Compartmentalized dendritic plasticity and input feature storage in neurons

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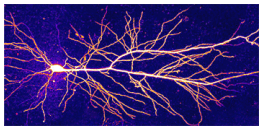

CA1 pyramidal neuron showing the extensively branched dendritic arborization. Each individual branch is a potential substrate for higher-order information storage.

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Jeffrey Magee is interested in how the biophysical properties of neurons produce the information-processing and storage capabilities of single and small networks of neurons.

Hebbian Plasticity: Cells that fire together wire together

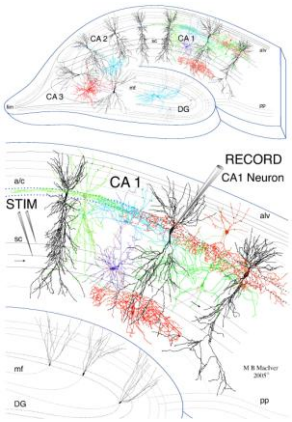
Opening NMDA receptor requires:
- depolarization
- glutamate

What is the extent of depolarization?

Dendritic spikes: dendrites contain voltage gated ion channels that produce local (dendritic) spikes.

Backward propagatation from the Soma to the dendrites.

Are dendrites isolated compartments for regulating plasticity?



DENDRITES ON THE SAME NEURON DIFFER MARKEDLY IN ABILITY TO PROPAGATE SPIKES

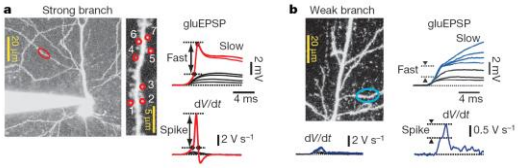


Fig. 1a Strong branch of Hippocampal CA1 neuron (circled).

Two photon glutamate uncaging at spines 1-7 indicated.

Voltage traces above recorded by the electrode in the soma, and derivative dV/dt, below.

Fast portion is dendritic spike.

Black: subthreshold gluEPSPs
Red: dendritic spike

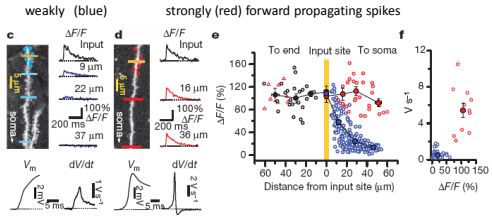
Weak branch of another neuron.

subthreshold gluEPSPs in black
Blue weak spike results in fast depolarization.

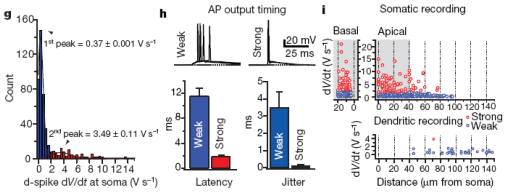
Note scale bars (left, same as A, right expanded)

Calcium imaging used to determine the magnitude of calcium transients as a function of distance from the initiation site.

Calcium transients propagating toward the soma decreased in ampliutde.
Calcium transients propagating away from soma were constant in amplitude



Note how the calcium transient fails in the weak dendrite, is constant in the strong dendrite.



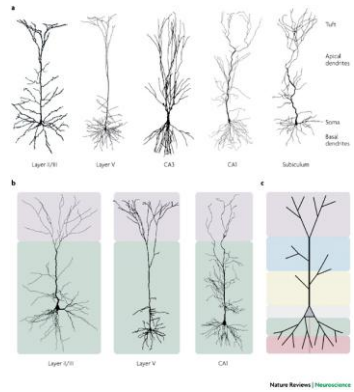
Histogram of magnitudes of dendritic spike dV/dt measured at the soma is bimodal.

Strong and weak

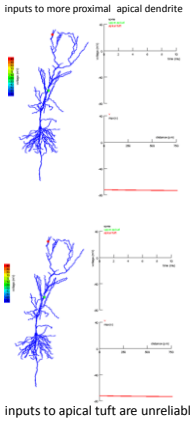
Action potential output latency is
Slow (weak)
Fast (strong)

Jitter is small for strong, large for weak.

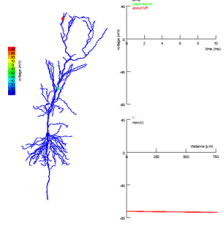
Do strong vs. weak dendrites differ in the spike height vs. distance?



inputs to more proximal apical dendrite



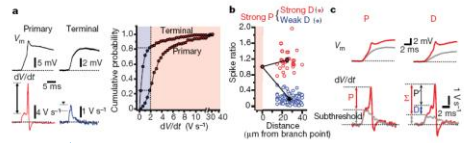
Conditional dendritic spike propagation following distal synaptic activation of hippocampal CA1 pyramidal neurons.
Jarsky T, Roxin A, Kath WL, Spruston N.
Nature Neurosci. 2005: 1667-76



http://www.scholarpedia.org/article/Pyramidal_neuron

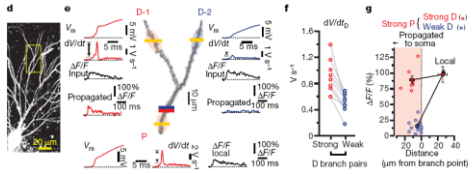
inputs to apical tuft are unreliable in firing the whole cell

Dendrites that branch:
Terminal segments are rarely strong spiking
Proximal segments are more often strong spiking.
Spike ratio within dendritic families of higher order daughter (D) branch divided by lower order parent branch (P)



strong distal branch compared to weak distal branch

strong distal branches had two components to spike (two origins, D and P)



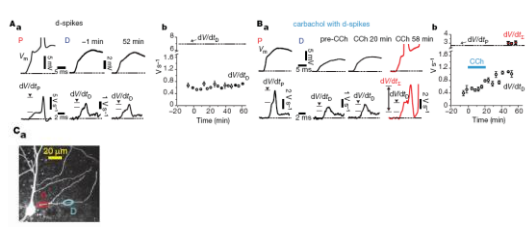
Example of one dendrite with two distal branches, one strong, one weak.

red and blue lines: scan lines for measuring Calcium spike signal.
Orange line: input site line scans
Input onto D1 branch evoked a strong spike
Input to branch D2 evoked a weak spike
Only the strong spike propagated into the parent branch.

Is the variable pattern of branch coupling between local branches of a dendrite regulated by some cellular process?

Tested on weak branches coming off a strong branch. Stimulate local spike initiation for 40 minutes produced no effect on coupling. Still weak spike in distal branch.

However adding transient carbachol (cholinergic agonist), a modulator of exploratory behavior , made distal branches strong.



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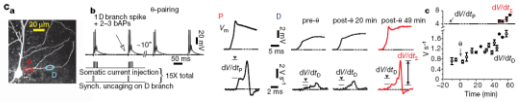


Yes, after theta pairing by back propagated spike paired with local dendrite stimulation enhanced branch strength coupling after 49 minutes of pairing.

Call this: "Branch strength potentiation" "BSP"

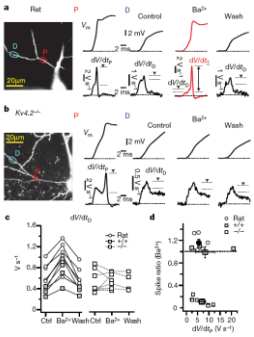
Both branches had to produce spikes in order for BSP to occur.

BSP is a form of associative plasticity.

The carbachol effect was blocked by atropine (must be a muscarinic Ach receptor)

In summary, repetitive local spiking in weak branches when associated with either mAChR activation or back propagating action potentials triggers an NMDAR-dependent signalling pathway that leads to a gradual enhancement of local spike propagation that eventually becomes effective enough to activate the more powerful proximal dendrites of the dendritic family.

Role of voltage-gate K + channels on BSP



Barium effect. First, voltage trace from proximal and distal denrites. Distal is not firing spikes. Under Barium ion, A-type K currents are blocked causing an increase in the spike and derivative. Thus A type K current may be involved in suppressing dendritic spikes in weak branches.

Mediated by Kv4.2K⁺ channel subunits.

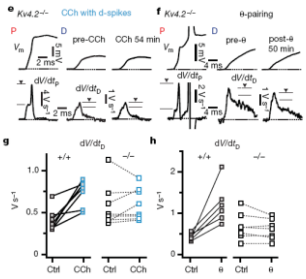
These Mice do not express Kv4.2.

Consistent with this, DVdt was higher in Kv4.2 mice bath application of Barium does not restore spike in distal dendrite,unlike rat.

in Kv4.2 ⁻/⁻ mice there is no effect of Barium.

Kv4.2 strongly implicated in BSP

Branch Strength Potentiation



Summary

1) Branch coupling strength is not static, it can be potentiated by pairing highly synchronized input with action potential output or by modulation with acetylcholine activing on mAchR