MFBs. These data provide one potential mechanism to explain the almost one order of magnitude higher transmitter initial release probability at the MF filopodial-interneuron synapse compared to the MFB-pyramidal cell synapse (Jonas et al., 1993; Lawrence et al., 2004).

While the data presented by Jonas and Engel firmly establish the active properties of MFBs, previous investigations at the NMJ and the calyx of Held (R.M. Leão et al., 2004, Soc. Neurosci., abstract) have argued for passive invasion of APs into these terminal structures where Na^+ channels concentrate at the heminode with K^+ channels dominating the presynapse. Whether the presence of a terminal Na^+ conductance is specific to MFBs or more generally defines a difference between en passant versus terminal boutons awaits further investigation. Regardless of the answer, it is clear that when technology does pace ambition to enable direct recordings from a larger number of central nerve terminals, the landmark studies of Jonas and colleagues describing MFB K^+, Ca^{2+}, and Na^+ conductances provide a very useful blueprint for molecularly dismantling presynaptic function.

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Selected Reading

Acsady, L., Kamondi, A., Sik, A., Freund, T., and Buzsaki, G. (1998). J. Neurosci. *18*, 3386–3403.

Bischofberger, J., Geiger, J.R., and Jonas, P. (2002). J. Neurosci. *22*, 10593–10602.

Chicurel, M.E., and Harris, K.M. (1992). J. Comp. Neurol. *325*, 169–182.

Debanne, D. (2004). Nat. Rev. Neurosci. *5*, 304–316.

Engel, D., and Jonas, P. (2005). Neuron *45*, this issue, 405–417.

Geiger, J.R., Bischofberger, J., Vida, I., Frobe, U., Pfitzinger, S., Weber, H.J., Haverkampf, K., and Jonas, P. (2002). Pflugers Arch. *443*, 491–501.

Geiger, J.R., and Jonas, P. (2000). Neuron *28*, 927–939.

Hallermann, S., Pawlu, C., Jonas, P., and Heckmann, M. (2003). Proc. Natl. Acad. Sci. USA *100*, 8975–8980.

Henze, D.A., Urban, N.N., and Barrionuevo, G. (2000). Neuroscience *98*, 407–427.

Jonas, P., Major, G., and Sakmann, B. (1993). J. Physiol. *472*, 615–663.

Lawrence, J.J., and McBain, C.J. (2003). Trends Neurosci. *26*, 631–640.

Lawrence, J.J., Grinspan, Z.M., and McBain, C.J. (2004). J. Physiol. *554*, 175–193.

Manor, Y., Koch, C., and Segev, I. (1991). Biophys. J. *60*, 1424–1437.

Urban, N.N., Henze, D.A., and Barrionuevo, G. (2001). Hippocampus *11*, 408–417.

von Kitzing, E., Jonas, P., and Sakmann, B. (1994). Adv. Second Messenger Phosphoprotein Res. *29*, 235–260.

Navigating a Sensorimotor Loop

Touch is an active process, but how do the body's somatic sensors influence its movement? In this issue of *Neuron*, Nguyen and Kleinfeld show that afferent activity from the whiskers on a rat's face trigger rapid and prolonged excitation of the motor neurons that drive movements of the same whiskers. Positive feedback through this sensorimotor loop may serve to optimize the interaction between sensors and stimuli.

Pull any general neuroscience book off your shelf, and you will probably find that the somatosensory and motor systems are described in separate chapters. In practice, however, these two systems are inextricably linked. To remove that book from the shelf successfully, your somatosensory and motor systems must interact. The somatosensory system usually relies on the motor system to bring its sensory receptors into contact with objects of interest. It has also been shown that active touch—somatic sensation aided by deliberate movements of the sensors—optimizes sensory perception (Gibson, 1962; Lederman and Klatzky, 1987).

The somatosensory and motor systems are linked at many anatomical levels. As tactile information ascends through the somatosensory system, some of it is sent to multiple locations within the motor system. Since movement guided by sensation in turn affects new sensory input, the metasystem can be conceptualized as a set of closed and nested sensorimotor feedback loops (see Kleinfeld et al., 1999 for discussion). One of the fundamental unanswered questions about these feedback loops is how sensory information influences motor output.

In this issue of *Neuron*, Nguyen and Kleinfeld (2005) study this question using a specialized but accessible somatosensory subsystem: the facial whiskers (vibrissae) of the rat. Rats explore the environment by rhythmically scanning their whiskers in the air or across objects, akin to the way humans use their fingertips. Such whisking provides highly detailed information about object texture, shape, size, and position. Nguyen and Kleinfeld studied the feedback loop that involves sensory information originating from the whiskers, which travels to the brain via the infraorbital branch of the trigeminal nerve (IoN) and synapses in the trigeminal brainstem nuclei. These nuclei project to higher levels of the somatosensory and motor systems, but they also connect directly and indirectly with the facial motor nucleus, which contains the motor neurons responsible for whisker movement. This constitutes the first sensorimotor loop, where tactile information that has not yet ascended beyond the brainstem might exert an influence on the neurons that drive the muscles involved in whisking.

It is important to note that sensory activity from the whiskers is not what provides the rhythmic drive for whisking itself; that apparently comes from a central pattern generator elsewhere in the brainstem (although precisely where is still anyone's guess; Hattox et al.,

2002). Trigeminal sensory inputs to the facial motor nucleus do, however, have the potential to alter the characteristics of whisker movements in response to incoming somatosensory input. But do they, and if so by what mechanism? The fact that this pathway is short suggested that the influence might be fast, but even the polarity of the effect was unknown. There is some structural evidence for inhibitory connections from the sensory to the motor nucleus (Li et al., 1997), but physiological evidence implies a net excitatory influence (Sachdev et al., 2003).

Nguyen and Kleinfeld used both in vitro and in vivo methods to test how trigeminal input affects vibrissae motor neurons and the muscles responsible for moving the whiskers. First, they employed a novel isolated slice preparation that should also prove highly valuable for a variety of future studies: careful dissection followed by judicious sectioning of the brainstem captured much of the infraorbital nerve, the trigeminal nuclear complex, the facial motor nucleus, and their interconnections in a single viable slice. Electrical stimulation of the infraorbital or trigeminal nerve elicited clusters of short- and long-latency EPSPs in ipsilateral facial motor neurons, and these EPSP barrages persisted for up to 1 s following a stimulus. Interestingly, these responses began to depress when the nerve was stimulated faster than 2 Hz, and they were attenuated by 40% after brief trains of 9 Hz, which is the mean frequency for exploratory whisking.

The authors then studied intact, anesthetized animals to test how this sensory input to the facial motor nucleus alters motor activity in the whisker pad itself. To do this, they inserted fine wire electrodes into the muscles responsible for moving the whiskers and recorded electromyographic (EMG) signals while stimulating the IoN. The results verified that sensory nerve activity elicited contractions of the whisker musculature with just the properties of timing and frequency sensitivity predicted by the in vitro results. Nguyen and Kleinfeld also showed that EMG responses could be elicited by moving the whiskers passively, or by triggering whisker movement with stimuli to the facial nucleus. These experiments demonstrate that the sensorimotor loop is indeed closed and excitatory at the brainstem level.

In their most interesting experiment, Nguyen and Kleinfeld showed that this sensorimotor loop probably exerts a strong influence on motor output. They evoked whisking movements by stimulating the facial motor nucleus, then introduced an object in the path of the whiskers; contact with this object caused an increase in the EMG response recorded in the whisking muscles, presumably via positive feedback through the sensorimotor loop. This result suggests that sensory signals rapidly facilitate whisking movements.

Nguyen and Kleinfeld's findings inspire new questions about the mechanisms of sensorimotor feedback, and about its functional relevance. On the cellular side, what is the role of inhibition in the sensorimotor brainstem loop? The trigeminal nuclei have GABAergic and glycinergic neurons (Li et al., 1997), and inhibitory processes must surely be involved. Inhibition may play a role in the frequency sensitivity or duration of the responses. It may also serve to modulate feedback as a function of behavioral state, when tactile responsiveness is dynamically regulated (Fanselow and Nicolelis, 1999). Also, among the first-order IoN neurons, not all are sensitive to contact with the environment; some primarily signal whisking—i.e., they sense the motor act itself (Szwed et al., 2003). Do these two classes of IoN axons have an equal influence on the brainstem feedback loop? Might they have opposite effects?

The functions of positive sensorimotor feedback in the whisker system are not obvious. The authors suggest that feedback may serve to enhance contact between whiskers and their sensory environment and otherwise optimize the mechanics of the sensory process. Perhaps this type of sensory feedback is less relevant to the whisking state and serves to encourage the initiation of whisking movements when an object brushes past relatively still whiskers. Would such feedback interfere with ongoing rhythmic whisking or refine it? In an interesting study, Szwed et al. (2003) showed that the first-order whisker afferents have very different sensory encoding schemes during active whisking compared to passive movements. Perhaps positive sensorimotor feedback compensates for movement-related distortions of the sensory transduction process.

Knowing how and why somatosensory feedback alters motor activity will be essential to understanding how we acquire and interpret a stable, coherent percept of the world. It may also inspire the design of better prosthetic devices that use sensory feedback to enhance their operation.

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Selected Reading

Fanselow, E.E., and Nicolelis, M.A. (1999). J. Neurosci. *19*, 7603–7616.

Gibson, J.J. (1962). Psychol. Rev. *69*, 477–491.

Hattox, A.M., Priest, C.A., and Keller, A. (2002). J. Comp. Neurol. *442*, 266–276.

Kleinfeld, D., Berg, R.W., and O'Connor, S.M. (1999). Somatosens. Mot. Res. *16*, 69–88.

Lederman, S.J., and Klatzky, R.L. (1987). Cognit. Psychol. *19*, 342–368.

Li, Y.Q., Takada, M., Kaneko, T., and Mizuno, N. (1997). J. Comp. Neurol. *378*, 283–294.

Nguyen, Q.-T., and Kleinfeld, D. (2005). Neuron *45*, this issue, 447–457.

Sachdev, R.N., Berg, R.W., Champney, G., Kleinfeld, D., and Ebner, F.F. (2003). Somatosens. Mot. Res. *20*, 163–169.

Szwed, M., Bagdasarian, K., and Ahissar, E. (2003). Neuron *40*, 621–630.