

Brain region & neuron type	Firing rate	Reference
VTA DA	~ 4 - 6 Hz	<p>*Cheer, J. F., Kendall, D. A., Mason, R. & Marsden, C. A. Differential cannabinoid-induced electrophysiological effects in rat ventral tegmentum. <i>Neuropharmacology</i> 44: 633–641 (2003);</p> <p>*Ungless, M. A., Magill, P. J., Bolam, J. P. Uniform inhibition of dopamine neurons in the ventral tegmental area by aversive stimuli. <i>Science</i> 303(5666): 2040-2042 (2004);</p> <p>*Li, W., Doyon, W. M. & Dani, J. A. Quantitative unit classification of ventral tegmental area neurons in vivo. <i>J. Neurophysiol.</i> 107(10):2808–2820 (2012);</p> <p>*Tolu, S., Eddine, R., Marti, F., David, V., Graupner, M., Pons, S., Baudonnat, M., Husson, M., Besson, M., Reperant, C., Zemdegs, J., Pages, C., Hay, Y. A. H., Lobolez, B., Caboche, J., Gutkin, B., Gardier, A. M., Changeaux, J.-P., Faure, P. & Maskos, U. Co-activation of VTA DA and GABA neurons mediates nicotine reinforcement. <i>Mol. Psychiatry</i> 18(3):382-392 (2013);</p> <p>*Tian, J., Huang, R., Cohen, J. Y., Osakada, F., Kobak, D., Machens, C. K., Callaway, E. M., Uchida, N. & Watabe-Uchida, M. Distributed and mixed information in monosynaptic inputs to dopamine neurons. <i>Neuron</i> 91:1374-1389 (2016);</p> <p>*Stauffer, W. R., Lak, A., Yang, A., Borel, M., Paulsen, O., Boyden, E. S. & Schultz, W. Dopamine neuron-specific optogenetic stimulation in rhesus macaques. <i>Cell</i> 166:1564-1571 (2016).</p>
VTA GABA	~ 12 - 17 Hz	<p>*Steffensen, S. C., Svingos, A. L., Pickel, V. M. & Henriksen, S. J. Electrophysiological characterization of GABAergic neurons in the ventral tegmental area. <i>J. Neurosci.</i> 18(19):8003-8015 (1998);</p> <p>*Steffensen, S. C., Taylor, S. R., Horton, M. L., Barber, E. N., Lyle, L. T., Stobbs, S. H. & Allsion, D. W. (Cocaine disinhibits dopamine neurons in the ventral tegmental area via use-dependent blockade of GABA neuron voltage-sensitive sodium channels. <i>Eur. J. Neurosci.</i> 28(10):2028-2040 (2008);</p> <p>*Steffensen, S. C., Walton, C. H., Hansen, D. M., Yorgason, J. T., Gallegos, R. A. & Criado, J. R. Contingent and non-contingent effects of low-dose ethanol on GABA neuron activity in the ventral tegmental area. <i>Pharmacol. Biochem. Behav.</i> 92(1):68-75 (2009);</p> <p>*Cohen, J., Haesler, S., Vong, L., Lowell, B. B. & Uchida, N. Neuron-type specific signals for reward and punishment in the ventral tegmental area. <i>Nature</i> 482(7383):85-88 (2012);</p> <p>*Tolu, S., Eddine, R., Marti, F., David, V., Graupner, M., Pons, S., Baudonnat, M., Husson, M., Besson, M., Reperant, C., Zemdegs, J., Pages, C., Hay, Y. A. H., Lobolez, B., Caboche, J., Gutkin, B., Gardier, A. M., Changeaux, J.-P., Faure, P. & Maskos, U. Co-activation of VTA DA and GABA neurons mediates nicotine reinforcement. <i>Mol. Psychiatry</i> 18(3):382-392 (2013).</p>
DRN 5-HT	~ 3 - 5 Hz	<p>*Allers, K. A. & Sharp, T. Neurochemical and anatomical identification of fast- and slow-firing neurones in the rat dorsal raphe nucleus using juxtacellular labelling methods in vivo. <i>Neuroscience</i> 122(1):193–204 (2003);</p> <p>*Judge, S. J. & Gartside, S. E. Firing of 5-HT neurones in the dorsal and median raphe nucleus in vitro shows differential alpha1-adrenoreceptor and 5-HT1A receptor modulation. <i>Neurochem. Int.</i> 48(2):100-107 (2006);</p> <p>*Hajós, M., Allers, K. A., Jennings, K., Sharp, T., Charette, G., Sík, A. & Kocsis, B.</p>

		<p>Neurochemical identification of stereotypic burst-firing neurons in the rat dorsal raphe nucleus using juxtacellular labelling methods. <i>Eur. J. Neurosci.</i> 25(1):119–126 (2007);</p> <p>*Ranade, S. P. & Mainen, Z. F. Transient firing of dorsal raphe neurons encodes diverse and specific sensory, motor, and reward events. <i>J. Neurophysiol.</i> 102(5):3026-3037 (2009);</p> <p>*Cohen, J. Y., Amoroso, M. W. & Uchida, N. Serotonergic neurons signal reward and punishment on multiple timescales. <i>eLife</i> 4:e06346 (2015). doi:10.7554/eLife.06346;</p> <p>*Li, Y., Zhong, W., Wang, D., Feng, Q., Liu, Z., Zhou, J., Jia, C., Hu, F., Zeng, J., Guo, Q., Fu, L. & Luo, M. Serotonin neurons in the dorsal raphe nucleus encode reward signals. <i>Nat. Commun.</i> 7:10503 (2016). https://doi.org/10.1038/ncomms10503;</p> <p>*Mlinar, B., Montalbano, A., Piszczek, L., Gross, C. & Corradetti, R. Firing properties of genetically identified dorsal raphe serotonergic neurons in brain slices. <i>Front. Cell. Neurosci.</i> 10:195 (2016). doi: 10.3389/fncel.2016.00195;</p> <p>*Srejic, L. R., Wood, K. M., Zeqja, A., Hashemi, P., Hutchison, W. D. Modulation of serotonin dynamics in the dorsal raphe nucleus via high frequency medial prefrontal cortex stimulation. <i>Neurobiol. Dis.</i> 94:129-138 (2016).</p>
DRN GABA	~ 15 - 25 Hz	<p>*Allers, K. A. & Sharp, T. Neurochemical and anatomical identification of fast- and slow-firing neurones in the rat dorsal raphe nucleus using juxtacellular labelling methods in vivo. <i>Neuroscience</i> 122(1):193–204 (2003);</p> <p>*Sakai K. Sleep-waking discharge profiles of dorsal raphe nucleus neurons in mice. <i>Neuroscience</i> 197:200-224 (2011);</p> <p>*Challis, C., Boulden, J., Veerakumar, A., Espallergues, J., Vassoler, F. M., Pierce, R. C., Beck, S. G. & Berton, O. Raphe GABAergic neurons mediate the acquisition of avoidance after social defeat. <i>J. Neurosci.</i> 33(35):13978-13988a (2013);</p> <p>*Li, Y., Zhong, W., Wang, D., Feng, Q., Liu, Z., Zhou, J., Jia, C., Hu, F., Zeng, J., Guo, Q., Fu, L. & Luo, M. Serotonin neurons in the dorsal raphe nucleus encode reward signals. <i>Nat. Commun.</i> 7:10503 (2016). https://doi.org/10.1038/ncomms10503;</p> <p>*Hernández-Vázquez, F., Garduño J. & Hernández-López, S. GABAergic modulation of serotonergic neurons in the dorsal raphe nucleus. <i>Rev. Neurosci.</i> 30(3):289-303 (2018).</p>
DRN Glu	~ 3 - 5 Hz	<p>*Taylor, N. E., Pei, J., Zhang, Vlasov, K. Y., Davis, T., Taylor, E., Weng, F.-J., Van Dort, C. J., Solt, K. & Brown, E. N. The role of glutamatergic and dopaminergic neurons in the periaqueductal gray/dorsal raphe: separating analgesia and anxiety. <i>eNeuro</i> 6(1):ENEURO.0018-18.2019 (2019). doi:10.1523/ENEURO.0018-18.2019.</p>