Accommodative response: Physiology and Behaviour

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Outline

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

**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

*Helmholtz theory (1880)
Mechanism of Accommodation

Ultrasound Biomicroscopy (UBM)

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

(Glasser and Kaufman, 1999)

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
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

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 ~1.75D (tonic level)
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

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 1 m). 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
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)

(after Glasser, 2000)

Speed of response

Reaction time is constant (affected by stimulus characteristics)
Response time increases as accommodative demand increases

(after Glasser, 2000)
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

The role of micro-fluctuations

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

- 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.
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

Accommodation - Wavefront Aberrations
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).
Wavefront changes when accommodating

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

Accommodation and ageing
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)  
  \[ \text{Duane, 1922} \]

• Emmetropes will start experiencing presbyopia symptoms through their 40s

• The “binocularity” advantage is also reduced with age

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

\[ \text{from Alpern, 1961} \]
Ageing: stimulus/response curves

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

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)

![Graph showing pupil diameter as a function of age for dark- and light-adapted conditions.](image)

From Kornsweig, 1954

Objective vs. Subjective accommodation
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.

Objective vs. subjective accommodation

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

WinHall and Glasser, 2008, 2009
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.

Pharmacologically-induced accommodation

Relaxed 52 yrs

Accommodated

4% pilocarpine
0.4 mm forward mvmnt
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

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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