



How eye movements improve vision and action – comment on Vickers

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TA COMMENTARY

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ABSTRACT

The review by Joan N. Vickers (2016) describes evidence for a link between eye movement behavior and performance in a wide range of motor tasks. Central to the review is the observation that elite athletes hold gaze steady within a fixed range of the target earlier and for longer durations as compared to novices, an ability referred to as 'quiet eye' (QE). However, the functional significance of QE for performance in targeting and interception tasks has not yet been established. We summarize findings from laboratory studies providing direct evidence for perceptual benefits of smooth pursuit, fixational and predictive eye movements and outline potential mechanisms underlying these benefits. Recent improvements in mobile eye tracking might lead to validation of these findings in sport settings and to a more refined definition of QE.

Keywords:

Quiet Eye – smooth pursuit eye movements – predictive eye movements – saccades – microsaccades – visual motion – sports vision

Eye movements enhance vision

As vision scientists we appreciate Joan Vickers' (2016) target article drawing attention to the importance of eye movements for control of actions in sports. We share with the author an interest in adding to the understanding of how vision guides and modulates motor behavior, and how eye movements, in turn, contribute to the effectiveness of the visual system. Humans use different types of eye movements to bring and hold objects of interest close to the fovea, the area of highest visual acuity in the eye. Smooth pursuit eye movements help us track moving visual objects. Quick displacements of gaze called 'sac-

ades' allow us to scan a visual scene. These movements are interspersed with periods of relative stability known as 'fixations' during which visual information can be acquired.

Vickers refers to any relative stability of the eye focused within three degrees of a critical location as 'Quiet Eye' (QE), whether this is during fixation on a stationary object or pursuit of a moving object. Vickers (2016) reports that elite athletes fixate or track locations of interest earlier and for longer durations as compared to novices or near-elite athletes. The underlying claim is that because experts have better QE performance this ability must have beneficial effects on performance in sports and other motor activities. It is Vicker's merit to have intro-

duced QE to the Sport Sciences community decades ago, when mobile eye tracking was in its infancy. Research on QE has had a significant impact on athlete development and training, and has advanced tools and technologies for improving vision and movement in sports.

Yet, it is unclear what mechanisms underlie beneficial effects of eye movements. Does QE boost performance by enhancing visual processing of target information? Or does it serve to ignore distracting context information? Or is QE simply a byproduct of improved prediction?

The benefit of smooth pursuit

Many studies have addressed the question whether and how pursuit eye movements enhance or impair vision. We systematically manipulated eye movements to assess whether and how accurate pursuit (a 'dynamic QE') improves the ability to predict motion trajectories (Spering, Schütz, Braun, & Gegenfurtner, 2011). Observers viewed a small object (the 'ball') moving across a computer display while their eye movements were recorded at high resolution. When the ball disappeared from view, observers had to predict its trajectory and estimate whether it would have hit or missed a line segment (the 'goal') if it had continued to move. Observers performed better when they were instructed to track the ball with their eyes than when they were asked to fixate the goal, and more accurate pursuit (higher velocity gain and smaller position error) resulted in better perceptual performance. Because we kept retinal motion information constant during pursuit and fixation, we could rule out visual processing differences as a source of pursuit benefits. Instead, our results indicate that such benefits are due to the act of moving the eyes vs. fixating (see also Brenner & Smeets, 2011; Uchida, Kudoh, Muramaki, Honda, & Kitazawa, 2011). When we move, our brain generates a corollary discharge, a neural copy of the movement command and sends it back to the sensory system (Crapse & Sommer, 2008). This efference copy provides an internal report of our own movements and has important motor and sensory functions: it enables monitoring of on-going movements and informs our ability to predict future sensory events (Chen-Harris, Joiner, Ethire, Zee, & Shadmur, 2008; Wolpert & Miall, 1996). Accordingly, pursuit and saccadic eye movements do not produce beneficial effects in patients with known deficiencies of efference copy function (Spering, Dias, Sanchez, Schütz, & Javitt, 2013; Thakkar, Schall, Heckers, & Park, 2015). We propose that use of efference copy information is one possible mechanism through which smooth pursuit (dynamic QE) can boost vision; another possible mechanism might be the narrowing of direction bandwidth during pursuit (Debono, Schütz, Spering & Gegenfurtner, 2010).

The role of predictive eye movements

The target article does not consider other aspects of eye movements with demonstrated beneficial effects on sports performance, such as predictive eye movements (Diaz, Cooper, Rothkopf, & Hayhoe, 2013; Hayhoe, Mc Kinney, Chajka, & Pelz, 2012; Land & McLeod, 2000). Pursuit and saccades reveal prediction of future events and reflect our ability to use cognitive expectations to guide motor behavior (Kowler, 2011). When a moving stimulus is temporarily occluded, observers' pursuit slows down but recovers in anticipation of target reappearance (Bennett & Barnes, 2004). In sports such as table tennis or cricket, athletes initially track the ball but then make a saccade to the anticipated bounce location 100-200 ms ahead of its impact (Land & Furneaux, 1997; Land & McLeod, 2000). Professional players initiate predictive saccades earlier, more accurately and more reliably than novice players. Studies in virtual-reality settings have identified ball and flight parameters that determine the kinematics of predictive eye movements by systematically manipulating properties of the pre- and post-bounce trajectory (Diaz et al., 2013). Such predictive eye movement strategies presumably allow players to extract information about the location and time of the bounce in order to estimate the post-bounce trajectory and to plan their next move, thus contributing to sports performance. Whereas the neurological framework presented in the target article for how the brain controls vision and movement is somewhat sparse, much is known about the neurological underpinnings of eye movement control in general (Krauzlis, 2005) and of predictive eye movements in particular (de Hemptinne, Lefèvre, & Missal, 2008; Kim, Badler, & Heinen, 2005). We argue that prediction might be another possible mechanism underlying QE performance, enhancing the ability to keep the eye on the target.

The eye is not quiet during 'QE'

The term 'QE' implies a stable gaze, but the eye is never motionless. Even when fixating on a stationary object the eye makes miniature eye movements such as 'microsaccades'. Due to methodological limitations (see next section), these miniature eye movements have not been investigated in actual sport tasks. However, many laboratory studies have shown that microsaccades improve visual perception: they control fixation, reduce perceptual fading and enhance spatial acuity (Martinez-Conde, Otero-Millan, & Macknik, 2013; Rolfs, 2009; Rucci, Iovin, Poletti, & Santini, 2007). Even though we do not yet know much about the role of microsaccades during active performance, we can assume that microsaccades are critical in maintaining a vivid percept of our visual environment, including when playing sports or performing other motor tasks such as driving (Benedetto, Pedrotti & Bridgeman, 2011). Because microsaccades can be considered as saccades on a smaller spatial scale we can assume that they allow observers to optimally sample visual information from critical target locations in the

environment, akin to regular saccades (Martinez-Conde et al., 2013). Following this logic, the beneficial effect of QE may be due to the actual instability of the eye during fixation, rather than fixational stability.

Methodological limitations and future directions

Most studies on QE employed mobile eye-tracking technology. These eye trackers are highly suitable for in situ testing, but the price to pay for mobility is low temporal and spatial resolution. Until recently, the highest tracking rate that could be achieved was 60 Hz (resulting in an eye position image approx. every 17 ms). Given the fast dynamics of eye movements (for example, an average saccade takes only around 30 ms to complete), the spatio-temporal accuracy of eye movement signals obtained with mobile tracking is low. Based on existing QE studies we cannot know how accurately an observer fixates or tracks an object. By definition, for QE the eye has to be within a 3-degree range of the target. Given that visual acuity drops to 50% of its maximum when a target is located 2 degrees away from the fovea (Land & Tatler, 2009) this range is too large to make accurate predictions about the role of eye movements for performance. It is also unclear how a low position error (i.e., QE) is achieved, whether through smooth tracking or catch-up saccades. Even results regarding the onset and duration of QE are questionable. The advent of mobile eye tracking technology at a higher frame rate (mobile eye glasses with 120 Hz tracking capability are now available) will help address this problem. At the same time, comparisons between experts and novices can be achieved in laboratory or immersive virtual-reality settings using more accurate eye trackers. Such studies could and should be used to study the functional role of eye movements in more detail.

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Competing Interests

The authors have declared that no competing interests exist.

Data Availability Statement

All relevant data are within the paper.

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