

REFERENCES

- 1 Tabot, G. A. *et al.* Restoring the sense of touch with a prosthetic hand through a brain interface. *Proc Natl Acad Sci U S A* **110**, 18279-18284, doi:10.1073/pnas.1221113110 (2013).
- 2 Medina, L. E., Lebedev, M. A., O'Doherty, J. E. & Nicolelis, M. A. Stochastic facilitation of artificial tactile sensation in primates. *J Neurosci* **32**, 14271-14275, doi:10.1523/JNEUROSCI.3115-12.2012 (2012).
- 3 O'Doherty, J. E., Lebedev, M. A., Hanson, T. L., Fitzsimmons, N. A. & Nicolelis, M. A. A brain-machine interface instructed by direct intracortical microstimulation. *Front Integr Neurosci* **3**, 20, doi:10.3389/neuro.07.020.2009 (2009).
- 4 O'Doherty, J. E. *et al.* Active tactile exploration using a brain-machine-brain interface. *Nature* **479**, 228-231, doi:10.1038/nature10489 (2011).
- 5 Hsiao, S. & Gomez-Ramirez, M. in *Handbook of Psychology* Vol. 3 (eds I.B. Weiner, R.J. Nelson, & N.S. Mizumori) Ch. 8, 206-239 (Wiley, 2012).
- 6 Hsiao, S. S. & Gomez-Ramirez, M. in *The Cognitive Neurosciences* (eds M.S. Gazzaniga & G.R. Mangun) Ch. IV, 375-388 (2014).
- 7 Kim, C. K., Adhikari, A. & Deisseroth, K. Integration of optogenetics with complementary methodologies in systems neuroscience. *Nat Rev Neurosci* **18**, 222-235, doi:10.1038/nrn.2017.15 (2017).
- 8 Fenno, L., Yizhar, O. & Deisseroth, K. The development and application of optogenetics. *Annu Rev Neurosci* **34**, 389-412, doi:10.1146/annurev-neuro-061010-113817 (2011).
- 9 Acker, L. C., Pino, E. N., Boyden, E. S. & Desimone, R. Large Volume, Behaviorally-relevant Illumination for Optogenetics in Non-human Primates. *J Vis Exp*, doi:10.3791/56330 (2017).
- 10 Yazdan-Shahmorad, A., Silversmith, D. B. & Sabes, P. N. Novel techniques for large-scale manipulations of cortical networks in non-human primates. *Conf Proc IEEE Eng Med Biol Soc* **2018**, 5479-5482, doi:10.1109/EMBC.2018.8513668 (2018).
- 11 Schroeder, C. E., Wilson, D. A., Radman, T., Scharfman, H. & Lakatos, P. Dynamics of Active Sensing and perceptual selection. *Curr Opin Neurobiol* **20**, 172-176, doi:10.1016/j.conb.2010.02.010 (2010).
- 12 Schroeder, C. E. & Lakatos, P. The gamma oscillation: master or slave? *Brain Topogr* **22**, 24-26, doi:10.1007/s10548-009-0080-y (2009).
- 13 Herrmann, C. S., Frund, I. & Lenz, D. Human gamma-band activity: a review on cognitive and behavioral correlates and network models. *Neurosci Biobehav Rev* **34**, 981-992, doi:10.1016/j.neubiorev.2009.09.001 (2010).
- 14 Gregoriou, G. G., Paneri, S. & Sapountzis, P. Oscillatory synchrony as a mechanism of attentional processing. *Brain Res* **1626**, 165-182, doi:10.1016/j.brainres.2015.02.004 (2015).
- 15 Siegle, J. H., Pritchett, D. L. & Moore, C. I. Gamma-range synchronization of fast-spiking interneurons can enhance detection of tactile stimuli. *Nat Neurosci* **17**, 1371-1379, doi:10.1038/nn.3797 (2014).
- 16 Carlen, M. *et al.* A critical role for NMDA receptors in parvalbumin interneurons for gamma rhythm induction and behavior. *Mol Psychiatry* **17**, 537-548, doi:10.1038/mp.2011.31 (2012).
- 17 Cardin, J. A. *et al.* Driving fast-spiking cells induces gamma rhythm and controls sensory responses. *Nature* **459**, 663-667, doi:10.1038/nature08002 (2009).
- 18 Sohal, V. S., Zhang, F., Yizhar, O. & Deisseroth, K. Parvalbumin neurons and gamma rhythms enhance cortical circuit performance. *Nature* **459**, 698-702, doi:10.1038/nature07991 (2009).
- 19 Lee, J., Ozden, I., Song, Y. K. & Nurmikko, A. V. Transparent intracortical microprobe array for simultaneous spatiotemporal optical stimulation and multichannel electrical recording. *Nat Methods* **12**, 1157-1162, doi:10.1038/nmeth.3620 (2015).
- 20 Hodgkin, A. L. & Huxley, A. F. Quantitative description of membrane current and its application to conduction and excitation in nerve. *Journal of Physiology* **117**, 500-544 (1952).
- 21 Penfield, W. & Boldrey, E. Somatic motor and sensory representation in the cerebral cortex of man as studied by electrical stimulation. *Brain* **60**, 389-443 (1937).
- 22 Asanuma, H., Stoney, S. D., Jr. & Abzug, C. Relationship between afferent input and motor outflow in cat motorsensory cortex. *Journal of Neurophysiology* **31**, 670-681 (1968).

- 23 Salzman, C. D., Murasugi, C. M., Britten, K. H. & Newsome, W. T. Microstimulation in visual area MT: Effects on direction discrimination performance. *Journal of Neuroscience* **12**, 2331-2355 (1992).
- 24 Romo, R., Hernández, A., Zainos, A. & Salinas, E. Somatosensory discrimination based on cortical microstimulation. *Nature* **392**, 387-390 (1998).
- 25 Schmidt, E. M. *et al.* Feasibility of a visual prosthesis for the blind based on intracortical microstimulation of the visual cortex. *Brain* **119** (Pt 2), 507-522 (1996).
- 26 Pezaris, J. S. & Reid, R. C. Demonstration of artificial visual percepts generated through thalamic microstimulation. *Proc Natl Acad Sci U S A* **104**, 7670-7675, doi:10.1073/pnas.0608563104 (2007).
- 27 Dadarlat, M. C., O'Doherty, J. E. & Sabes, P. N. A learning-based approach to artificial sensory feedback leads to optimal integration. *Nat Neurosci* **18**, 138-144, doi:10.1038/nn.3883 (2015).
- 28 Mazurek, K. A. & Schieber, M. H. Injecting Instructions into Premotor Cortex. *Neuron* **96**, 1282-1289 e1284, doi:10.1016/j.neuron.2017.11.006 (2017).
- 29 Flesher, S. N. *et al.* Intracortical microstimulation of human somatosensory cortex. *Sci Transl Med* **8**, 361ra141, doi:10.1126/scitranslmed.aaf8083 (2016).
- 30 Chapin, J. K., Moxon, K. A., Markowitz, R. S. & Nicolelis, M. A. Real-time control of a robot arm using simultaneously recorded neurons in the motor cortex [see comments]. *Nature Neuroscience* **2**, 664-670 (1999).
- 31 Taylor, D. M., Tillery, S. I. & Schwartz, A. B. Direct cortical control of 3D neuroprosthetic devices. *Science* **296**, 1829-1832, doi: 10.1126/science.1073998 (2002).
- 32 Serruya, M. D., Hatsopoulos, N. G., Paninski, L., Fellows, M. R. & Donoghue, J. P. Instant neural control of a movement signal. *Nature* **416**, 141-142 (2002).
- 33 Hochberg, L. R. Turning thought into action. *N Engl J Med* **359**, 1175-1177, doi:10.1056/NEJMcibr0805122 (2008).
- 34 Hochberg, L. R. *et al.* Reach and grasp by people with tetraplegia using a neurally controlled robotic arm. *Nature* **485**, 372-375, doi:10.1038/nature11076 (2012).
- 35 Velliste, M., Perel, S., Spalding, M. C., Whitford, A. S. & Schwartz, A. B. Cortical control of a prosthetic arm for self-feeding. *Nature* **453**, 1098-1101 (2008).
- 36 Simeral, J. D., Kim, S. P., Black, M. J., Donoghue, J. P. & Hochberg, L. R. Neural control of cursor trajectory and click by a human with tetraplegia 1000 days after implant of an intracortical microelectrode array. *J Neural Eng* **8**, 025027, doi:10.1088/1741-2560/8/2/025027 (2011).
- 37 Ajiboye, A. B. *et al.* Restoration of reaching and grasping movements through brain-controlled muscle stimulation in a person with tetraplegia: a proof-of-concept demonstration. *Lancet* **389**, 1821-1830, doi:10.1016/S0140-6736(17)30601-3 (2017).
- 38 McMullen, D. P. *et al.* Demonstration of a semi-autonomous hybrid brain-machine interface using human intracranial EEG, eye tracking, and computer vision to control a robotic upper limb prosthetic. *IEEE Trans Neural Syst Rehabil Eng* **22**, 784-796, doi:10.1109/TNSRE.2013.2294685 (2014).
- 39 Collinger, J. L. *et al.* Neuroprosthetic technology for individuals with spinal cord injury. *J Spinal Cord Med* **36**, 258-272, doi:10.1179/2045772313Y.00000000128 (2013).
- 40 Collinger, J. L. *et al.* Collaborative approach in the development of high-performance brain-computer interfaces for a neuroprosthetic arm: translation from animal models to human control. *Clin Transl Sci* **7**, 52-59, doi:10.1111/cts.12086 (2014).
- 41 Fifer, M. S. *et al.* Simultaneous neural control of simple reaching and grasping with the modular prosthetic limb using intracranial EEG. *IEEE Trans Neural Syst Rehabil Eng* **22**, 695-705, doi:10.1109/TNSRE.2013.2286955 (2014).
- 42 Hochberg, L. R. *et al.* Neuronal ensemble control of prosthetic devices by a human with tetraplegia. *Nature* **442**, 164-171, doi:10.1038/nature04970 (2006).
- 43 Histed, M. H., Bonin, V. & Reid, R. C. Direct activation of sparse, distributed populations of cortical neurons by electrical microstimulation. *Neuron* **63**, 508-522, doi:10.1016/j.neuron.2009.07.016 (2009).
- 44 Michelson, N. J., Eles, J. R., Vazquez, A. L., Ludwig, K. A. & Kozai, T. D. Y. Calcium activation of cortical neurons by continuous electrical stimulation: Frequency dependence, temporal fidelity, and activation density. *J Neurosci Res*, doi:10.1002/jnr.24370 (2018).

45 Romo, R., Hernandez, A., Zainos, A., Brody, C. D. & Lemus, L. Sensing without touching: psychophysical performance based on cortical microstimulation. *Neuron* **26**, 273-278 (2000).

46 Lacey, S. & Sathian, K. Visuo-haptic multisensory object recognition, categorization, and representation. *Front Psychol* **5**, 730, doi:10.3389/fpsyg.2014.00730 (2014).

47 Bernstein, J. G. & Boyden, E. S. Optogenetic tools for analyzing the neural circuits of behavior. *Trends Cogn Sci* **15**, 592-600, doi:10.1016/j.tics.2011.10.003 (2011).

48 Deisseroth, K. Optogenetics: 10 years of microbial opsins in neuroscience. *Nat Neurosci* **18**, 1213-1225, doi:10.1038/nn.4091 (2015).

49 Berglund, K. *et al.* Combined Optogenetic and Chemogenetic Control of Neurons. *Methods Mol Biol* **1408**, 207-225, doi:10.1007/978-1-4939-3512-3_14 (2016).

50 Tung, J. K., Berglund, K. & Gross, R. E. Optogenetic Approaches for Controlling Seizure Activity. *Brain Stimul* **9**, 801-810, doi:10.1016/j.brs.2016.06.055 (2016).

51 Tung, J. K., Gutekunst, C. A. & Gross, R. E. Inhibitory luminopsins: genetically-encoded bioluminescent opsins for versatile, scalable, and hardware-independent optogenetic inhibition. *Sci Rep* **5**, 14366, doi:10.1038/srep14366 (2015).

52 Zhu, H. *et al.* Cre-dependent DREADD (Designer Receptors Exclusively Activated by Designer Drugs) mice. *Genesis* **54**, 439-446, doi:10.1002/dvg.22949 (2016).

53 Zhang, F., Wang, L. P., Boyden, E. S. & Deisseroth, K. Channelrhodopsin-2 and optical control of excitable cells. *Nat Methods* **3**, 785-792, doi:10.1038/nmeth936 (2006).

54 Baker, C. A., Elyada, Y. M., Parra, A. & Bolton, M. M. Cellular resolution circuit mapping with temporal-focused excitation of soma-targeted channelrhodopsin. *Elife* **5**, doi:10.7554/eLife.14193 (2016).

55 Mahn, M. *et al.* High-efficiency optogenetic silencing with soma-targeted anion-conducting channelrhodopsins. *Nat Commun* **9**, 4125, doi:10.1038/s41467-018-06511-8 (2018).

56 Kravitz, A. V. *et al.* Regulation of parkinsonian motor behaviours by optogenetic control of basal ganglia circuitry. *Nature* **466**, 622-626, doi:10.1038/nature09159 (2010).

57 O'Connor, D. H. *et al.* Neural coding during active somatosensation revealed using illusory touch. *Nat Neurosci* **16**, 958-965, doi:10.1038/nn.3419 (2013).

58 Severson, K. S. *et al.* Active Touch and Self-Motion Encoding by Merkel Cell-Associated Afferents. *Neuron* **94**, 666-676 e669, doi:10.1016/j.neuron.2017.03.045 (2017).

59 Minamisawa, G., Kwon, S. E., Chevee, M., Brown, S. P. & O'Connor, D. H. A Non-canonical Feedback Circuit for Rapid Interactions between Somatosensory Cortices. *Cell Rep* **23**, 2718-2731 e2716, doi:10.1016/j.celrep.2018.04.115 (2018).

60 Sofroniew, N. J., Cohen, J. D., Lee, A. K. & Svoboda, K. Natural whisker-guided behavior by head-fixed mice in tactile virtual reality. *J Neurosci* **34**, 9537-9550, doi:10.1523/JNEUROSCI.0712-14.2014 (2014).

61 Chen, Z., Wimmer, R. D., Wilson, M. A. & Halassa, M. M. Thalamic Circuit Mechanisms Link Sensory Processing in Sleep and Attention. *Front Neural Circuits* **9**, 83, doi:10.3389/fncir.2015.00083 (2015).

62 Wimmer, R. D. *et al.* Thalamic control of sensory selection in divided attention. *Nature* **526**, 705-709, doi:10.1038/nature15398 (2015).

63 Kim, D. *et al.* Distinct Roles of Parvalbumin- and Somatostatin-Expressing Interneurons in Working Memory. *Neuron* **92**, 902-915, doi:10.1016/j.neuron.2016.09.023 (2016).

64 Kim, H., Ahrlund-Richter, S., Wang, X., Deisseroth, K. & Carlen, M. Prefrontal Parvalbumin Neurons in Control of Attention. *Cell* **164**, 208-218, doi:10.1016/j.cell.2015.11.038 (2016).

65 Kim, Y. C. *et al.* Optogenetic Stimulation of Frontal D1 Neurons Compensates for Impaired Temporal Control of Action in Dopamine-Depleted Mice. *Curr Biol* **27**, 39-47, doi:10.1016/j.cub.2016.11.029 (2017).

66 Li, N., Daie, K., Svoboda, K. & Druckmann, S. Robust neuronal dynamics in premotor cortex during motor planning. *Nature* **532**, 459-464, doi:10.1038/nature17643 (2016).

67 Li, Y. *et al.* Optogenetic Activation of Adenosine A2A Receptor Signaling in the Dorsomedial Striatopallidal Neurons Suppresses Goal-Directed Behavior. *Neuropsychopharmacology* **41**, 1003-1013, doi:10.1038/npp.2015.227 (2016).

- 68 Zhang, F. *et al.* Optogenetics in Freely Moving Mammals: Dopamine and Reward. *Cold Spring Harb Protoc* **2015**, 715-724, doi:10.1101/pdb.top086330 (2015).
- 69 Allen, W. E. *et al.* Global Representations of Goal-Directed Behavior in Distinct Cell Types of Mouse Neocortex. *Neuron* **94**, 891-907 e896, doi:10.1016/j.neuron.2017.04.017 (2017).
- 70 Akrami, A., Kopec, C. D., Diamond, M. E. & Brody, C. D. Posterior parietal cortex represents sensory history and mediates its effects on behaviour. *Nature* **554**, 368-372, doi:10.1038/nature25510 (2018).
- 71 May, T. *et al.* Detection of optogenetic stimulation in somatosensory cortex by non-human primates--towards artificial tactile sensation. *PLoS One* **9**, e114529, doi:10.1371/journal.pone.0114529 (2014).
- 72 Nassi, J. J., Avery, M. C., Cetin, A. H., Roe, A. W. & Reynolds, J. H. Optogenetic Activation of Normalization in Alert Macaque Visual Cortex. *Neuron* **86**, 1504-1517, doi:10.1016/j.neuron.2015.05.040 (2015).
- 73 Chernov, M. M., Friedman, R. M., Chen, G., Stoner, G. R. & Roe, A. W. Functionally specific optogenetic modulation in primate visual cortex. *Proc Natl Acad Sci U S A* **115**, 10505-10510, doi:10.1073/pnas.1802018115 (2018).
- 74 Nurminen, L., Merlin, S., Bijanzadeh, M., Federer, F. & Angelucci, A. Top-down feedback controls spatial summation and response amplitude in primate visual cortex. *Nat Commun* **9**, 2281, doi:10.1038/s41467-018-04500-5 (2018).
- 75 Dai, J., Brooks, D. I. & Sheinberg, D. L. Optogenetic and electrical microstimulation systematically bias visuospatial choice in primates. *Curr Biol* **24**, 63-69, doi:10.1016/j.cub.2013.11.011 (2014).
- 76 Fetsch, C. R. *et al.* Focal optogenetic suppression in macaque area MT biases direction discrimination and decision confidence, but only transiently. *Elife* **7**, doi:10.7554/eLife.36523 (2018).
- 77 Stauffer, W. R. *et al.* Dopamine Neuron-Specific Optogenetic Stimulation in Rhesus Macaques. *Cell* **166**, 1564-1571 e1566, doi:10.1016/j.cell.2016.08.024 (2016).
- 78 Jazayeri, M., Lindbloom-Brown, Z. & Horwitz, G. D. Saccadic eye movements evoked by optogenetic activation of primate V1. *Nat Neurosci* **15**, 1368-1370, doi:10.1038/nn.3210 (2012).
- 79 Gerits, A. *et al.* Optogenetically induced behavioral and functional network changes in primates. *Curr Biol* **22**, 1722-1726, doi:10.1016/j.cub.2012.07.023 (2012).
- 80 Cavanaugh, J. *et al.* Optogenetic inactivation modifies monkey visuomotor behavior. *Neuron* **76**, 901-907, doi:10.1016/j.neuron.2012.10.016 (2012).
- 81 El-Shamayleh, Y., Ni, A. M. & Horwitz, G. D. Strategies for targeting primate neural circuits with viral vectors. *J Neurophysiol* **116**, 122-134, doi:10.1152/jn.00087.2016 (2016).
- 82 Inoue, K., Takada, M. & Matsumoto, M. Neuronal and behavioural modulations by pathway-selective optogenetic stimulation of the primate oculomotor system. *Nat Commun* **6**, 8378, doi:10.1038/ncomms9378 (2015).
- 83 Afraz, A., Boyden, E. S. & DiCarlo, J. J. Optogenetic and pharmacological suppression of spatial clusters of face neurons reveal their causal role in face gender discrimination. *Proc Natl Acad Sci U S A* **112**, 6730-6735, doi:10.1073/pnas.1423328112 (2015).
- 84 Tamura, K. *et al.* Conversion of object identity to object-general semantic value in the primate temporal cortex. *Science* **357**, 687-692, doi:10.1126/science.aan4800 (2017).
- 85 Theogarajan, L. Strategies for restoring vision to the blind: current and emerging technologies. *Neurosci Lett* **519**, 129-133, doi:10.1016/j.neulet.2012.02.001 (2012).
- 86 Cao, G. *et al.* Genetically targeted optical electrophysiology in intact neural circuits. *Cell* **154**, 904-913, doi:10.1016/j.cell.2013.07.027 (2013).
- 87 Marc, R., Pfeiffer, R. & Jones, B. Retinal prosthetics, optogenetics, and chemical photoswitches. *ACS Chem Neurosci* **5**, 895-901, doi:10.1021/cn5001233 (2014).
- 88 Nghiem, B. T. *et al.* Providing a sense of touch to prosthetic hands. *Plast Reconstr Surg* **135**, 1652-1663, doi:10.1097/PRS.0000000000001289 (2015).
- 89 Michoud, F. *et al.* Optical cuff for optogenetic control of the peripheral nervous system. *J Neural Eng* **15**, 015002, doi:10.1088/1741-2552/aa9126 (2018).
- 90 Yan, B. & Nirenberg, S. An Embedded Real-Time Processing Platform for Optogenetic Neuroprosthetic Applications. *IEEE Trans Neural Syst Rehabil Eng* **26**, 233-243, doi:10.1109/TNSRE.2017.2763130 (2018).

- 91 Markakis, E. A. *et al.* Comparative transduction efficiency of AAV vector serotypes 1-6 in the substantia nigra and striatum of the primate brain. *Mol Ther* **18**, 588-593, doi:10.1038/mt.2009.286 (2010).
- 92 Alikaya, A., Rack-Wildner, M. & Stauffer, W. R. Reward and value coding by dopamine neurons in non-human primates. *J Neural Transm (Vienna)* **125**, 565-574, doi:10.1007/s00702-017-1793-9 (2018).
- 93 O'Shea, D. J. *et al.* Development of an optogenetic toolkit for neural circuit dissection in squirrel monkeys. *Sci Rep* **8**, 6775, doi:10.1038/s41598-018-24362-7 (2018).
- 94 Yazdan-Shahmorad, A. *et al.* A Large-Scale Interface for Optogenetic Stimulation and Recording in Nonhuman Primates. *Neuron* **89**, 927-939, doi:10.1016/j.neuron.2016.01.013 (2016).
- 95 Yazdan-Shahmorad, A. *et al.* Widespread optogenetic expression in macaque cortex obtained with MR-guided, convection enhanced delivery (CED) of AAV vector to the thalamus. *J Neurosci Methods* **293**, 347-358, doi:10.1016/j.jneumeth.2017.10.009 (2018).
- 96 Voigt, M. B., Yusuf, P. A. & Kral, A. Intracortical Microstimulation Modulates Cortical Induced Responses. *J Neurosci* **38**, 7774-7786, doi:10.1523/JNEUROSCI.0928-18.2018 (2018).
- 97 Engel, A. K., Konig, P., Singer, W., Schillen, T. B. & Kreiter, A. K. Temporal coding in the visual cortex: New vistas on integration in the nervous system. *Trends in Neurosciences* **15**, 218-226 (1992).
- 98 Fetz, E. E. Temporal coding in neural populations? *Science* **278**, 1901-1902 (1997).
- 99 Fries, P., Roelfsema, P. E., Engel, A. E., Konig, P. & Singer, W. Synchronized gamma frequency oscillations correlated with perception during binocular rivalry in awake squinting cats. *Neuroscience* **23**, 262 (1996).
- 100 Fries, P., Roelfsema, P. R., Engel, A. K., Konig, P. & Singer, W. Synchronization of oscillatory responses in visual cortex correlates with perception in interocular rivalry. *Proceedings of the National Academy of Sciences of the United States of America* **94**, 12699-12704 (1997).
- 101 Konig, P. & Engel, A. K. Correlated firing in sensory-motor systems. *Current Opinion in Neurobiology* **5**, 511-519 (1995).
- 102 Konig, P., Engel, A. K., Roelfsema, P. R. & Singer, W. How precise is neuronal synchronization? *Neural Computation* **7**, 469-485 (1995).
- 103 Konig, P., Engel, A. K. & Singer, W. Relation between oscillatory activity and long-range synchronization in cat visual cortex. *Proceedings of the National Academy of Sciences of the United States of America* **92**, 290-294 (1995).
- 104 Lakatos, P., Chen, C. M., O'Connell, M. N., Mills, A. & Schroeder, C. E. Neuronal oscillations and multisensory interaction in primary auditory cortex. *Neuron* **53**, 279-292 (2007).
- 105 Senkowski, D. *et al.* Multisensory processing and oscillatory activity: analyzing non-linear electrophysiological measures in humans and simians. *Exp Brain Res* **177**, 184-195, doi:10.1007/s00221-006-0664-7 (2007).
- 106 Lakatos, P., Karmos, G., Mehta, A. D., Ulbert, I. & Schroeder, C. E. Entrainment of neuronal oscillations as a mechanism of attentional selection. *Science* **320**, 110-113, doi:10.1126/science.1154735 (2008).
- 107 Kelly, S. P., Gomez-Ramirez, M. & Foxe, J. J. The strength of anticipatory spatial biasing predicts target discrimination at attended locations: a high-density EEG study. *Eur J Neurosci* **30**, 2224-2234, doi:10.1111/j.1460-9568.2009.06980.x (2009).
- 108 Gomez-Ramirez, M. *et al.* Oscillatory sensory selection mechanisms during intersensory attention to rhythmic auditory and visual inputs: a human electrocorticographic investigation. *J Neurosci* **31**, 18556-18567, doi:10.1523/JNEUROSCI.2164-11.2011 (2011).
- 109 Thut, G., Nietzel, A., Brandt, S. A. & Pascual-Leone, A. Alpha-band electroencephalographic activity over occipital cortex indexes visuospatial attention bias and predicts visual target detection. *Journal of Neuroscience* **26**, 9494-9502 (2006).
- 110 Fries, P., Reynolds, J. H., Rorie, A. E. & Desimone, R. Modulation of oscillatory neuronal synchronization by selective visual attention. *Science* **291**, 1560-1563 (2001).
- 111 Womelsdorf, T., Fries, P., Mitra, P. P. & Desimone, R. Gamma-band synchronization in visual cortex predicts speed of change detection. *Nature* **439**, 733-736 (2006).

112 Womelsdorf, T. *et al.* Modulation of neuronal interactions through neuronal synchronization. *Science* **316**, 1609-1612 (2007).

113 Fiebelkorn, I. C., Saalmann, Y. B. & Kastner, S. Rhythmic sampling within and between objects despite sustained attention at a cued location. *Curr Biol* **23**, 2553-2558, doi:10.1016/j.cub.2013.10.063 (2013).

114 Fiebelkorn, I. C. *et al.* Cortical cross-frequency coupling predicts perceptual outcomes. *Neuroimage* **69**, 126-137, doi:10.1016/j.neuroimage.2012.11.021 (2013).

115 Fiebelkorn, I. C., Pinsk, M. A. & Kastner, S. A Dynamic Interplay within the Frontoparietal Network Underlies Rhythmic Spatial Attention. *Neuron* **99**, 842-853 e848, doi:10.1016/j.neuron.2018.07.038 (2018).

116 Fiebelkorn, I. C., Pinsk, M. A. & Kastner, S. The mediodorsal pulvinar coordinates the macaque frontoparietal network during rhythmic spatial attention. *Nat Commun* **10**, 215, doi:10.1038/s41467-018-08151-4 (2019).

117 Shin, H., Law, R., Tsutsui, S., Moore, C. I. & Jones, S. R. The rate of transient beta frequency events predicts behavior across tasks and species. *Elife* **6**, doi:10.7554/eLife.29086 (2017).

118 Womelsdorf, T. *et al.* Orientation selectivity and noise correlation in awake monkey area V1 are modulated by the gamma cycle. *Proc Natl Acad Sci U S A* **109**, 4302-4307, doi:10.1073/pnas.1114223109 (2012).

119 Engel, A. K. & Singer, W. Temporal binding and the neural correlates of sensory awareness. *Trends in Cognitive Sciences* **5**, 16-25 (2001).

120 Engel, A. K., Fries, P. & Singer, W. Dynamic predictions: oscillations and synchrony in top-down processing. *Nature Reviews Neuroscience* **2**, 704-716 (2001).

121 Fries, P., Neuenschwander, S., Engel, A. K., Goebel, R. & Singer, W. Rapid feature selective neuronal synchronization through correlated latency shifting. *Nat. Neurosci* **4**, 194-200 (2001).

122 Niebur, E., Hsiao, S. S. & Johnson, K. O. Synchrony: a neuronal mechanism for attentional selection? *Current Opinion in Neurobiology* **12** 190-194 (2002).

123 Womelsdorf, T. & Fries, P. The role of neuronal synchronization in selective attention. *Current Opinion in Neurobiology* **17**, 154-160 (2007).

124 Engelhard, B., Ozeri, N., Israel, Z., Bergman, H. & Vaadia, E. Inducing gamma oscillations and precise spike synchrony by operant conditioning via brain-machine interface. *Neuron* **77**, 361-375, doi:10.1016/j.neuron.2012.11.015 (2013).

125 Lepousez, G. & Lledo, P. M. Odor discrimination requires proper olfactory fast oscillations in awake mice. *Neuron* **80**, 1010-1024, doi:10.1016/j.neuron.2013.07.025 (2013).

126 Whittington, M. A., Traub, R. D. & Jefferys, J. G. Synchronized oscillations in interneuron networks driven by metabotropic glutamate receptor activation. *Nature* **373**, 612-615 (1995).

127 Whittington, M. A. & Traub, R. D. Interneuron diversity series: inhibitory interneurons and network oscillations in vitro. *Trends in Neurosciences* **26**, 676-682 (2003).

128 Traub, R. D., Whittington, M. A., Stanford, I. M. & Jeffreys, J. G. A mechanism for generation of long-range synchronous fast oscillations in the cortex. *Nature* **383**, 621-624 (1996).

129 Traub, R. D., Whittington, M. A. & Jerrereys, J. G. Gamma oscillation model predicts intensity coding by phase rather than frequency. *Neural Computation* **9**, 1251-1264 (1997).

130 Csicsvari, J., Jamieson, B., Wise, K. D. & Buzsaki, G. Mechanisms of gamma oscillations in the hippocampus of the behaving rat. *Neuron* **37**, 311-322 (2003).

131 Bartho, P. *et al.* Characterization of neocortical principal cells and interneurons by network interactions and extracellular features. *Journal of Neurophysiology* **92**, 600-608 (2004).

132 Buzsaki, G. & Draguhn, A. Neuronal oscillations in cortical networks. *Science* **304**, 1926-1929 (2004).

133 Buzsaki, G. & Wang, X. J. Mechanisms of gamma oscillations. *Annu Rev Neurosci* **35**, 203-225, doi:10.1146/annurev-neuro-062111-150444 (2012).

134 Tiesinga, P. H. & Sejnowski, T. J. Rapid temporal modulation of synchrony by competition in cortical interneuron networks. *Neural Computation* **16**, 251-275 (2004).

135 Tiesinga, P. H., Fellous, J. M., Salinas, E., Jose, J. V. & Sejnowski, T. J. Inhibitory synchrony as a mechanism for attentional gain modulation. *J Physiol Paris* **98**, 296-314, doi:10.1016/j.jphysparis.2005.09.002 (2004).

- 136 Tiesinga, P. H., Fellous, J. M., Salinas, E., Jose, J. V. & Sejnowski, T. J. Synchronization as a mechanism for attentional gain modulation. *Neurocomputing* **58-60**, 641-646, doi:10.1016/j.neucom.2004.01.108 (2004).
- 137 Tiesinga, P. & Sejnowski, T. J. Cortical enlightenment: are attentional gamma oscillations driven by ING or PING? *Neuron* **63**, 727-732, doi:10.1016/j.neuron.2009.09.009 (2009).
- 138 Moore, C. I., Carlen, M., Knoblich, U. & Cardin, J. A. Neocortical interneurons: from diversity, strength. *Cell* **142**, 189-193, doi:10.1016/j.cell.2010.07.005 (2010).
- 139 Hasenstaub, A., Otte, S. & Callaway, E. Cell Type-Specific Control of Spike Timing by Gamma-Band Oscillatory Inhibition. *Cereb Cortex* **26**, 797-806, doi:10.1093/cercor/bhv044 (2016).
- 140 Jurgens, E., Rosler, F., Henninghausen, E. & Heil, M. Stimulus-induced gamma oscillations: harmonics of alpha activity? *Neuroreport* **6**, 813-816 (1995).
- 141 Mazurek, M. E. & Shadlen, M. N. Limits to the temporal fidelity of cortical spike rate signals. *Nature Neuroscience* **5**, 463-471 (2002).
- 142 Henrie, J. A. & Shapley, R. LFP power spectra in V1 cortex: the graded effect of stimulus contrast. *Journal of Neurophysiology* **94**, 479-490 (2005).
- 143 Burns, S. P., Xing, D. & Shapley, R. M. Is gamma-band activity in the local field potential of V1 cortex a "clock" or filtered noise? *J Neurosci* **31**, 9658-9664, doi:10.1523/JNEUROSCI.0660-11.2011 (2011).
- 144 Ray, S. & Maunsell, J. H. Different origins of gamma rhythm and high-gamma activity in macaque visual cortex. *PLoS Biol* **9**, e1000610, doi:10.1371/journal.pbio.1000610 (2011).
- 145 Ray, S. & Maunsell, J. H. Differences in gamma frequencies across visual cortex restrict their possible use in computation. *Neuron* **67**, 885-896, doi:10.1016/j.neuron.2010.08.004 (2010).
- 146 Ray, S., Ni, A. M. & Maunsell, J. H. Strength of gamma rhythm depends on normalization. *PLoS Biol* **11**, e1001477, doi:10.1371/journal.pbio.1001477 (2013).
- 147 Ray, S., Hsiao, S. S., Crone, N. E., Franaszczuk, P. J. & Niebur, E. Effect of stimulus intensity on the spike-local field potential relationship in the secondary somatosensory cortex. *Journal of Neuroscience* **28**, 7334-7343 (2008).
- 148 Palanca, B. J. & DeAngelis, G. C. Does neuronal synchrony underlie visual feature grouping? *Neuron* **46**, 333-346 (2005).
- 149 Ray, S. & Maunsell, J. H. Do gamma oscillations play a role in cerebral cortex? *Trends Cogn Sci* **19**, 78-85, doi:10.1016/j.tics.2014.12.002 (2015).
- 150 Singer, W. Synchronization of cortical activity and its putative role in information processing and learning. *Annual Review of Physiology* **55**, 349-374 (1993).
- 151 Bartos, M., Vida, I. & Jonas, P. Synaptic mechanisms of synchronized gamma oscillations in inhibitory interneuron networks. *Nature Reviews Neuroscience* **8**, 45-56 (2007).
- 152 Fries, P. Neuronal gamma-band synchronization as a fundamental process in cortical computation. *Annu Rev Neurosci* **32**, 209-224, doi:10.1146/annurev.neuro.051508.135603 (2009).
- 153 Weiss, J. M., Flesher, S. N., Franklin, R., Collinger, J. L. & Gaunt, R. A. Artifact-free recordings in human bidirectional brain-computer interfaces. *J Neural Eng* **16**, 016002, doi:10.1088/1741-2552/aae748 (2019).
- 154 Pei, Y. C. & Bensmaia, S. J. The neural basis of tactile motion perception. *J Neurophysiol* **112**, 3023-3032, doi:10.1152/jn.00391.2014 (2014).
- 155 Pei, Y. C., Hsiao, S. S., Craig, J. C. & Bensmaia, S. J. Shape invariant coding of motion direction in somatosensory cortex. *PLoS Biol* **8**, e1000305 (2010).
- 156 Pei, Y. C., Hsiao, S. S., Craig, J. C. & Bensmaia, S. J. Neural mechanisms of tactile motion integration in somatosensory cortex. *Neuron* **69**, 536-547, doi:10.1016/j.neuron.2010.12.033 (2011).
- 157 Salzman, C. D., Britten, K. H. & Newsome, W. T. Cortical microstimulation influences perceptual judgements of motion direction. *Nature* **346**, 174-177, doi:10.1038/346174a0 (1990).
- 158 DeAngelis, G. C. & Newsome, W. T. Perceptual "Read-Out" of Conjoined Direction and Disparity Maps in Extrastriate Area MT. *PLoS Biol* **2**, E77 (2004).
- 159 Gu, Y., Deangelis, G. C. & Angelaki, D. E. Causal links between dorsal medial superior temporal area neurons and multisensory heading perception. *J Neurosci* **32**, 2299-2313, doi:10.1523/JNEUROSCI.5154-11.2012 (2012).

- 160 Steinmetz, P. N. *et al.* Attention modulates synchronized neuronal firing in primate somatosensory cortex. *Nature* **404**, 187-190 (2000).
- 161 Gomez-Ramirez, M., Trzcinski, N. K., Mihalas, S., Niebur, E. & Hsiao, S. S. Temporal correlation mechanisms and their role in feature selection: a single-unit study in primate somatosensory cortex. *PLoS Biol* **12**, e1002004, doi:10.1371/journal.pbio.1002004 (2014).
- 162 O'Connell, R. G. *et al.* Uncovering the neural signature of lapsing attention: electrophysiological signals predict errors up to 20 s before they occur. *J Neurosci* **29**, 8604-8611, doi:10.1523/JNEUROSCI.5967-08.2009 (2009).
- 163 Lakatos, P. *et al.* Global dynamics of selective attention and its lapses in primary auditory cortex. *Nat Neurosci* **19**, 1707-1717, doi:10.1038/nn.4386 (2016).
- 164 Jones, S. R. *et al.* Cued spatial attention drives functionally relevant modulation of the mu rhythm in primary somatosensory cortex. *J Neurosci* **30**, 13760-13765, doi:10.1523/JNEUROSCI.2969-10.2010 (2010).
- 165 Hakim, R., Shamardani, K. & Adesnik, H. A neural circuit for gamma-band coherence across the retinotopic map in mouse visual cortex. *Elife* **7**, doi:10.7554/eLife.28569 (2018).
- 166 Veit, J., Hakim, R., Jadi, M. P., Sejnowski, T. J. & Adesnik, H. Cortical gamma band synchronization through somatostatin interneurons. *Nat Neurosci* **20**, 951-959, doi:10.1038/nn.4562 (2017).
- 167 Dimidschstein, J. *et al.* A viral strategy for targeting and manipulating interneurons across vertebrate species. *Nat Neurosci* **19**, 1743-1749, doi:10.1038/nn.4430 (2016).
- 168 Juttner, J. *et al.* Targeting neuronal and glial cell types with synthetic promoter AAVs in mice, non-human primates, and humans. *BioRxiv* (2018).
- 169 Kim, S. S., Gomez-Ramirez, M., Thakur, P. H. & Hsiao, S. S. Multimodal Interactions between Proprioceptive and Cutaneous Signals in Primary Somatosensory Cortex. *Neuron* **86**, 555-566, doi:10.1016/j.neuron.2015.03.020 (2015).
- 170 Wu, F. *et al.* Monolithically Integrated muLEDs on Silicon Neural Probes for High-Resolution Optogenetic Studies in Behaving Animals. *Neuron* **88**, 1136-1148, doi:10.1016/j.neuron.2015.10.032 (2015).
- 171 Cogan, S. F., Ludwig, K. A., Welle, C. G. & Takmakov, P. Tissue damage thresholds during therapeutic electrical stimulation. *J Neural Eng* **13**, 021001, doi:10.1088/1741-2560/13/2/021001 (2016).
- 172 Mihalas, S. & Niebur, E. A generalized linear integrate-and-fire neural model produces diverse spiking behaviors. *Neural Comput* **21**, 704-718, doi:10.1162/neco.2008.12-07-680 (2009).
- 173 Dong, Y., Mihalas, S., Russell, A., Etienne-Cummings, R. & Niebur, E. Estimating parameters of generalized integrate-and-fire neurons from the maximum likelihood of spike trains. *Neural Comput* **23**, 2833-2867, doi:10.1162/NECO_a_00196 (2011).
- 174 Dong, Y., Mihalas, S. & Niebur, E. Improved integral equation solution for the first passage time of leaky integrate-and-fire neurons. *Neural Comput* **23**, 421-434, doi:10.1162/NECO_a_00078 (2011).
- 175 Wagatsuma, N., von der Heydt, R. & Niebur, E. Spike synchrony generated by modulatory common input through NMDA-type synapses. *J Neurophysiol* **116**, 1418-1433, doi:10.1152/jn.01142.2015 (2016).
- 176 Han-Lin, H., Wong, Y. T., Pesaran, B. & Shanechi, M. M. Multiscale decoding for reliable brain-machine interface performance over time. *Conf Proc IEEE Eng Med Biol Soc* **2017**, 197-200, doi:10.1109/EMBC.2017.8036796 (2017).
- 177 Vargas-Irwin, C. E. *et al.* Decoding complete reach and grasp actions from local primary motor cortex populations. *J Neurosci* **30**, 9659-9669, doi:10.1523/JNEUROSCI.5443-09.2010 (2010).
- 178 Malik, W. Q., Hochberg, L. R., Donoghue, J. P. & Brown, E. N. Modulation depth estimation and variable selection in state-space models for neural interfaces. *IEEE Trans Biomed Eng* **62**, 570-581, doi:10.1109/TBME.2014.2360393 (2015).
- 179 Shanechi, M. M. Brain-Machine Interface Control Algorithms. *IEEE Trans Neural Syst Rehabil Eng* **25**, 1725-1734, doi:10.1109/TNSRE.2016.2639501 (2017).
- 180 Padmanaban, S., Baker, J. & Greger, B. Feature Selection Methods for Robust Decoding of Finger Movements in a Non-human Primate. *Front Neurosci* **12**, 22, doi:10.3389/fnins.2018.00022 (2018).

181 Yoshimura, Y. & Callaway, E. M. Fine-scale specificity of cortical networks depends on inhibitory cell
 type and connectivity. *Nature Neuroscience* **8**, 1552-1559 (2005).

182 Yoshimura, Y., Dantzker, J. L. & Callaway, E. M. Excitatory cortical neurons form fine-scale functional
 networks. *Nature* **433**, 868-873 (2005).

183 Wu, T. L. *et al.* Effects of isoflurane anesthesia on resting-state fMRI signals and functional
 connectivity within primary somatosensory cortex of monkeys. *Brain Behav* **6**, e00591,
 doi:10.1002/brb3.591 (2016).

184 G, N. *et al.* Channelrhodopsins: visual regeneration and neural activation by a light switch. *N Biotechnol*
30, 461-474, doi:10.1016/j.nbt.2013.04.007 (2013).

185 Airan, R. D., Thompson, K. R., Fenno, L. E., Bernstein, H. & Deisseroth, K. Temporally precise in vivo
 control of intracellular signalling. *Nature* **458**, 1025-1029, doi:10.1038/nature07926 (2009).

186 Lin, J. Y. Optogenetic excitation of neurons with channelrhodopsins: light instrumentation, expression
 systems, and channelrhodopsin variants. *Prog Brain Res* **196**, 29-47, doi:10.1016/B978-0-444-59426-
 6.00002-1 (2012).

187 Aschauer, D. F., Kreuz, S. & Rumpel, S. Analysis of transduction efficiency, tropism and axonal
 transport of AAV serotypes 1, 2, 5, 6, 8 and 9 in the mouse brain. *PLoS One* **8**, e76310,
 doi:10.1371/journal.pone.0076310 (2013).

188 Cohen, M. R. & Maunsell, J. H. Attention improves performance primarily by reducing interneuronal
 correlations. *Nat Neurosci* **12**, 1594-1600, doi:10.1038/nn.2439 (2009).

189 Hagan, M. A., Dean, H. L. & Pesaran, B. Spike-field activity in parietal area LIP during coordinated
 reach and saccade movements. *J Neurophysiol* **107**, 1275-1290, doi:10.1152/jn.00867.2011 (2012).

190 Yu, Z., Nurmikko, A. & Ozden, I. Widespread functional opsin transduction in the rat cortex via
 convection-enhanced delivery optimized for horizontal spread. *J Neurosci Methods* **291**, 69-82,
 doi:10.1016/j.jneumeth.2017.08.008 (2017).