Journal of Optometry (2016) 9, 40–46

Journal of Optometry

www.journalofoptometry.org

ORIGINAL ARTICLE

Accommodation and pupil responses to random-dot stereograms

Rajaraman Suryakumar*, **Robert Allison**

Center for Vision Research, Toronto, Ontario, Canada

Received 17 December 2014 ; received in revised form 5 March 2015
Available online 16 April 2015

KEYWORDS
Pupil;
Disparity;
Accommodation;
Stereopsis;
Photorefraction

Abstract We investigated the dynamics of accommodative and pupillary responses to random-dot stereograms presented in crossed and uncrossed disparity in six visually normal young adult subjects (mean age = 25.8 ± 3.1 years). Accommodation and pupil measures were monitored monocularly with a custom built photorefraction system while subjects fixated at the center of a random-dot stereogram. On each trial, the stereogram initially depicted a flat plane and then changed to depict a sinusoidal corrugation in depth while fixation remained constant. Increase in disparity specified depth resulted in pupil constriction during both crossed and uncrossed disparity presentations. The change in pupil size between crossed and uncrossed disparity conditions was not significantly different ($p > 0.05$). The change in pupil size was also accompanied by a small concomitant increase in accommodation. In addition, the dynamic properties of pupil responses varied as a function of their initial (starting) diameter. The finding that accommodation and pupil responses increased with disparity regardless of the sign of retinal disparity suggests that these responses were driven by apparent depth rather than shifts in mean simulated distance of the stimulus. Presumably the need for the increased depth of focus when viewing stimuli extended in depth results in pupil constriction which also results in a concomitant change in accommodation. Starting position effects in pupil response confirm the non-linearity in the operating range of the pupil.

PALABRAS CLAVE
Pupila;
Disparidad;

Respuestas acomodativa y pupilar a los estereogramas de puntos aleatorios

Resumen Investigamos la dinámica de las respuestas acomodativa y pupilar a los estereogramas de puntos aleatorios (RDS) que se presentaron en disparidad cruzada y no cruzada en

* Corresponding author at: Department of Computer Science and Engineering, 4700 Keele Street, Toronto, Ontario M3J1P3, Canada.
E-mail addresses: Rajaraman.Suryakumar@alcon.com, raj.suryakumar@gmail.com (R. Suryakumar).

http://dx.doi.org/10.1016/j.optom.2015.03.002

Acomodación;
Estereopsis;
Foto-refracción

seis sujetos jóvenes adultos con visión normal (edad media= 25,8 ± 3,1 años). Se supervisaron monocularmente las respuestas acomodativa y pupilar con un sistema de foto-refracción desarrollado para tal fin, mientras los sujetos fijaban la vista en el centro de un estereograma de puntos aleatorios. En cada prueba, el estereograma representaba inicialmente un plano liso, representando a continuación una ondulación sinusoidal en profundidad, mientras que la fijación permanecía constante. El incremento de la profundidad debido a la disparidad dio lugar a una constricción de la pupila durante las presentaciones de disparidad cruzada y no cruzada. El cambio del tamaño pupilar en las situaciones de disparidad cruzada y no cruzada no resultó significativamente diferente (p > 0,05). El cambio del tamaño pupilar se vio también acompañado de un pequeño incremento acomodativo concomitante. Además, las propiedades dinámicas de las respuestas pupilares variaron en función de su diámetro inicial (de partida). El hallazgo del incremento de las respuestas acomodativa y pupilar con la disparidad, independientemente del signo de la disparidad retiniana, sugiere que dichas respuestas fueron impulsadas por la profundidad aparente, en lugar de deberse a los cambios en la distancia simulada media del estímulo. Presumiblemente, la necesidad de un incremento de enfoque al visionar los estímulos ampliados en profundidad deriva en una constricción pupilar, que deriva a su vez en un cambio acomodativo concomitante. Los efectos de la posición de partida sobre la respuesta pupilar confirman la no linealidad del rango operativo de la pupila.

Introduction

The pupil is an important oculomotor system that is affected by a diverse set of stimuli including changes in retinal luminance,[1,2] sudden changes in stimulus motion,[3] emotional[4] and cognitive factors,[5] grating stimulus parameters and color.[6,7] In addition, changes in accommodation[8,9] and/or vergence[10] have also been shown to result in pupil constriction (miosis) via the near triad.[11] Functionally, the constriction of the pupil limits the amount of light entering the eye, reduces optical aberrations (until the eye becomes diffraction limited) and improves the depth of focus. These latter changes also have strong effects on the performance of other oculomotor systems. For example, pupil constriction improves the depth of focus of the eye and this reduces the demand for precise accommodation.[12] Pupil responses to optical blur, changes in ambient luminance and fusional vergence eye movements have also been shown to exhibit a strong nonlinearity in their response characteristics depending on the pupil's initial diameter. Specifically, pupil miosis is larger in amplitude when initiated from intermediate starting diameters (4–5 mm) compared to larger or smaller diameters.[13,14] It has been suggested that this effect reflects a non-linearity within the iris motor plant.

It has been reported that pupil responses can be elicited by disparity in dynamic random-dot stereograms. Li et al.[15,16] studied pupil responses to dynamic random-dot stereograms (DRDS) that changed from depicting a flat surface to a sinusoidal corrugation in depth (appearing in uncrossed retinal disparity) using an infrared pupillometer. In all three subjects, there was transient constriction of the pupil concomitant with the change in disparity. The pupillary response was characterized by a long reaction time (~500 ms) and was not accompanied by a change in vergence.[16] The constriction was not apparent with monocular viewing of one half-image of the DRDS and, under binocular viewing, its magnitude increased with increase in the spatial-frequency and amplitude of the corrugation. Since there were no changes in either blur or luminance, the dependence on the disparity-defined form led the authors to suggest that 'stereo information' drove the pupil constriction although they did not speculate whether this might serve any behavioral purpose.[15,16]

When such step changes in retinal disparity are introduced in a random-dot stereogram (RDS), the perception changes from a flat surface without depth to a surface with stereoscopic apparent depth. The direction of the apparent depth depends on the sign of retinal disparity. Crossed disparities depict depth in front of a fixation plane and uncrossed disparities depict depth extending beyond the fixation plane. The magnitude of the simulated depth increases with increase in the disparity in the RDS. Introducing a mean uncrossed or crossed disparity simulates increases or decreases (respectively) in the mean distance as well as the depth of the stimulus. This apparent distance change could induce proximal accommodation, even if fixation distance were held constant, assuming spatial pooling of the retinal stimulus to accommodation.[17,18] While earlier studies recorded changes in pupil size, measurements of accommodation were not attempted. It is possible that, due to the commonalities in the neural control, pupil responses to stereoscopic stimuli such as RDS could be accompanied by concomitant changes in accommodation. It is also possible that the oculomotor system works to achieve more accurate accommodation in response to a large range of apparent depth, resulting in an increase in the accommodative response to partially or fully offset the typical accommodative lag for the stimulus demand or the increased depth of focus from pupil constriction could decrease the demand for accurate accommodation. In either case, it would be expected that such changes in ocular focus would be modest in the interest of maintaining a clear perception of the