod tempor
incididunt ut labore et dolore magna aliqua.

● Gaze Fixation

(Radius represents duration)

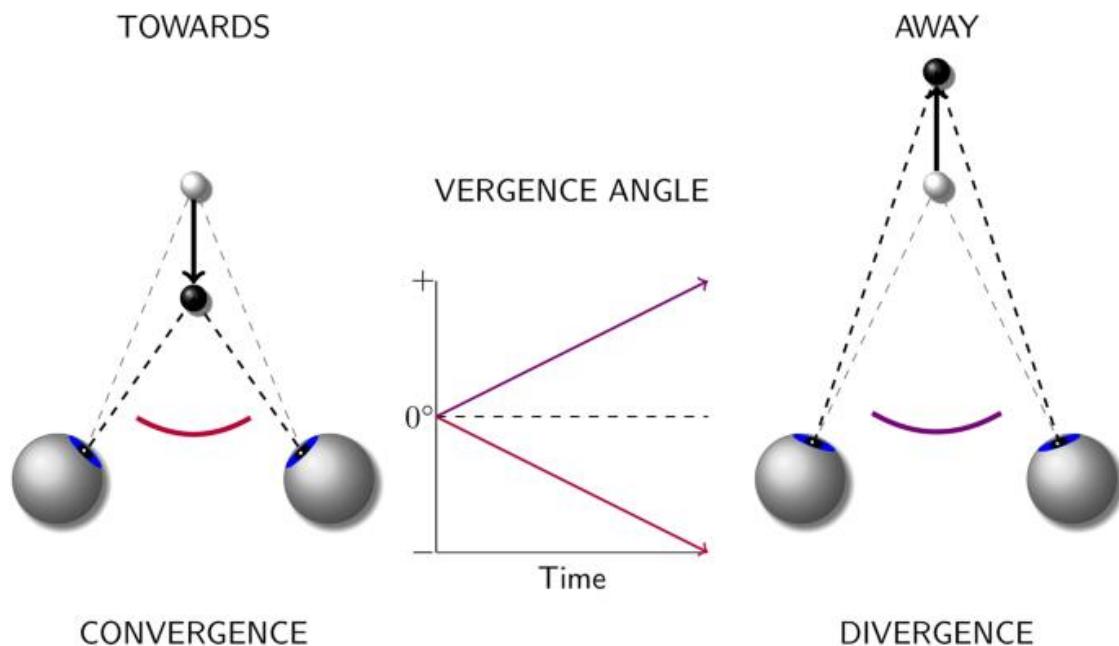
— Saccadic movement

(between Fixations)

(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 tüübид

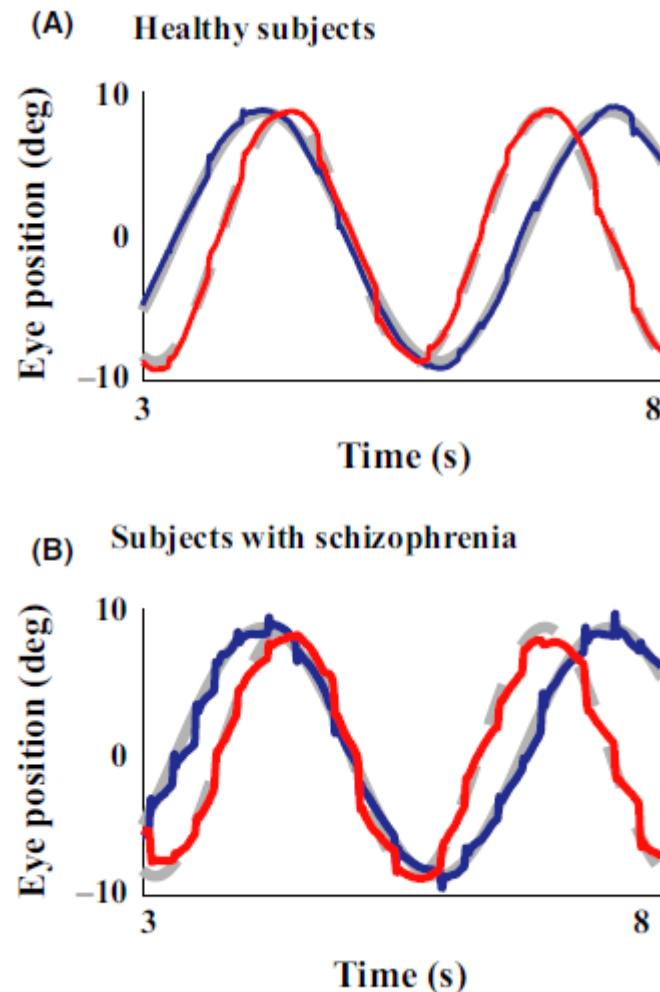


Metskurvits (aasta lind 2022)

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 tüübidi



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.

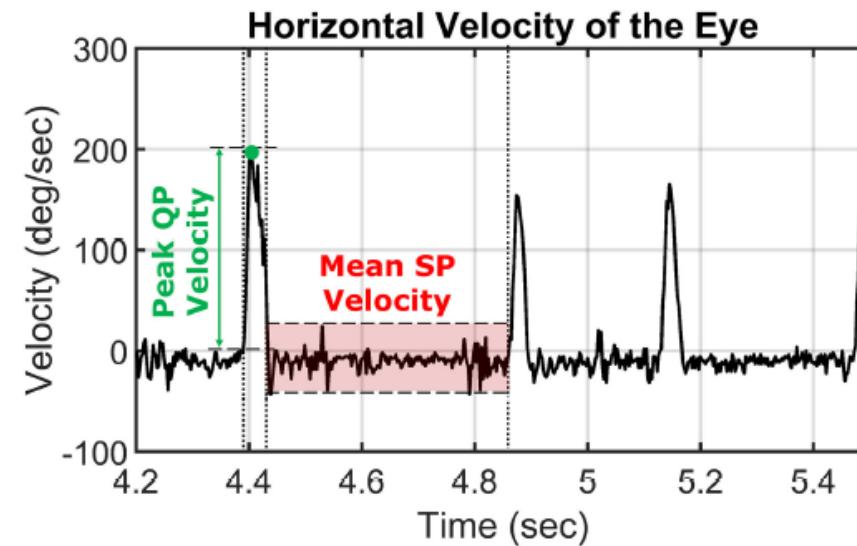
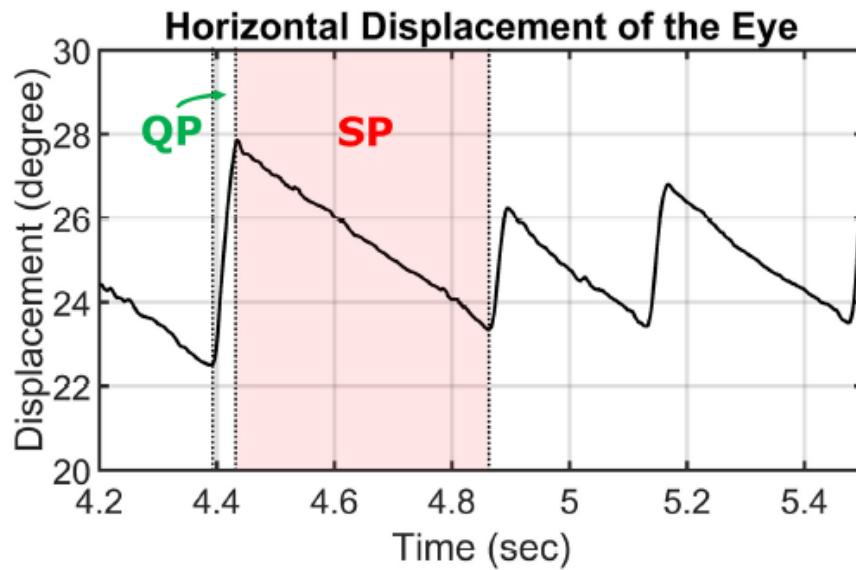


(Duchowski, 2007)

Peamised silmaliigutuste tüübid

Optokineetiline nüstagnm – 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 tüübид



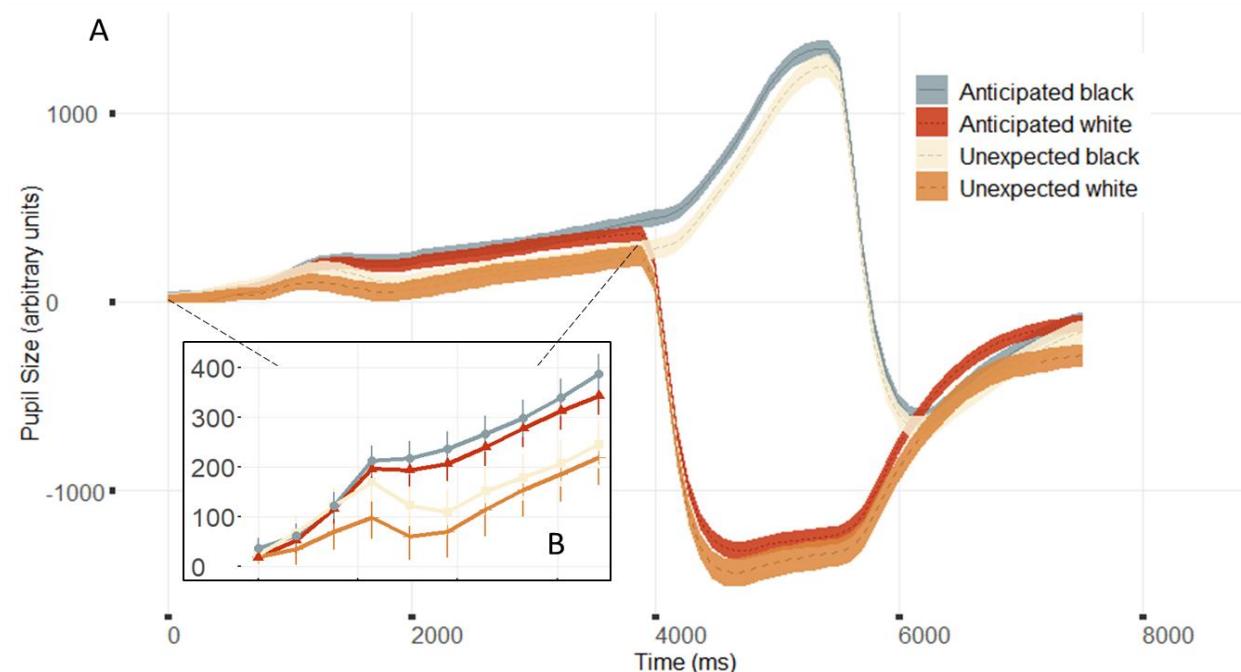
Vertical optokinetic nystagmus testing using an OKN drum. If a vertical nystagmus can be elicited, vision is .20/400 or better

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

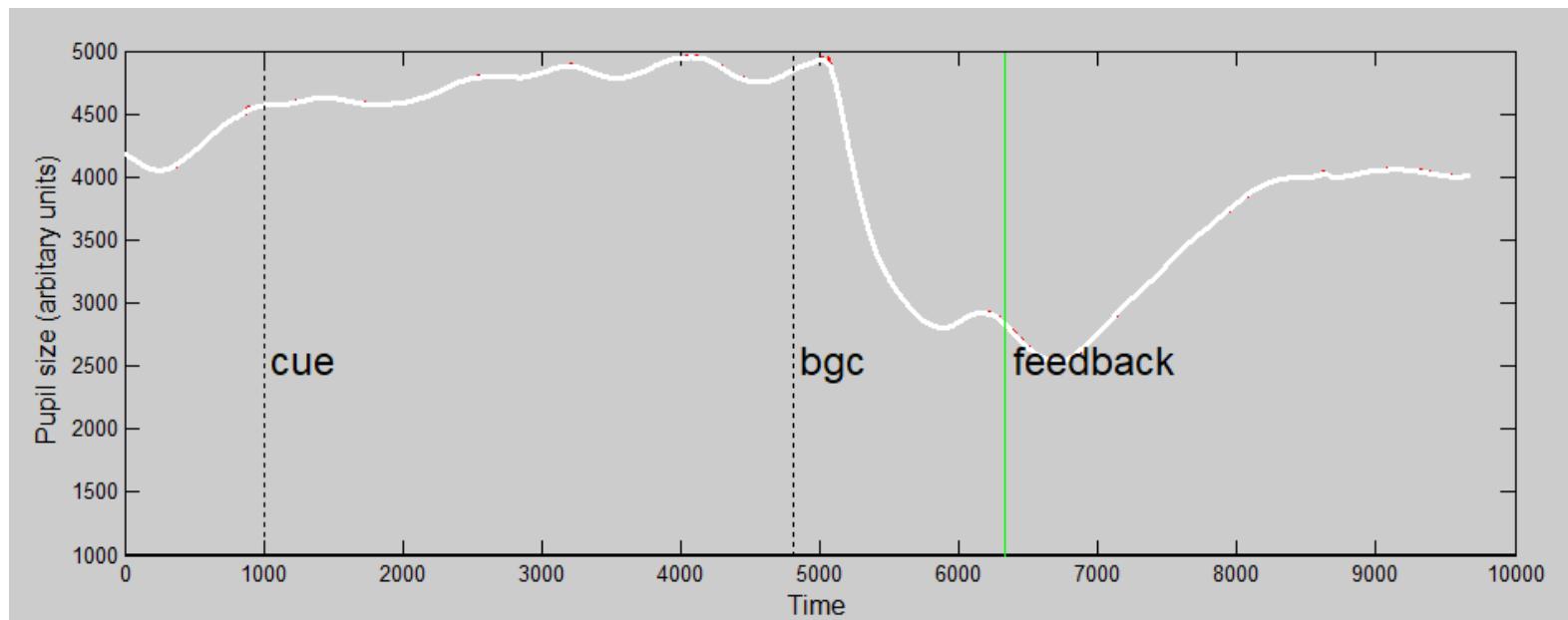
Peamised silmaliigutuste tüübidi

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



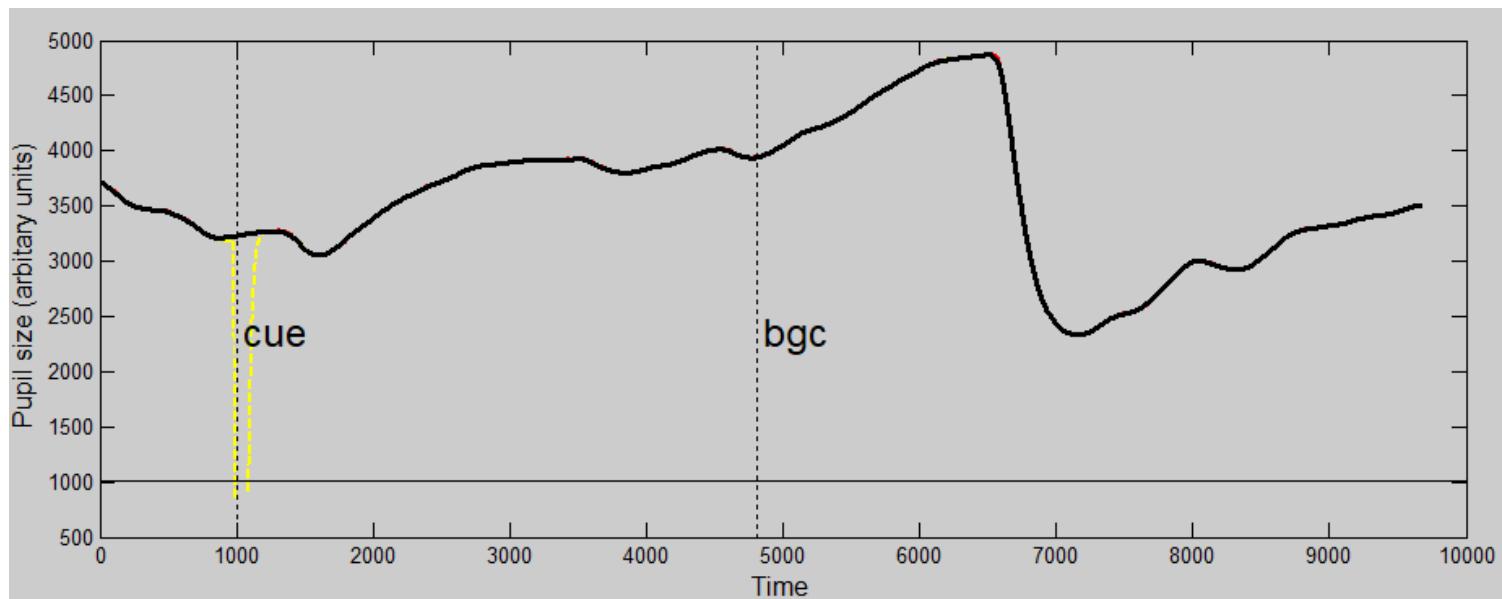
Peamised silmaliigutuste tüübidi

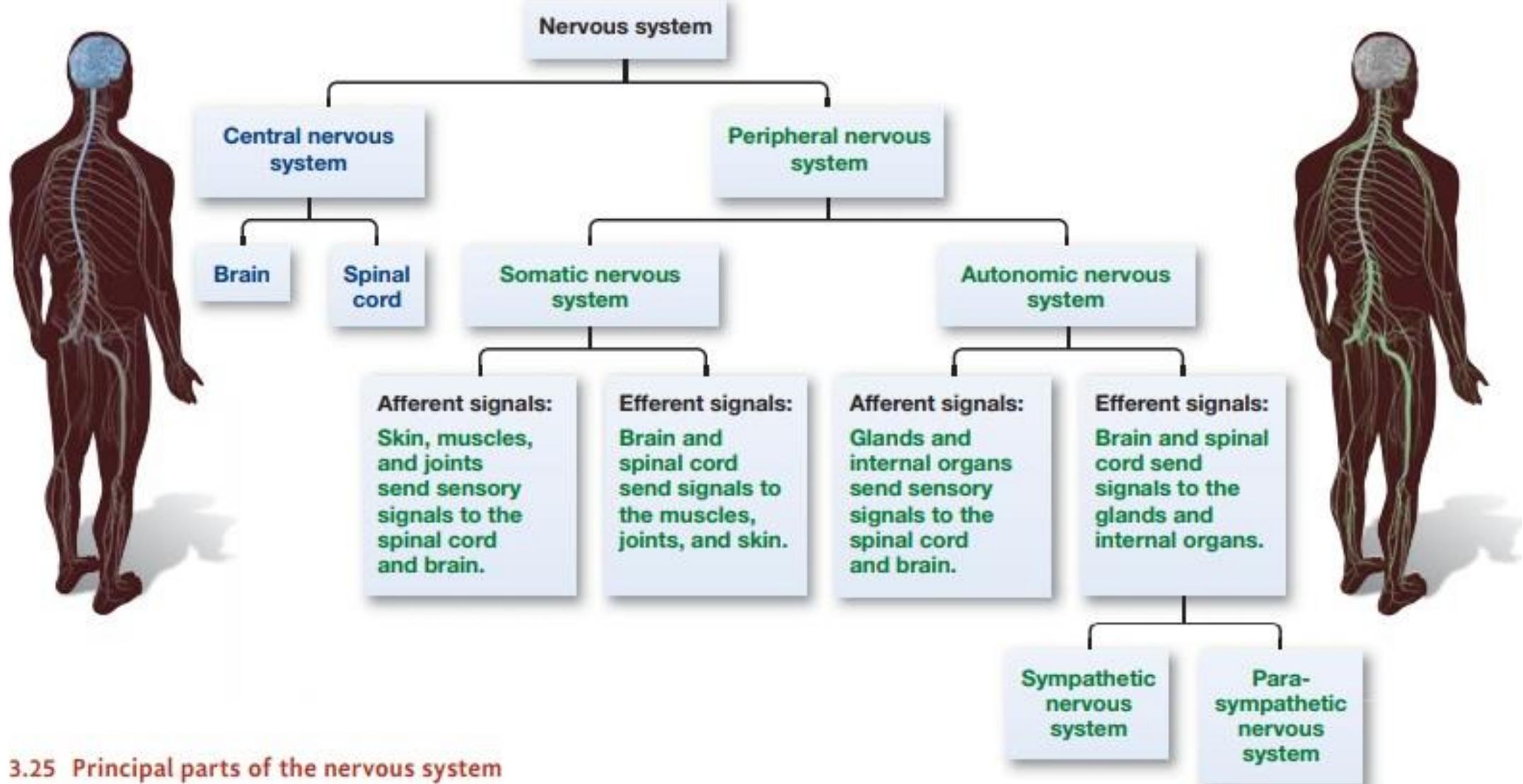
Silmaavaahenemine ehk **mioos** toimub parasümpaatilise närvi juhitud silmaavaahendaja sõõrjalt paikneva lihase (*m. sphincter pupillae*) abil (Ellis, 1981).



Peamised silmaliigutuste tüübidi

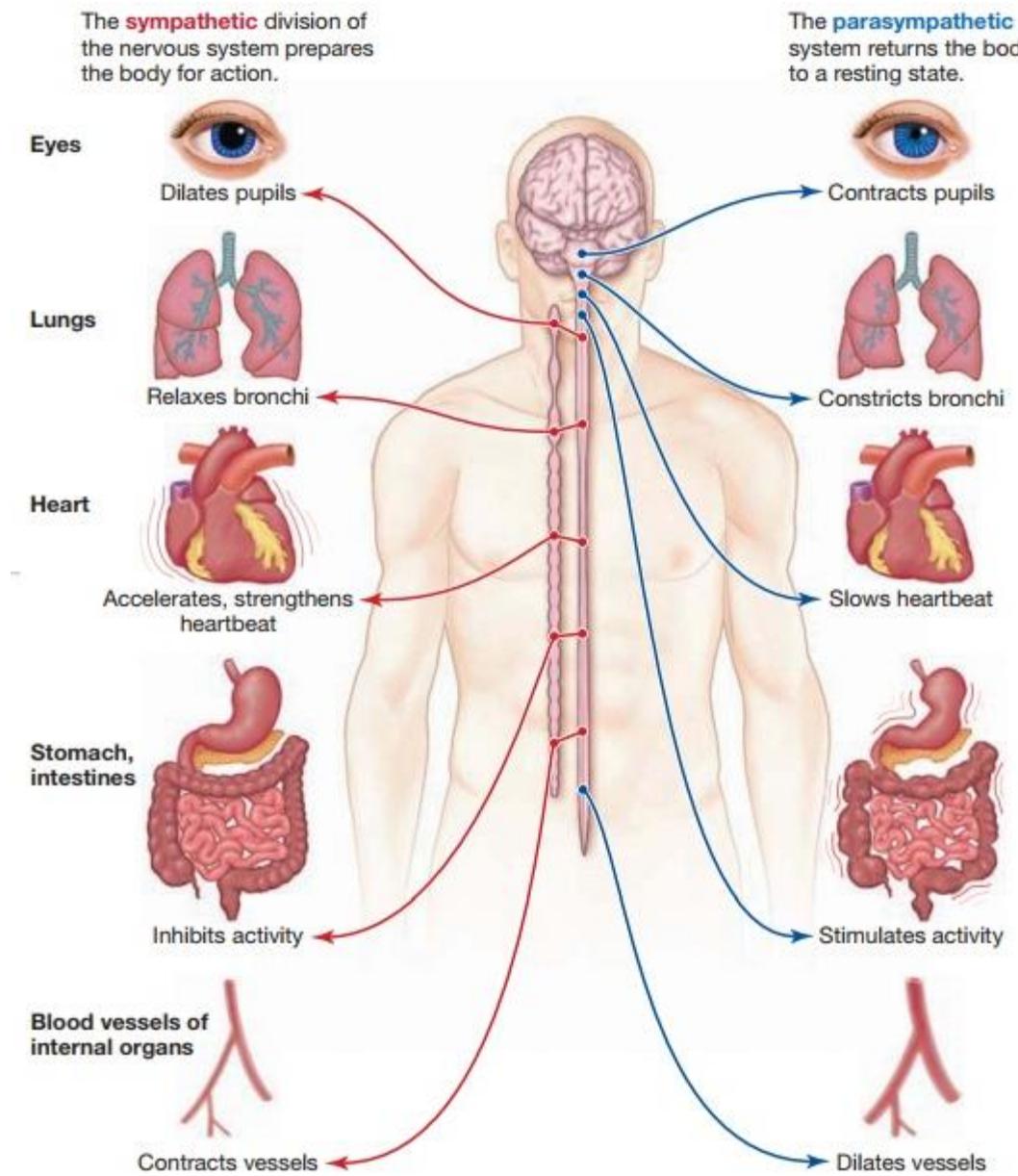
Silmaava suurenemine ehk **müdriaas** toimub silmaavalaiendaja (*m. dilatator pupillae*) radiaalselt paiknevate lihaste toimel. Selle juhtimine kuulub sümpaatilise närvisüsteemi alla (Ellis, 1981).





3.25 Principal parts of the nervous system

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



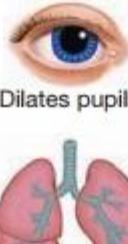
3.26 Sympathetic and parasympathetic systems

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



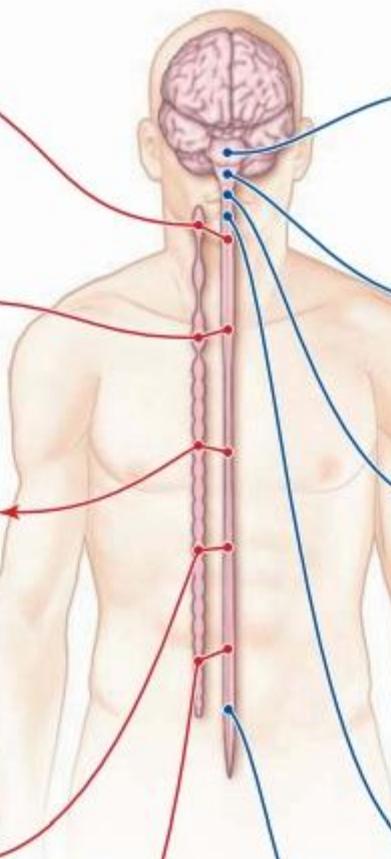
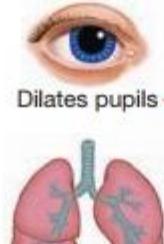
The **sympathetic** division of the nervous system prepares the body for action.

Eyes



Dilates pupils

Lungs



The **parasympathetic** system returns the body to a resting state.



Contracts pupils



Blood vessels of internal organs



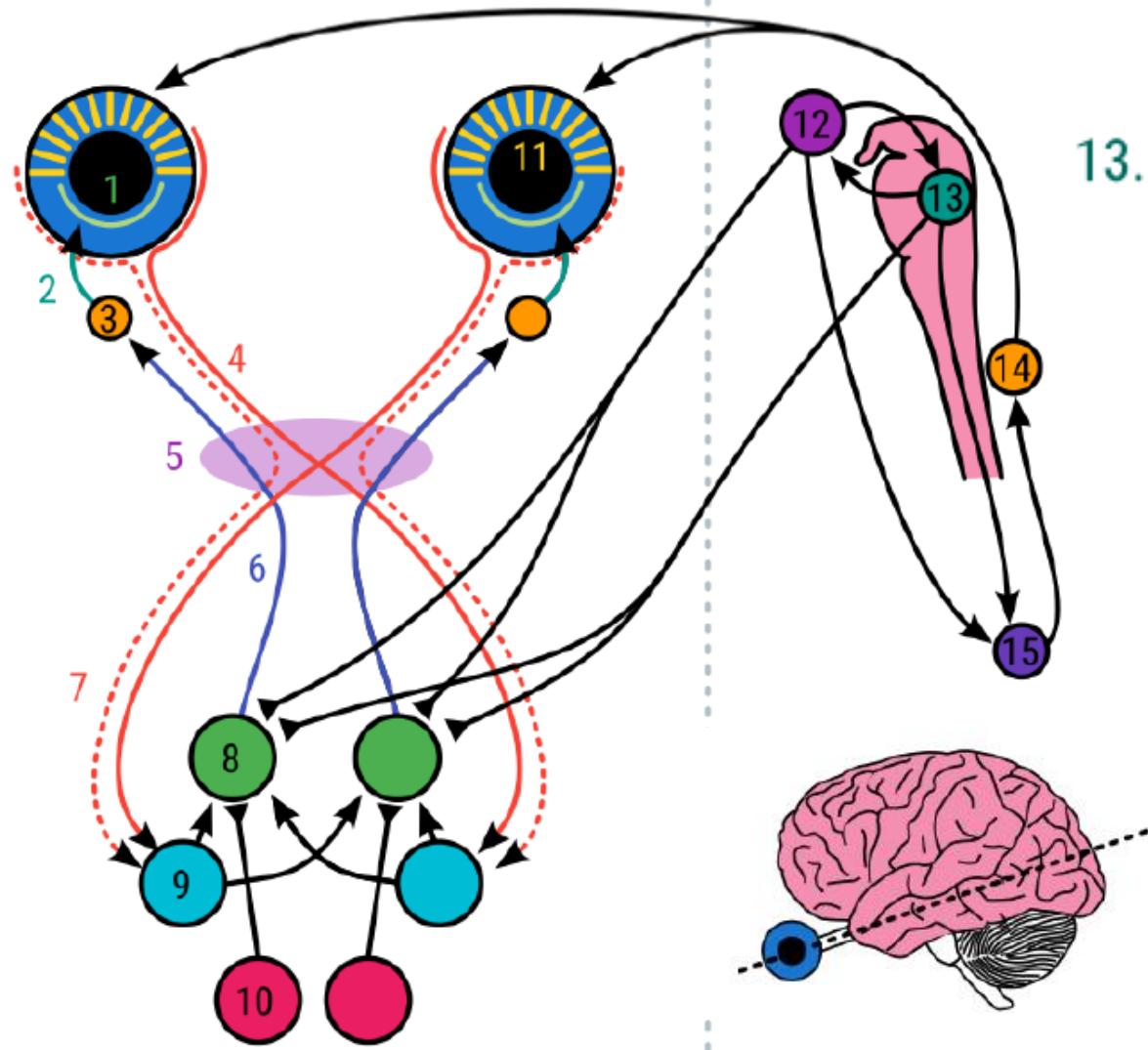
Contracts vessels



Dilates vessels

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 olfactory nucleus (PON)
10. Superior colliculus (SC)

ahenemine (mioos)

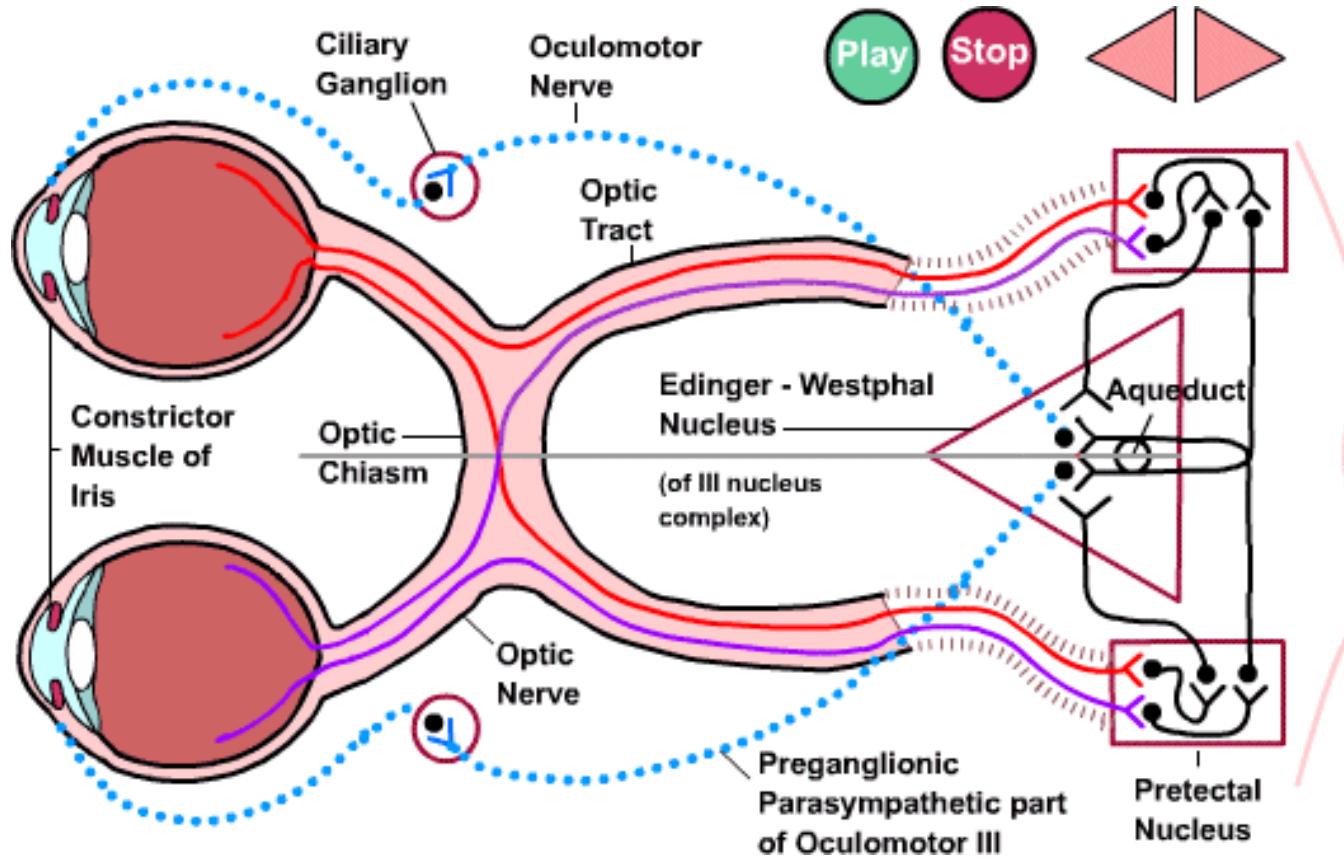


(Mathôt, 2018)

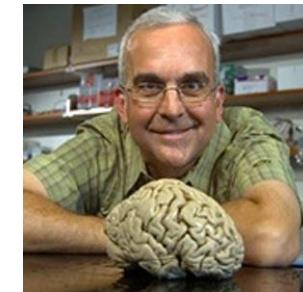
11. Iris dilator muscle
12. Hypothalamus
13. Locus coeruleus (LC)
14. Superior cervical ganglion (SCG)
15. Intermedio-lateral column (IML)

laienemine (müdriaas)

Mis juhtub kui näidata valgust vaid ühte silma?



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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

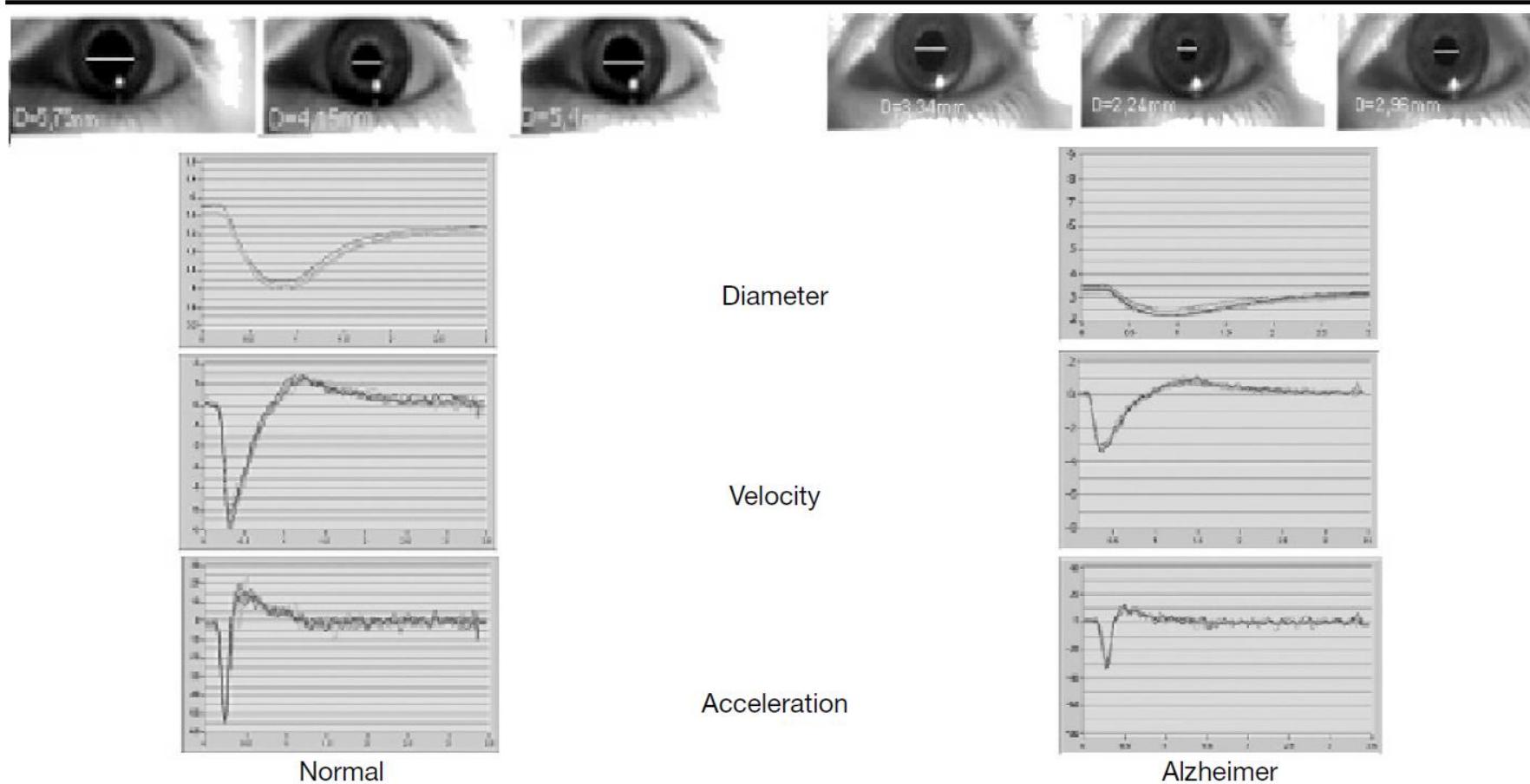


Fig. 2 - Pupil size after 2-min dark adaptation before pupil's reaction to light, maximum constriction and re-dilatation as response to light stimulus. Note the difference in baseline pupil diameter (D_1), maximum constriction velocity (V_{Cmax}), maximum constriction acceleration (AC_{max}) in both normal subjects and AD patients.



reflex



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 & Papes, 2012; Kahneman & Beatty, 1966)

Motoorne aktiivsus (Hayashi et al., 2010; Simpson, 1969)

Motoorse vastuse ettevalmistamine (Adam et al., 2014; Richer & Beatty, 1985)

Millega pupilli suurus veel sõltuda võib?

Heledusrepresentatsioonide kognitiivsest töötlemisest

Sisemise ruumitähhelepanu keskmest (Binda et al., 2013; Mathôt et al., 2013; Naber et al., 2013)

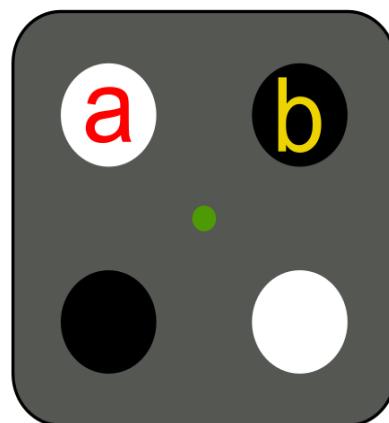
Kujutlusest (Laeng & Sulutvedt, 2014)

Töömälu sisust (Hustá et al., 2018)

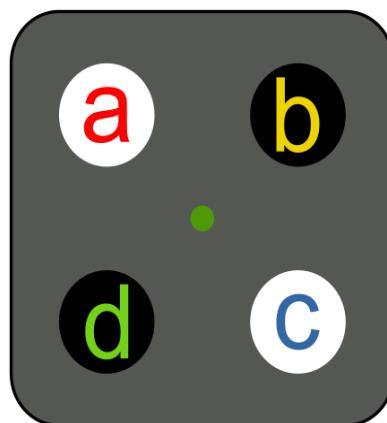
Sõnade semantiline sisu (Mathôt et al., 2016; 2019)

Pupillomeetrial põhineva aju-arvuti liidese näide

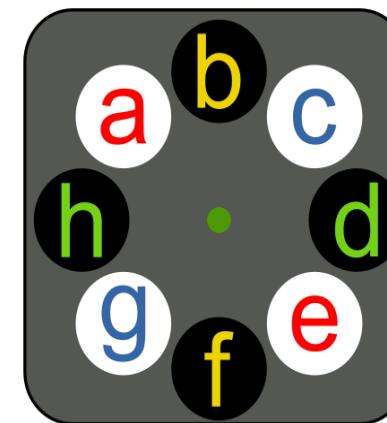
a) Example configurations



Two items (Phase 1)

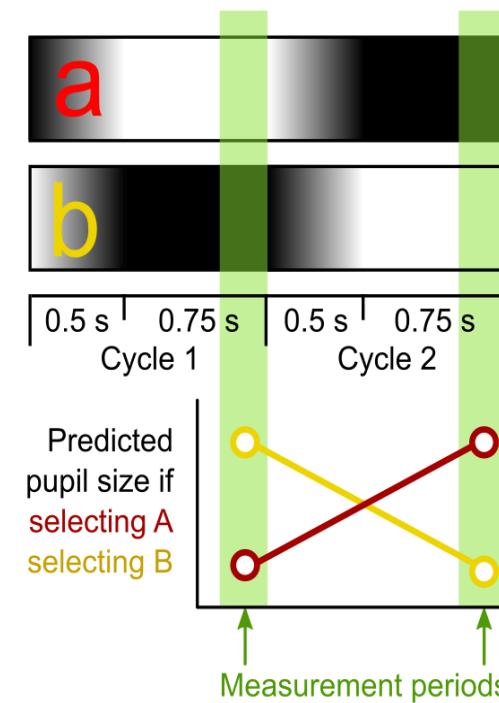


Four items (Phase 2)



Eight items (Phase 3)

b) Brightness alternations



(Mathôt et al., 2016)



Millega 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!

<https://assistivetechnologyblog.com/2016/08/eye-tracking-101-how-does-it-work.html>