retina in relation to the cornea. For example, an increase in axial length increases myopia of an eye by increasing the distance between the cornea and retina.

[0005] While the defocus of images can play a role in choroidal thickness and changes in the axial length of the eye, the prior approaches are less than ideally suited to address to refractive error of the eye related to axial length. Although pharmaceutical treatments have been proposed to treat myopia associated with axial length growth, these treatments can have less than ideal results and have not been shown to safely treat refractive error in at least some instances. Although light has been proposed as a stimulus to alter the growth of the eye, at least some of the prior devices can provide less than ideal results. Also, the time of treatment can be longer than would be ideal, and at least some of the prior approaches may be more complex than would be ideal.

[0006] Therefore, new approaches are needed to treat refractive error of the eye that ameliorate at least some of the above limitations of the prior approaches.

SUMMARY

[0007] The presently disclosed methods, devices and apparatus provide improved treatment of refractive error with decreased treatment times. In some embodiments, the stimulus comprises one or more of a spatial frequency distribution or a ratio of stimulus intensity to background illumination intensity to promote an improved response. In some embodiments, the stimulus is presented at an appropriate time of day to promote the response.

[0007a] In an aspect, the present disclosure provides an apparatus for treating refractive error of an eye, the apparatus comprising: a plurality of stimuli; and one or more optics to image the plurality of stimuli anterior or posterior to a peripheral portion of the retina to form a plurality of defocused images on a peripheral portion of the retina; wherein the plurality of stimuli and the one or more optics are arranged to reduce interference with a central vision of the eye.

[0008] An apparatus to treat refractive error of the eye comprises one or more optics configured to project stimuli comprising out of focus images onto the peripheral retina outside the macula. While the stimuli can be configured in many ways, in some embodiments the stimuli are arranged to decrease interference with central vison such as macular vision. The stimuli can be out of focus images may comprise an amount of defocus within a range from about 2 Diopters (“D”) to about 6 D, and the range can be from about 3 D to about 6D. In some embodiments, the brightness of the stimuli is

greater than a brightness of background illumination by an appropriate amount such as at least 3 times the background brightness. In some embodiments, each of a plurality of stimuli comprises a spatial frequency distribution with an amplitude profile having substantial spatial frequencies within a range from about range of $1X10^{-1}$ to $1X10^{1}$ cycles per degree. In some embodiments, each of the stimuli is sized and shaped with an intensity profile distribution so as to provide spatial frequencies to promote a response to

CLAIMS

WHAT IS CLAIMED IS:

1. An apparatus for treating refractive error of an eye, the apparatus comprising:

a plurality of stimuli; and

one or more optics to image the plurality of stimuli anterior or posterior to a peripheral portion of the retina to form a plurality of defocused images on a peripheral portion of the retina;

wherein the plurality of stimuli and the one or more optics are arranged to reduce interference with a central vision of the eye.

2. The apparatus of claim 1 wherein a brightness of said plurality of defocused images is higher than a brightness of background illumination by a factor of at least 3, optionally at least 5 times the brightness of background illumination, optionally within a range from 3 to 20 times the brightness of background illumination and further optionally within a range from 5 to 15 times the brightness of background illumination.

3. The apparatus of claim 1 wherein each of said plurality of defocused images comprises an intensity profile distribution, the intensity profile distribution comprising one or more peaks distributed around an inner portion with a decreased intensity relative to the one or more peaks.

4. The apparatus of claim 3, wherein the one or more peaks comprises a plurality of peaks and wherein the inner portion is located between the plurality of peaks.

5. The apparatus of claim 4, wherein the plurality of peaks comprises four peaks and the inner portion is located between the four peaks.

6. The apparatus of claim 5, wherein the inner portion comprises a cross extending between the four peaks.

7. The apparatus of claim 3, wherein the one or more peaks comprises an annular peak and wherein the inner portion is located within the annular peak.

8. The apparatus of claim 1 wherein each of said plurality of defocused images comprises a polychromatic icon on a darker background to provide contrast and optionally wherein the polychromatic icon comprises a white icon and said darker background comprises a substantially black background.

9. The apparatus of claim 1, wherein each of the plurality of stimuli comprises a length, edges, and an intensity profile distribution to generate spatial frequencies in a range of $1X10^{-1}$ to $2.5X10^{1}$ cycles per degree as imaged into the eye

anterior or posterior to the retina and optionally within a range from $1X10^{-1}$ to $1X10^{1}$ cycles per degree.

10. The apparatus of claim 1 wherein said plurality of stimuli as imaged in the eye comprises a spatial frequency distribution providing a decrease in spatial frequency amplitude with an increase in spatial frequency for a range of spatial frequencies from about $1X10^{-1}$ to about $2.5X10^{1}$ cycles per degree and optionally from $1X10^{-1}$ to about $5X10^{0}$ cycles per degree.

11. The apparatus of claim 10, wherein the decrease in spatial frequency intensity is within a range from $1/(\text{spatial frequency})^{0.5}$ to $1/(\text{spatial frequency})^{2}$ for the spatial frequency amplitude in arbitrary units and optionally from 1/(spatial frequency) to $1/(\text{spatial frequency})^{2}$ for the spatial frequency amplitude in arbitrary units.

12. The apparatus of claim 10, wherein the range of spatial frequencies is from about $3X10^{-1}$ to about $1.0X10^{1}$ cycles per degree and optionally within a range from about $3X10^{-1}$ to about $2.0X10^{0}$ and further optionally from about $3X10^{-1}$ to about $1.0X10^{0}$.

13. The apparatus of claim 1, wherein each of the plurality of stimuli as imaged in the eye is overlaid onto a substantially uniform grey background, said each of the plurality of stimuli comprising a white icon, such that said icons have a total length of edges that generate features of spatial frequency predominantly in a range from $1X10^{-1}$ cycles per degree to $2.5X10^{1}$ cycles per degree and optionally within a range from $1X10^{-1}$ cycles per degree to $1X10^{1}$ cycles per degree.

14. The apparatus of claim 1, wherein each of the plurality of stimuli as imaged in the eye comprises a polychromatic icon having an edge profile on a background that generates features of spatial frequency predominantly in a range from $1X10^{-1}$ cycles per degree to $2.5X10^{1}$ cycles per degree and optionally within a range from $1X10^{-1}$ cycles per degree to $1X10^{1}$ cycles per degree.

15. The apparatus of claim 1 wherein each of the plurality of stimuli comprises a global contrast factor greater than 0.7 and optionally greater than 8.0.

16. The apparatus of claim 1, further comprises a sensor to measure a size of the pupil and further comprising a processor configured with instructions to direct the optical stimulus toward the eye in response to the size of the pupil and optionally wherein the size of the pupil comprises a diameter of the pupil.

17. The apparatus of claim 16, wherein the processor is configured to adjust one or more of an intensity or a duration of the optical stimulus in response to the size of the pupil.

18. The apparatus of claim 16, wherein the sensor comprises a sensor array and optionally wherein the sensor array comprises a sensor array of a camera.

19. The apparatus of claim 16, wherein the plurality of stimuli is configured to allow dilation of a natural pupil when illuminated with plurality of stimuli.

20. The apparatus of claim 1, wherein plurality of stimuli is configured to constrict the pupil by no more than one millimeter (mm) when the stimulus is provided as compared to a diameter of the pupil when the stimulus has not yet been provided.

21. The apparatus of claim 1, wherein the pupil comprises a stimulation diameter when the eye is exposed to the plurality of stimuli and wherein the eye comprises a photopic diameter when the eye is exposed to photopic viewing conditions without the plurality of stimuli, and wherein the photopic diameter is at least one millimeter smaller than the stimulation diameter and optionally wherein the photopic viewing condition comprises a luminance of at least 3 Candela (cd) per meter squared (m^2).

22. The apparatus of claim 1, wherein the stimulus is configured to illuminate the peripheral portion of the retina with an eccentricity of greater than 35 degrees with a pupil of the eye dilated by at least about 1 millimeter as compared to photopic illumination while the stimulus is provided to the peripheral retina with the eccentricity of greater than 35 degrees.

23. The apparatus of claim 1, wherein no more than 10% of a total amount of energy of the plurality of stimuli is directed to a fovea of the eye in order to decrease constriction of the pupil in response to the plurality of stimuli and optionally no more than 5% of the total amount and optionally no more than 1% of the total amount.