

Role of Posterior Parietal Gamma Activity in Planning Prosaccades and Antisaccades

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Although the components of the cerebral network mediating saccade preparation in humans have been extensively outlined by numerous functional magnetic resonance imaging (fMRI) studies (e.g., Schluppeck et al., 2006; Curtis and Connolly, 2008), the fine temporal and spectral dynamics of its underlying electrophysiology and their relationship to findings reported in animal studies still remain poorly understood. The delayed saccade paradigm explored by Van Der Werf et al. (2008) using the high temporal precision of magnetoencephalography (MEG) reveals unprecedented evidence in humans that gamma-band activity recorded in posterior parietal cortex (PPC) during the delay period is associated with the encoding of forthcoming saccades.

The main finding in the article is the emergence of sustained direction-selective high-frequency gamma activity over posterior parietal regions during planning of saccades. Using a delayed saccade paradigm, the authors set out to sep-

arate the brain activity involved in visual perception (the “stimulus component”) from activity representing a motor goal (the “goal component”). The basic assumption behind this design is that saccades toward the memorized location (prosaccade condition) and away from it (antisaccade condition) have the same stimulus component but an opposite goal component. The participants were asked to memorize the position of a stimulus that was flashed peripherally for 0.1 s while they maintained central fixation. After a delay of 1.5 s, the fixation cross disappeared, instructing the subjects to perform a prosaccade or an antisaccade depending on the experimental condition. By contrasting the topographies of MEG signal power for left versus right prosaccades across frequencies, the authors found significant sustained parietal gamma activity contralateral to target location [Van Der Werf et al. (2008), their Fig. 2 (<http://www.jneurosci.org/cgi/content/full/28/34/8397/F2>)]. Next, by comparing these results to the outcome of the same analysis obtained in the antisaccade condition [Van Der Werf et al. (2008), their Fig. 3 (<http://www.jneurosci.org/cgi/content/full/28/34/8397/F3>)], two temporally distinct gamma components were distinguishable. An early broadband (40–120 Hz) component was modulated by stimulus location but not by the spatial target of the motor goal. In contrast, ~500 ms

after stimulus presentation, a second narrowband gamma component (85–105 Hz) appeared to be selective to the direction of the upcoming saccade [Van Der Werf et al. (2008), their Fig. 4 (<http://www.jneurosci.org/cgi/content/full/28/34/8397/F4>)]. Compared with the widespread spatial distribution of the transient stimulus-related activity, the cortical sources showing goal-related modulations were found more focally in PPC [Van Der Werf et al. (2008), their Fig. 5A,B (<http://www.jneurosci.org/cgi/content/full/28/34/8397/F5>)]. Finally, the dissociation between the two components was not found for frequencies <30 Hz, suggesting that it is indeed specific to the gamma range [Van Der Werf et al. (2008), their Fig. 7 (<http://www.jneurosci.org/cgi/content/full/28/34/8397/F7>)].

One possible confound in the attempt to separate stimulus and motor components in delayed saccade paradigms with a short response delay period is the coactivation of neural networks involved in visual persistence (i.e., afterimages). This phenomenon produces an optical illusion in which an image remains perceived after the true visual stimulus has ended. Although most theories explain afterimages through the adaptation of different retinal cell populations to the properties of the inducing stimulus [e.g., chromatic characteristics, luminance, or contrast as in the study by Wede and Francis (2006)],

This work was supported by European Community Research Program NeuroProbes (FP6-IST 027017) to K.J., the EC Marie Curie Fellowship (FP7-221097) to S.S.D., the Comisión Nacional de Investigación Científica y Tecnológica (Chile) Doctoral Fellowship to C.M.H., and a doctoral fellowship from the Ministère de l'Éducation Nationale et la Recherche (France) to T.O.

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they also recognize an important role of cortical structures. Afterimage-related activity has been observed as occipital and temporal scalp event-related potentials (Kobayashi et al., 2002) as well as gamma oscillations over occipital and parietal sensors using MEG (Tikhonov et al., 2007). So can the persistent parietal gamma activity identified by the authors after the offset of the peripheral stimulus be interpreted as a neural correlate of visual persistence of the stimulus? The inversion of hemispheric bias that was found for the late-gamma component (>500 ms) between prosaccade and antisaccades [Van Der Werf et al. (2008), their Fig. 2 (<http://www.jneurosci.org/cgi/content/full/28/34/8397/F2>) and Fig. 3 (<http://www.jneurosci.org/cgi/content/full/28/34/8397/F3>)] argues against this. Furthermore, results of a previous MEG study by the same group with a delayed double-step saccade task only show high parietal gamma enhancement preceding the saccade “go” signal but not after the first cue (Medendorp et al., 2007). An explanation of the sustained gamma solely on the account of afterimages can therefore be ruled out.

Another critical factor that might require additional investigation is the putative link between the reported gamma activity and visuospatial attention orienting. Clearly, subjects planning a saccade attend to the target location during the delay. In the case of a prosaccade, this is the same location as the stimulus, but for an antisaccade, subjects likely shift and maintain their attention to the opposite side of the screen. The authors note that this explanation is unlikely given the tendency of the sustained gamma activity to increase closer toward saccade execution. It is conceivable, however, that purely attentional neural processes might also be enhanced closer toward the onset of a planned movement and thereby account at least partially for the observed increase. This question is worth pursuing in future studies using a modified delayed saccade paradigm that explicitly controls for spatial attention. Most importantly, the endeavor to elucidate whether high-gamma activity in human PPC is specifically related to intention or to attention is part of a longstanding debate on the separability of neural representations of motor goals and spatial attention (preceding movement execution). Indeed, saccade planning and the allocation of spatial attention have been shown to be mediated by overlapping neural substrates (Kowler et al., 1995). This is an intuitively appealing idea given that visual attention and saccades

both mediate the selection of a portion of the visual scene. Nevertheless, several studies have also provided evidence in favor of a putative segregation between goal representation and spatial attention across parietal and frontal areas (Colby and Goldberg, 1999; Juan et al., 2004; Quian Quiroga et al., 2006). Clearly, the attempt to fully dissociate the neural correlates of the two processes carries the inherent risk of misrepresenting the intricate interaction between them. However, recent findings, including the present study by Van Der Werf et al. (2008), suggest that the fine-scale spatial and temporal resolution of gamma-band activity might be particularly helpful in linking the findings of animal and human studies exploring the overlap and segregation between attention and intention (Pesaran et al., 2002; Brovelli et al., 2005).

Many variants of the delayed saccade task have been reported in the literature. As described above, the paradigm implemented by Van Der Werf et al. (2008) requires visuospatial processing and memorization of a flashed stimulus position (or its mirror location) in addition to motor planning. One way to probe the neural processes underlying oculomotor intention while minimizing the effect of target location is to place the visual stimulus instructing saccade direction at the center of the screen, e.g., as an arrow pointing left or right toward targets that remain visible throughout the experiment (Khonsari et al., 2007; Milea et al., 2007). Such delayed saccade paradigms significantly reduce lateralized perceptual and visuospatial memory demands because the instruction is provided centrally, and the peripheral targets are not flashed but remain present (cf. Curtis and Connolly, 2008). This places the emphasis during the delay on the motor goal and visuomotor transformation rather than the visual stimulus location. Whether such a paradigm reveals gamma patterns comparable with those reported by Van Der Werf et al. (2008) still remains to be shown.

A further important issue which could impact the interpretation of the findings reported by Van Der Werf et al. (2008) is the fact that scalp muscle activity and electromagnetic interference can contaminate MEG and EEG data yielding artifactual activity in the high-gamma frequency range. Indeed, a recent study may introduce some additional concerns; Yuval-Greenberg et al. (2008) showed that with a visual EEG experiment, broadband gamma activity may appear to arise from occipital regions when in fact they are di-

rect manifestations of miniature saccade transients. Therefore, given that microsaccades have been shown to be modulated by shifts of spatial attention (Engbert and Kliegl, 2003), it is important to rule out that the gamma-band activity detected by Van Der Werf et al. (2008) is of artifactual origin. Such an explanation is unlikely for several reasons: First, it is unclear if the miniature saccade artifact phenomenon extends to MEG. In EEG recordings, such an artifact may be a consequence of reference electrode placement (Yuval-Greenberg et al., 2008); in contrast, MEG may not be susceptible to this problem because it is inherently reference-free. Additionally, the beamforming source reconstruction method provides a degree of protection from artifacts arising from outside the brain. Beamforming estimates either the time course or power modulations of neural activity over the brain volume using adaptive spatial filters (Van Veen et al., 1997). This method does not require a priori assumptions about the location or number of sources and so does not assume sources are restricted to the brain. Sources of ocular origin would therefore be localized near the eyes rather than projected to distant parts of the brain (Bardouille et al., 2006). A third argument in favor of a cortical origin of the reported gamma activity findings is that they are in agreement with results from direct recordings in monkeys at several levels. For instance, the reported hemisphere-specific contralateral selectivity of spectral power for an upcoming saccade is in line with findings obtained with gamma-range components of local field potentials recorded in monkey PPC (Pesaran et al., 2002). Furthermore, the timing of gamma power modulation shift from stimulus processing to goal encoding appears to coincide with the average inversion time of lateral intraparietal neurons remapping from stimulus location to goal encoding as reported in a memory-delayed saccade task in monkeys (Zhang and Barash, 2004). Finally, the significance of the parietal high-gamma findings is further enhanced by a growing body of evidence linking population-level gamma activity to the blood oxygenation level-dependent signal recorded in fMRI, both in monkeys (Logothetis et al., 2001) and in humans (Lachaux et al., 2007).

The authors propose that parietal gamma-band activity reflects visuomotor encoding mechanisms that determine the saccade goal. Given that the neural network involved in oculomotor planning and execution spreads across multiple ce-

rebral areas, including parietal and frontal regions, one might have expected to also find comodulations of gamma activity in frontal areas, including dorsolateral prefrontal cortex or frontal and supplementary eye fields (Lachaux et al., 2006). The absence of such findings in this study could either be attributable to the experimental design used (trial number, delay latency, etc.), or to important differences in amplitude between parietal and frontal gamma activity, or alternatively to the dependency of MEG source estimation on various properties of the underlying generators such as the orientation and size of the activated patch of cortex.

To conclude, although much still needs to be done to fully disentangle the neural correlates of visuomotor processing, spatial attention and motor goal encoding in PPC, the study by Van Der Werf et al. (2008) brings us one step closer toward elucidating the role of high-gamma activity in these processes and provides fundamental findings that help bridge the gap between electrophysiological recordings in monkeys and humans during visually guided motor behavior.

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