



## UvA-DARE (Digital Academic Repository)

### Scene statistics: neural representation of real-world structure in rapid visual perception

Groen, I.I.A.

**Publication date**  
2014

[Link to publication](#)

#### **Citation for published version (APA):**

Groen, I. I. A. (2014). *Scene statistics: neural representation of real-world structure in rapid visual perception*. [Thesis, fully internal, Universiteit van Amsterdam].

#### **General rights**

It is not permitted to download or to forward/distribute the text or part of it without the consent of the author(s) and/or copyright holder(s), other than for strictly personal, individual use, unless the work is under an open content license (like Creative Commons).

#### **Disclaimer/Complaints regulations**

If you believe that digital publication of certain material infringes any of your rights or (privacy) interests, please let the Library know, stating your reasons. In case of a legitimate complaint, the Library will make the material inaccessible and/or remove it from the website. Please Ask the Library: <https://uba.uva.nl/en/contact>, or a letter to: Library of the University of Amsterdam, Secretariat, Singel 425, 1012 WP Amsterdam, The Netherlands. You will be contacted as soon as possible.

## References

- Adelson EH, Bergen JR (1991) The plenoptic function and the elements of early vision. In: *Computational Models of Visual Processing* (Landy MS, Movshon JA, eds), pp 3–20. Cambridge, MA: MIT Press.
- Akaike H (1973) Information theory and an extension of the maximum likelihood principle. In: *Second international Symposium on Information Theory* (Petrov BN, Csaki F, eds), pp. 267-281. Budapest: Akademiai Kiado.
- Alvarez GA, Oliva A (2009) Spatial ensemble statistics are efficient codes that can be represented with reduced attention. *Proc Natl Acad Sci U S A* 106:7345–7350.
- Bacon-Macé N, Kirchner H, Fabre-Thorpe M, Thorpe SJ (2007) Effects of task requirements on rapid natural scene processing: from common sensory encoding to distinct decisional mechanisms. *J Exp Psychol Hum Percept Perform* 33:1013–1026.
- Bacon-Macé N, Macé MJ-M, Fabre-Thorpe M, Thorpe SJ (2005) The time course of visual processing: backward masking and natural scene categorisation. *Vision Res* 45:1459–1469.
- Baddeley R (1996) Searching for filters with “interesting” output distributions: an uninteresting direction to explore? *Netw Comput Neural Syst* 7:409–421.
- Baddeley R (1997) The correlational structure of natural images and the calibration of spatial representations. *Cogn Sci* 21:351–372.
- Bankó EM, Gál V, Kortvélyes J, Kovács G, Vidnyánsky Z (2011) Dissociating the effect of noise on sensory processing and overall decision difficulty. *J Neurosci* 31:2663–2674.
- Bar M (2004) Visual objects in context. *Nat Rev Neurosci* 5:617–629.
- Bar M, Aminoff E (2003) Cortical analysis of visual context. *Neuron* 38:347–358.
- Bar M, Kassam KS, Ghuman AS, Boshyan J, Schmid AM, Dale AM, Hamalainen MS, Marinkovic K, Schacter DL, Rosen BR, Halgren E (2006) Top-down facilitation of visual recognition. *Proc Natl Acad Sci USA* 103:449–454.
- Bergen JR, Julesz B (1983) Parallel versus serial processing in rapid pattern discrimination. *Nature* 303:696–698.
- Biederman I (1972) Perceiving real world scenes. *Science* (80- ) 177:77–80.
- Biederman I (1987) Recognition-by-components: a theory of human image understanding. *Psychol Rev* 94:115–147.
- Bieniek MM, Frei LS, Rousselet GA (2013) Early ERPs to faces: aging, luminance, and individual differences. *Front Psychol* 4:268.
- Bieniek MM, Pernet CR, Rousselet GA (2012) Early ERPs to faces and objects are driven by phase, not amplitude spectrum information: Evidence from parametric, test-retest, single-subject analyses. *J Vis* 12:1–24.
- Blank H, Biele G, Heekeren HR, Philiastides MG (2013) Temporal characteristics of the influence of punishment on perceptual decision making in the human brain. *J Neurosci* 33:3939–3952.
- Bonin V, Mante V, Carandini M (2005) The suppressive field of neurons in lateral geniculate nucleus. *J Neurosci* 25:10844–10856.
- Bouvrie J, Rosasco L, Poggio T (2009) On invariance in hierarchical models. *Adv Neural Inf Process Syst* 22.
- Brady N, Field DJ (2000) Local contrast in natural images: normalisation and coding efficiency. *Perception* 29:1041–1055.
- Brainard DH (1997) The Psychophysics Toolbox. *Spat Vis* 10:433–436.
- Braun J (2003) Natural scenes upset the visual applecart. *Trends Cogn Sci* 7:7–9.

- Bruyer R, Brysbaert M (2011) Combining speed and accuracy in cognitive psychology: is the inverse efficiency score (IES) a better dependent variable than the mean reaction time (RT) and the percentage of errors (PE)? *Psychol Belg*:5–13.
- Burnham KP, Anderson DR (2004) Multimodel inference: understanding AIC and BIC in model selection. *Sociol Methods Res* 33:261–304.
- Camprodon JA, Zohary E, Brodbeck V, Pascual-Leone A (2010) Two phases of V1 activity for visual recognition of natural images. *J Cogn Neurosci* 22:1262–1269.
- Cant JS, Xu Y (2012) Object ensemble processing in human anterior-medial ventral visual cortex. *J Neurosci* 32:7685–7700.
- Chen L, Zhang S, Srinivasan M V (2003) Global perception in small brains: topological pattern recognition in honey bees. *Proc Natl Acad Sci U S A* 100:6884–6889.
- Cichy RM, Pantazis D, Oliva A (2014) Resolving human object recognition in space and time. *Nat Neurosci*:1–10.
- Cohen MA, Alvarez GA, Nakayama K (2011) Natural-scene perception requires attention. *Psychol Sci* 22:1165–1172.
- Conroy B, Sajda P (2012) Fast, exact model selection and permutation testing for L2-regularized logistic regression. In: *Proceedings of the 15th International Conference on Artificial Intelligence and Statistics*, pp 246–254. La Palma, Canary Islands.
- Croner LJ, Kaplan E (1995) Receptive fields of P and M ganglion cells across the primate retina. *Vision Res* 35:7–24.
- Daniels HE (1944) The relation between measures of correlation in the universe of sample permutations. *Biometrika* 33:129–135.
- De Valois RL, De Valois KK (1990) *Spatial Vision*. New York: Oxford University Press.
- Delorme A, Richard G, Fabre-Thorpe M (1999) Rapid processing of complex natural scenes: A role for the magnocellular visual pathways? *Neurocomputing* 26-27:663–670.
- Delorme A, Rousselet GA, Macé MJ-M, Fabre-Thorpe MM (2004) Interaction of top-down and bottom-up processing in the fast visual analysis of natural scenes. *Cogn Brain Res* 19:103–113.
- Deng J, Dong W, Socher R, Li L-J, Li K, Fei-Fei L (2009) ImageNet: A large-scale hierarchical image database. *2009 IEEE Conf Comput Vis Pattern Recognit* 248–255.
- DiCarlo JJ, Cox DD (2007) Untangling invariant object recognition. *Trends Cogn Sci* 11:333–341.
- DiCarlo JJ, Zoccolan D, Rust NC (2012) How does the brain solve visual object recognition? *Neuron* 73:415–434.
- Dilks DD, Julian JB, Paunov AM, Kanwisher N (2013) The occipital place area is causally and selectively involved in scene perception. *J Neurosci* 33:1331–6a.
- Doi E, Lewicki MS (2005) Relations between the statistical regularities of natural images and the response properties of the early visual system. In: *Japanese Cognitive Science Society*, pp 1–8.
- Drucker DM, Aguirre GK (2009) Different spatial scales of shape similarity representation in lateral and ventral LOC. *Cereb Cortex* 19:2269–2280.
- Duda R, Hart P, Stork D (2001) *Pattern Classification*. New York: Wiley.
- Eickhoff SB, Stephan KE, Mohlberg H, Grefkes C, Fink GR, Amunts K, Zilles K (2005) A new SPM toolbox for combining probabilistic cytoarchitectonic maps and functional imaging data. *Neuroimage* 25:1325–1335.

- Einhäuser W, Rutishauser U, Frady EP, Nadler S, König P, Koch C (2006) The relation of phase noise and luminance contrast to overt attention in complex visual stimuli. *J Vis* 6:1148–1158.
- Elder JH, Velisavljevic L (2009) Cue dynamics underlying rapid detection of animals in natural scenes. *J Vis* 9:1–20.
- Elder JH, Zucker SW (1998) Local scale control for edge detection and blur estimation. *IEEE Trans Pattern Anal Mach Intell* 20:699–716.
- Epstein R (2005) The cortical basis of visual scene processing. *Vis Cogn* 12:954–978.
- Epstein R, Kanwisher N (1998) A cortical representation of the local visual environment. *Nature* 392:598–601.
- Evans KK, Treisman A (2005) Perception of objects in natural scenes: is it really attention free? *J Exp Psychol Hum Percept Perform* 31:1476–1492.
- Fahrenfort JJ, Scholte HS, Lamme VAF (2007) Masking disrupts reentrant processing in human visual cortex. *J Cogn Neurosci* 19:1488–1497.
- Fei-Fei L, Fergus R, Perona P (2007a) Learning generative visual models from few training examples: An incremental Bayesian approach tested on 101 object categories. *Comput Vis Image Underst* 106:59–70.
- Fei-Fei L, Iyer A, Koch C, Perona P (2007b) What do we perceive in a glance of a real-world scene? *J Vis* 7:10.
- Fei-Fei L, VanRullen R, Koch C, Perona P (2005) Why does natural scene categorization require little attention? Exploring attentional requirements for natural and synthetic stimuli. *Vis Cogn* 12:893–924.
- Felsen G, Dan Y (2005) A natural approach to studying vision. *Nat Neurosci* 8:1643–1646.
- Felsen G, Touryan J, Han F, Dan Y (2005) Cortical sensitivity to visual features in natural scenes. *PLoS Biol* 3:e342.
- Field DJ (1987) Relations between the statistics of natural images and the response properties of cortical cells. *J Opt Soc Am* 4:2379–2394.
- Fize D, Fabre-Thorpe M, Richard G, Doyon B, Thorpe SJ (2005) Rapid categorization of foveal and extrafoveal natural images: associated ERPs and effects of lateralization. *Brain Cogn* 59:145–158.
- Frazor RA, Geisler WS (2006) Local luminance and contrast in natural images. *Vision Res* 46:1585–1598.
- Freeman J, Simoncelli EP (2011) Metamers of the ventral stream. *Nat Neurosci* 14:1195–1201.
- Freeman J, Ziemba CM (2011) Unwrapping the ventral stream. *J Neurosci* 31:2349–2351.
- Garthwaite PH (1996) Confidence intervals from randomization tests. *Biometrics* 52:1387–1393.
- Gaspar CM, Rousset GA (2009) How do amplitude spectra influence rapid animal detection? *Vision Res* 49:3001–3012.
- Gaspar CM, Rousset GA, Pernet CR (2011) Reliability of ERP and single-trial analyses. *Neuroimage* 58:620–629.
- Gavves E, Snoek CGM, Smeulders AWM (2011) Visual synonyms for landmark image retrieval. *Comput Vis Image Underst* 116:238–249.
- Geisler WS (2008) Visual perception and the statistical properties of natural scenes. *Annu Rev Psychol* 59:167–192.
- Geusebroek J-M, Smeulders AWM (2002) A physical explanation for natural image statistics. In: Paper presented at the 2nd International Workshop on Texture Analysis, Heriot-Watt University.

- Geusebroek J-M, Smeulders AWM (2003) Fragmentation in the vision of scenes. *Proc Ninth IEEE Int Conf Comput Vis*:130–135 vol.1.
- Geusebroek J-M, Smeulders AWM (2005) A six-stimulus theory for stochastic texture. *Int J Comput Vis* 62:7–16.
- Ghebreab S, Smeulders AWM, Scholte HS, Lamme VAF (2009) A biologically plausible model for rapid natural image identification. In: *Advances in Neural Information Processing Systems*, pp 629–637.
- Gilbert CD, Li W (2013) Top-down influences on visual processing. *Nat Rev Neurosci* 14:350–363.
- Goffaux V, Jacques C, Mouraux A, Oliva A, Schyns PPG, Rossion B (2005) Diagnostic colours contribute to the early stages of scene categorization: Behavioural and neurophysiological evidence. *Vis Cogn* 12:878–892.
- Graham N (1979) Does the brain perform a Fourier analysis of the visual scene? *Trends Neurosci* 2:207–208.
- Gratton, Coles (1983) A new method for off-line removal of ocular artifact. *Electroencephalogr Clin Neurophysiol* 55:468–484.
- Greene MR, Oliva A (2009a) The briefest of glances: the time course of natural scene understanding. *Psychol Sci* 20:464–472.
- Greene MR, Oliva A (2009b) Recognition of natural scenes from global properties: seeing the forest without representing the trees. *Cogn Psychol* 58:137–176.
- Grill-Spector K (2003) The neural basis of object perception. *Curr Opin Neurobiol* 13:159–166.
- Grill-Spector K, Malach R (2004) The human visual cortex. *Annu Rev Neurosci* 27:649–677.
- Groen IIA, Ghebreab S, Lamme VA, Scholte HS (2012a) Spatially pooled contrast responses predict neural and perceptual similarity of naturalistic image categories. *PLoS Comput Biol* 8:e1002726.
- Groen IIA, Ghebreab S, Lamme VAF, Scholte HS (2010) The role of Weibull statistics in rapid object detection in natural scenes [Meeting Abstract]. *J Vis* 10:992.
- Groen IIA, Ghebreab S, Lamme VAF, Scholte HS (2012b) Low-level contrast statistics are diagnostic of invariance of natural textures. *Front Comput Neurosci* 6:34.
- Groen IIA, Ghebreab S, Prins H, Lamme VAF, Scholte HS (2013) From image statistics to scene gist: evoked neural activity reveals transition from low-level natural image structure to scene category. *J Neurosci* 33:18814–18824.
- Handy TC, Soltani M, Mangun GR (2001) Perceptual load and visuocortical processing: event-related potentials reveal sensory-level selection. *Psychol Sci* 12:213–218.
- Hansen BC, Jacques T, Johnson AP, Ellemborg D (2011) From spatial frequency contrast to edge preponderance: the differential modulation of early visual evoked potentials by natural scene stimuli. *Vis Neurosci* 28:221–237.
- Hansen BC, Johnson AP, Ellemborg D (2012) Different spatial frequency bands selectively signal for natural image statistics in the early visual system. *J Neurophysiol* 108:2160–2172.
- Harel A, Kravitz DJ, Baker CI (2012) Deconstructing visual scenes in cortex: gradients of object and spatial layout information. *Cereb Cortex* 23:947–957.
- Harel A, Kravitz DJ, Baker CI (2014) Task context impacts visual object processing differentially across the cortex. *Proc Natl Acad Sci*: 962–971.
- Heeger DJ, Simoncelli EP, Movshon JA (1996) Computational models of cortical visual processing. *Proc Natl Acad Sci U S A* 93:623–627.
- Hegd  J (2008) Time course of visual perception: Coarse-to-fine processing and beyond. *Prog Neurobiol* 84:405–439.

- Hochstein S, Ahissar M (2002) View from the top: Hierarchies and reverse hierarchies in the visual system. *Neuron* 36:791–804.
- Honey C, Kirchner H, VanRullen R (2008) Faces in the cloud: Fourier power spectrum biases ultrarapid face detection. *J Vis* 8:1–13.
- Hsaio WH, Millane RP (2005) Effects of occlusion, edges, and scaling on the power spectra of natural images. *J Opt Soc Am A* 22:1789.
- Huang L, Dobkins KR (2005) Attentional effects on contrast discrimination in humans: evidence for both contrast gain and response gain. *Vision Res* 45:1201–1212.
- Hubel DH, Wiesel TN (1968) Receptive fields and functional architecture in monkey striate cortex. *J Physiol* 195:215–243.
- Intraub H (1981) Rapid conceptual identification of sequentially presented pictures. *J Exp Psychol Hum Percept Perform* 7:604–610.
- Jahfari S, Ridderinkhof KR, Scholte HS (2013) Spatial frequency information modulates response inhibition and decision-making processes. *PLoS One* 8:e76467.
- Jahfari S, Waldorp L, van den Wildenberg WPM, Scholte HS, Ridderinkhof KR, Forstmann BU (2011) Effective connectivity reveals important roles for both the hyperdirect (fronto-subthalamic) and the indirect (fronto-striatal-pallidal) fronto-basal ganglia pathways during response inhibition. *J Neurosci* 31:6891–6899.
- Jegou H, Douze M, Schmid C (2008) Hamming embedding and weak geometric consistency for large scale image search. In: *Proceedings of the 10th European conference on Computer Vision*.
- Jégou H, Perronnin F, Douze M, Jorge S, Patrick P, Schmid C (2011) Aggregating local image descriptors into compact codes. *IEEE Trans Pattern Anal Mach Intell*.
- Jenkinson M, Bannister P, Brady M, Smith S (2002) Improved optimisation for the robust and accurate linear registration and motion correction of brain images. *Neuroimage* 17:825–841.
- Johnson JS, Olshausen BA (2003) Timecourse of neural signatures of object recognition. *J Vis* 3:499–512.
- Joubert OR, Rousset GA, Fabre-Thorpe M, Fize D (2009) Rapid visual categorization of natural scene contexts with equalized amplitude spectrum and increasing phase noise. *J Vis* 9:2.1–16.
- Joubert OR, Rousset GA, Fize D, Fabre-Thorpe M (2007) Processing scene context: fast categorization and object interference. *Vision Res* 47:3286–3297.
- Kadar I, Ben-Shahar O (2012) A perceptual paradigm and psychophysical evidence for hierarchy in scene gist processing. *J Vis* 12:1–17.
- Kahn DA, Harris AM, Wolk DA, Aguirre GK (2010) Temporally distinct neural coding of perceptual similarity and prototype bias. *J Vis* 10:1–12.
- Kaping D, Tzvetanov T, Treue S (2007) Adaptation to statistical properties of visual scenes biases rapid categorization. *Vis cogn* 15:12–19.
- Karklin Y, Lewicki MS (2009) Emergence of complex cell properties by learning to generalize in natural scenes. *Nature* 457:83–86.
- Kastner S, Weerd P De, Ungerleider LG (2000) Texture segregation in the human visual cortex: A functional MRI study. *J Neurophysiol*: 2453–2457.
- Kay KN, Naselaris T, Prenger RJ, Gallant JL (2008) Identifying natural images from human brain activity. *Nature* 452:352–355.
- Kingdom FAA, Hayes A, Field DJ (2001) Sensitivity to contrast histogram differences in synthetic wavelet-textures. *Vision Res* 41:585–598.
- Kirchner H, Thorpe SJ (2006) Ultra-rapid object detection with saccadic eye movements: visual processing speed revisited. *Vision Res* 46:1762–1776.

- Koenderink JJ, van de Grind WA, Bouman MA (1972) Opponent color coding: A mechanistic model and a new metric for color space. *Kybernetik* 10:78–98.
- Koivisto M, Kastrati G, Revonsuo A (2013) Recurrent processing enhances visual awareness but is not necessary for fast categorization of natural scenes. *J Cogn Neurosci* 26:223–231.
- Koivisto M, Railo H, Revonsuo A, Vanni S, Salminen-Vaparanta N (2011) Recurrent processing in V1/V2 contributes to categorization of natural scenes. *J Neurosci* 31:2488–2492.
- Kravitz DJ, Peng CS, Baker CI (2011) Real-world scene representations in high-level visual cortex: it's the spaces more than the places. *J Neurosci* 31:7322–7333.
- Kravitz DJ, Saleem KS, Baker CI, Ungerleider LG, Mishkin M (2013) The ventral visual pathway: an expanded neural framework for the processing of object quality. *Trends Cogn Sci* 17:26–49.
- Kriegeskorte N, Kievit RA (2013) Representational geometry: integrating cognition, computation, and the brain. *Trends Cogn Sci* 1216:1–12.
- Kriegeskorte N, Mur M, Bandettini P (2008a) Representational similarity analysis - connecting the branches of systems neuroscience. *Front Syst Neurosci* 2:4.
- Kriegeskorte N, Mur M, Ruff DA, Kiani R, Bodurka J, Esteky H, Tanaka K, Bandettini PA (2008b) Matching categorical object representations in inferior temporal cortex of man and monkey. *Neuron* 60:1126–1141.
- Lamme V, Roelfsema P (2000) The distinct modes of vision offered by feedforward and recurrent processing. *Trends Neurosci* 23:571–579.
- Lamme VAF (1995) The neurophysiology of figure-ground segregation in primary visual cortex. *J Neurosci* 15:1605–1615.
- Lamme VAF, Zipser K, Spekreijse H (2002) Masking interrupts figure-ground signals in V1. *J Cogn Neurosci* 14:1044–1053.
- Landy MS, Graham N (2004) Visual perception of texture. In *The Visual Neurosciences* (Chalupa LM, Werner JS, eds), pp 1106–1118. Cambridge, MA: MIT Press.
- Laughlin S (1981) A simple coding procedure enhances a neuron's information capacity. *Z Naturforsch* 36 c:910–912.
- Lavie N (1995) Perceptual load as a necessary condition for selective attention. *J Exp Psychol Hum Percept Perform* 21:451–468.
- Li A, Zaidi Q (2000) Perception of three-dimensional shape from texture is based on patterns of oriented energy. *Vision Res* 40:217–242.
- Li F-F, VanRullen R, Koch C, Perona P (2002) Rapid natural scene categorization in the near absence of attention. *Proc Natl Acad Sci* 99:9596–9601.
- Liu H, Agam Y, Madsen JR, Kreiman G (2009) Timing, timing, timing: fast decoding of object information from intracranial field potentials in human visual cortex. *Neuron* 62:281–290.
- Loschky LC, Larson AM (2008) Localized information is necessary for scene categorization, including the Natural/Man-made distinction. *J Vis* 8:1–9.
- Loschky LC, Larson AM (2010) The natural/man-made distinction is made before basic-level distinctions in scene gist processing. *Vis Cogn* 18:513–536.
- Loschky LC, Sethi A, Simons DJ, Pydimarri TN, Ochs D, Corbeille JL (2007) The importance of information localization in scene gist recognition. *J Exp Psychol Hum Percept Perform* 33:1431–1450.
- Luck S, Woodman G, Vogel E (2000) Event-related potential studies of attention. *Trends Cogn Sci* 4:432–440.
- Luck SJ (2005) *An Introduction to the Event-Related Potential Technique*. Cambridge, MA: MIT Press.
- Mack A, Clarke J (2012) Gist perception requires attention. *Vis Cogn* 20:300–327.

- Macmillan NA, Creelman CD (1991) *Detection theory: A user's guide*. New York: Cambridge University Press.
- Malach R, Reppas JB, Benson RR, Kwong KK, Jiang H, Kennedy WA, Ledden PJ, Brady TJ, Rosen BR, Tootell RB (1995) Object-related activity revealed by functional magnetic resonance imaging in human occipital cortex. *Proc Natl Acad Sci U S A* 92:8135–8139.
- Malcolm GL, Henderson JM (2009) The effects of target template specificity on visual search in real-world scenes: Evidence from eye movements. *J Vis* 9:1–13.
- Malcolm GL, Nuthmann A, Schyns PG (2014) Beyond gist: Strategic and incremental information accumulation for scene categorization. *Psychol Sci*.
- Malik J, Perona P (1990) Preattentive texture discrimination with early vision mechanisms. *J Opt Soc Am* 7:923–932.
- Malik J, Rosenholtz R (1997) Computing local surface orientation and shape from texture for curved surfaces. *Int J Comput Vis* 23:149–168.
- Mantel N, Valand RS (1970) A technique of nonparametric multivariate analysis. *Biometrics* 26:547–558.
- Martinovic J, Mordal J, Wuergler SM (2011) Event-related potentials reveal an early advantage for luminance contours in the processing of objects. *J Vis* 11:1–15.
- Maunsell JHR, Newsome WT (1987) Visual processing in monkey extrastriate cortex. *Annu Rev Neurosci* 10:363–401.
- McCotter M, Gosselin F, Sowden P, Schyns PG (2005) The use of visual information in natural scenes. *Vis Cogn* 12:938–953.
- Mullin CR, Steeves JKE (2013) Consecutive TMS-fMRI reveals an inverse relationship in BOLD signal between object and scene processing. *J Neurosci* 33:19243–19249.
- Naselaris T, Stansbury DE, Gallant JL (2012) Cortical representation of animate and inanimate objects in complex natural scenes. *J Physiol Paris* 106:239–249.
- Nothdurft HC (1991) Texture segmentation and pop-out from orientation contrast. *Vision Res* 31:1073–1078.
- Nunez PL, Srinivasan R (2006) *The neurophysics of EEG*, 2nd ed.,. Oxford, UK: Oxford University Press.
- Oliva A (2005) Gist of the scene. In: *Neurobiology of Attention*, pp 251–257.
- Oliva A, Schyns PG (1997) Coarse blobs or fine edges? Evidence that information diagnosticity changes the perception of complex visual stimuli. *Cogn Psychol* 34:72–107.
- Oliva A, Schyns PG (2000) Diagnostic colors mediate scene recognition. *Cogn Psychol* 41:176–210.
- Oliva A, Torralba A (2001) Modeling the shape of the scene: A holistic representation of the spatial envelope. *Int J Comput Vis* 42:145–175.
- Oliva A, Torralba A (2006) Building the gist of a scene: the role of global image features in recognition. *Prog Brain Res* 155:23–36.
- Oliva A, Torralba A (2007) The role of context in object recognition. *Trends Cogn Sci* 11:520–527.
- Oliva A, Torralba AB, Guerin-Dugue A, Herault J (1999) Global semantic classification of scenes using power spectrum templates. In: *Proceedings of the Challenge of Image Retrieval, Electronic Workshops in Computing Series*. Newcastle: Springer-Verlag.
- Olmos A, Kingdom FAA (2004) A biologically inspired algorithm for the recovery of shading and reflectance images. *Perception* 33:1463–1473.
- Olshausen BA, Field DJ (1996a) Natural image statistics and efficient coding. *Netw Comput Neural Syst* 7:333–339.



- Olshausen BA, Field DJ (1996b) Emergence of simple-cell receptive field properties by learning a sparse code for natural images. *Nature* 381:607–610.
- Olshausen BA, Field DJ (2005) How close are we to understanding v1? *Neural Comput* 17:1665–1699.
- Op de Beeck HP, Wagemans J, Vogels R (2008) The representation of perceived shape similarity and its role for category learning in monkeys: a modeling study. *Vision Res* 48:598–610.
- Opelt A, Pinz A, Fussenegger M, Auer P (2004) Generic object recognition with boosting. *IEEE Trans Pattern Anal Mach Intell* 28:416–431.
- Park S, Brady TF, Greene MR, Oliva A (2011) Disentangling scene content from spatial boundary: complementary roles for the parahippocampal place area and lateral occipital complex in representing real-world scenes. *J Neurosci* 31:1333–1340.
- Parra L, Alvino C, Tang A, Pearlmutter B, Yeung N, Osman A, Sajda P (2002) Linear spatial integration for single-trial detection in encephalography. *Neuroimage* 230:223–230.
- Peelen M V, Fei-Fei L, Kastner S (2009) Neural mechanisms of rapid natural scene categorization in human visual cortex. *Nature* 460:94–97.
- Peelen M V, Kastner S (2014) Attention in the real world: toward understanding its neural basis. *Trends Cogn Sci*:1–9.
- Pelli DG (1997) The VideoToolbox software for visual psychophysics: Transforming numbers into movies. *Spat Vis*:437–442.
- Perrin F (1989) Spherical splines for scalp potential and current density mapping. *Electroencephalogr Clin Neurophysiol* 72:184–187.
- Philiastides MG, Ratcliff R, Sajda P (2006) Neural representation of task difficulty and decision making during perceptual categorization: a timing diagram. *J Neurosci* 26:8965–8975.
- Philiastides MG, Sajda P (2006) Temporal characterization of the neural correlates of perceptual decision making in the human brain. *Cereb Cortex* 16:509–518.
- Poggio T, Serre T (2013) Models of visual cortex. *Scholarpedia* 8:3516.
- Potter MC (1975) Meaning in visual search. *Science* 187:965–966.
- Potter MC (2012) Recognition and memory for briefly presented scenes. *Front Psychol* 3:32.
- Ratcliff R, Philiastides MG, Sajda P (2009) Quality of evidence for perceptual decision making is indexed by trial-to-trial variability of the EEG. *Proc Natl Acad Sci U S A* 106:6539–6544.
- Renninger LW, Malik J (2004) When is scene identification just texture recognition? *Vision Res* 44:2301–2311.
- Rieger JW, Gegenfurtner KR, Koechy N, Heinze H-J, Grueschow M (2013) BOLD responses in human V1 to local structure in natural scenes: Implications for theories of visual coding. *J Vis* 13:1–15.
- Riesenhuber M, Poggio T (1999) Hierarchical models of object recognition in cortex. *Nat Neurosci* 2:1019–1025.
- Rockland KS, Pandya DN (1979) Laminar origins and terminations of cortical connections of the occipital lobe in the rhesus monkey. *Brain Res* 179:3–20.
- Roelfsema PR (2006) Cortical algorithms for perceptual grouping. *Annu Rev Neurosci* 29:203–227.
- Roelfsema PR, Lamme VAF, Spekreijse H (2000) The implementation of visual routines. *Vision Res* 40:1385–1411.
- Rousset GA, Fabre-Thorpe M, Thorpe SJ (2002) Parallel processing in high-level categorization of natural images. *Nat Neurosci* 5:629–630.

- Rousselet GA, Gaspar CM, Kacper P, Pernet CR (2011) Modeling single-trial ERP reveals modulation of bottom-up face visual processing by top-down task constraints (in some subjects). *Front Psychol* 2:1–19.
- Rousselet GA, Husk JS, Bennett PJ, Sekuler AB (2005a) Spatial scaling factors explain eccentricity effects on face ERPs. *J Vis* 5:755–763.
- Rousselet GA, Husk JS, Bennett PJ, Sekuler AB (2008a) Time course and robustness of ERP object and face differences. *J Vis* 8:1–18.
- Rousselet GA, Joubert OR, Fabre-Thorpe M (2005b) How long to get to the “gist” of real-world natural scenes? *Vis Cogn* 12:852–877.
- Rousselet GA, Pernet CR (2011) Quantifying the time course of visual object processing using ERPs: It’s time to up the game. *Front Psychol* 2:1–6.
- Rousselet GA, Pernet CR, Bennett PJ, Sekuler AB (2008b) Parametric study of EEG sensitivity to phase noise during face processing. *BMC Neurosci* 9.
- Rousselet GA, Thorpe SJ, Fabre-Thorpe M (2004) How parallel is visual processing in the ventral pathway? *Trends Cogn Sci* 8:363–370.
- Ruderman DL (1997) Origins of scaling in natural images. *Vision Res* 37:3385–3398.
- Rust NC, Movshon JA (2005) In praise of artifice. *Nat Neurosci* 8:1647–1650.
- Salin PA, Bullier J (1995) Corticocortical connections in the visual system: structure and function. *Physiol Rev* 75:107–154.
- Salinas E, Stanford TR (2013) The countermanding task revisited: fast stimulus detection is a key determinant of psychophysical performance. *J Neurosci* 33:5668–5685.
- Scholte HS, Ghebreab S, Waldorp L, Smeulders AWM, Lamme VAF (2009) Brain responses strongly correlate with Weibull image statistics when processing natural images. *J Vis* 9:1–15.
- Scholte HS, Jolij J, Fahrenfort JJ, Lamme VAF (2008) Feedforward and recurrent processing in scene segmentation: electroencephalography and functional magnetic resonance imaging. *J Cogn Neurosci* 20:2097–2109.
- Scholte HS, Sligte IG, Groen IIA, Lamme VAF, Ghebreab S (2013) The posterior part of the lateral occipital complex analyzes the spatial correlation structure of natural visual scenes [Meeting Abstract]. *J Vis* 13:1098.
- Scholte HS, Witteveen SC, Spekreijse H, Lamme VAF (2006) The influence of inattention on the neural correlates of scene segmentation. *Brain Res* 1076:106–115.
- Schwartz O, Simoncelli EP (2001) Natural signal statistics and sensory gain control. *Nat Neurosci* 4:819–825.
- Schyns PG, Oliva A (1994) From blobs to boundary edges: Evidence for time- and spatial-scale-dependent scene recognition. *Psychol Sci* 5:195–200.
- Schyns PG, Thut G, Gross J (2011) Cracking the code of oscillatory activity. *PLoS Biol* 9:e1001064.
- Serre T, Oliva A, Poggio T (2007) A feedforward architecture accounts for rapid categorization. *Proc Natl Acad Sci* 104:6424–6429.
- Shepard RN (1964) Attention and the metric structure of the stimulus space. *J Math Psychol* 1:54–87.
- Simoncelli EP (1999) Modeling the joint statistics of images in the wavelet domain. *Proc SPIE D*:188–195.
- Simoncelli EP (2003) Vision and the statistics of the visual environment. *Curr Opin Neurobiol* 13:144–149.
- Smith ML, Fries P, Gosselin F, Goebel R, Schyns PG (2009) Inverse mapping the neuronal substrates of face categorizations. *Cereb Cortex* 19:2428–2438.
- Tadmor Y, Tolhurst DJ (2000) Calculating the contrasts that retinal ganglion cells and LGN neurones encounter in natural scenes. *Vision Res* 40:3145–3157.

- Thorpe S (2009) The speed of categorization in the human visual system. *Neuron* 62:168–170.
- Thorpe S, Fize D, Marlot C (1996) Speed of processing in the human visual system. *Nature* 381:520–522.
- Torralba A (2003) Contextual priming for object detection. *Int J Comput Vis* 53:169–191.
- Torralba A, Oliva A (2003) Statistics of natural image categories. *Netw Comput Neural Syst* 14:391–412.
- Townsend JT, Ashby FG (1978) Methods of modeling capacity in simple processing systems. In: *Cognitive Theory* (Castellan J, Restle F, eds), pp 200–239. Hillsdale, N. J.: Erlbaum.
- Troiani V, Stigliani A, Smith ME, Epstein RA (2014) Multiple object properties drive scene-selective regions. *Cereb Cortex* 24:883–897.
- Uijlings JRR, Sande KEA, Gevers T, Smeulders AWM (2013) Selective Search for Object Recognition. *Int J Comput Vis* 104:154–171.
- Ungerleider LG, Mishkin M (1982) Two cortical visual systems. In: *Analysis of Visual Behavior* (Ingle DJ, Goodale MA, Mansfield RJW, eds), pp 549–586. Cambridge, MA: MIT Press.
- Van Loon AM, Scholte HS, Gaal S Van, van der Hoort BJJ, Lamme VAF (2012) GABA A agonist reduces visual awareness: A masking – EEG experiment. *J Cogn Neurosci* 24:965–974.
- Van Rijsbergen NJ, Schyns PG (2009) Dynamics of trimming the content of face representations for categorization in the brain. *PLoS Comput Biol* 5:e1000561.
- VanRullen R, Reddy L, Fei-Fei L (2005) Binding is a local problem for natural objects and scenes. *Vision Res* 45:3133–3144.
- VanRullen R, Thorpe S (2001) The time course of visual processing: from early perception to decision-making. *J Cogn Neurosci* 13:454–461.
- VanRullen R, Thorpe SJ (2002) Surfing a spike wave down the ventral stream. *Vision Res* 42:2593–2615.
- Verbruggen F, Logan GD (2009) Models of response inhibition in the stop-signal and stop-change paradigms. *Neurosci Biobehav Rev* 33:647–661.
- Vinje WE, Gallant JL (2000) Sparse coding and decorrelation in primary visual cortex during natural vision. *Science* 287:1273–1276.
- Vinje WE, Gallant JL (2002) Natural stimulation of the nonclassical receptive field increases information transmission efficiency in V1. *J Neurosci* 22:2904–2915.
- Wagge JR, Olzak LA (2008) Contributions of contrast gain and response gain in pattern masking. *J Vis* 8:89.
- Walther DB, Caddigan E, Fei-Fei L, Beck DM (2009) Natural scene categories revealed in distributed patterns of activity in the human brain. *J Neurosci* 29:10573–10581.
- Wichmann FA, Braun DI, Gegenfurtner KR (2006) Phase noise and the classification of natural images. *Vision Res* 46:1520–1529.
- Wolfe JM, Võ ML-H, Evans KK, Greene MR (2011) Visual search in scenes involves selective and nonselective pathways. *Trends Cogn Sci* 15:77–84.
- Woolrich MW (2008) Robust group analysis using outlier inference. *Neuroimage* 41:286–301.
- Woolrich MW, Ripley BD, Brady JM, Smith SM (2001) Temporal autocorrelation in univariate linear modeling of fMRI data. *Neuroimage* 14:1370–1386.
- Worsley KJ (2001) Statistical analysis of activation images. In: *Functional MRI: An introduction to methods* (Jezzard P, Matthews PM, Smith SM, eds). Oxford University Press.

- Wyatte D, Curran T, O'Reilly R (2012) The limits of feedforward vision: recurrent processing promotes robust object recognition when objects are degraded. *J Cogn Neurosci* 24:2248–2261.
- Yanulevskaya V, Marsman JB, Cornelissen F, Geusebroek J-M (2011) An image statistics-based model for fixation prediction. *Cognit Comput* 3:94–104.
- Yi D-J, Woodman GF, Widders D, Marois R, Chun MM (2004) Neural fate of ignored stimuli: dissociable effects of perceptual and working memory load. *Nat Neurosci* 7:992–996.
- Zhu SC, Mumford D (1997) Prior learning and Gibbs reaction-diffusion. In: *IEEE Transactions on Pattern Analysis and Machine Intelligence*, pp 1236–1250.
- Zipser K, Lamme VAF, Schiller PH (1996) Contextual modulation in primary visual cortex. *J Neurosci* 16:7376–7389.