Ametropia and visual acuity

Introduction

The human eye's optical system can be thought of in terms of two elements. The majority of the focusing of light is done by a fixed refractive surface - the cornea - but there is also a biconvex crystalline lens whose power can be changed by the relaxation of zonular tension to ensure that light that would converge behind the retina is focussed onto it. This adjustment is known as accommodation. The change in power occurs from the distortion of the lenticular shape: making the lens more convex. If the eye is not ametropic, parallel light (in practical terms from objects over 6m away) should be focused onto the retina when the lens is not accommodating at all. (Weale, 1992)

Visual acuity testing is performed to ascertain fitness for visual tasks, to determine the power required of corrective lenses and to provide criteria for visual components of products to meet. There are many different visual acuity tests, but the one that will be used here is the Landolt C test, following the protocol from BS EN ISO 8596:2009 (British Standards Institute, 2009). The optotypes used are circular rings of diameter *d*, with a gap out of the ring measuring *d/5*, and the width of the ring also measuring *d/5*, as seen in *Figure 1*. The optotype can be presented with the gap in 8 positions: top, left, bottom and right, as well as the diagonals in between these, as seen in *Figure 2*.

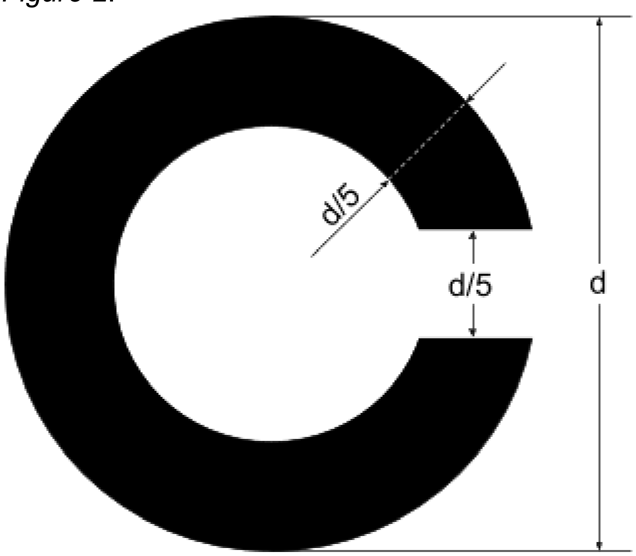

Figure 1: Landolt C optotype format - adapted from BS EN ISO 8596:2009 (BSI, 2009)

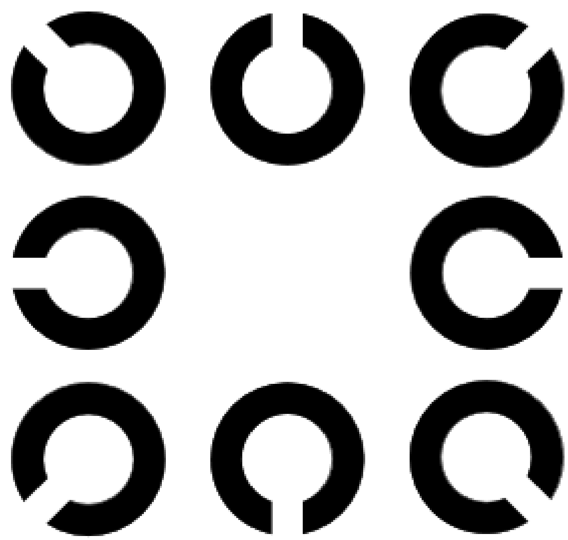

Figure 2: Landolt C possible optotype orientations

This protocol is particularly useful as a common test across cultures and ages because it does not require the testee to have any understanding of a particular language, unlike more traditional vision tests such as the Snellen test. The optotype itself remains the same, only its orientation changes, again different from language-based tests where the optotypes differ in shape, some being easier to differentiate than others.The difference in acuity between different levels is also more consistent and easily quantified than many other protocols (Ricci, Cedrone and Cerulli, 1998). These factors make the Landolt C test more valid and reliable than the other common visual acuity test protocols.

The visual acuity grading is done on a scale from 0 to 2, where 1 is considered normal vision. The number is calculated as "the reciprocal of the gap width measured in minutes of arc" (British Standards Institute, 2009). From this source we see that the expected resolution of the human eye at its maximum (with light focussing on the fovea) is 1 minute of arc.

Ametropia occurs when there is a mismatch between the optical power of the eye and the distance between the optical elements and the retina. In comparison to emmetropia, where functionally parallel light coming into the relaxed eye from a point source will converge to a focal point on the retina, myopia occurs when the focal point occurs between the optical elements and the retina, and hypermetropia occurs when the focal point is behind the retina (although light does not actually reach this point). Parallel light from a point source entering a myopic or hypermetropic eye will fall on the retina in a blur shape that depends on the aperture (the pupil) - so a blur circle for humans (Helmholtz and Southall, 1962). As light comes from multiple points in the environment, the blur circles overlap, resulting in what would be recognised as a blurry or out of focus image.

Method

Equipment

- Spherical lenses in varying powers (dioptres):
    - Concave: +3.00, +2.00, +1.50, +1.00, +0.50
    - Convex: -0.50, -1.00, -1.50, -2.00, -3.00
- A computer running FrACT software
    - with a keyboard that preferably has a numeric keypad
- A chair
- A tape measure

Procedure

For the purposes of this trial, only one of the participant's eyes was tested. At all times during the testing phase they were required to cover their other eye with the corresponding hand. Where lenses were used, they were held in place by the participant's spare hand, with their thumb contacting a consistent place on their nose to keep the distance from the eye to the lens relatively steady and constant. The participant was asked to familiarise themself with the lenses before they were tested with them, and they were encouraged to find their near and far focal points by identifying the closest and furthest distances at which they could focus. Text was used as a target for the near focal point.

The participant was sat 4 metres away from the screen on which the optotype was displayed, and FrACT's settings were altered to account for this. They covered one eye and held up a lens as described earlier. The FrACT program showed optotypes of different sizes, located centrally on the screen. For each, the participant had to say which of the 8 positions in *Figure 2* they thought the gap was in: "top", "top-right", "right", "bottom-right", "bottom", "bottom-left", "left" and "top-left". They had to give an answer and were not allowed to pass. The tester pressed the corresponding key on the numeric keypad on the computer's keyboard. Following the BSI protocol, the test ended when the participant correctly answered less than approximately 60% (see BS EN

ISO 8596:2009 for specifics) of the ring positions at a particular size (British Standards Institute, 2009). Once the test was ended, the program presented the tester with a visual acuity score corresponding to the level before that at which the test ended. This was noted, and the test was then repeated with the next lens. The tests were done once in the following order of correction: +3.00, +2.00, +1.50, +1.00, +0.50, 0, -0.50, -1.00, -1.50, -2.00, -3.00, where every condition except 0 used the corresponding lens, and 0 used no lens, but still kept the untested eye covered. The lighting conditions and screen contrast were kept constant throughout, as these have been shown to affect visual acuity scores in Landolt C tests (Johnson and Casson, 1996).

Results

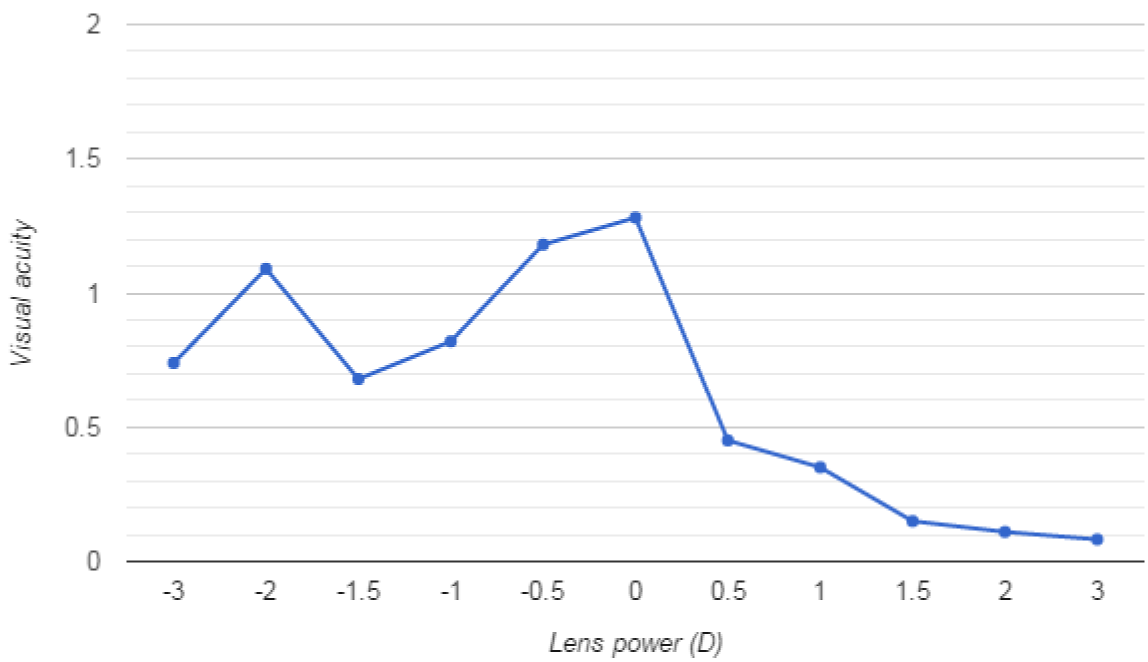

Figure 3: Graph showing the change in visual acuity with different lens powers

As can be seen on the graph in *Figure 3*, the greatest visual acuity is 1.28 at 0 dioptres, where no lens was used. This suggests that the participant, who wore no glasses or contact lenses during the trial, has no refractive error. The graph is not symmetrical around 0: visual acuity drops off suddenly as the lenses become more positive, simulating greater myopia and bringing the focal point closer to the optical elements. As the power of the corrective lens becomes negative (it diverges the light), the drop-off in acuity is not as sharp. This is likely due to the accommodative power of the participant's crystalline lens.

There is a spike in visual acuity with the -2 lens, although this can possibly be explained by an element of chance - as the participant has to state a direction of the 'C', it is possible that they guessed the correct direction multiple times. The standard requires a minimum of 3/5 correct answers to reach that acuity grade (British Standards Institute, 2009). It is also possible that any number of individual characteristics may have come into play. The participant may have been less distracted by their environment, they may have had a step change in interpreting the blur pattern they saw (Bondarko and Danilova (1997) suggest that there is an element of training in determining Landolt C results), or they may have simply been trying harder to accommodate as much as possible.

Discussion

If the participant were more myopic, the points on the right side of the graph would drop off faster and the highest point would move to the left, as the diverging lenses would start correcting for the myopia rather than causing accommodation to be required. Conversely, if the participant were more hypermetropic, the high point would move to the right as the positive lenses brought the focal point back onto the retina. There would likely still be a long tail on the left as the eye would still be able to accommodate a significant amount.

The participant is 19 years old, and so their lens will still be relatively flexible, which allows for a large degree of accommodation. With age, the lens becomes more presbyopic: more tissue grows on it, and its density increases; it will decrease in elasticity, correspondingly diminishing its accommodative power (Spector, 1982; Weale, 1963). Along with a loss of accommodative amplitude, the presbyopic lens changes in shape, resulting in an increased focal length and a more hypermetropic eye (Glasser and Campbell,1998; Weale, 1992). As a result, if the same test was performed a couple of decades later, a more symmetrical graph, with the peak moved to the right, would be expected. This same development of the lens, along with other processes such as generation of high molecular weight protein aggregates, decrease its transparency, and increase the internal light scattering (Spector, 1982) - leading to an expected diminishing of visual acuity at all levels. This theoretical prediction is empirically corroborated by studies such as that by Gittings and Fozard (1986).

The process of familiarising themself with the lenses would have given the participant a rough idea of their own refractive error as it would have allowed them to find a lens that was subjectively the clearest at short distances while still allowing them to focus sharply to optical infinity. The participant's refractive error would be approximately the negative of the value of that lens, as it is returning the eye to emmetropia; the powers of the eye and the corrective lens cancel to 0.

To conclude, the participant's visual acuity is at its best without external correction, drops off sharply when myopia is simulated and drops off slightly but is largely accommodated for when hypermetropia is simulated. As they age, the participant's visual acuity will diminish across the board, but will lessen most greatly where accommodation is required.

References

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Appendix A: Visual acuity raw data

Lens power	Visual acuity
-3	0.74
-2	1.09
-1.5	0.68
-1	0.82
-0.5	1.18
0	1.28
0.5	0.45
1	0.35
1.5	0.15
2	0.11
3	0.082