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# Spectacle lens compensation in the pigmented guinea pig

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ABSTRACT

When a young growing eye wears a negative or positive spectacle lens, the eye compensates for the imposed defocus by accelerating or slowing its elongation rate so that the eye becomes emmetropic with the lens in place. Such spectacle lens compensation has been shown in chicks, tree-shrews, marmosets and rhesus monkeys. We have developed a model of emmetropisation using the guinea pig in order to establish a rapid and easy mammalian model. Guinea pigs were raised with a +4D, +2D, 0D (plano), −2D or −4D lens worn in front of one eye for 10 days or a +4D on one eye and a 0D on the fellow eye for 5 days or no lens on either eye (littermate controls). Refractive error and ocular distances were measured at the end of these periods. The difference in refractive error between the eyes was linearly related to the lens-power worn. A significant compensatory response to a +4D lens occurred after only 5 days and near full compensation occurred after 10 days when the effective imposed refractive error was between 0D and 8D of hyperopia. Eyes wearing plano lenses were slightly more myopic than their fellow eyes (−1.7D) but showed no difference in ocular length. Relative to the plano group, plus and minus lenses induced relative hyperopic or myopic differences between the two eyes, inhibited or accelerated their ocular growth, and expanded or decreased the relative thickness of the choroid, respectively. In individual animals, the difference between the eyes in vitreous chamber depth and choroid thickness reached ±100 and ±40 μm, respectively, and was significantly correlated with the induced refractive differences. Although eyes responded differentially to plus and minus lenses, the plus lenses generally corrected the hyperopia present in these young animals. The effective refractive error induced by the lenses ranged between −2D of myopic defocus to +10D of hyperopic defocus with the lens in place, and compensation was highly linear between 0D and 8D of effective hyperopic defocus, beyond which the compensation was reduced. We conclude that in the guinea pig, ocular growth and refractive error are visually regulated in a bidirectional manner to plus and minus lenses, but that the eye responds in a graded manner to imposed effective hyperopic defocus.



## 1. Introduction

If defocus is imposed on a growing eye by a spectacle lens, the rate of ocular elongation and emmetropisation is modified, so that the eye eventually becomes emmetropic with the lens in place. When hyperopic defocus is imposed with a negative lens, the eye elongates more rapidly and becomes relatively myopic (when measured without the lens in place). Conversely, when myopic defocus is imposed with a positive lens, the eye decreases its rate of ocular elongation and becomes hyperopic relative to untreated eyes (Fig. 1). This phenomenon is known as *spectacle lens compensation.* Compensation to both plus and minus spectacle lenses was first shown in the chick (Schaeffel, Glasser, & Howland, 1988); and subsequently in the tree shrew (Siegwart & Norton, 1993); rhesus monkey (Hung, Crawford, & Smith, 1995; Smith & Hung, 1999) and marmoset (Graham & Judge, 1999). Preliminary reports suggest that the guinea pig also compensates for spectacle lenses (McFadden, Howlett, & Mertz, 2004; McFadden & Wallman, 1995).

The chick eye compensates to an extraordinary range of lens powers from −10D to +15D (Irving, Sivak, & Callender, 1992) while other species studied compensate to a comparably smaller range, particularly for plus lenses (macaque: −3D to +3D, Hung et al., 1995; Smith & Hung, 1999; Smith, Hung, & Harwerth, 1999; marmosets: −8D to <+4D, Graham & Judge, 1999; tree shrew: −10D to +4D, Metlapally & McBrien, 2008). The magnitude of the ocular change within these ranges is well matched to compensate for the effective power of the imposed defocus.

In the chick eye, the initial compensatory response to plus or minus lenses involves a rapid thickening or thinning of the choroid, respectively, which repositions the photoreceptor plane to partially compensate for the imposed defocus (Wildsoet & Wallman, 1995). During +15D lens-wear the choroid can thicken 2.6-fold, expanding as much as 300 μm (Wildsoet & Wallman, 1995) which can account for up to 9D of change in the refractive error. After sev-

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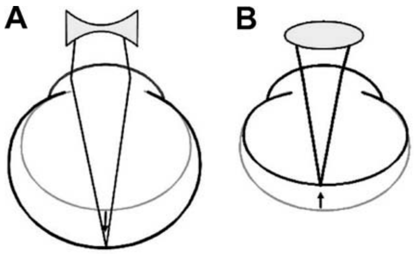


**Fig. 1.** Spectacle lens compensation. (A) The eye expands to compensate for a negative lens, and (B) reduces its rate of growth to compensate for a positive lens.

eral days, the choroidal response dissipates, and is substituted by a slower compensatory change in ocular length. In other species studied, bidirectional changes in the thickness of the choroid have also been found to precede ocular length changes, but they are significantly smaller in magnitude. In macaque monkeys wearing a plus lens on one eye and a minus lens over the other eye, the maximum difference in the thickness of the choroid was 40–50 μm, equivalent to only 0.5D of the refractive error disparity (12D) and accounted for less than 15% of the compensatory anisometropia (Hung, Wallman, & Smith, 2000). In the tree shrew, the choroid thins by 15 μm after five days of −5D lens-wear (Gentle & McBrien, 1999), accounting for 0.7D, or 11% of the refractive error difference between the lens-wearing and fellow eye. Choroidal thickening associated with eyes recovering from myopic defocus arising from previous form deprivation is also much larger in chicks (+400 μm, Wallman et al., 1995) compared to tree shrews (+10 μm, Gentle & McBrien, 1999), marmosets (+50 μm, Troilo, Nickla, & Wildsoet, 2000), macaques (+23μm, Hung et al., 2000; Qiao-Grider, Hung, Kee, Ramamirtham, & Smith, 2004) or guinea pigs (+18 μm, Howlett & McFadden, 2006).

Given the difference between the avian, mammalian and primate choroids, a difference in the magnitude of the choroidal response might be expected. In particular, most of the choroidal volume of the chick consists of a dilated lymphatic system, presumably due to fluid accumulation when the eye experiences myopic defocus (De Stefano & Mugnaini, 1997). In contrast, the lymphatic capillaries of the primate occupy a much smaller proportion of the choroid (Hung et al., 2000). In the current study, we sought to determine the magnitude of the response of the guinea pig eye to low powered spectacle lenses, and to determine the nature of the choroidal response. The guinea pig retina, like the avian retina is also avascular.

It is reported here, that spectacle lenses altered the ocular development and choroidal thickness of the guinea pig eye in a manner dependent upon both the sign and the magnitude of the imposed lens power. Some of this work has been previously presented in abstract form (Howlett & McFadden, 2002; McFadden & Howlett, 2002).

## 2. Methods

### 2.1. Animals and housing

Fifty-six guinea pigs (*Cavia porcellus*, pigmented, tricoloured) were reared and housed with their mothers and littermates as previously described (Howlett & McFadden, 2007; McFadden et al., 2004). In brief, animals were housed in opaque hard plastic boxes ($65 \times 45 \times 20$ cm) with wire mesh lids which allowed unrestricted vision to the room ceiling with the exception of a small opaque section ($38 \times 18$ cm) located at the rear of each lid. The lighting was provided by ceiling fluorescent lights with a 12/12 hour day/night cycle. All procedures were approved by the University of Newcastle under Australian legislative requirements and were in accordance with NIH Guidelines.

### 2.2. Procedures

Guinea pigs were raised from 2 to 3 days of age with a +4D ($n = 8$), +2D ($n = 6$), 0D ($n = 11$) (plano), −2D ($n = 6$), or −4D ($n = 12$) lens worn on one eye for 10 days (Experiment 1, monocular lens-wear) or with a +4D on the left eye and 0D on the right eye for 5 days ($n = 7$, Experiment 2, binocular lens-wear) or no lens on either eye (age-matched controls, $n = 6$). The age that lenses were worn was during the most rapid period of emmetropisation (Howlett & McFadden, 2007). Refractive error and axial parameters were measured in both eyes after the lens-wear period (at 12–13 days of age in Exp. 1 and the age-matched controls, and at 7 days of age in Exp. 2). Additionally, in thirty guinea pigs in Experiment 1 ($n = 6$ for each lens group) the refractive error of both eyes was also measured immediately prior to lens-wear.

#### 2.2.1. Lenses and their application

Concave lenses made of polymethylmethacrylate (diameter, 12mm; optic zone, 10.5–11.5mm; back optic radii, 8mm) were worn in front of the eye with the distance from the cornea to the lens apex being approximately 5mm. The effective power ($F_e$) of the +4D, +2D, −2D and −4D lenses at the cornea was +4.08, +2.02, −1.98 and −3.92D, respectively (approximated as $F_e = F/(1 - d * F)$ where $F$ is the nominal lens power in $D$, and $d$ is the distance of the lens from the corneal vertex in m). For convenience, lens power is referred to in terms of the nominal rather than the effective power of the lenses. Lenses were attached using Velcro®, two arcs of which were glued above and below the eye (Fig. 2A) while the animal was briefly anaesthetised with halothane (induction: 5%, maintenance: 1–2%, oxygen flow rate: 1 L/min). The following day, lenses attached to a ring backed with Velcro, were attached onto the matching arcs (Fig. 2B). Lenses were worn continuously except when they were removed for cleaning which took up to 2 min, 3 times/day. During cleaning animals were placed in the dark. Soft tape was applied to the back foot ipsilateral to the lens-wearing eye to reduce damage to the lens from scratching.

#### 2.2.2. Refractive error

Refractive error was measured by streak retinoscopy in hand-held, awake, cyclopleged animals as previously described (Howlett & McFadden, 2007; McFadden et al., 2004). Cycloplegia was induced with 2–3 drops of 1% cyclopentolate hydrochloride (Cyclogyl™, Alcon). Refractive errors are presented as the mean refractive error in the horizontal and vertical meridians (see Fig 1 in Howlett & McFadden, 2006). Refractive error data was not corrected for any possible artefact of retinoscopy, which is relatively small in the guinea pig (i.e. 0.73D at 12 days, 0.69D at 30 days of age, Howlett & McFadden, 2007).

#### 2.2.3. Ocular dimensions

The dimensions of the eye on the optic axis were measured using ultrasound (20 MHz) in anaesthetised guinea pigs (1–2% Hal-

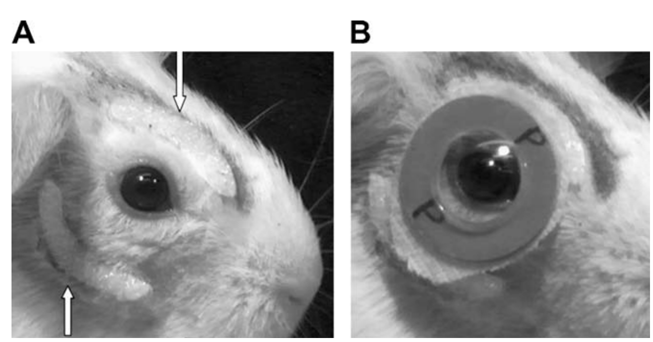


**Fig. 2.** Lens attachment. (A) Lenses were attached to arcs made of velcro® (white arrows). (B) Lens with matching velcro® base in place over the eye.