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"160 years on. Is there any evidence supporting Helmholtz' mechanism of accommodation?"

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INTRODUCTION

Accommodation is a process of change that the eye undergoes to view near objects. Essentially a power change of the eye [1,2,3,4]. Although much research has tried to ascertain the mechanism of accommodation, this mechanism has still not been fully agreed upon [2,5,6,7,8]. This leads to the title of ‘theory’ in descriptions that have been put forward. The main accepted theory is that of Helmholtz. This theory has been around since 1855 [5,6] and is still considered as the most widely accepted model [6].

The theory of Helmholtz considers the following aspects that lead to accommodation:

- Lens is elastic
- Capsule is elastic [6]
- Ciliary muscle contracts
  - Moves anteriorly
  - Ciliary ring diameter reduces
- Zonules relax [6]

Due to the lack of tension now applied to the lens it is free to take up its accommodated state whereby:

- Lens thickens
- Lens surfaces steepen [9]
- Equatorial diameter reduces [2,5]

Not all will agree with this accepted theory, such as Schachar who has done much research into accommodation, whose theory implies that although zonules do relax on contraction of the ciliary body [7] this does not apply to the equatorial zonules. The equatorial zonules become tenser [9] and cause the central region of the lens to become steeper, but this is accompanied by a flattening of the periphery due to equatorial zonular tension and hence an increase in equatorial diameter [5].

Both theories, although similar in certain aspects, differ in what is expected to happen to parameters of the lens.

What is therefore being considered is whether there is still evidence in the current literature to support the widely accepted 1855 Helmholtz theory [10,11] when alternative suggestions with more advanced research techniques have been put convincingly forward [9] and the theory itself is fast approaching its 160th year.

In order to see if Helmholtz’ theory is still supported a review of the current literature was undertaken.

Of the studies found some reported effects on lens stretching. Although these are not giving parameters for the lens under accommodation, they are considered useful to demonstrate what occurs under zonular tension and therefore can be useful in determining that the opposite effect may occur on zonular relaxation.

The table opposite provides a summary of the findings within the papers supporting Helmholtz. The table opposite is created with titles that relate to the lens in the accommodative state, that would be expected parameter changes under Helmholtz’ theory [5]. However it must be stressed that some studies did not observe these changes directly and those with asterisks demonstrate the following changes that have been concluded utilising the experiments involving the lens in its unaccommodated state.

To elaborate on this summary table each item will be discussed considering each of the expected parameter changes that would be supportive of the Helmholtz theory.

CRYSTALLINE LENS THICKENS?

There is much support to indicate that the central crystalline lens thickens with accommodation [1,2,10,12-17]. There has been found a mean change of 0.09 +/-0.12mm per dioptre of response in 19 pre-presbyopic subjects with 3-dimensional MRI [10]. Another study using MRI found these increases in thickness in the accommodated lens to be 0.05 +/- 0.024mm per dioptre [18]. Scheimpflug imaging and use of a parametric model found these values to be 0.04mm per dioptre with accommodation [15] and in the study utilising both MRI and Scheimpflug images the rate of change was found to be 0.061 +/-0.03mm with the MRI and 0.045 +/-0.045mm with the Scheimpflug [16]. It can be seen that there are variable values here, but it does show that the thickness has been found to increase. Another study found thickness increase to be 0.33 +/- 0.06mm [1]. A finding of changes in lens thickness with accommodation is significantly reduced after the age of 50 and knowing that this is a presbyopic stage of life can mean that its inability to make this change can mean that the lens must therefore thicken to provide accommodation [12]. In application of tension on the zonules of primate lenses, the thickness was found to reduce, thereby demonstrating that in the relaxed zonular state the lens was of a thicker state [13]. In a geometric model showing parameter changes when a lens undergoes zonular tension the lens was found to decrease in thickness [2]. Hence further demonstrating that the lens without zonular tension may need to be thicker. Another paper providing results for a test geometries model found that the lens reduces in thickness when unaccommodated [14] and hence may be assumed to be thicker in its accommodated form.

Author and date	Lens elastic	Capsule elastic	Ciliary muscle moves anteriorly	Ciliary muscle moves inwards	Zonules relax	Lens diameter reduces	Crystalline lens thickens	Crystalline lens surface radii decrease
Kasthurirangan et al *(2011)*				Y	Y	Y	Y	Y
Kasthurirangan et al *(2011)*					Y*	Y*	Y*	Y*
Sheppard et al *(2011)*		Y			Y	Y	Y	Y
Ljubimova et al *(2008)*					Y*	Y*	Y*	Y*
Heron & Charman *(2004)*	Y	Y						
Strenk et al *(1999)*				Y	Y	Y	Y	
Hermans et al *(2007)*					Y	Y	Y*	Y
Jones et al *(2007)*					Y	Y	Y	Y
Hermans et al *(2009)*	Y	Y			Y	Y	Y	Y
Reilly & Ravi *(2010)*					Y*	Y*	Y*	Y*

***These items were demonstrated by the opposite effect on the lens being unaccommodated.**

CRYSTALLINE LENS SURFACE STEEPENS (REDUCTION IN SURFACE RADII)?

There is also quite a lot of evidence to suggest that the crystalline lens surfaces do steepen [1,2,10,13-16]. Radii of both the crystalline lens surfaces have been shown to reduce, steepening the lens surfaces [10]. Results for the change in posterior surface radius have been reported as a decrease of 0.58 +/- 0.3mm [1]. The use of Scheimpflug images with a parametric model found anterior surface decrease to be 0.14mm per dioptre and 0.07mm per dioptre for the reduction of the posterior surface radii [15]. Using MRI and Scheimpflug images have produced results of a reduction of -0.51 +/- 0.5mm and -0.14 +/- 0.13mm per dioptre for the anterior and posterior surfaces respectively for the MRI, and -0.64 +/- 0.1mm per dioptre for the anterior surface and -0.16 +/-0.1 mm per dioptre change for the posterior surface with Scheimpflug imaging [16]. Again, here there are variable results, but do provide evidence that the crystalline lens steepens. When applying tension to the zonules of primate lenses to simulate relaxation of the ciliary body the lenses were found to flatten from an accommodated more steepened state [13]. In a geometric model showing parameter changes when a lens undergoes zonular tension the surface of the lens was found to flatten [2], further demonstrating that the lens without zonular tension would be steeper. An increase in lens surface radii was also concluded when applying geometries for an unaccommodated eye [14] and hence again indicative that the lens would be more rounded and steeper in its accommodative state.

The two above parameter changes put forward by Helmholtz [5] are not necessarily disputed by other researchers and theorists [2]. The increase in lens thickness is a generally accepted view [1,5,6,8,9,18,] as is a steepening of the lens surfaces [1].

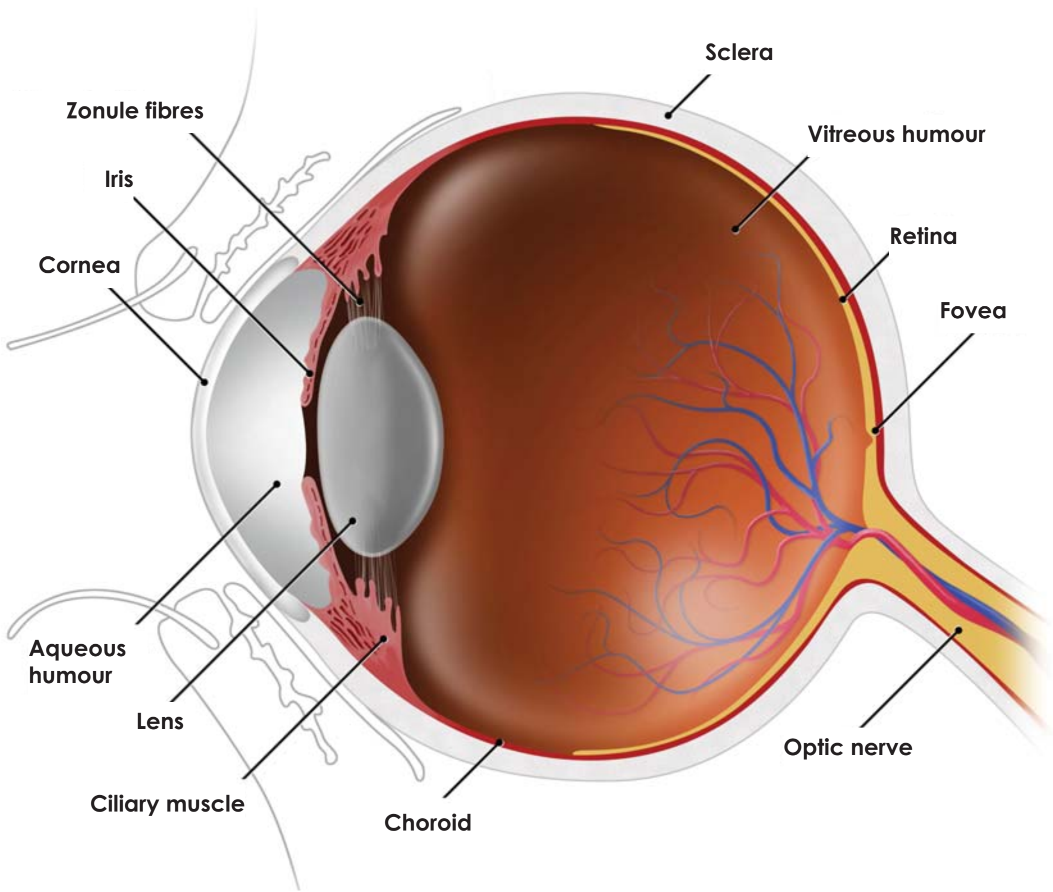
Therefore what needs to be ascertained if there is evidence to support the other parameter changes expected when applying Helmholtz' theory on what occurs during accommodation.

LENS ELASTIC?

A study using MRI and Scheimpflug imaging demonstrated that the volume of the lens was shown to be preserved and assumed to have elastic properties in order to deform. They observed changes in surface area on the capsule and this led them to conclude that the capsule is also elastic in nature [16]. In an analysis of accommodative responses in nineteen observers it was suggestive that the ciliary body maintains its function when the accommodative response has been reduced. This analysis has led to the conclusion that it is the loss of the elastic properties in the lens and capsule that give rise to presbyopia [19] and hence the lens is elastic. This ability for the ciliary muscle to still contract with age has also been found in a study using 2-dimensional MRI [12] .

CAPSULE ELASTIC?

Elasticity in the capsule has been demonstrated by observing the reduction in surface area of the capsule in comparison to any volumetric changes. It has been found that as the lens volume



increases when surface area decreases being indicative of the capsule being elastic in nature [10]. Another study using MRI and Scheimpflug imaging demonstrated that the volume of the lens was shown to be preserved and assumed to have elastic properties in order to deform. They, like Hermans et al, also observed changes in surface area on the capsule concluding that both the lens and the capsule are elastic in nature[18]. A study which observed responses in nineteen observers with an accommodative stimulus suggested that the ciliary body function is not impaired with age and this was indicative that the capsule had elastic properties [19]. As already mentioned, this ability to still contract with age has also been found in a study using 2-dimensional MRI [12].

LENS EQUATOR MOVES INWARDS *(REDUCTION IN EQUATORIAL DIAMETER)*?

Results have been provided to show a mean change of -0.14 +/-0.17mm per dioptre of response using 3-dimensional MRI10. Another study utilising MRI found these changes to be 0.067 +/- 0.03mm per dioptre [17]. The results when using Scheimpflug images with the parametric model were 0.05mm per dioptre [15]. With MRI the results found were -0.037 +/-0.004mm per dioptre [16]. As with previous discussed parameters the results differ but do suggest the equatorial diameter reduces. Another study had results of 0.32 +/- 0.04mm for the equatorial diameter [1]. Referring to the primate study where lenses were stretched, this showed an increase in equatorial diameter, thereby demonstrating that it would be reduced in the zonular relaxed state [13]. Another study that used a geometrical model to simulate a lens when zonular tension is present found that the lens equator moved towards the ciliary body [2]. This again demonstrates a decrease would occur in the relaxed zonular state. Another study applying geometric tests demonstrated that the lens' equatorial radius does increase in its unaccommodated state [14], therefore indicating that upon accommodation this parameter should reduce. A study in 1999 observed that the len's ability to decrease its equatorial thickness when it had reached the age of 50 years [12] and this therefore may be indicative that the lens has to reduce in diameter to provide accommodation as at this age the subjects were presbyopic.

ZONULES RELAX?

It was suggested that the zonules relaxing caused the lens to expand [10]. When considering if the zonules relax, it can potentially be assumed that if the lens equatorial diameter reduces then the zonules may therefore be in a relaxed state. As Schachar states in his theory that the equatorial zonules increase in tension [18] and the lens itself increases in diameter [5] then this theory can be used to infer that the lens not under tension will be in a relaxed state and the diameter may reduce when under no tension at all. Therefore in the table above, those studies that observed a decrease in equatorial diameter are considered potentially demonstrating that the zonules are to relax for this parameter change to be observed. This parameter change was observed or concluded from other observations in 9 of the 10 studies used [1,2,10,12-16]. In addition to this assumption, one study applied tensile stress on the zonules of primates and noticed that this stress caused the lens to flatten and elongate. Therefore this can be said to demonstrate that when the starting point of the thickened and more curved state of the lens is apparent is when the zonules are in their relaxed state [13]. The move towards the ciliary body of the lens equator undergoing zonular tension in the study utilising a geometric model also helps demonstrate that the lens would be in its accommodative state when the zonules are relaxed [2].

CILIARY MUSCLE MOVES INWARDS *(REDUCTION IN CILIARY RING DIAMETER)?*

Results have been found for a decrease of 0.44 +/- 0.17mm in the ciliary ring diameter [1] and observations in a study utilising MRI showing ciliary muscle diameter changes with age found it also changes with accommodation [12].

CILIARY MUSCLES MOVES ANTERIORLY?

This is one area in which no evidence has been found.

CONCLUSION

There is certainly recent evidence to suggest that the parameter of lens thickness increases and the crystalline lens steepens, supporting Helmholtz' theory. However, current theorists do not appear to dispute these two parameter changes. The case for the lens and the capsule having elastic properties does have support in the current literature as does the reduction in equatorial diameter. Particularly supportive is the study conducted with three dimensional MRI. MRI allows images to be obtained of structures within the human body in high quality without the limitations of other measurement techniques [1]. The zonules undergoing tension in the lens's unaccommodated state and relaxation in its accommodated state does also appear to have support from a couple of experiments and a geometrical model. It can also be assumed studies which observed or concluded a reduction in equatorial diameter would have this occur when the zonules are in their relaxed state. However, the aspect of the zonules 'relaxing' was not found to be an item that had been directly and dynamically observed in the literature. However, analysis of the current literature does allow support for this parameter change put forward by Helmholtz. There is support in the current literature regarding the reduction in the ciliary ring diameter, however only two suitable studies were found to support this and no evidence was found to support the anterior movement of the ciliary muscle. Modern theorists are providing further evidence of the mechanism of accommodation and improving our understanding. Nevertheless, evidence has been found within the current literature to still support Helmholtz' original observations, nearly 160 years on.

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APPENDIX I

Papers used within the review to acquire recent evidence to support Helmholtz's theory.

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