

## Accommodative response: Physiology and Behaviour

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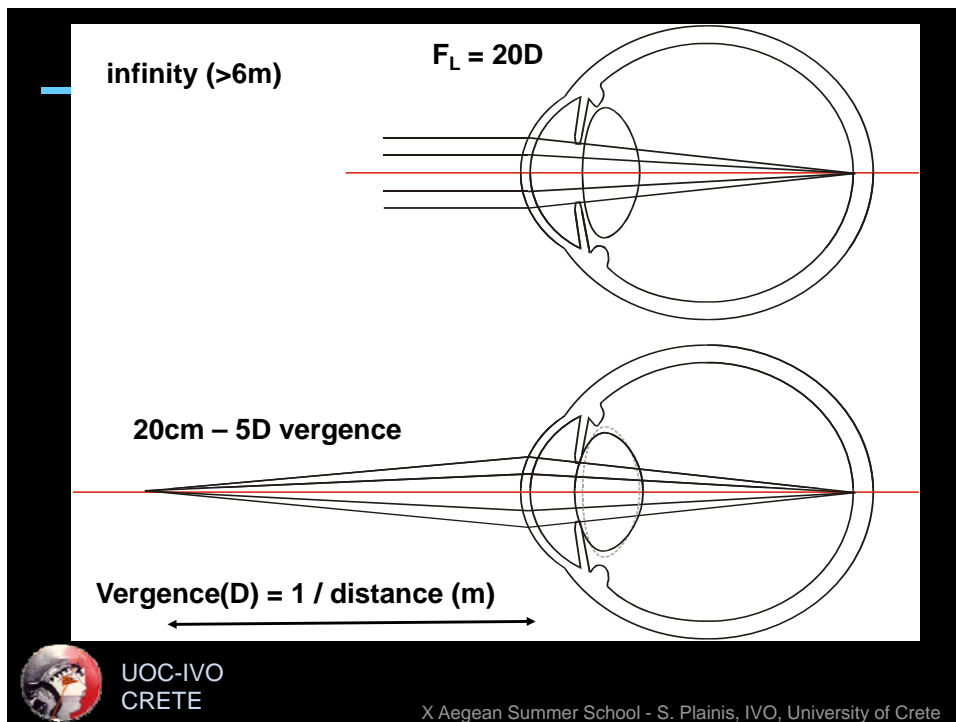
## Outline

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- The «Accommodation» mechanism
- Performance of the accommodation system
- Accommodation and higher order aberrations
- Accommodation and ageing
- Subjective vs. objective accommodation



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## Accommodative function

**Accommodation** refers to a lenticular-based\* change in overall refractive power of the eye to *obtain and maintain a retinal image of a near object in-focus*.

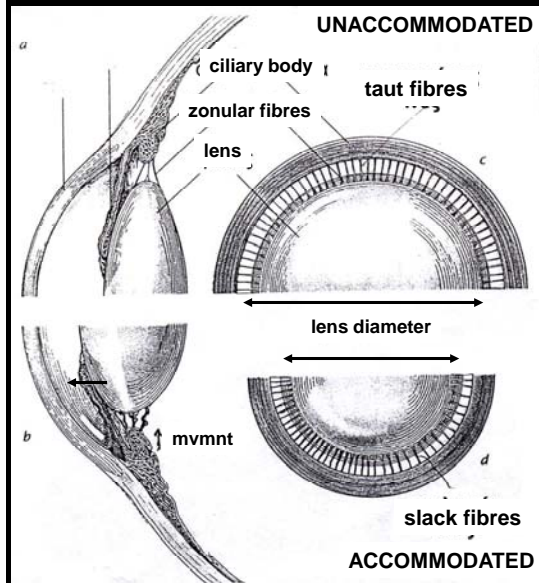
Defocus blur is considered to be the primary stimulus that controls (monocular) accommodative response.

When fixating near objects [near triad ]

- changes in accommodation (increase in lens power)
- changes in vergence (convergence),
- pupil constriction («accommodative miosis» or «near miosis»)
- changes in higher order aberrations (e.g. spherical aberration)

\*recognised since 17th century (Scheiner, Kepler, Descartes)

## Mechanism of Accommodation\*



\*Helmholtz theory (1880)

## Mechanism of accommodation\*

### In relaxed state (focusing far objects):

The ciliary muscle is relaxed, the ciliary ring is of large diameter, creating tension in the zonular fibres (attached to the capsule) and flattening the lens.

### In accommodated state (focusing near objects):

- Ciliary ring contracts (reduces in diameter)
- It moves towards the lens
- Zonular tension is reduced
- Lens **decreases** in diameter, **moves away from the sclera**, and takes up its natural more convex (powerful) form (Scachar/Tscherning?)
- Lens moves forward to the iris
- The power of the lens/eye increases



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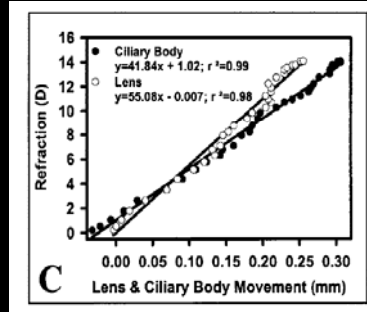
\*Helmholtz theory (1880)

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# Mechanism of Accommodation



Ultrasound Biomicroscopy (UBM)



When accommodating both the ciliary muscle and the lens equator are moving away from the sclera



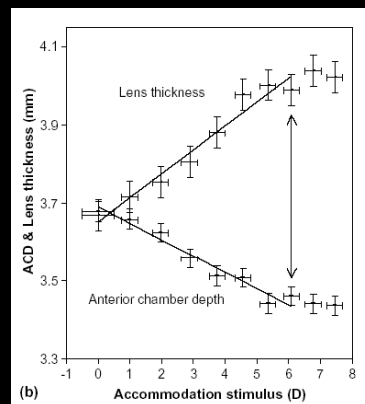
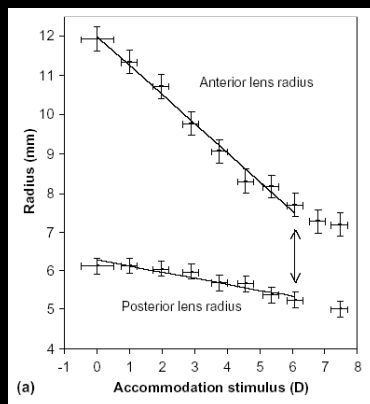
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(Glasser and Kaufman, 1999)

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# Accommodation: Changes in lens parameters

- Changes in lens radii are greater for the anterior surface (tension of anterior zonules, thickness of anterior capsule)
- Lens thickness increases with accommodation



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## Performance of the accommodation system

- Accuracy of response: response/stimulus curve
- Tonic levels
- Speed of response: reaction and response times etc
- Stability of response: fluctuations



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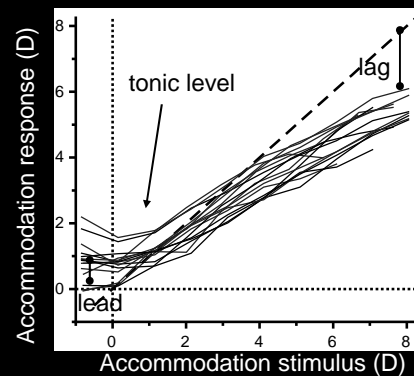
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## Accuracy of accommodation

...is denoted by the Response / Stimulus curve

- Over-accommodation (**lead**) for distant targets
- Under-accommodation (**lag**) for near targets

- Response equals stimulus vergence at about  $\sim 1.75D$  (tonic level)



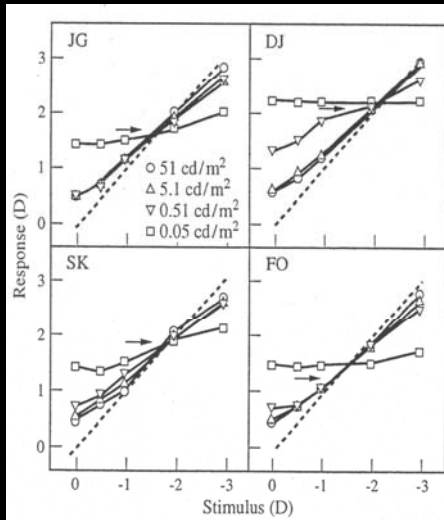
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## Accuracy of accommodation (light levels)

- System becomes ineffective at lowered light levels (i.e. response is driven by cones)

- In dark, response reaches a tonic level, corresponding to the resting state of accommodation



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Owens, 1978

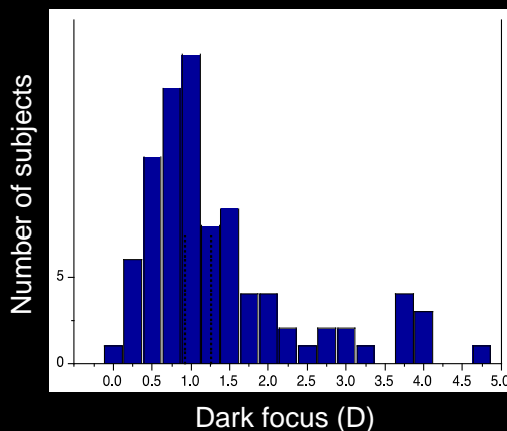
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## Dark focus - Tonic levels

- In the absence of any stimulus (total darkness, empty field) the refractive state of the eye is about 1.0 to 1.5 D (66 cm to 1m). This has been defined as "dark focus" or "empty field myopia".

- It has been proposed that it coincides with the resting point of accommodation (equilibrium between parasympathetic/sympathetic).

- Note, the significant variability between subjects



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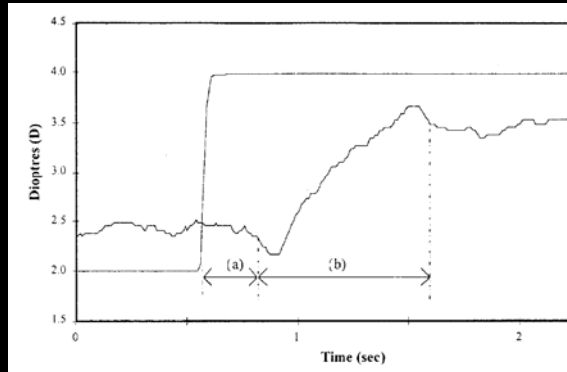
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## Speed of response

Reaction time (latency): time until the initiation of the response (~ 0.3 sec)

Response time: time until the response reaches a steady level (~ 1.0 sec)

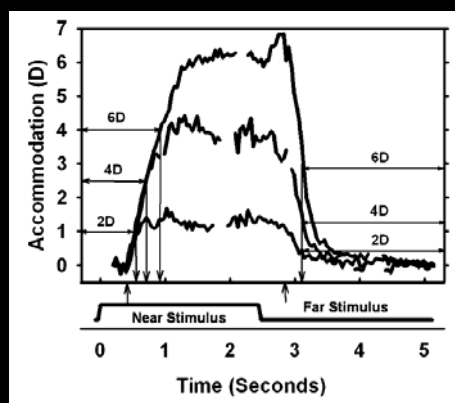
Variability in response time (e.g. late-onset myopes vs. emmetropes)



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## Speed of response



after Glasser, 2000

Reaction time is constant (affected by stimulus characteristics)

Response time increases as accommodative demand increases

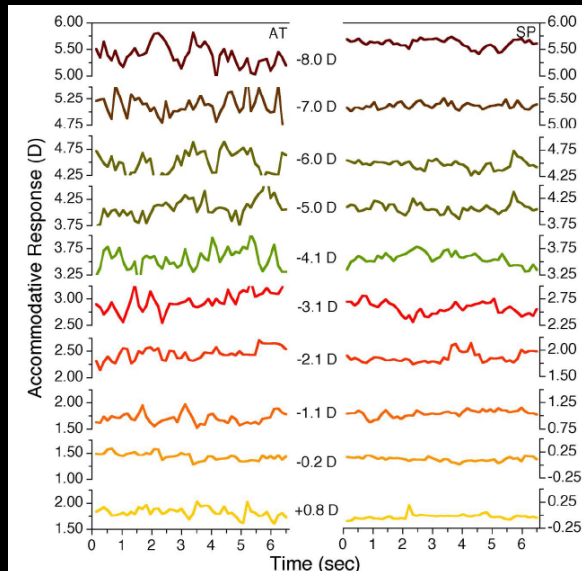


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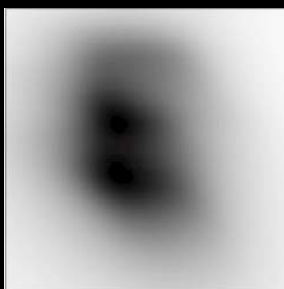
## Stability of Accommodative Response

- Rapid changes (fluctuations) in response
- Highest stability at infinity
- Considerable variation among subjects, in both the magnitude and in their changes with target vergence



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## The role of micro-fluctuations



Target vergence: 4.0 D,  
Average response: 3.55 D  
Response range: between 3.23 and 4.02

from Plainis et al., 2005

- Fluctuations in accommodation seem to play an important role in providing a feedback mechanism in accommodation.
- Their increased amplitude preserves image quality, when errors of accommodation are moderate, by temporarily bringing the image into the best focus.



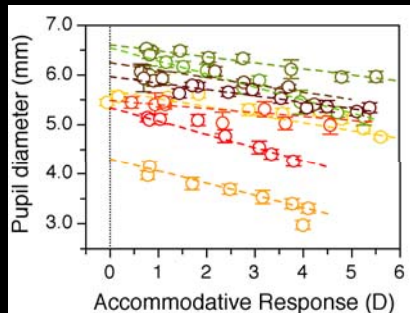
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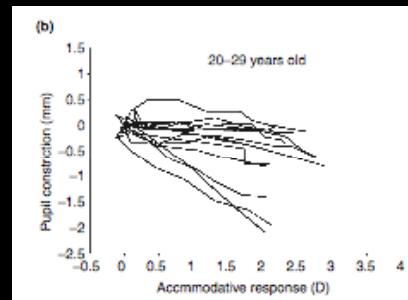
## Accommodation-induced pupillary miosis

- For each subject, the higher the accommodative response, the greater the miotic effect, with the relationship being fairly linear
- However, miosis does not necessarily accompany accommodation and its magnitude is not related to ciliary muscle contraction



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Plainis et al., 2005



Radhakrishnan & Charman, 2007

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## Accommodation - Wavefront Aberrations

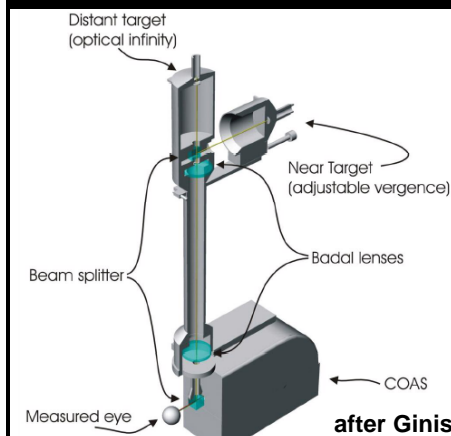


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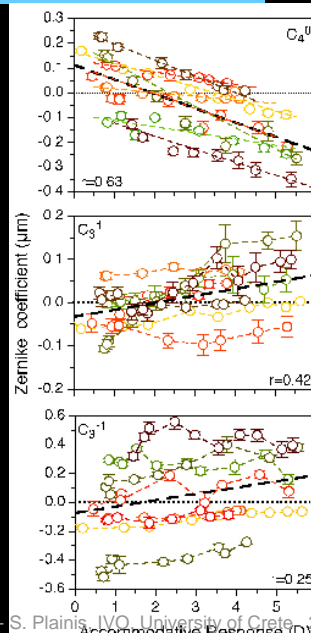
## Objective measurement - Badal optometer

The Badal optometer -COAS sensor set-up allowed recording of the wavefront aberration of the **tested eye while accommodating**



## Accommodation: higher-order ocular aberrations

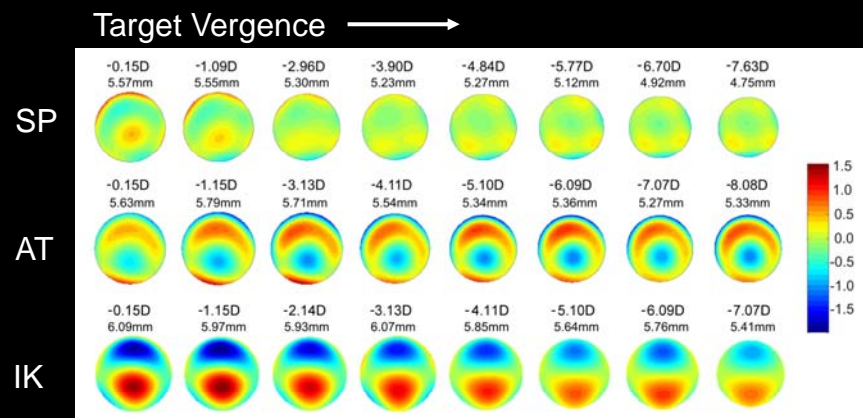
- Spherical aberration ( $c_4^0$ ) moves to negative values with accommodation (but there is significant inter-subject variation).
- Coma-like aberrations ( $c_3^{-1}$ ) ( $c_3^1$ ) on average change to positive values.
- These are probably attributed to changes in lens shape and lens position (e.g. lateral displacement / tilt) during accommodation (Drexler et al., 1997; Roorda & Glasser, 2004)



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## Wavefront changes when accommodating



There is a considerable variation in the wavefront patterns from individual to individual at each accommodation level.



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## Accommodation and ageing



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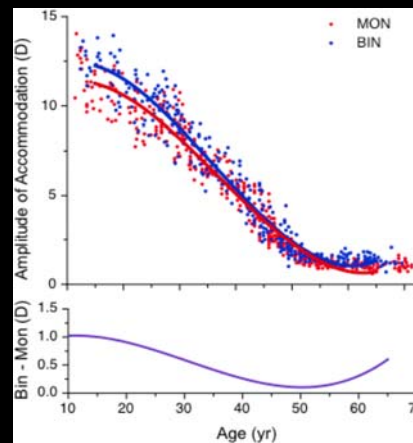
## Ageing: Amplitude of accommodation

- The ability of the eye to focus on objects at close distances decreases linearly with age (up to 50-55 years)

*Duane, 1922*

- Emmetropes will start experiencing presbyopia symptoms through their 40s

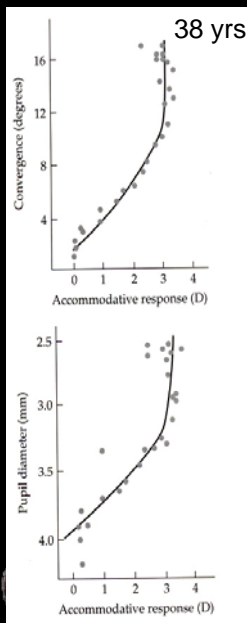
- The “binocularity” advantage is also reduced with age



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## Ageing: Near triad



Although accommodation cannot increase further than 3D, increased accommodative stimuli elicit more convergence and pupil constriction

Absence of accommodation is not due to absence of a neural signal, but is limited due to changes in lens/ciliary body/zonules

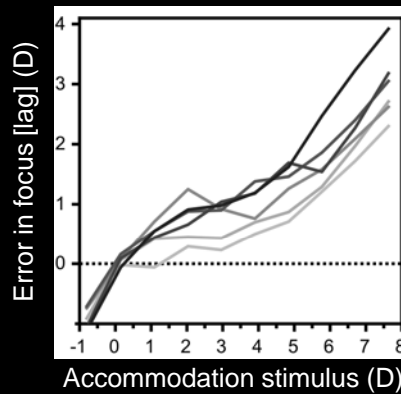
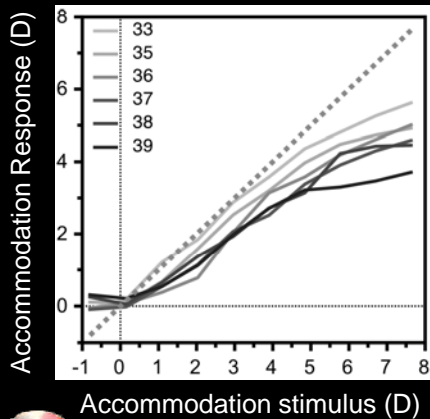
Pupillary miosis may enhance near vision by increasing depth-of-focus

*from Alpern, 1961*

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## Ageing: stimulus/response curves

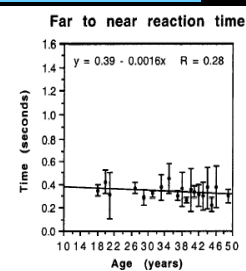
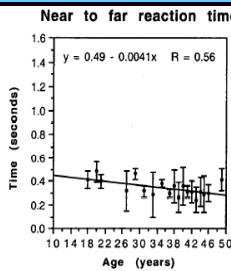
- Ageing is accompanied by changes in the stimulus/response curve: increased levels of lag of accommodation and fluctuations.



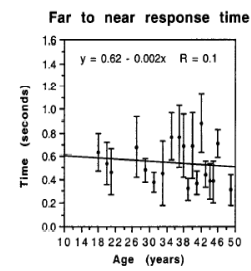
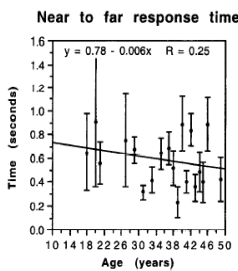
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## Ageing: reaction and response times

Reaction time



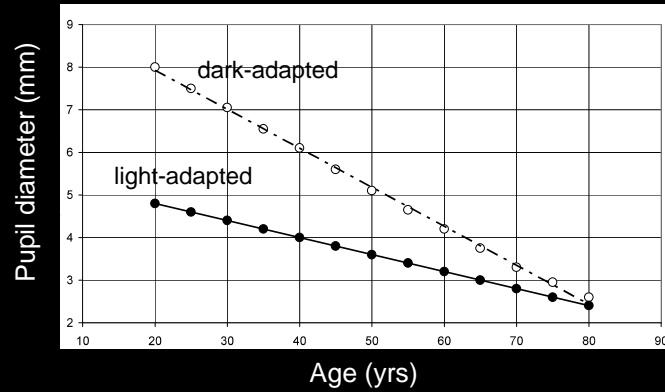
Response time



from Heron and Charman  
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## Ageing: pupil size

Fully dark- and light-adapted pupil diameters decrease as a function of age (leading to increased depth-of-focus)



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*From Kornswieg, 1954*

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## Objective vs. Subjective accommodation

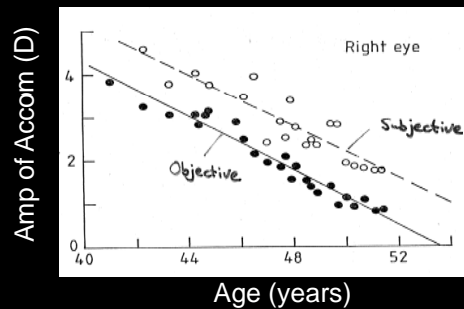


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## Ageing: Amplitude of accommodation

- Both subjective / objective amplitudes decrease with age. Objective accommodation (real accommodation) zeros at ~ 50-55.
- When measured subjectively (push-up test) an elderly emmetrope has at least 1.0-1.5 D depth-of-focus due to multifocality (from small pupil diameter, aberrations, fluctuations) - this is defined as **pseudo-accommodation** Longitudinal data, after Charman



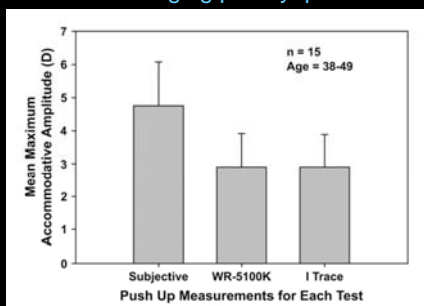
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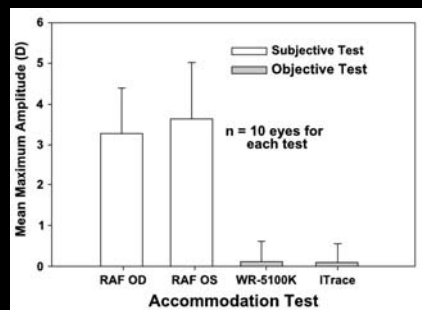
## Objective vs. subjective accommodation

- The “push-up” test overestimates subjective amplitude relative to objective measures. This is more pronounced in pseudophakes

Emerging presbyopes



pseudophakes



WinHall and Glasser, 2008, 2009



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## Subjective testing: through-focus performance

- Through-focus performance (*defocus curve*) shows a 2.00 D range of functional acuity in pseudophakes, compared to over 7.00D for young phakic subjects

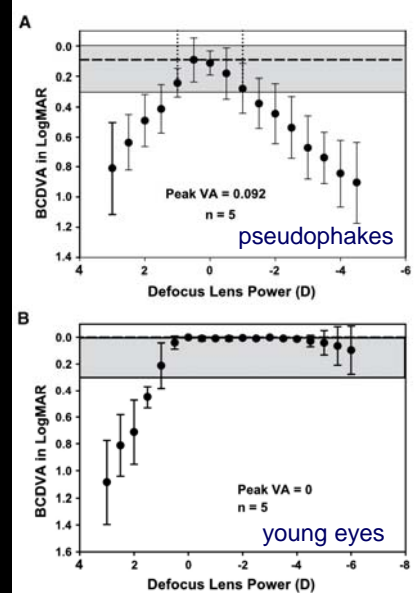
- It does not measure true accommodation



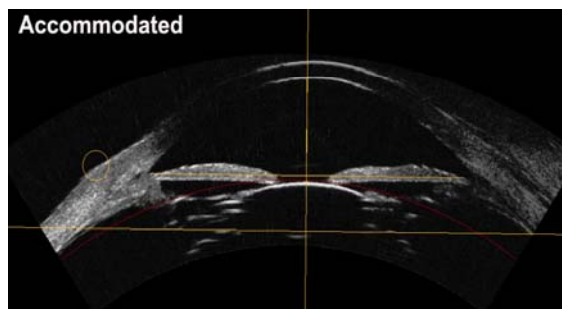
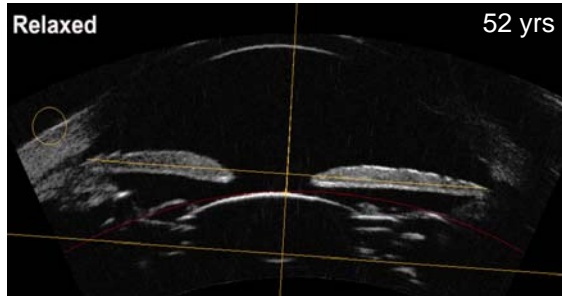
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WinHall and Glasser, 2009

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## Pharmacologically-induced accommodation

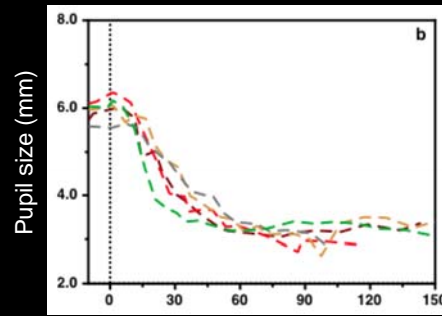
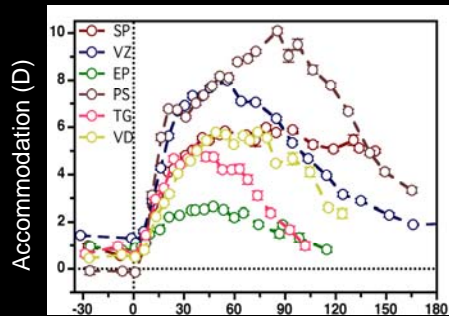


4% pilocarpine  
0.4 mm forward mvmt  
Acc ~ 0.50 D



## Pilocarpine-induced accommodation

- High inter-subject differences in pilocarpine-induced accommodation – usually referred to as a “superstimulus” response (no variability in pupil response)
- No correlation between the magnitude of stimulus-driven response for the higher dioptic level and pilocarpine-induced accommodation



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Time (min)

Plainis et al., 2009

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## Summary

- Accommodation response change takes about 1 sec to complete
- Errors in mean focus (lags / leads) are an intrinsic part of the system
- Response shows fluctuations (instability)
- Accommodation is reduced before presbyopia onset
- Increased depth-of-focus with ageing may lead to higher lags
- Objective methods are needed to differentiate “true accommodation” from “pseudo-accommodation”
- Stimulating accommodation by application of pilocarpine may be inappropriate for evaluating the efficacy of accommodation reversal



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Thank you for listening

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