

Visual Neuroscience: Locomotion Changes How Mice See

Richard J. Krauzlis

Laboratory of Sensorimotor Research, National Eye Institute, National Institutes of Health, Bethesda, MA 20892, USA

Correspondence: richard.krauzlis@nih.gov

<https://doi.org/10.1016/j.cub.2019.04.016>

How sensory signals are processed by the visual cortex is not fixed but changes depending on our spatial goals and whether or not we are moving. New research helps explain why these two effects do not always work well together.

You are walking along, perhaps out for a stroll in your local park, when you detect the approaching hazard. The signs are clear even from a distance: the downward tilt of the head, the gaze fixed on the hand, the arm held unnaturally still above the rhythmic steps. You are approaching a cell-phone-distracted pedestrian. To avoid a direct collision, you may need to announce an urgent “heads-up!” or abruptly maneuver out of the way as they pass. Careful laboratory measurements of people walking while texting confirm the seriousness of this problem [1]. Why is it so difficult to be a conscientious pedestrian and use your cell phone at the same time? A new study by McBride *et al.* [2], reported in this issue of *Current Biology*, helps answer this question by showing how visual processing and locomotion interact in the brains of mice.

Mice are a useful animal model to investigate this issue because there are a wide range of modern genetic tools that can be used to measure and manipulate their brain activity, and they also like to run [3]. They have much lower visual acuity than primates — they see about as well as we do in our peripheral vision [4]. But by carefully choosing the visual stimuli and behavioral tasks, mice can be used to address questions about visual processing that would otherwise be out of reach [5].

In their study, McBride *et al.* [2] placed mice on a running wheel so that they faced a pair of computer monitors showing striped patterns and trained the mice to lick whenever they detected a change in the relative brightness (contrast) of the stripes. One group of mice was trained to detect changes on either the left or right visual display

(‘nonselective’ mice; Figure 1). A second group of mice were trained to expect changes only on one side (‘selective’ mice), similar to our approaching hazard focused on the cell phone in their hand.

Sometimes the mice performed the task while stationary on the wheel, and other times they did it while walking or running (Figure 1). When the mice were stationary, the nonselective mice performed well for changes on either the left or right, and the selective mice performed well only for changes on the expected side, consistent with their different training histories. When the mice ran on the wheel, however, the two groups showed very different effects. The performance of the nonselective mice was about the same when they walked or ran as when they were stationary, but the performance of the selective mice was much worse. It seems mice also find that selective visual processing does not always mix well with walking.

Along with these changes in task performance, McBride *et al.* [2] tested whether there were changes in the activity of neurons located in the primary visual cortex of the mice, previously shown to be crucial for this type of visual task [6]. To obtain these data, silicone probes with multiple recording contacts were placed in the visual cortex so that spiking activity and field potentials could be recorded from many sites simultaneously as mice performed the visual task.

Previous work in primates has identified particular ways that neuronal activity in visual cortex changes when the behavioral task requires selectivity — for example, when attention is directed to a particular spatial location [7]. These changes in

primate visual cortex can make it easier to read out the sensory signals relevant to the task. One thing that changes is spike-count correlations (r_{SC}): if the spiking activity of neurons in the population becomes less correlated, so that each neuron conveys more independent information about the stimulus on each trial, this can improve the sensitivity of the read-out [8]. Another is Fano factor: if the firing rates become less variable across trials, this can improve the reliability of the read-out [9].

Both of these effects were found in the mice as they performed the task while standing [2]. Where they showed up in V1, however, depended on the behavioral training. For the nonselective mice, neurons in both the left and right V1 showed reductions in spike-count correlations on correctly performed trials, as well as decreases in Fano factor. For the selective mice, there were similar effects on spike-count correlations and Fano factor, but only for neurons in the V1 corresponding to where the contrast change was expected. As a result of the difference in training history between the two groups of animals, the same visual stimuli were represented differently in V1, potentially making the expected visual changes easier to detect.

The results took an unexpected turn when these measurements of V1 activity were made with the mice running or walking [2]. Previous studies have shown that locomotion in mice increases firing rates in the visual cortex and also improves the transmission of stimulus information by reducing spike-count correlations, perhaps to accommodate the need for faster and better vision when moving [10,11]. In the McBride *et al.* [2]



study, the effects were more complicated, and differed between the selective and nonselective mice. Consistent with previous findings, locomotion increased stimulus-evoked activity in both hemispheres of both groups of mice, and in nonselective mice it also decreased spike-count correlations, changes that would be expected to boost performance. But in the selective mice, locomotion increased spike-count correlations before the contrast change, which would make it harder to accurately read out the visual signal. This effect is seemingly at odds with previous findings but consistent with the impaired task performance of the selective mice during locomotion.

The same detrimental effect of locomotion was found when McBride *et al.* [2] used a linear classifier to interpret V1 activity. A linear classifier can be a useful way to estimate how well you can distinguish between different conditions based only on the pattern of the experimental measurements. In this case, a linear classifier was used to estimate how well you could identify the contrast change based on the population activity of V1 neurons. In nonselective mice, the population activity in either the right or left V1 did a good job of identifying the contrast change and did about the same regardless of whether the mice were running or stationary. In selective mice, the population activity in the V1 did even better, but only for the side corresponding to where the contrast change was expected, and classification was significantly worse during running, again consistent with the behavior of these mice.

These results are an important demonstration that the effects of global arousal, like those linked to locomotion, are not always compatible with other mechanisms that regulate how sensory signals are processed. There are multiple modulatory systems that can influence signal processing by the cortex, and these act through circuits whose details in the mouse are now becoming clearer. Locomotion is controlled by a midbrain locomotor region that also has projections to the basal forebrain, a major source of cholinergic inputs to the cortex [12]. In the visual cortex, these cholinergic inputs target a particular class of inhibitory interneurons (positive for vasoactive intestinal peptide) that, during

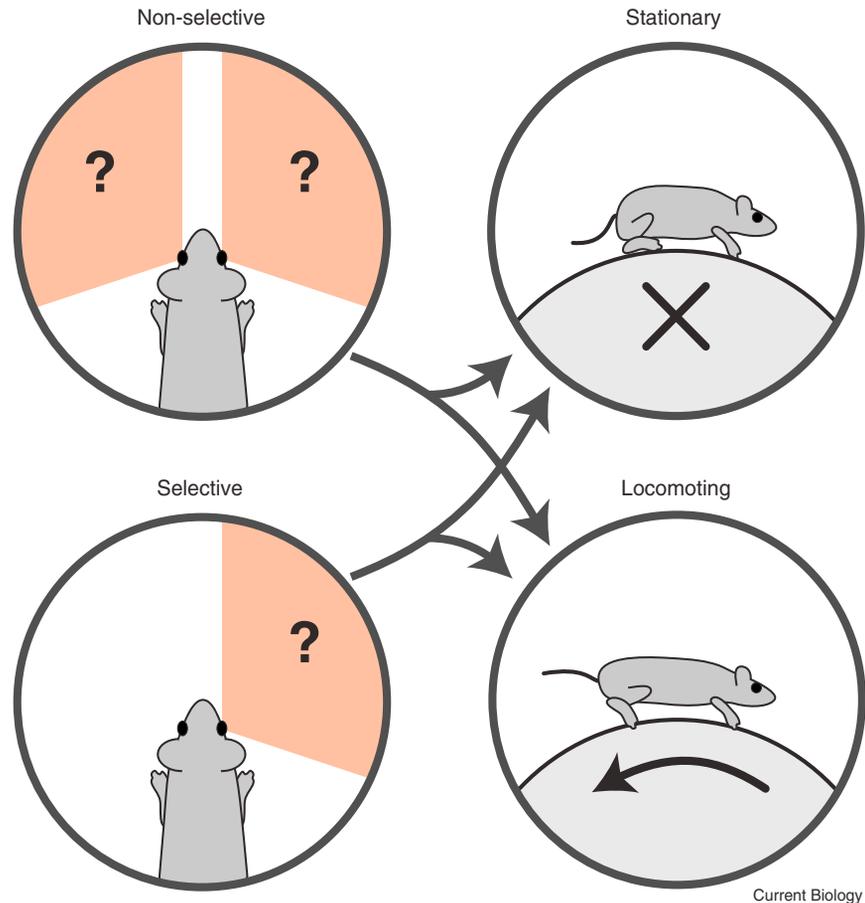


Figure 1. Investigating how spatial selection and locomotion interact.

One group of mice were trained to detect changes in either the left or right side of the visual display ('non-selective') whereas another group were trained to expect changes only on one side ('selective'). Both groups were then tested while either stationary or locomoting on a running wheel, with strikingly different results.

locomotion, interact with other cortical interneurons to enhance the visual responses of nearby excitatory pyramidal cells [13–15].

The logic of this locomotor modulatory circuit is apparently at odds with the mechanism that allows the selective mice in McBride *et al.* [2] to focus so well to visual stimuli on one side. It will be interesting to discover exactly why. Other classes of interneurons in visual cortex are also modulated by acetylcholine and in primates, this cholinergic modulation can mimic the effects of visual selective attention [16,17]. Testing these interactions in mice provides an opportunity to identify how useful but generic notions like 'behavioral context' correspond to specific circuit elements and patterns of activity. Such findings

can reveal general principles of cortical processing, but it should also be kept in mind that there are major differences in the development and organization of the visual cortex between rodents and primates [18].

It is also an open question how these mechanisms are related to visual selective attention. As McBride *et al.* [2] acknowledge, the selectivity of their mice was not the same as attention, because the selective mice only responded to visual stimuli on that one side. It would be interesting to know whether these effects and interference with locomotion would still be present in mice that flexibly switched their selective attention from side to side [19]. It is possible that locomotion is more compatible with forms of visual selection that shift across locations over time, compared to those

that remain fixed at one location, especially given the challenges of navigating through a natural environment [20].

In other words, when out for a walk it might be best to put away the cell phone, look around and appreciate the scenery.

REFERENCES

- Schabrun, S.M., van den Hoorn, W., Moorcroft, A., Greenland, C., and Hodges, P.W. (2014). Texting and walking: strategies for postural control and implications for safety. *PLoS One* 9, e84312.
- McBride, E.G., Lee, S.-Y.J., and Callaway, E.M. (2019). Local and global influences of visual spatial selection and locomotion in mouse primary visual cortex. *Curr. Biol.* 29, 1592–1605.
- Huberman, A.D., and Niell, C.M. (2011). What can mice tell us about how vision works? *Trends Neurosci.* 34, 464–473.
- Histed, M.H., Carvalho, L.A., and Maunsell, J.H.R. (2012). Psychophysical measurement of contrast sensitivity in the behaving mouse. *J. Neurophysiol.* 107, 758–765.
- Carandini, M., and Churchland, A.K. (2013). Probing perceptual decisions in rodents. *Nat. Neurosci.* 16, 824–831.
- Glickfeld, L.L., Histed, M.H., and Maunsell, J.H.R. (2013). Mouse primary visual cortex is used to detect both orientation and contrast changes. *J. Neurosci.* 33, 19416–19422.
- Maunsell, J.H.R. (2015). Neuronal mechanisms of visual attention. *Annu. Rev. Vis. Sci.* 1, 373–391.
- Ruff, D.A., and Cohen, M.R. (2014). Attention can either increase or decrease spike count correlations in visual cortex. *Nat. Neurosci.* 17, 1591–1597.
- Mitchell, J.F., Sundberg, K.A., and Reynolds, J.H. (2007). Differential attention-dependent response modulation across cell classes in macaque visual area V4. *Neuron* 55, 131–141.
- Niell, C.M., and Stryker, M.P. (2010). Modulation of visual responses by behavioral state in mouse visual cortex. *Neuron* 65, 472–479.
- Dadarlat, M.C., and Stryker, M.P. (2017). Locomotion enhances neural encoding of visual stimuli in mouse V1. *J. Neurosci.* 37, 3764–3775.
- Lee, A.M., Hoy, J.L., Bonci, A., Wilbrecht, L., Stryker, M.P., and Niell, C.M. (2014). Identification of a brainstem circuit regulating visual cortical state in parallel with locomotion. *Neuron* 83, 455–466.
- Fu, Y., Tucciarone, J.M., Espinosa, J.S., Sheng, N., Darcy, D.P., Nicoll, R.A., Huang, Z.J., and Stryker, M.P. (2014). A cortical circuit for gain control by behavioral state. *Cell* 156, 1139–1152.
- Pfeffer, C.K., Xue, M., He, M., Huang, Z.J., and Scanziani, M. (2013). Inhibition of inhibition in visual cortex: the logic of connections between molecularly distinct interneurons. *Nat. Neurosci.* 16, 1068–1076.
- Dipoppa, M., Ranson, A., Krumin, M., Pachitariu, M., Carandini, M., and Harris, K.D. (2018). Vision and locomotion shape the interactions between neuron types in mouse visual cortex. *Neuron* 98, 602–615.
- Krueger, J., and Disney, A.A. (2019). Structure and function of dual-source cholinergic modulation in early vision. *J. Comp. Neurol.* 527, 738–750.
- Herrero, J.L., Roberts, M.J., Delicato, L.S., Gieselmann, M.A., Dayan, P., and Thiele, A. (2008). Acetylcholine contributes through muscarinic receptors to attentional modulation in V1. *Nature* 454, 1110–1114.
- Betizeau, M., Cortay, V., Patti, D., Pfister, S., Gautier, E., Bellemin-Ménard, A., Afanassieff, M., Huissoud, C., Douglas, R.J., Kennedy, H., et al. (2013). Precursor diversity and complexity of lineage relationships in the outer subventricular zone of the primate. *Neuron* 80, 442–457.
- Wang, L., and Krauzlis, R.J. (2018). Visual selective attention in mice. *Curr. Biol.* 28, 676–685.
- Matthis, J.S., Yates, J.L., and Hayhoe, M.M. (2018). Gaze and the control of foot placement when walking in natural terrain. *Curr. Biol.* 28, 1224–1233.

Environmental Stress: Salinity Ruins a Plant's Day in the Sun

Katie J. Magallon¹ and José R. Dinneny^{1,2,*}

¹Carnegie Institution for Science, Department of Plant Biology, Stanford, CA 94305, USA

²Stanford University, Department of Biology, Stanford, CA 94305, USA

*Correspondence: dinneny@stanford.edu

<https://doi.org/10.1016/j.cub.2019.04.006>

New research reveals how low levels of salinity in soil inhibit a plant's ability to respond to shade through a signaling mechanism involving the plant stress hormone abscisic acid.

Plant shoots detect and absorb light energy above ground to power photosynthesis. In the chloroplast, chlorophyll and the light-harvesting complex absorb photosynthetically active light, comprised primarily of red and blue wavelengths [1]. Plants also utilize light as a resource to gain information about their surrounding environment. For example, plants can

interpret the difference between the shade produced by clouds and the shade produced by nearby plant competitors. Differences in light quality and quantity are measured through a series of proteins called photoreceptors, which function outside of the chloroplast. Phytochromes absorb red and far-red light and are responsible for determining the quality of shaded light [2].

Far-red light is not efficiently absorbed and will either be reflected or transmitted by plant tissues [1]. When crops are planted in dense fields, a tall plant will have a competitive advantage over its shorter neighbors. The taller plant will absorb light in the photosynthetically useful range, letting all other light pass through. A shorter neighbor will consequently sense a larger amount of

