

Preface

Biological motion is an essential piece of sensory information for living organism and therefore motion processing units, from simple elementary motion detectors to dedicated motion sensitive cortical areas, have been identified over a broad spectrum of animals. Biological visual motion systems are among the ones having been the most scrutinized at many different levels from microcircuits to perception (see Born and Bradley 2005; Bartels et al. 2008; Callaway 2005; Sincich and Horton 2005; Demb 2007; Britten 2008; Bradley and Goyal 2008; Kourtzi et al. 2008; Orban 2008 for recent reviews). In parallel, since the early work of Reichardt (1961), theoretical approaches of motion detection have been always tightly linked with experimental work so that nowadays, most experiments are conducted within rather well-defined theoretical frameworks (e.g. Carandini et al. 2005). Visual motion has thus become a representative of system neurosciences where similar approaches can be applied across very different levels of brain organization. In particular, neuronal activity at both single-cell and population levels can be accurately linked to simple action system driven by visual motion such as tracking eye movements (Lisberger et al. 1987) as well as motion perception (Parker and Newsome 1998). This integrative approach is rooted on decades of psychophysics that have explored human motion perception (Nakayama 1985; Vaina 1998; Snowden and Freeman 2004; Lu and Sperling 2001). Visual psychophysics provides all of us with a large class of calibrated motion stimuli that can be used to dissect out the different aspects of motion integration and segmentation as needed to accurately measure the velocity of an object that is, the direction and speed of its movement. We decided to open this book with a review paper describing what are the different classes of visual stimuli and what aspects of biological motion processing each of them can unveil. Focusing of low-level motion, Lorenceau presents in great details the different elements of this artillery and how they can be used at both behavioral and neurophysiological levels. By doing so, he set the stage over which most of the work presented inside this book will take place. As for the other chapters, corresponding movies can be found in the DVD joined to the book. However, Lorenceau also stresses out that a motion perception most often involves a tight link between form and motion cues. Such form–motion interactions will be illustrated by other contributions, further demonstrating that biological motion processing escapes the strict modular approach and call for a more integrative

view as needed to understand the root of the problem: how to measure the motion of an object, usually represented as a visual surface, singled out from its complex environment. The following chapters will survey how this can be performed at cellular and network levels, with either static or moving eyes.

Dynamics of Neural Mechanisms

Surprisingly, several key aspects of motion perception have not been emphasized over the years. First, although a few psychophysical studies had pointed out that perceived motion undergoes complex time course when human subjects are presented with ambiguous motion signals (e.g. Yo and Wilson 1992; Castet et al. 1993; Lorenceau et al. 1993), it is only very recently that temporal dynamics of motion processing has received attention from physiologists. Before the pioneering work of Pack and colleagues, neurons were classified between those who solve the aperture problem and those who do not. This selection was based on the steady-state properties of their direction selectivity tuning when presented with bars, gratings, or plaid patterns (Movshon et al. 1985). Pack and Born (2001) presented MT neurons with sets of tilted bars, the neuronal counterpart of the elongated moving bars used in psychophysical experiments, and analyzed the time course of direction selectivity of the single-unit responses. They found that such a basic response property of MT neuron is indeed not static. Instead, early part of their tuning showed interactions between direction and orientation while ~100 ms after response onset, optimal direction became independent of lines orientation. Several studies, largely summarized here in the chapters by Pack et al. and Smith et al., have looked at the dynamics of direction selectivity in macaque area MT in response to various 2D motions such as plaid patterns, barber poles, or lines. Although there is a common agreement on the similar timing characteristics across motion stimuli (see chapter by Smith et al.), the origin of such neuronal dynamics is still highly controversial, carrying on a long debate about which, and how, local features are extracted from the image flow. Born and coworkers favor an explanation based on feature-extraction mechanisms such as end-stopped cells found in area V1 (Hubel and Wiesel 1968; Pack et al. 2003). On the other hand, Smith and coworkers argue for a filter-based approach where global motion is computed by merging excitatory and inhibitory inputs from different spatio-temporal channels (see Rust et al. 2006). Within these two frameworks, the dynamics can be seen either as a result of a delayed feature-extraction mechanisms, as the by-product of the different signal strength between channels or by the time course of contextual modulation such as implemented by center-surround interactions or recurrent circuits. The book offers the opportunity for these different views to be presented back to back.

Motion information is extracted locally, but there is many evidence that the brain pools information to solve the aperture problem, to improve signal-to-noise ratio or to normalize inputs across the image, to take a few examples of motion integration. Since all these different aspects involved the diffusion of information between neighboring neurons, there is an urgent need to explore the neural dynamics at population level.

Frégnac and coworkers introduce the concepts and techniques used to investigate the relationships between fundamental properties of individual neurons such as orientation- and direction-selective cells in primary visual cortex and the dynamics of their surrounding network. They point out that descriptive tuning functions in fact reflect the very large diversity of inputs that a single neuron would receive through feed-forward, lateral, and recurrent connectivity. This message is to keep in mind in the design of detailed biophysical models at both cellular and network levels. It remains coherent with the current view that direction selectivity emerges from the convergence of many different feed-forward inputs (both excitatory and inhibitory) covering a very broad range of the spatiotemporal spectrum in Fourier space (see Rust et al. 2006; Lennie and Movshon 2005). However, the evidence gathered by intracellular recordings that responses dynamics of V1 neurons reflect non-iso-oriented inputs (Monier et al. 2003) from distant part of the cortex (Bringuier et al. 1999) urge us to take into account the role of intra- and intercortical connections. The fact that they all have different timing shall help us in constraining dynamical models of motion integration.

Linking population dynamics and integrative properties of individual neurons will be most certainly a future challenge in sensory neuroscience. Visual motion once again shall offer an excellent approach. Jancke, Chavane, and Grinvald provide one very attractive insight into this perspective. Using different and complementary techniques such as voltage-sensitive dye optical imaging and population reconstruction from extracellular recordings, they propose a fresh look at how motion information is represented. In particular, their approach stresses one point often ignored in most electrophysiological, and psychophysical, studies. Motion is primarily a displacement in the visual space and therefore a moving object will elicit a traveling wave along the cortical representation of its trajectory. Moreover, linear and nonlinear interactions along such cortical trajectories can be identified in cat area V1 (Jancke et al. 2004). Most certainly, future work will be able to relate such population dynamics to single-unit activity within direct projection areas such as V2 or MT as well as with perceptual performance in primates (Chen et al. 2006).

Overall, looking at the temporal dynamics of contextual biological motion processing, as well as for other elementary aspects of image features extractions such as orientation, texture, and illusory contours has reinvigorated the investigations on the underpinning neural mechanisms. The results gathered might turned out to be important to decipher which theoretical approach is more closely related to cortical computation. They might also force us to finally take into account the different connectivity rules, operating at different spatial and temporal scales, which are important to compute global object motion.

Visual Motion and Eye Movements

Measuring speed and direction of a moving object is an essential step for many sensorimotor transformations, in particular when controlling eye movements. The impact of low-to-high level motion processing onto the dynamics of oculomotor

behavior is reviewed in several chapters. Sheliga and Miles summarize their seminal work in elucidating the basic properties of motion detection in the context of triggering reflexive eye movements at ultrashort latency. Their work illustrates how much can be learned about the spatial and temporal characteristics of the earliest, preattentive stage of local motion extraction when using very accurate behavioral probes. From this, as well as from the work of other groups, it becomes possible to sketch a detailed model of early, and fast, motion processing that incorporates many aspects investigated previously at psychophysical and physiological levels: how is motion information extracted by luminance-based motion detectors, how are their activity normalized across directions and so on and so forth. More than simply confirming what was learned from other approaches, the experiments conducted on ocular following responses unveil functional consequences of such linear and non-linear processing such as automatic motion segmentation and integration (see Miles et al. 2004; Masson 2004). If tracking eye movements are primarily driven by luminance-based local motion detection, this so-called first-order motion mechanisms might not be the only one contributing to a nearly perfect pursuit performance under a wide range of conditions. Other types of motion information can be extracted under constant luminance conditions, either at preattentive or at attentive stages. System view of the primate motion system postulates the existence of three different motion systems, called first order, second order, and third order (see Lu and Sperling 2001 for a review). The exact contribution of second- and third-order motion information to perceptual performance is still a matter of debate and it is unclear where and how they are computed by the primate brain. Chapter by Ilg and Churan reviews the existing evidence, supporting the idea that second-order motion is indeed extracted within posterior parietal areas. The authors point out, however, that investigating second-order motion, as well as pattern motion, had defeated the simplistic view that global motion is computed once for all in area MT and therefore that area MT must be seen as the key, if not unique area responsible for motion perception in both human and nonhuman primates (see Ilg 2008 for a review).

Once motion is locally extracted, several processing steps are still necessary to reconstruct speed and direction of the object to be pursued. Chapters presenting new results on motion integration, obtained at both psychophysical and physiological levels, have introduced the idea that the integration stage presents complex dynamics. This approach is further extended in the chapter by Masson and colleagues, showing such dynamics of motion integration can have a major impact on how the brain controls action. Taking advantage of the fast visuomotor transformation underlying that pursuit eye movements as well as their smooth acceleration, the oculomotor system can trigger tracking responses based only on the coarse estimate of motion direction that arises from the feed-forward motion pathway but then gradually correct the pursuit direction by taking into account features motion extracted at a finer scale. Thus, time course is closely related to the temporal dynamics of motion integration that we have discussed above. In return, this work stresses the fact that eye movements are an exquisite tool to probe the properties of early motion processing stages, since initial eye acceleration reflects visual velocity signals encoded at the level of macaque areas MT and MST (Krauzlis 2004; Masson 2004).

However, it is well known since the early 1970s that pursuit responses depend on both visual and nonvisual signals, the later being related to eye velocity memory (Yasui and Young 1975; Miles and Fuller 1975). Moreover, the perceived direction of oriented after-images presented during on-going pursuit is always biased toward the axis normal to the orientation of the flashed bars (Goltz et al. 2003). This intriguing result suggests first that the aperture problem contaminates egocentric motion and second that more is yet to learn about motion integration during eye movements (Murakami 2004). Indeed, motion integration tasks such as introduced by Lorenceau offer a great deal to investigate the link between perception and action, as well as the dependency or the lack of dependency of early visual stages upon cognitive factors such as prediction or anticipation. Masson and colleagues report results arguing for a mere independence between low-level vision and higher cognitive processing such as engaged in anticipating future motion events or predicting target trajectory. They suggest that low-level motion integration and spatial reconstruction of target motion acts more or less independently, as illustrated by the difference observed between neuronal responses in either areas MT or MSTl/FEF when using complex line drawing stimuli avoiding the center of the receptive field (Ilg and Thier 2003). These latter experiments suggest that pursuit-related neurons in the lateral part of macaque area MST (also called visual-tracking neurons) integrate both visual and nonvisual information (see Ilg 2008 for a review). Whether these neurons compute the motion-in-space of a pursued target (Newsome et al. 1988) or reflect the existence of a more abstract representation of the inferred motion already emerging at the level of area MT (Assad and Maunsell 1995; Schlack and Albright 2007) is still a matter of debate. Recording activities of MSTl neurons during tracking of different line-drawing objects is one piece of evidence. Furthermore, looking at the dynamics of direction selectivity using tilted bars that are transiently occluded (see Assad and Maunsell 1995 for a similar paradigm although with a simple spot) might also largely contribute to a better understanding about what and how information is represented at various stages along the motion pathway. Clearly, more investigations are needed about the dynamical interactions between posterior parietal and prefrontal cortical areas for motion integration in the context of pursuit eye movements, as well as perception (see Pasternak and Greenlee 2005). However, once again, these studies point out how using simple motion stimuli such as designed for psychophysics can highlight the mechanisms of sensorimotor transformation when the biological motion stage is not collapsed into a simple black box extracting retinal velocity in some unspecified way. Obviously, there is need for models of oculomotor behavior with a more complex front-end dynamics.

In the aforementioned chapters, motion is seen as the source of information for driving perception or simple actions such as tracking responses. Although active vision has been a very productive field of research trying to understand how visual information is actively extracted by means of our eye movements, much more attention has been paid to saccadic eye movements rather than smooth pursuit in this context (Findlay and Gilchrist 2003). Tracking an object aims at stabilizing its image onto the retina, but a mere consequence of the eyeball rotation is a steady

continuous retinal sweep of the background image. Dozens of studies have been conducted to understand how such background motion can be either eliminated to perceive a stable world during tracking or on the contrary taken into account to compute object motion in a spatial frame of reference (see Abadi and Kulikowski 2008). Hafed and Krauzlis take a different approach, trying to demonstrate that smooth eye movements can be useful to resolve perceptual ambiguities. This approach is rooted on the motion stimuli, and psychophysical paradigms described by Lorenceau but offer a fresh view of the fascinating problem of perception–action coupling. Their experimental work, summarized in Chap. 9, shows that partially occluded objects can be perceived coherently thanks to the pattern of eye movements produced by human subjects. This seminal study opens the door to a closer examination to the interaction between perception and action using both well-defined behavior and calibrated tasks where retinal flows can be matched between pursuit and fixation condition.

Visual motion processing is not only related to the execution of pursuit eye movements. Both saccadic and pursuit eye movements introduce major changes in the retinal images. However, how motion perception and eye movements are coupled with respect to saccades has been a matter of intense debates over the last decades. One acute example is a phenomenon called “saccadic suppression” (see Ross et al. 2001). That visual perception is largely reduced during saccades is a well-documented phenomenon that everyone can experience everyday. Indeed, psychophysical studies have convincingly demonstrated that intrasaccadic detection thresholds are strongly deteriorated at the time of a saccade (e.g. Volkmann 1986; Burr et al. 1994). Several recent physiological studies have demonstrated that some, but not all direction-selective cells in macaque area MT are consistently inhibited during saccade. On the contrary, some cells also show a strong postsaccadic rebound of activity that could be correlated to the postsaccadic enhancement originally reported by Miles and colleagues when recording ocular following responses (Miles et al. 1986). In Chap. 8, Mike Ibbotson summarizes these studies and relates these saccade-related changes in activity at the level of area MT with the changes in perceptual performance described earlier in human subjects. However, the use of the term “suppression” has led to the stronger, but wrong, assumption that vision is prevented during saccades. Textbooks and nonspecialist review articles have even further cartooned this saying that the entire visual system, not only visual perception, is turned off during saccadic flight. The chapter by Castet offers a very helpful re-examination of the different perceptual changes that occur before, during, and after a saccade. He points out the difficulty in interpreting a wide diversity of perceptual phenomena within the unique, stringent hypothesis of an active (i.e. extraretinal) suppression or modulation of visual inflow at its earliest stages (Ross et al. 2001). One goal of this book was to publish back-to-back articles offering different, sometimes even opposite, stand-points onto a specific aspect of motion processing. The chapters by Ibbotson on one hand and Castet on the other hand give such an opportunity and remind us that solving controversies in neuroscience often needs first to (re)clarify key concepts as often popular ideas drift far away from the conclusions that were drawn from the original experimental results.

Modeling Visual Motion: From Natural Scenes Statistics to Motion Recognition

Listing the existing computational models of visual motion would probably take a couple of pages. Computer as well as biological vision researches have produced a huge number of models, based on many different theoretical approaches such as linear filtering, probabilistic inference, or dynamical systems. Several recent books are available from the library shelves (see Blake 1998; Paragios et al. 2005; Stocker 2004; Watanabe 1998 for a few recent examples) to explore these different aspects. There is, however, clearly the need for a more theoretical approach unifying all these computational efforts. Herein, we have preferred to highlight some key aspects of visual motion information processing. First, Dong summarizes the statistical approach trying to understand what is the critical information in sequences of natural images. Relating the window of visibility, and its neuronal counterpart defined as a set of optimal filters, to the statistics of still natural images has been an intensive area of research over the last two decades. The same approach is now conducted using movies of the image flow experienced by an observer moving in complex, natural environments. From these, Dong demonstrates that spatial–temporal contrast sensitivity of human observers is tuned to extract the most pertinent and reliable motion information that is mainly low temporal frequencies.

A second aspect of motion processing is integration, which involves diffusion of information over neighboring parts of the images to reconstruct the global motion of the object of interest and single it out from its surround. Grossberg summarizes the work conducted by his group in implementing dynamical models of motion segmentation and integration. His solution relies on a strong interplay between modules extracting either form (i.e. features) or motion. Diffusion of information is done by means of recurrent connectivity between areas working at different spatial scales. Once again, this class of model reminds us that motion pathways are highly recurrent and that we absolutely need to better understand how feed-forward and feedback flows of information interplay to solve problems such as motion binding. The model reviewed here sums up a decade of progressive improvement of the class of models developed by himself and his group. Clearly, this approach highlights the interest of computational principles that can be implemented by set of differential equations. The cost is then to overview the detailed connectivity rules corresponding to the actual cortical mechanisms. But we clearly need such a more generic approach, complementary to the more detailed, but also more focused, models proposed by others. Lastly, Grossberg introduces one new aspect of the dynamical approach. The brain takes decision about the incoming stimulus speed or direction. Its model succeeds in simulating the time course of such a decision, as seen in parietal cortices (e.g. Britten et al. 1992; Shadlen and Newsome 2001; Hanks et al. 2006; Huk and Shadlen 2005) but also question on what information processing such decision is taken. This links to a rapidly growing field of research about sensory decisions along the motion pathways. Recent reviews about this topic can be found elsewhere (Shadlen 2002; Rorie and Newsome 2005; Gold and Shadlen 2007).

Motion is a useful source of information not only for controlling our basic actions but also to solve highest cognitive tasks such as face recognition (see Roark et al. 2003) or biological action recognition (see Blake and Shiffrar 2007). Understanding how biological motion is analyzed by dedicated brain loci within the superior temporal sulcus (STS) for instance has been the focus of a vast literature. However, biological motion stimuli carry information not only the type of action being executed but also more fine-grained, cognitive cues that are used for social interactions. Giese and coworkers detailed their recent modeling work asking how human emotions can be recognized for sequences of point-light walkers. Here again, a key point is to be able to extract remarkable features such as joint-angle trajectories using sparse feature learning. This approach not only defines a compact visual representation for complex information but depart from more classical models assuming that visual recognition involves the activation of motor representations. Instead, this model demonstrates that human subjects can nearly optimally use the visual information extracted from joint trajectories.

Features, trajectories, dynamic motion integration: these terms have been found in nearly all chapters of this book. By highlighting a few recent approaches, the contributors have shown how much an integrative approach can be useful to understand how the brain computes global motion of an object, being a simple line or a full body. Some of these issues still remain controversial and we want to thank the different contributors to have accepted that chapters with different views are presented back to back. We hope that our colleagues and their students will consider this book for what it was originally proposed: an incentive to bridge approaches across levels and models, using tasks and stimuli as an Ariadne's thread.

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References

- Abadi RV, Kulikowski JJ (2008) Perceptual stability: going with the flow. *Perception* 37(9):1461–1463
- Assad JA, Maunsell JHR (1995) Neuronal correlates of inferred motion in primate posterior parietal cortex. *Nature* 373:518–521
- Bartels A, Logothetis NK, Moutoussis K (2008) fMRI and its interpretations: an illustration on directional selectivity in area V5/MT. *Trends Neurosci* 31(9):444–453
- Blake A (1998) Active contours: the application of techniques from graphics, vision, control theory and statistics to visual tracking of shapes in motion. Springer, Berlin
- Blake R, Shiffrar, M (2007) Perception of human motion. *Annu Rev Psychol* 58:47–73
- Bradley DC, Goyal MS (2008) Velocity computation in the primate visual system. *Nat Rev Neurosci* 9(9):686–695
- Britten KH (2008) Mechanisms of self-motion perception. *Annu Rev Neurosci* 31:389–410
- Britten KH, Shadlen MN, Newsome WT, Movshon JA (1992) The analysis of visual motion: a comparison of neuronal and psychophysical performance. *J Neurosci* 12(12):4745–4765
- Born RT, Bradley DC (2005) Structure and function of visual area MT. *Annu Rev Neurosci* 28:157–189

- Bringuier V, Chavane F, Glaeser L, Frégnac Y (1999) Horizontal propagation of visual activity in the synaptic integration field of area 17 neurons. *Science* 283(5402):695–699
- Britten KH (2008) Mechanisms of self-motion perception. *Annu Rev Neurosci* 31:389–410
- Burr DC, Morrone MC, Ross J (1994) Selective suppression of the magnocellular visual pathway during saccadic eye movements. *Nature* 371:511–513
- Callaway EM (2005) Neural substrates within primary visual cortex for interactions between parallel visual pathways. *Prog Brain Res* 149:59–64
- Carandini M, Demb JB, Mante V, Tolhurst DJ, Dan Y, Olshausen BA, Gallant JL, Rust NC (2005) Do we know what the early visual system does? *J Neurosci* 25(46):10577–10597
- Castet E, Lorenceau J, Shiffrar M, Bonnet C (1993) Perceived speed of moving lines depends on orientation, length, speed and luminance. *Vision Res* 33(14):1921–1936
- Chen Y, Geilser WS, Seidemann E (2006) Optimal decoding of correlated neural population responses in the primate visual cortex. *Nat Neurosci* 9(11):1412–1420
- Demb JB (2007) Cellular mechanisms for direction selectivity in the retina. *Neuron* 55(2):179–286
- Dobbins A, Zucker SW, Cynader MS (1987) Endstopped neurons in the visual cortex as a substrate for calculating curvature. *Nature* 329:438–441
- Findlay JM, Gilchrist ID (2003) Active vision. The psychology of looking and seeing. Oxford University Press, Oxford
- Gold JJ, Shadlen MN (2007) The neural basis of decision making. *Annu Rev Neurosci* 30:535–574
- Goltz HC, DeSouza JF, Menon RS, Tweed DB, Vilis T (2003) Interactions of retinal image and eye velocity in motion perception. *Neuron* 39(3):569–579
- Hanks TD, Ditterich J, Shadlen MN (2006) Microstimulation of macaque area LIP affects decision making in a motion discrimination task. *Nat Neurosci* 9(5):682–689
- Hubel DH, Wiesel TN (1968) Receptive fields and functional architecture of monkey striate cortex. *J Physiol (Lond)* 195(1):215–243
- Huk AC, Shadlen MN (2005) Neural activity in macaque parietal cortex reflects temporal integration of visual motion signals during perceptual decision making. *J Neurosci* 25(45):10420–10436
- Ilg UJ (2008) The role of areas MT and MST in coding of visual motion underlying the execution of smooth pursuit. *Vision Res* 48(20):2062–2069
- Ilg UJ, Thier P (2003) Visual tracking neurons in primate area MST are activated by smooth-pursuit eye movements of an “imaginary” target. *J Neurophysiol* 90(3):1489–1502
- Jancke D, Chavane F, Naaman S, Grinvald A (2004) Imaging cortical correlates of illusion in early visual cortex. *Nature* 428(6981):423–426
- Kourtzi Z, Krekelberg B, Van Wezel RJ (2008) Linking form and motion in the primate brain. *Trends Cogn Sci* 12(6):230–236
- Krauzlis RJ (2004) Recasting the smooth pursuit eye movement system. *J Neurophysiol* 91(2):591–603
- Lennie P, Movshon, JA (2005) Coding of color and form in the geniculostriate visual pathway. *J Opt Soc Am A* 22(10):2013–2033
- Lisberger SG, Morris EJ, Tychsen L (1987) Visual motion processing and sensory-motor integration for smooth pursuit eye movements. *Annu Rev Neurosci* 10:97–129
- Lorenceau J, Shiffrar M, Wells N, Castet E (1993) Different motion sensitive units are involved in recovering the direction of moving lines. *Vision Res* 33(9):1207–1217
- Lu ZL, Sperling G (2001) Three-systems theory of human visual motion perception: review and update. *J Opt Soc Am A* 18(9):2331–2370
- Masson GS (2004) From 1D to 2D via 3D: dynamics of surface motion segmentation for ocular tracking in primates. *J Physiol (Paris)* 1–3:35–52
- Miles FA, Fuller JH (1975) Visual tracking and the primate flocculus. *Science* 189:1000–1002
- Miles FA, Kawano K, Optican LM (1986) Short-latency ocular following responses of monkey. I. Dependence on spatiotemporal properties of visual input. *J Neurophysiol* 56(5):1321–1354

- Miles FA, Busetini C, Masson GS, Yang D-Y (2004) Short-latency eye movements: evidence for parallel processing of optic flow. In: Vaina L, Beardsley SA, Rushton S (eds) *Optic flow and beyond*. Kluwer, New York, pp 70–103
- Monier C, Chavane F, Baudot P, Graham LJ, Frégnac Y (2003) Orientation and direction selectivity of synaptic inputs in visual cortex neurons: a diversity of combinations produces spike tuning. *Neuron* 37(4):663–680
- Murakami I (2004) The aperture problem in egocentric motion. *Trends Neurosci* 27(4):174–177
- Nakayama K (1985) Biological image motion processing: a review. *Vision Res* 25(5):625–660
- Newsome WT, Wurtz RH, Komatsu H (1988) Relation of cortical areas MT and PST to pursuit eye movements. II. Differentiation of retinal from extraretinal inputs. *J Neurophysiol* 60:604–620
- Orban GS (2008) Higher-order visual processing in macaque extrastriate cortex. *Physiol Rev* 88(1):59–89
- Pack CC, Born RT (2001) Temporal dynamics of a neural solution to the aperture problem in visual area MT of macaque brain. *Nature* 409:1040–1042
- Pack CC, Livingstone MS, Duffy KR, Born RT (2003) End-stopping and the aperture problem: two-dimensional motion signals in macaque V1. *Neuron* 39(4):671–680
- Paragios N, Chen Y, Faugeras O (2005) *Handbook of mathematical models in computer vision*. Springer, Berlin
- Parker AJ, Newsome WT (1998) Sense and the single neuron: probing the physiology of perception. *Annu Rev Neurosci* 21:227–277
- Pasternak T, Greenlee MW (2005) Working memory in primate sensory systems. *Nat Rev Neurosci* 6(2):97–107
- Reichardt W (1961). Autocorrelation, a principle for evaluation of sensory information by the central nervous system. In: Rosenblith WA (ed) *Sensory communication* (p. 303). Wiley, New York, pp 303–317
- Roark DA, Barrett SE, Spence MJ, Abdi T, O'Toole AJ (2003) Psychological and neural perspectives on the role of motion in face recognition. *Behav Cogn Neurosci Rev* 2(1):15–46
- Rorie AE, Newsome WT (2005) A general mechanism for decision-making in the human brain? *Trends Neurosci* 9(2):363–375
- Ross J, Morrone MC, Goldberg ME, Burr DC (2001) Changes in visual perception at the time of saccades. *Trends Neurosci* 24(2):113–121
- Rust NC, Movshon JA (2005) In praise of artifice. *Nature Neuroscience* 8(12):1647–1650
- Rust NC, Mante V, Simoncelli EP, Movshon JA (2006) How MT cells analyze the motion of visual patterns. *Nature Neuroscience* 9(11):1421–1431
- Schlack A, Albright TD (2007) Remembering visual motion: neural correlates of associative plasticity and motion recall in cortical area MT. *Neuron* 53:881–890
- Shadlen MN (2002) Pursuing commitments. *Nat Neurosci* 5(9):819–821
- Shadlen MN, Newsome WT (2001) Neural basis of a perceptual decision in the parietal cortex (areas LIP) of the rhesus monkey. *J Neurophysiol* 86(4):1916–1936
- Sincich LC, Horton JC (2005) The circuitry of V1 and V2: integration of color, form and motion. *Annu Rev Neurosci* 28:303–326
- Snowden RJ, Freeman TC (2004) The visual perception of motion. *Curr Biol* 14(9):R828–R831
- Vaina LM (1998) Complex motion perception and its deficits. *Curr Opin Neurobiol* 8(4):494–502
- Volkman FC (1986) Human visual suppression. *Vision Res* 26(9):1401–1416
- Watanabe T (1998) *High-level motion processing: computational, neurobiological and psychophysical perspective*. MIT Press, Cambridge, MA
- Yasui S, Young LR (1975) Perceived visual motion as effective visual stimulus for pursuit eye movement system. *Science* 190:906–908
- Yo C, Wilson HR (1992) Perceived direction of moving two-dimensional patterns depends on duration, contrast and eccentricity. *Vision Res* 32(1):135–147

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