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Quantifying eye dominance strength – New insights into the neurophysiological bases of saccadic asymmetries

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ABSTRACT

The saccadic system presents asymmetries. Notably, saccadic peak velocity is higher in temporal than in nasal saccades, and in centripetal than in centrifugal saccades. It has already been shown that eye dominance strength relates to naso-temporal asymmetry, but its links with centripetal-centrifugal asymmetry has never been tested. The current study tested both naso-temporal and centripetal-centrifugal asymmetries simultaneously to provide a finer and continuous measure of eye dominance strength. We asked 63 participants to make centripetal and centrifugal saccades from five different locations. Analysis of saccadic peak velocity shows that eye dominance strength modulates every saccadic asymmetry tested. For the first time, we propose a graduated measure of eye dominance strength on a continuum model. The model ranges from weak to very strong eye dominance. Weak eye dominance corresponds to increased saccadic asymmetries whereas strong eye dominance corresponds to no asymmetries. Furthermore, our results provide new insights into the neurophysiological origins of saccadic asymmetries. Modulation of both naso-temporal and centripetal-centrifugal asymmetries by eye dominance strength supports the involvement of V1 in these saccadic asymmetries.

1. Introduction

When someone is asked to report his dominant hand, she/he unhesitatingly knows what to answer, but few people are able to indicate their eye dominance (ED). This is probably because ED is a complex property that can take several forms. By evaluating thirteen different ED tests, Coren and Kaplan (1973) indeed revealed three types of ED: the *sighting* dominant eye is the eye preferentially used when performing a monocular task; the *sensory* dominant eye is the eye for which the percept is stronger during binocular rivalry; and the *acuity* dominant eye is the eye with the best visual acuity. As the authors showed that the most robust and less variable ED within participants and between tests is *sighting* ED, we decided to focus on this ED type. Sighting ED is usually assessed with tests providing a binary categorization (dominant left *vs.* dominant right eye). One of the most commonly used tests to assess sighting ED is the “hole-in-card-test” (Durand and Gould, 1910; Miles, 1930), in which participants sight a dot through a hole in a cardboard held at arm's length, and bring the cardboard close to their face. In this situation, the cardboard is preferentially moved toward the dominant eye. This test is very robust and has great test-retest reliability (Coren and Kaplan, 1973; Crider, 1944; Ho et al., 2018; Seijas et al., 2007). However, by comparing four sighting ED tests, Rice et al. (2008) and Seijas et al. (2007) have shown that while each individual test has great test-retest reliability, these tests do not globally correlate very well with each other. Contrary to handedness questionnaires - which provide a continuous percentage-based measure - tests of sighting ED only provide binary information, as they merely force participants to favor one eye. Moreover, while handedness questionnaires have revealed that some people have no hand preference, current sighting ED tests provide no opportunity to identify participants with no ED. However, a number of recent studies have been carried out to develop a continuous measure of ED strength (Carey and Hutchinson, 2013; Chaumillon et al., 2015; Dalton et al., 2015; Ho et al., 2018; Johansson et al., 2015; Vergilino-Perez et al., 2012).

Interestingly, Khan and Crawford (2001) have shown that sighting ED varies as a function of gaze angle. Using a paradigm adapted from the hole-in-card test, they showed that ED switches from gaze angle of 15.5° from the straight-ahead direction. On the basis of these findings,

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Carey and Hutchinson (2013) proposed an estimation of sighting ED strength. They suggested that the gaze angle from which the participant's sighting eye begins to switch could be used as an estimate of ED strength - the higher the gaze angle, the greater the ED strength. In their study, participants were seated in front of a semi-circular array of rings arranged at 10° intervals from 50° in both directions from the straight-ahead. Each trial required participants to use either their left or right hand to bring the target close to their face, forcing them to sight from one eye only. However, the authors found that their estimate of ED strength depended on the hand used to perform the task: in fact, participants tended to use their left eye when using their left hand and vice-versa. In their studies, Dalton and colleagues (Dalton et al., 2015; Ho et al., 2018) proposed to measure ED strength based on the near-far alignment test, another test of sighting ED. Participants were exposed to a graduated chart and had to align their joined forefingers with a cross situated at the center of the chart. As participants used both hands, any possible influence of the hand used on the ED strength measure was excluded. Then, participants had to close one eye and report the graduation on which their fingers had moved on the chart. Indeed, when one closes one's dominant eye, one is under the impression that one's fingers have moved ipsilaterally on the chart. The authors suggested that greater deviation reflected stronger ED, but they have shown that their ED strength measure varied as a function of the testing distance (Dalton et al., 2015; Ho et al., 2018; see also Rice et al., 2008).

Vergilino-Perez et al. (2012) proposed to quantify sighting ED strength based on asymmetric saccadic peak velocities between leftward and rightward saccades. It is well known that peak velocity is higher when saccades are directed toward the temple (i.e., leftward for the left eye and rightward for the right eye) than toward the nose (i.e., rightward for the left eye and leftward for the right eye) (Collewijn et al., 1988; Cook et al., 1966; Fricker, 1971; Hyde, 1959; Jóhannesson and Kristjánsson, 2013; Robinson, 1964; Tagu et al., 2018). This asymmetry is referred to as naso-temporal asymmetry (NTA). Examples of temporal and nasal saccades are illustrated in Fig. 1 by solid and dotted arrows, respectively. Note that while NTA has been widely found in peak velocity, its expression in other saccadic parameters is not so clear (Bompas et al., 2008; Honda, 2002; Jóhannesson et al., 2012; Rafal et al., 1991). A possible explanation is that peak velocity is less sensitive to top-down influences than other parameters such as saccade latency (Galley, 1989; see also: Di Stasi et al., 2013; Leigh and Zee, 2006). Therefore, asymmetries may exist in other saccadic parameters; but their presence may be masked by other massive effects linked to top-down influences (for similar arguments, see discussions in Bompas et al., 2008; Tagu et al., 2018). Vergilino-Perez et al. (2012) have shown that while some participants exhibited the standard NTA, others exhibited higher peak velocities toward the hemifield ipsilateral to their dominant eye (as measured using the hole-in-card test). They suggested that the former participants had a weak ED whereas the latter ones had a strong ED. Note that this initial criterion based on the data from eighteen participants has recently been refined thanks to studies involving larger samples of participants (Chaumillon et al., 2017; Tagu et al., 2016). Strong ED would be reflected in higher peak velocities toward the same hemifield, regardless of the eye, not just toward the hemifield ipsilateral to the dominant eye. In other words, participants with strong ED are those who do not exhibit NTA in saccadic peak velocity. Importantly, ED strength, as measured via this criterion, has been shown to affect perceptual (Chaumillon et al., 2017) and visuo-motor (Tagu et al., 2016) processes. Indeed, Chaumillon et al. (2017) used a Poffenberger task (Poffenberger, 1912) to show that participants with strong ED, i.e., with no NTA in saccadic peak velocity, detected a lateralized target in the hemifield contralateral to their dominant eye faster than in the other hemifield. Interestingly, this asymmetry was not found in participants with weak ED, i.e., with NTA in saccadic peak velocity. Similarly, Tagu et al. (2016) found that participants with strong ED made more accurate saccades toward the hemifield contralateral to their dominant eye than toward the ipsilateral hemifield. Again, this result was not found in participants with weak ED. Taken together, these studies suggest (1) that ED strength as estimated by the criterion proposed by Vergilino-Perez et al. (2012) clearly affects perceptual and visuo-motor abilities and (2) that the hemifield contralateral to the dominant eye is processed in a privileged manner by participants with strong ED. This can be explained in terms of neural correlates of sighting ED. Indeed, using functional magnetic resonance imaging (MRI), Rombouts et al. (1996) have shown that stimulating the dominant eye led to enhanced activation of the primary visual cortex (V1) than stimulating the non dominant eye. Moreover, anatomical MRI has led Erdogan et al. (2002) to notice that the visual cortex ipsilateral to the dominant eye was larger than the contralateral one. Functional imaging using magneto-encephalography (MEG) has corroborated this structural asymmetry: Shima et al. (2010) found that presenting a diode to the dominant eye led to greater activation of its contralateral V1 than of its ipsilateral one. On the other hand, stimulating the non dominant

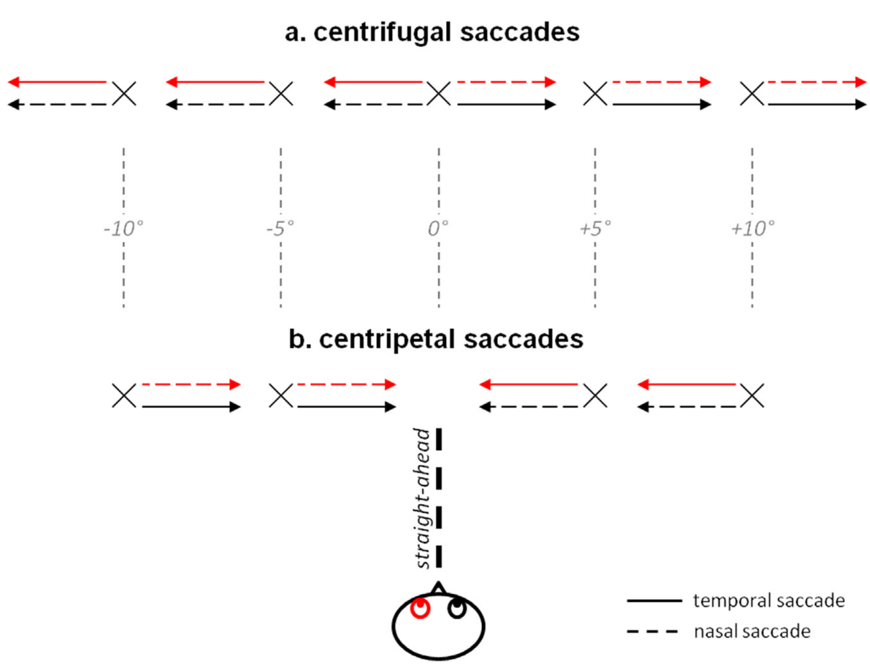

Fig. 1. Illustration of temporal, nasal, centripetal and centrifugal saccades. Panel (a) presents centrifugal saccades, directed away from the straight-ahead direction (location 0°), and panel (b) presents centripetal saccades, directed toward the straight-ahead direction. Red arrows are saccades from the left eye and black arrows are saccades from the right eye. Solid arrows are temporal saccades whereas dotted arrows are nasal saccades. Thereby, in panel (a) solid arrows are centrifugal-temporal saccades and dotted arrows are centrifugal-nasal saccades; and in panel (b) solid arrows are centripetal-temporal saccades and dotted arrows are centripetal-nasal saccades. The five showed starting positions (− 10°, − 5°, 0°, + 5°, + 10°) are the one used in Tagu et al. (2018) and in the current study. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)