Vision with one eye: a review of visual function following unilateral enucleation

JENNIFER K. E. STEEVES 1,2,3,4,*, ESTHER G. GONZÁLEZ 1,3,4,5 and MARTIN J. STEINBACH 1,2,3,4,5

1 Centre for Vision Research, York University, Toronto, Canada
2 Department of Psychology, York University, Toronto, Canada
3 Department of Ophthalmology and Vision Sciences, University of Toronto, Canada
4 The Hospital for Sick Children, Toronto, Canada
5 Vision Science Research Program, Toronto Western Hospital, Toronto, Canada

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Abstract—What happens to vision in the remaining eye following the loss of vision in the fellow eye? Does the one-eyed individual have supernormal visual ability with the remaining eye in order to adapt and compensate for the loss of binocularity and the binocular depth cue, stereopsis? There are subtle changes in visual function following the complete loss of one eye from unilateral enucleation. Losing binocularity early in life results in a dissociation in form perception and motion processing: some aspects of visual spatial ability are enhanced, whereas motion processing and oculomotor behaviour appear to be adversely affected suggesting they are intrinsically linked to the presence of binocularity in early life. These differential effects may be due to a number of factors, including plasticity through recruitment of resources to the remaining eye; the absence of binocular inhibitory interactions; and/or years of monocular practice after enucleation. Finally, despite this dissociation of spatial vision and motion processing, research that has examined visual direction and performance on monocular tasks shows adaptive effects as a result of the loss of one eye. Practically speaking, one-eyed individuals maintain perfectly normal lives and are not limited by their lack of binocularity.

Keywords: Enucleation; monocular deprivation; spatial vision; motion processing; visual direction.

INTRODUCTION

It is a popular belief that losing the ability to use one sensory system results in a ‘sharpening’ of the other remaining senses. For example, the typical layperson might hold the belief that a person who is completely blind will have more acute hearing than someone with full vision. This is an empirical question — are blind
people more perceptive to barely audible sounds or are they able to hear a wider range of frequencies than normally sighted individuals?

Looking at another sensory modality and using functional brain imaging, research on visual ability in deaf individuals with hearing loss early in life has demonstrated cortical changes in functional activation for visual stimuli. Specifically, enhanced sensitivity in multimodal areas in early deaf individuals has been shown (Bavelier et al., 2001). This would suggest that losing hearing early in life has allowed for adaptive cortical reorganization. In a more recent paper, however, Bavelier and colleagues (2006) note that the story is not completely straightforward — deaf individuals exhibit both enhanced and diminished visual ability that is selective to specific visual capacities compared to hearing controls. In short, enhanced visual skills in deaf individuals is not widespread but rather, limited to those visual abilities that are attentionally demanding and that would normally benefit from a convergence of sensory information from both the auditory and visual domains.

Consider the case of losing just one eye. A similar question can be asked; does the remaining eye compensate for the loss of binocularity and lead to enhanced visual function with the remaining eye? Here we review human behavioural studies of visual performance in individuals who have complete monocularity following the loss of one eye (unilateral enucleation). The majority of the research has been done on individuals who have lost one eye early in life, during postnatal visual development, but a few studies have examined the loss of one eye later in life. It is important to note that unilateral enucleation is unique in that it results in the most complete form of deprivation because the brain has absolutely no visual input from that eye once the end organ has been removed. This is unlike other forms of monocular visual deprivation such as cataract, strabismus, ptosis or anisometropia that leave some, frequently abnormal, visual input. Complete monocular deafferentation provides a unique human model for examining the consequences of the loss of binocularity.

Do one-eyed individuals see better with the remaining eye? The answer is similar to the findings from Bavelier’s work on early deaf individuals, both ‘yes’ and ‘no’. Losing one eye leads to both enhanced and reduced visual function depending upon the visual capacity that is being measured and also on the age of the individual at the time of the loss. This dissociation in visual performance appears to lie in whether one is measuring visual spatial ability or visual motion processing and oculomotor systems. That is, some aspects of visual spatial ability appear to be enhanced by the loss of binocularity; however, motion processing and oculomotor behaviour appear to be intrinsically linked to normal binocularity.

Here, we review the findings of studies that have specifically examined the visual consequences of unilateral enucleation, the complete loss of one eye, on spatial vision and motion systems as well as on visual direction and performance during monocular tasks. We also discuss the issue of what is the appropriate control comparison group and how best to test this group. Finally, we conclude with a brief overview of physiological mechanisms that could account for cortical changes.