Vision Research 48 (2008) 1613–1624

Contents lists available at ScienceDirect

Vision Research

journal homepage: www.elsevier.com/locate/visres

The use of cues to convergence and accommodation in naïve, uninstructed participants

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ARTICLE INFO

Article history:
Received 30 November 2007
Received in revised form 18 April 2008

Keywords:
Accommodation
Vergence
Near cues
Naturalistic
Photorefraction

ABSTRACT

A remote haploscopic video refractor was used to assess vergence and accommodation responses in a group of 32 emmetropic, orthophoric, symptom free, young adults naïve to vision experiments in a minimally instructed setting. Picture targets were presented at four positions between 2 m and 33 cm. Blur, disparity and looming cues were presented in combination or separately to asses their contributions to the total near response in a within-subjects design.

Response gain for both vergence and accommodation reduced markedly whenever disparity was excluded, with much smaller effects when blur and proximity were excluded. Despite the clinical homogeneity of the participant group there were also some individual differences.

1. Introduction

Ocular convergence and accommodation occur in response to cues from the visual environment as a target approaches. The main cues are blur and binocular disparity, with a smaller part being played by proximal cues such as looming, motion parallax and overlay of contours. Under typical conditions, all cues to an approaching target are available and provide consistent depth information. In this study, we looked at the contributions of these cues to concurrent convergence and accommodation in a visually normal group of participants. Accommodation and vergence responses to a naturalistic target with full cues to depth were measured, and compared to responses when different cues to depth were removed. The purpose of the study was to determine the range of individual differences in cue use in visually mature individuals with no visuomotor deficits.

Much of the previous research in this area has studied either vergence or accommodation in response to single depth cues, including defocus (blur), disparity or proximal cues. This has provided data for systems models of accommodation, vergence and their interactions (Eadie & Carlin, 1995; Hung, 1992; Schor, 1992). Early studies suggested that blur was the primary drive to accommodation and provided a sufficient cue in isolation (Phillips & Stark, 1977). It was suggested that blur was also the main drive to vergence via the accommodative vergence cross-linkage (Alpern, 1962; Maddox, 1893). More recently, however, disparity cues have been shown to provide the primary drive to vergence (Semmlow & Wetzel, 1979), and there is also evidence to suggest that these provide the main drive to accommodation via the convergence accommodation/convergence (CA/C) crosslink (Crone, 1973; Fincham & Walton, 1957; Judge, 1996; Semmlow & Wetzel, 1979). While retinal disparity and blur have been accepted as driving the accommodation and vergence systems, the role of proximity is less clear. Some studies report variable and idiosyncratic use of proximal cues (Ogle & Martens, 1957), whereas, in other studies, proximal responses have been shown to be linearly related to target distance (Rosenfield, Ciuffreda, & Hung, 1991).

In order to assess typical vergence and accommodation responses, it is necessary to assess the role of multiple cues to depth in driving both accommodation and vergence simultaneously. Some researchers have attempted such studies (McLin, Schor, & Kruger, 1988a; Okada et al., 2006; Rosenfield et al., 1991; Weiss, Seidemann, & Schaeffel, 2004), but this is relatively rare in the literature. In contrast, most previous studies have tended to measure responses to individual cues in isolation (Arnott & O'Callaghan, 1971; Breinin, 1971; Filipovic, 1998; Havertape, Cruz, & Miyazaki, 1999; Hung, 1991, 1997; Hung, Ciuffreda, & Rosenfield, 1994; Jiang, 1994; Rosenfield, Ciuffreda, & Chen, 1995; Schor, 1983, 1986, 1992; Wick, 1985; Wick & Currie, 1991). While the results of these single cue studies can be related to some clinical conditions, they are likely to have less relevance to uncontrolled, naturalistic responses in typical individuals because they fail to reflect real life situations where it is very rare that only one of the near cues is present or varies in isolation. Multiple cue studies will have more clinical relevance since there are many conditions where, for instance, one cue to appropriate near focus is unavailable, impoverished or conflicting. For example, blur cues can be impoverished due to

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doi:10.1016/j.visres.2008.04.023

refractive error or media opacity, but disparity and proximity cues are still available; disparity detection can be disrupted by strabismus but blur and proximal cues are often still intact; and in heterophoria, disparity cues can be in conflict with blur cues. The effect of cue conflict was demonstrated by Okada et al. (2006) who found that convergence driven accommodation responses dominated when cue conflict was high, but not in low conflict conditions.

A second problem with many experimental reports is that no attempt is made to control for participants' higher level perception of the apparent nearness of the target. "Awareness of nearness", and voluntary factors driven by perceived nearness are known to induce convergence and accommodation (Charman & Tucker, 1977; Mein & Trimble, 1991; Morgan, 1968; Schober, Dehler, & Kassel, 1970; Thompson, 1952) and this can be trained as part of conventional orthoptic treatment (Ansons, Trimble, Davis, & Mein, 2001; Griffin & Grisham, 2002; Pratt-Johnson & Tillson, 1994). Despite this, experimental participants are frequently staff and students from optometry departments who are likely to be more aware of their accommodation and vergence response than the general population, and many studies require extensive participant training. It is therefore possible that "expert" participants could be invoking undefined higher level conscious control, even when efforts are made to reduce this (Ciuffreda, 1991; Ciuffreda & Hokoda, 1985; Francis, Jiang, Owens, & Tyrrell, 2003; Karania & Evans, 2006).

Thirdly, while both early, and some more recent, studies of convergence and accommodation emphasise the variability in the range of normal responses (Fincham & Walton, 1957; Harb, Thorn, & Troilo, 2006; Judge, 1996; Ogle & Martens, 1957; Schaeffel, Wilhelm, & Zrenner, 1993; Whitefoot & Charman, 1992), it is common in adult studies to tighten experimental control in order to produce more repeatable results. Developmental studies, in contrast, frequently report greater variability in responses (Currie & Manny, 1997; Hainline, Riddell, Grose Fifer, & Abramov, 1992; Tondel & Candy, 2007; Tondel, Wang, & Candy, 2002; Turner, Horwood, Houston, & Riddell, 2002), implying that there is a progression from the reported wide variability in developing infants and children to more reliable adult responses. In addition, it is accepted by clinicians that there is a substantial degree of variability in characteristics, symptoms and responses to treatment in all age groups. The differences between developmental, clinical and experimental studies might not result from purely developmental and pathological variation, but could also reflect differences in methodology, particularly in instruction set and experimental control.

In order to bridge the gap between highly controlled, adult, lab-based studies, and developmental and clinical studies there is a clear need for a methodology that can be used to assess the relative contributions of the cues to simultaneous vergence and accommodation across a range of participant groups. We have combined and adapted previously published methods to produce a flexible and non-invasive paradigm to study the response to depth targets when all cues are available, when each is minimised, and when predominantly one single cue is provided in isolation. Here, we report the results from a group of minimally instructed, visually mature, participants. This data provides baseline measures of the relative influences of the main cues to convergence and accommodation and the range of individual differences within this population. From our previous studies (Horwood & Riddell, 2002; Horwood, Turner, Houston, & Riddell, 2001; Turner et al., 2002), we predicted that most participants would show the greatest reduction in convergence and accommodation when the retinal disparity cue was removed, but that there would be a some degree of individual differences in the pattern of response to each cue even in this visually normal population.

2. Methods

The study was designed according to the tenets of the Declaration of Helsinki, in accordance with institutional ethics regulations and the participants gave fully informed consent.

2.1. Participants

We made strenuous efforts to recruit naïve, orthophoric and emmetropic participants. We tested 94 asymptomatic individuals using a battery of tests. Participants who might not have been naïve to manipulation of vergence and accommodation due to previous therapy were excluded. All testing was completed in a single session, with conventional clinical tests being performed between two repeated experimental sessions. All participants had equal visual acuity of at least 0.0 logMAR in each eye tested using a logMAR acuity chart and none were able to overcome more than +0.5 D lenses at 6 m. All participants had attended an optometrist within the last 4 years but had not been prescribed spectacles or any other treatment. Heterophoria was measured using alternate prism cover test at 6 m and 33 cm with subjective confirmation that the phi phenomenon was minimised with the correcting prism. No participant had an exophoria greater than 4Δ for near (mean 0.6Δ ± 1.4Δ), any measurable heterophoria at distance, or any esophoria. Prism cover tests were repeated with +3.0 D lenses at 33 cm and −3.00 D lenses at 6 m with the participants clearing a 0.1 logMAR letter so that a clinical gradient stimulus AC/A ratio could be assessed. Particular care was taken to allow time for the participants to clear the target before alternate occlusion. AC/A ratios were all less than 3Δ:1D (mean 1.50 ± 1.13Δ/1D). All had at least 60 s of arc stereoacuity using the TNO stereotest (mean 50.7 ± 14.1 s of arc) and all had a near point of accommodation of less than 7 cm from the bridge of the nose both binocularly and monocularly (mean 6.15 ± 0.44 cm). Fusion was assessed with prisms. At 33 cm all participants had a base out blur point of at least 20Δ (mean 37.2 ± 11.5Δ) and break point of at least 35Δ (mean 43.6 ± 10.7Δ), and a base in break point of at least 8Δ (mean 12.4±3.5Δ). At 6 m they all had a distance base out prism fusion range of at least 20Δ (22.3 ± 2.4Δ) to break and 18Δ (20.4 ± 2.7Δ) to blur, and a base in range of at least 6Δ to break (mean 7.9 ± 1.5Δ: blur was rarely noticed before break). All could converge binocularly to at least 6 cm (mean 5.6 ± 0.6 cm). The relatively large standard deviations reflect considerably better responses than our minimum inclusion criteria.

Of the 94 individuals tested, 62 participants were excluded because they had mild refractive errors, asymptomatic heterophorias, mild accommodation or convergence insufficiency, or had received some form of vision therapy in the past. Of the remaining 32 participants who passed the screening, 23 participants were psychology undergraduates aged between 18 and 24 years of age with no history of ocular symptoms, spectacles, or participation in any previous visual experiment. Nine participants were typically developing children aged 8 years 8 months to 9 years 10 months who had had no ocular treatment. We wanted to explore two distinct age groups in the young, "visually mature" age range to ascertain whether developmental changes occur between late childhood and adulthood.

The participants were told that the purpose of the experiment was to measure how their eyes responded to pictures at different distances, but were given no further details until the end of the testing session. When asked, no participants were able to accurately describe what had been tested and most erroneously guessed that we had been studying pupil reactions.

2.2. Apparatus

We used an adaptation of the Remote Haploscopic Photorefractor designed by Israel Abramov and Louise Hainline, Infant Study Centre, Brooklyn College of the City University of New York. Our modifications were suggested by experience from our previously published studies (Horwood & Riddell, 2004; Horwood et al., 2001; Turner et al., 2002) and the availability of new commercially produced equipment (Erdurmus, Yagci, Karadag, & Durmus, 2007; Hunt, Wolffsohn, & Gilmartin, 2003; Schimitzek & Lagreze, 2005; Wolffsohn, Hunt, & Gilmartin, 2002). The remote haploscopic photorefractor (Fig. 1) consists of two optical pathways, one for off-axis infra-red continuous photorefraction and the other for target presentation so that binocular photorefraction can take place independent of target manipulation.

2.2.1. Target pathway

The equipment is fully enclosed in black painted shuttering except for the aperture through which the target is visible. The room lighting was dimmed so that light levels are low. Dim lighting is necessary to allow the pupils to dilate sufficiently for accurate photorefraction at the closest target distance, but does not result in significant dark adaptation (see later for target details and luminance).

The target was presented on a monitor mounted on a motorised beam that moves between the different fixation distances. The monitor moves in a pseudo random sequence between five different fixation distances (0.33 m, 2 m, 0.25 m, 1 m and 0.5 m), representing 3, 0.5, 4, 1, and 2 dioptres (D), or metre angles (MA), demand, so that a near target is always followed and preceded by a far target. Thus, linear responses across target distance demonstrate that participants have detected and responded to both near and distance cues appropriately.