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Reducing the lag of accommodation by auditory biofeedback: A pilot study

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ABSTRACT

The purpose of this study was to investigate whether a reduction of the accommodative lag is possible by training the accuracy of accommodation using auditory biofeedback. Accommodation responses were measured in thirty-one young adults with myopia for dioptric target distances of 2.0, 2.5, and 3.0 D using an eccentric infrared photorefractor. For the biofeedback training, subjects were randomly assigned to an experimental (n = 15) or a control group (n = 16). Subjects of the experimental group were provided with two tones while fixating a target, one tone was related to their accommodative response and the second to the target distance. Their task was to match these tones. The control group did not receive any auditory biofeedback. Two different training methods were applied, a continuous training of 200 s, and ten consecutive sessions of 20 s each. The training effects on the lag of accommodation (change Δ) were highly variable. Regarding the entire study group, the observed change in the accommodative lag was greater at closer distances, while no difference between the two training methods was revealed. Nevertheless, seven experimental subjects reduced their lag by $\geqslant$0.3 D (3.0 D target distance: $\Delta_{long} = -0.29 \pm 0.20$ D, $\Delta_{short} = -0.24 \pm 0.21$ D). This reduction was also seen in two control subjects. Remeasurement revealed that the average training effect cannot be preserved over a period of 5–7 days. The current investigation has shown that the accuracy of accommodation can be trained in some subjects using auditory biofeedback for target distances of 2.5 D or closer.

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1. Introduction

Myopia is the most common refractive error in the younger population with increasing worldwide prevalence (Pan, Ramamurthy, & Saw, 2012; Vitale, Sperduto, & Ferris, 2009; Williams et al., 2015; Wolfram et al., 2014).

Moreover, as myopia raises the risk of serious eye diseases like retinal detachment or glaucoma, it has become a public health problem (Dandona & Dandona, 2001), and research has been challenged to understand the mechanisms of its development and progression. The aetiology of myopia however is multi-faceted. A hint for a possible relation between myopia and near work was revealed with the discovery that an increased prevalence of myopia is associated with the intensity and the amount of time spent reading as well as the educational level (Morgan & Rose, 2005, 2013; Saw et al., 2001, 2007). One hypothesis to explain the link to near work and reading is that accommodation is insufficient at close target distances ("lag of accommodation") so that the focal plane ends up behind the retina (Charman, 1999; Gwiazda, Thorn, Bauer, & Held, 1993). This lag of accommodation is a normal behaviour during near-vision activities. However, larger accommodative lags result in larger hyperopic defocus and could therefore be a trigger for axial elongation of the eye. It is known from animal experiments that imposed hyperopic defocus promotes axial eye growth and myopia (monkeys: Hung, Crawford, & Smith, 1995; Smith & Hung, 1999; chickens: Irving, Callender, & Sivak, 1991; Schaeffel, Glasser, & Howland, 1988; tree shrews: Norton, Amedo, & Siegwart, 2010; Siegwart & Norton, 1999). Further support for this hypothesis came from findings that myopic children display a larger lag of accommodation (Gwiazda et al., 1993). Some investigators have provided evidence against the hypothesis that a higher lag of accommodation is the cause of myopia development (Gwiazda, Thorn, & Held, 2005; Koomson et al., 2016; Mutti et al., 2006; Rosenfield, Desai, & Portello, 2002).

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Several studies have been conducted to quantify the lag of accommodation and it was found to be strikingly variable among different studies. Variances arises for example from the used measurement device, the accommodative demand, viewing conditions, the subjects' refractive error, age, and age of onset of myopia (Abbott, Schmid, & Strang, 1998; Berntsen, Sinnott, Mutti, & Zadnik, 2011; Bullimore, Gilmartin, & Royston, 1992; Gwiazda, Bauer, Thorn, & Held, 1995; Gwiazda, Grice, & Thorn, 1999; Gwiazda et al., 1993; Mutti et al., 2006; Nakatsuka, Hasebe, Nonaka, & Ohtsuki, 2005; Rosenfield et al., 2002; Schaeffel, Weiss, & Seidel, 1999; Seidemann & Schaeffel, 2003).

During the past decades, researchers have investigated whether accommodation can be trained by means of biofeedback. Biofeedback is a treatment technique in which the subjects receive auditory or visual feedback concerning functions of their body that are usually controlled unconsciously (Andrasik, Coleman, & Epstein, 1982). The aim is to gain self-regulation over the trained function (Rief & Birbaumer, 2006). Biofeedback training was also used to gain control over the accommodation response and to transfer this ability to everyday life in order to finally reduce the amount of myopia (Gilmartin, Gray, & Winn, 1991).

Almost 40 years ago, Joseph N. Trachtman developed an infrared optometer that measured accommodation and provided auditory feedback that was proportional to the amount of accommodation (Trachtman, 1978). While Trachtman and colleagues reported a decrease in accommodation and a reduction of the myopic refractive error (Trachtman, 1978; Trachtman, Giambalvo, & Feldman, 1981), further studies with the same device generated conflicting results. One investigation could only demonstrate an improvement of visual acuity (VA) in some subjects, but no change in refractive error (Gallaway, Pearl, Winkelstein, & Scheiman, 1987). Another study could not establish significant differences between the experimental and the control group at all (Koslowe, Spierer, Rosner, & Belkin, 1991). Using the *Visual Training System* (VTS, Epsilon Srl, Florence, Italy), Angi et al. (1996) could only show an improvement in visual acuity, but again no change in refraction. The observed enhancement of the visual acuity without changes of the refractive errors might reflect an influence of contrast adaptation (Mon-Williams, Tresilian, Strang, Kochhar, & Wann, 1998). Randle (Randle, 1988) successfully implemented biofeedback training to extend the position of the far point in subjects with low myopia. In another study, subjects were trained to harmonise the pitches of a given tone and the biofeedback tone without providing visual stimulation (Cornsweet & Crane, 1973). Biofeedback approaches were also used to train accommodation by either voluntarily inducing positive accommodation (Provine & Enoch, 1975) or by extending the accommodation amplitude and speed in subjects with accommodative insufficiencies (Liu et al., 1979; Scheiman et al., 2011; Sterner, Abrahamsson, & Sjöström, 1999, 2001).

The studies reviewed above are based on the assumption that accommodation, which normally operates as a negative feedback closed-loop system with retinal blur and convergence as error signals (Morrison, Seidel, Strang, & Gray, 2010), could also be trained to include a voluntary input. It has already been demonstrated that accommodation is controlled not only by retinal defocus blur, but also by changing object size (looming), chromatic aberration, higher order monochromatic aberrations, proximal cues, and their combinations (Kruger & Pola, 1986, 1987; McLin & Schor, 1988; Phillips & Stark, 1977; Weiss, Seidemann, & Schaeffel, 2004). The aim of the mentioned biofeedback trials was to train myopes to voluntarily produce negative accommodation by increasing the sympathetic muscle tone (Angi et al., 1996; Gallaway et al., 1987; Koslowe et al., 1991; Randle, 1988; Trachtman, 1978, 1987). Such attempts appear promising if myopia is due to accommodative spasm after long periods of near work. It was described already in 1892 that extended near work can induce spasm of the ciliary muscle (Cohn, 1892) and a recent study found that myopia may be reduced under cycloplegia, providing evidence that tonic accommodation is also present during distance vision (Ohlendorf, Leube, & Wahl, 2015).

However, out of these trials, only two groups reported a reduction of myopia (Randle, 1988; Trachtman, 1978; Trachtman et al., 1981), whereas all the others could only measure an increase in visual acuity.

In contrast to previous biofeedback studies, the current investigation aimed to introduce auditory biofeedback training in order to improve positive accommodation rather than inducing negative accommodation. The purpose was to find out whether the voluntary input could be used to reduce the lag of accommodation.

2. Methods

2.1. Subjects

Thirty-one students and employees of the University of Tuebingen (Germany) participated in the experiments. Their mean age was 23.74 ± 2.66 years. The right eyes' mean spherical equivalent refractive error was −2.06 ± 1.06 D (inclusion criteria: spherical equivalent −0.50 to −4.00 D, astigmatism ⩽2.00 D) and the corrected distance Snellen VA was at least 6/6 (20/20) in each eye (detailed description in Section 2.2.1.). Subjects diagnosed with binocular vision disorders, ocular pathologies, or any systemic condition that could influence accommodation were excluded from the study. The same applied to subjects on medication that might affect accommodation. The study followed the tenets of the Declaration of Helsinki and was approved by the Institutional Review Board of the medical faculty of the University of Tuebingen. Informed consent was obtained from all participants after the content and possible consequences of the study were explained.

2.2. Procedure of measurements and trainings

2.2.1. Pre-measurements

The objective refraction of the subjects' eyes was measured during an initial visit, using a wavefront aberrometer (*ZEISS i.Profiler^plus^*, Carl Zeiss Vision GmbH, Aalen, Germany). Subjective refraction was subsequently measured using a digital phoropter (*ZEISS Visuphor 500*, Carl Zeiss Vision GmbH, Aalen, Germany) and a digital screen to display the Snellen optotypes (*ZEISS Visuscreen 500*, Carl Zeiss Vision GmbH, Aalen, Germany). Best corrected visual acuity was measured under monocular and binocular conditions, based on the least negative correction for maximum achievable VA.

After determination of the dominant eye by means of an eye sighting method with the hands forming a triangle (Lopes-Ferreira et al., 2013), the amplitude of accommodation of the right eye was measured by taking the mean of three readings using the push-up method (Rutstein, Fuhr, & Swiatocha, 1993) and a Duane's figure (Kohnen, Baumeister, & Strenger, 2008), presented on an organic light emitting diode (OLED) microdisplay (SVGA + OLED-XL™, eMagin, Hopewell Junction, NY, USA). The subjects' average amplitude of accommodation was 8.45 ± 1.88 D. Only the right eyes of the subjects were used for the further measurements.

2.2.2. Calibration of eccentric photorefractor

The accommodative response was measured using a custom-built eccentric infrared photorefractor (Fig. 1) as described earlier (Choi et al., 2000; Gekeler, Schaeffel, Howland, & Wattam-Bell, 1997; Schaeffel, Wilhelm, & Zrenner, 1993). Furthermore, the custom-developed software of the photorefractor was extended

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