Synaptic Plasticity (Chapter 8)

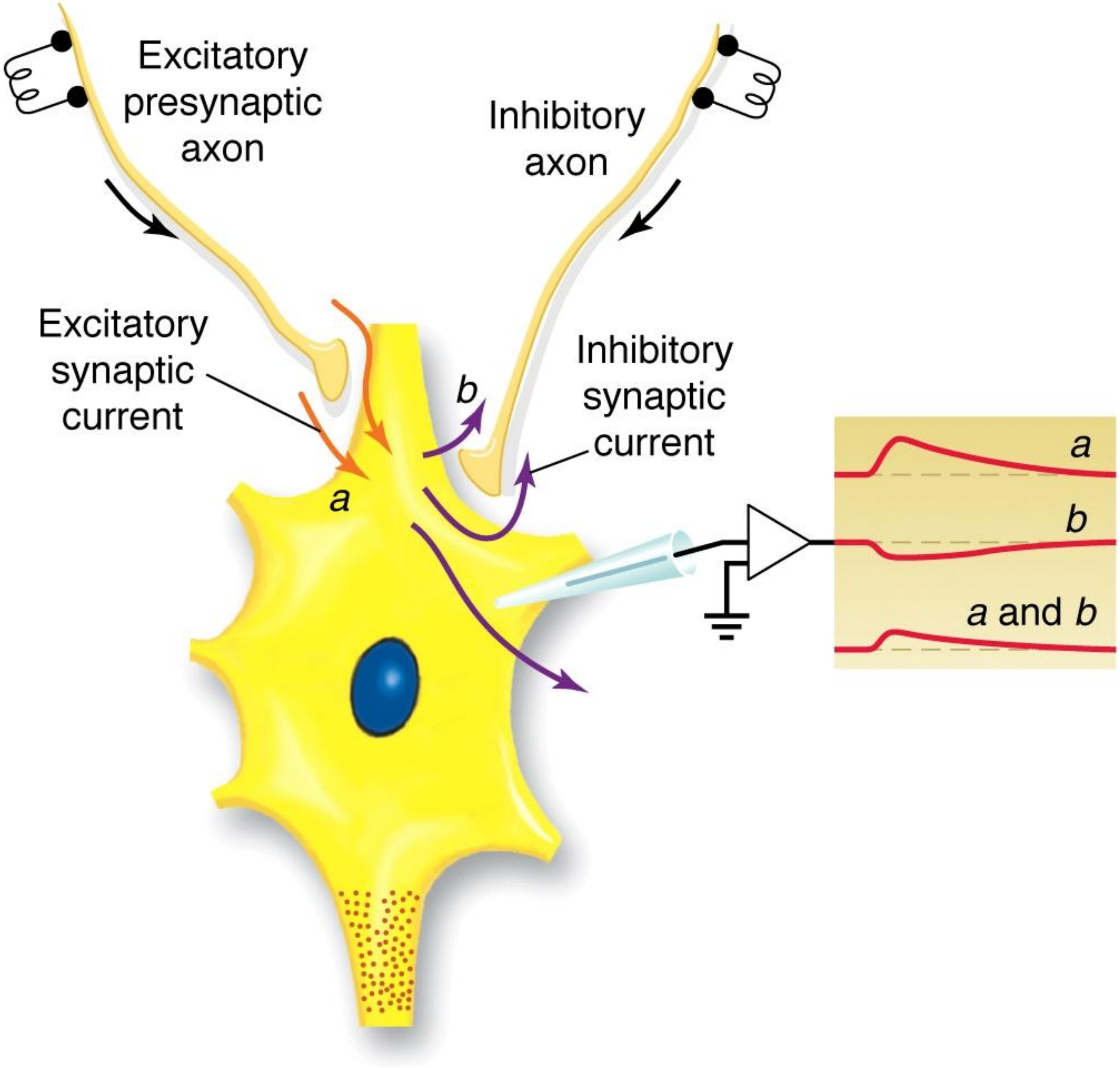
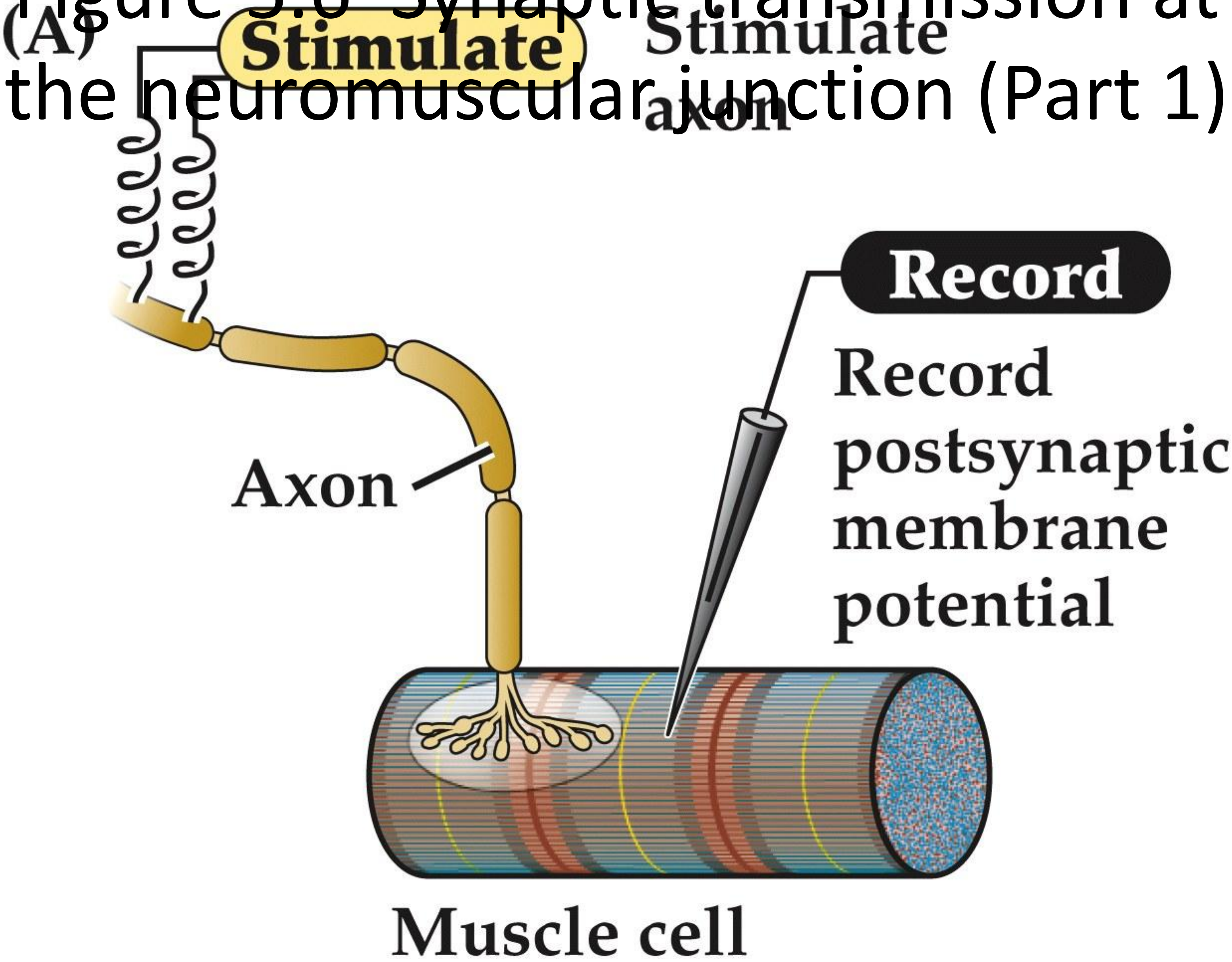
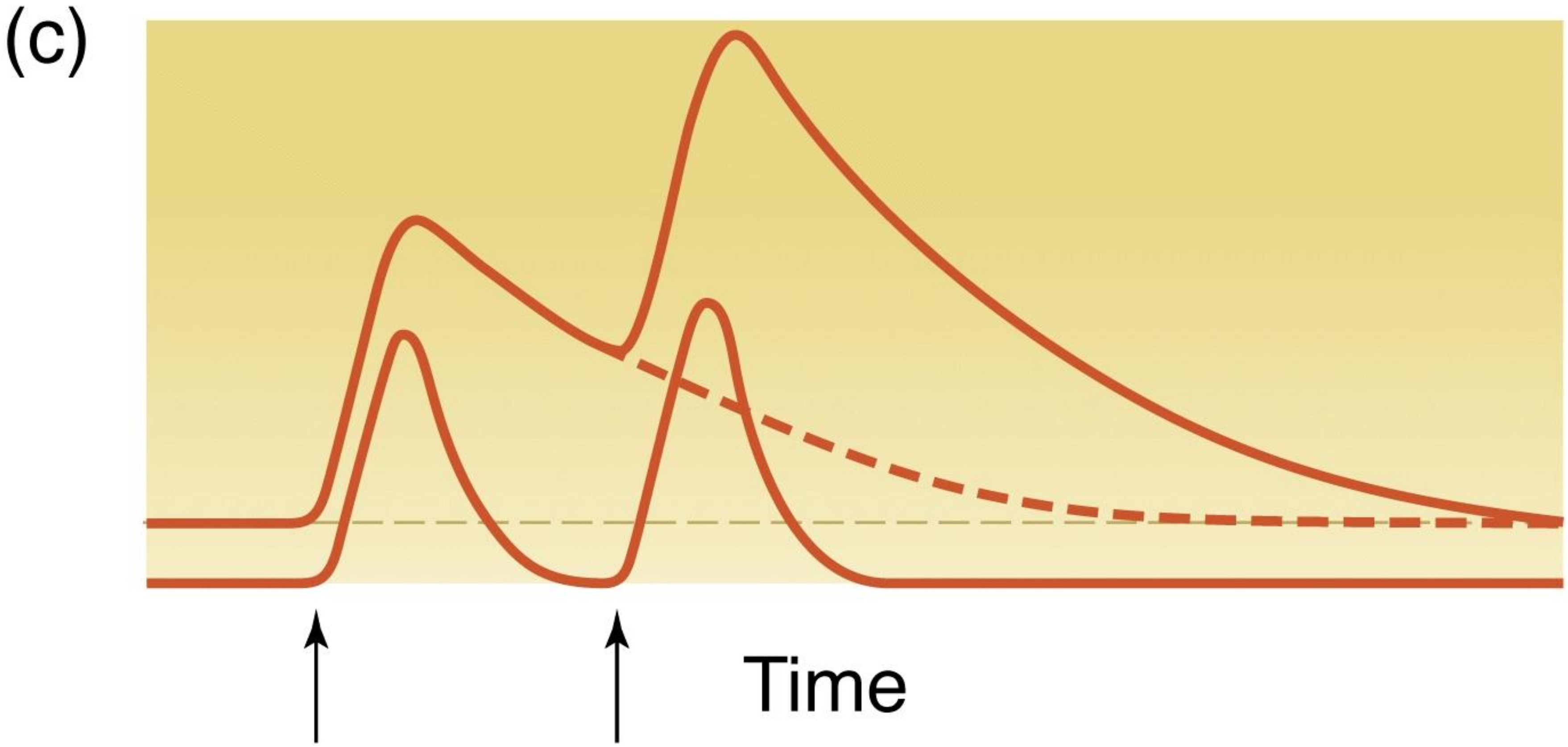
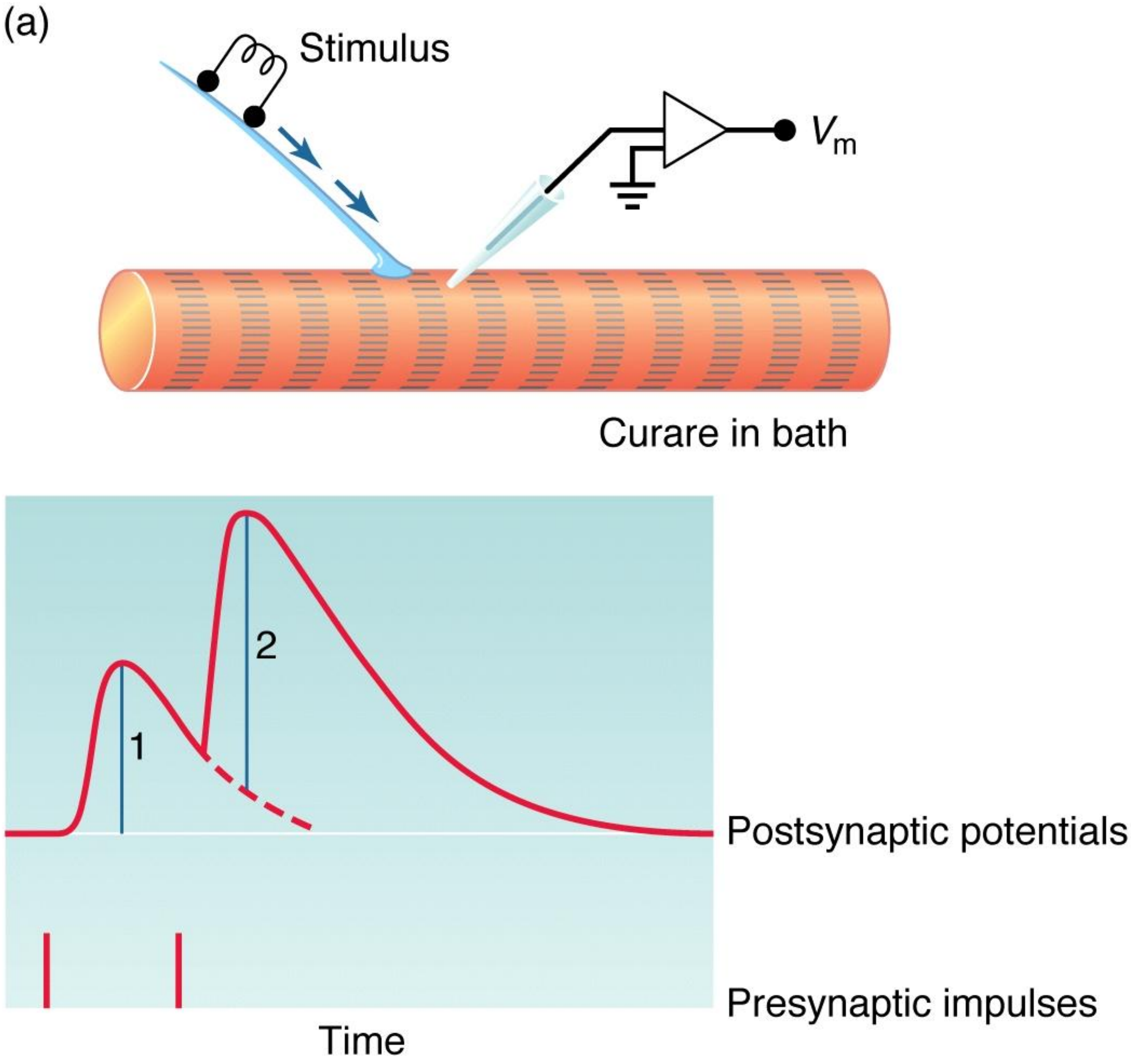

Excitatory presynaptic axon
Inhibitory axon
Excitatory synaptic current
b
Inhibitory synaptic current
a
a
b
a and b

Figure 5.6 Synaptic transmission at the neuromuscular junction (Part 1)

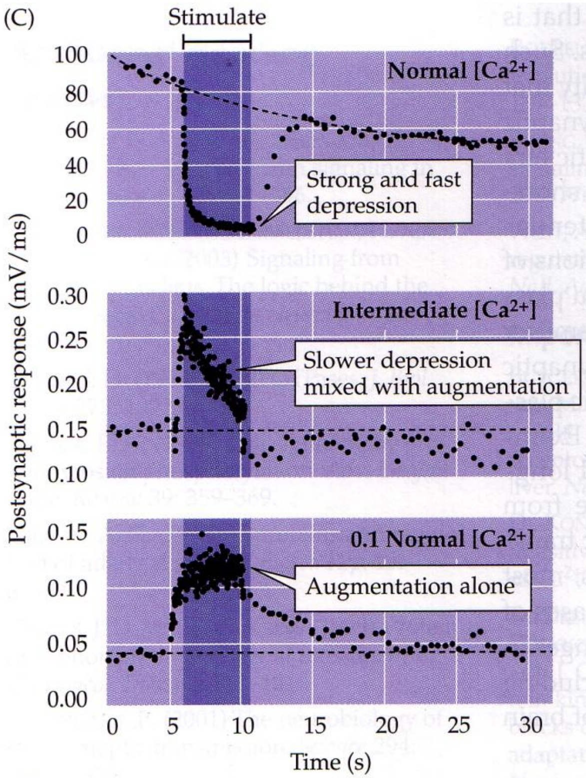


***NEUROSCIENCE 5e*, Figure 5.6 (Part 1)**

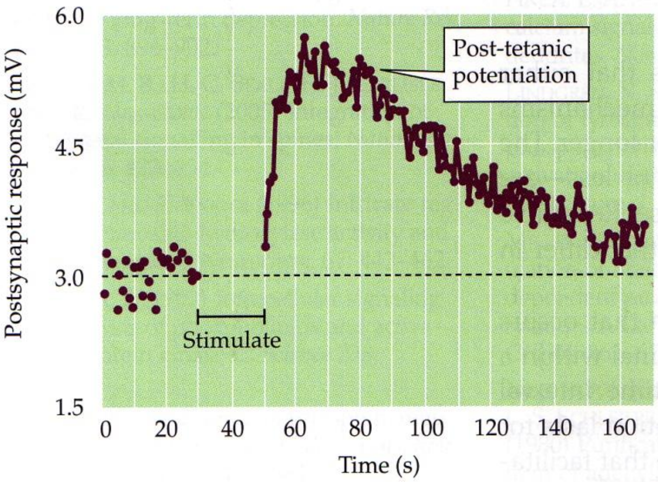

(c)
Time

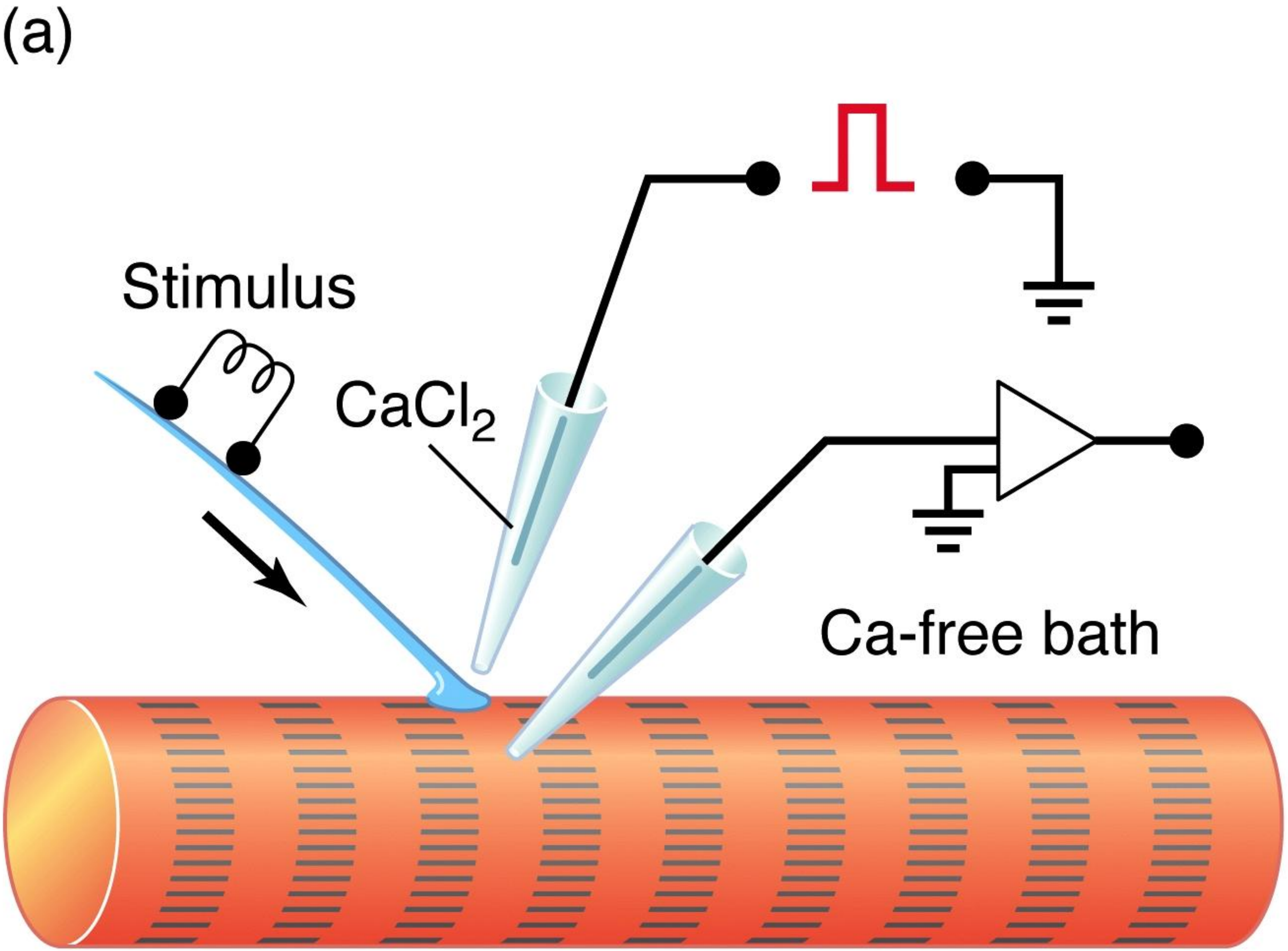

(a)
Stimulus
V_m
Curare in bath
2
1
Postsynaptic potentials
Presynaptic impulses
Time

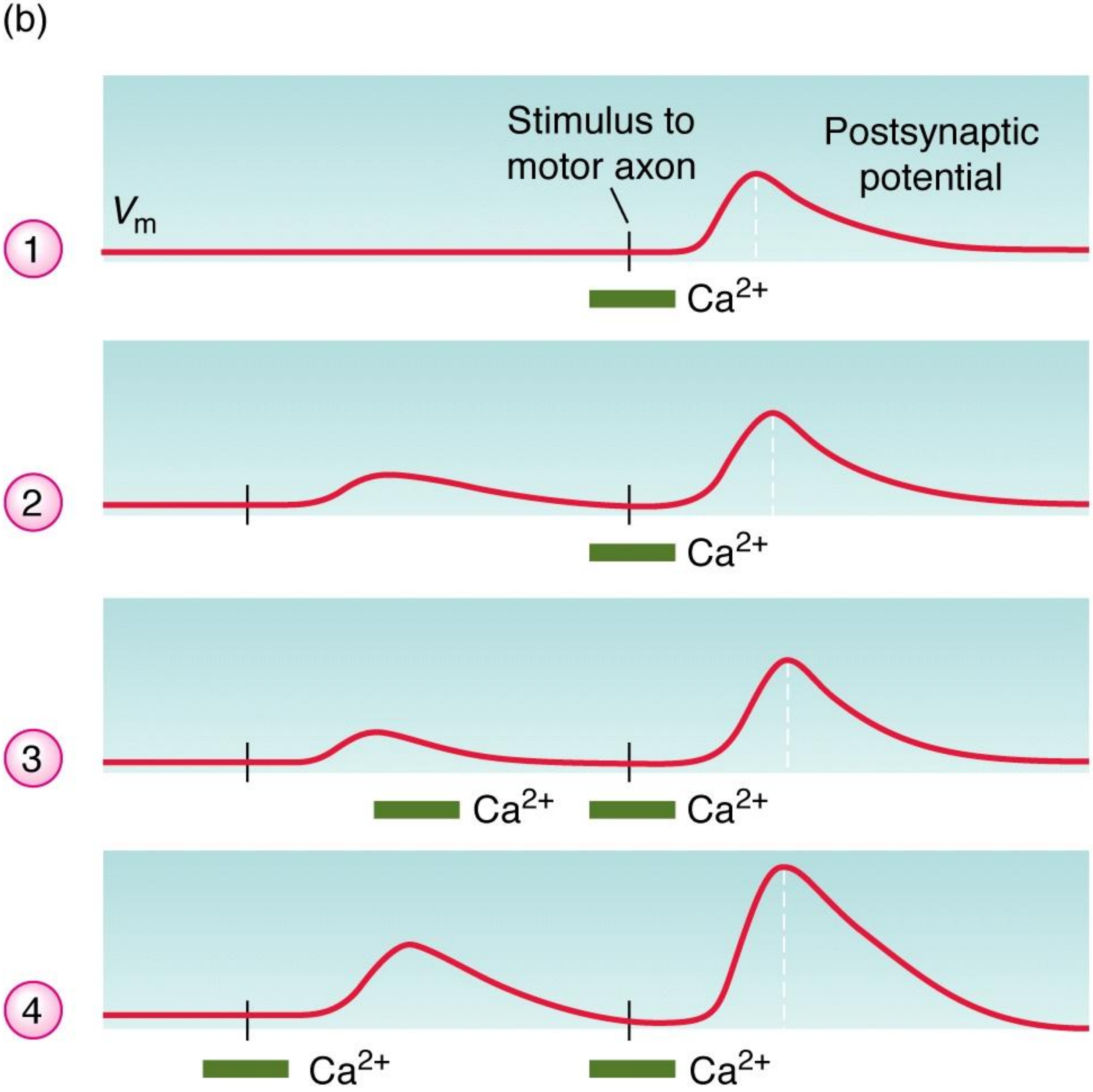
(C)


Stimulate
Normal [Ca2+]
Strong and fast depression
Intermediate [Ca2+]
Slower depression mixed with augmentation
0.1 Normal [Ca2+]
Augmentation alone
Postsynaptic response (mV/ms)
100
80
60
40
20
0
0.30
0.25
0.20
0.15
0.10
0.15
0.10
0.05
0.00
0
5
10
15
20
25
30
Time (s)

(E)


Post-tetanic potentiation
Stimulate
Postsynaptic response (mV)
6.0
4.5
3.0
1.5
0
20
40
60
80
100
120
140
160
Time (s)


(a)
Stimulus
CaCl2
Ca-free bath

(b)
Stimulus to motor axon
Postsynaptic potential
V_m
1
Ca²⁺
2
Ca²⁺
3
Ca²⁺
Ca²⁺
4
Ca²⁺
Ca²⁺

LTF and LTP: history

Experiments in crayfish might possibly be the first to demonstrate facilitation at the neuromuscular (NMJ) (Richet, 1879; also see Richet, 1881). Over the next few decades crayfish NMJs were being described anatomically and physiologically in respect to tension development and anatomy (Van Harreveld and Wiersma, 1936). http://www.jove.com/video/1595/historical-view-and-physiology-demonstration-at-the-nmj-of-the-crayfish-opener-muscle

1953 that Fatt and Katz recorded transmembrane potentials of short term facilitation in crab muscle fibers.

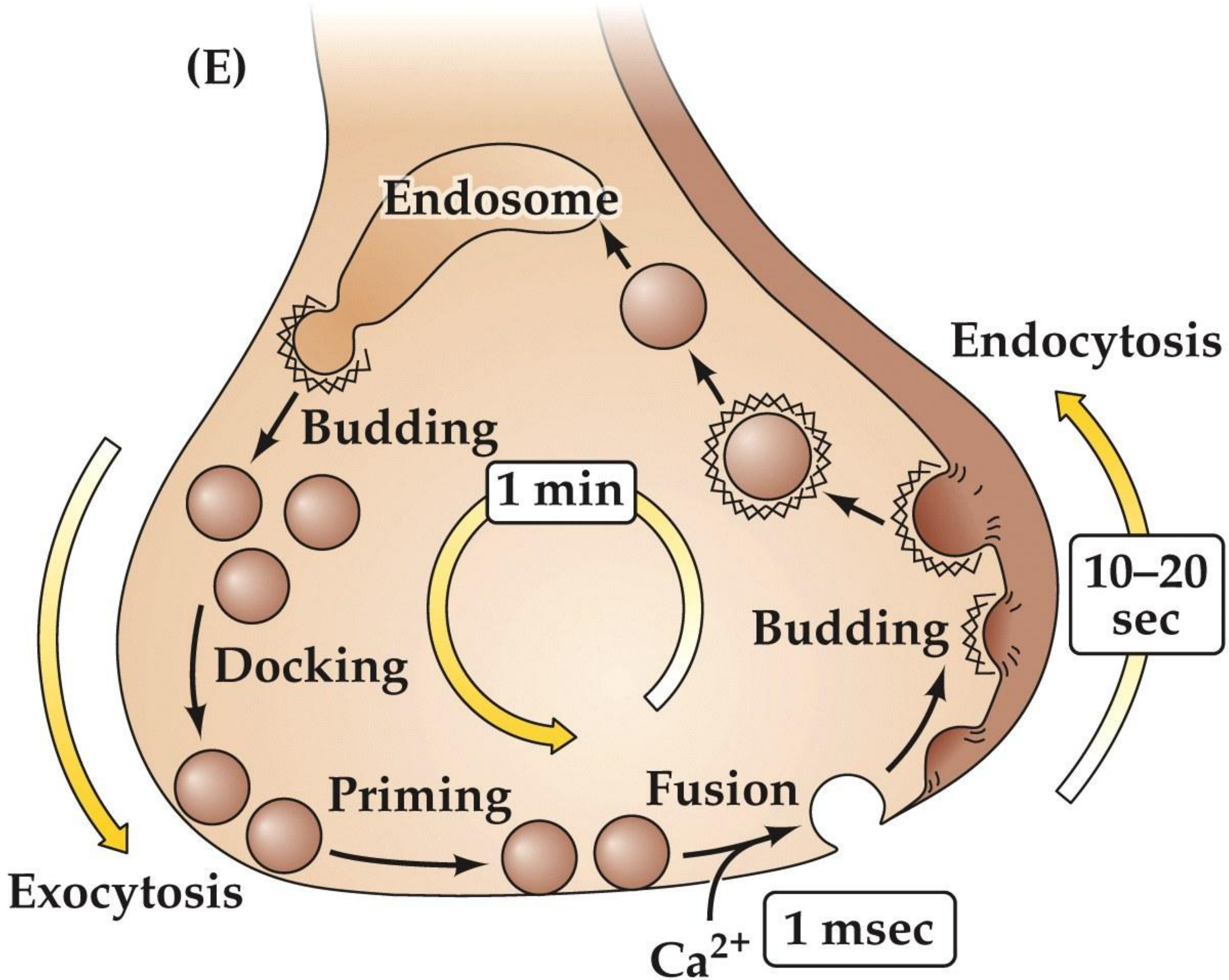
With the seminal discover that the opener NMJ in crayfish exhibited long-term facilitation (LTF) (Sherman and Atwood, 1971), in addition to short-term facilitation, the mechanistic underpinnings for these phenomena needed to be addressed.

As a side note, long-term potentiation (LTP) was discovered in the vertebrate brain two years later (Bliss and Lømo, 1973) without citation to the original discovery of the phenomenon at the crayfish NMJ.

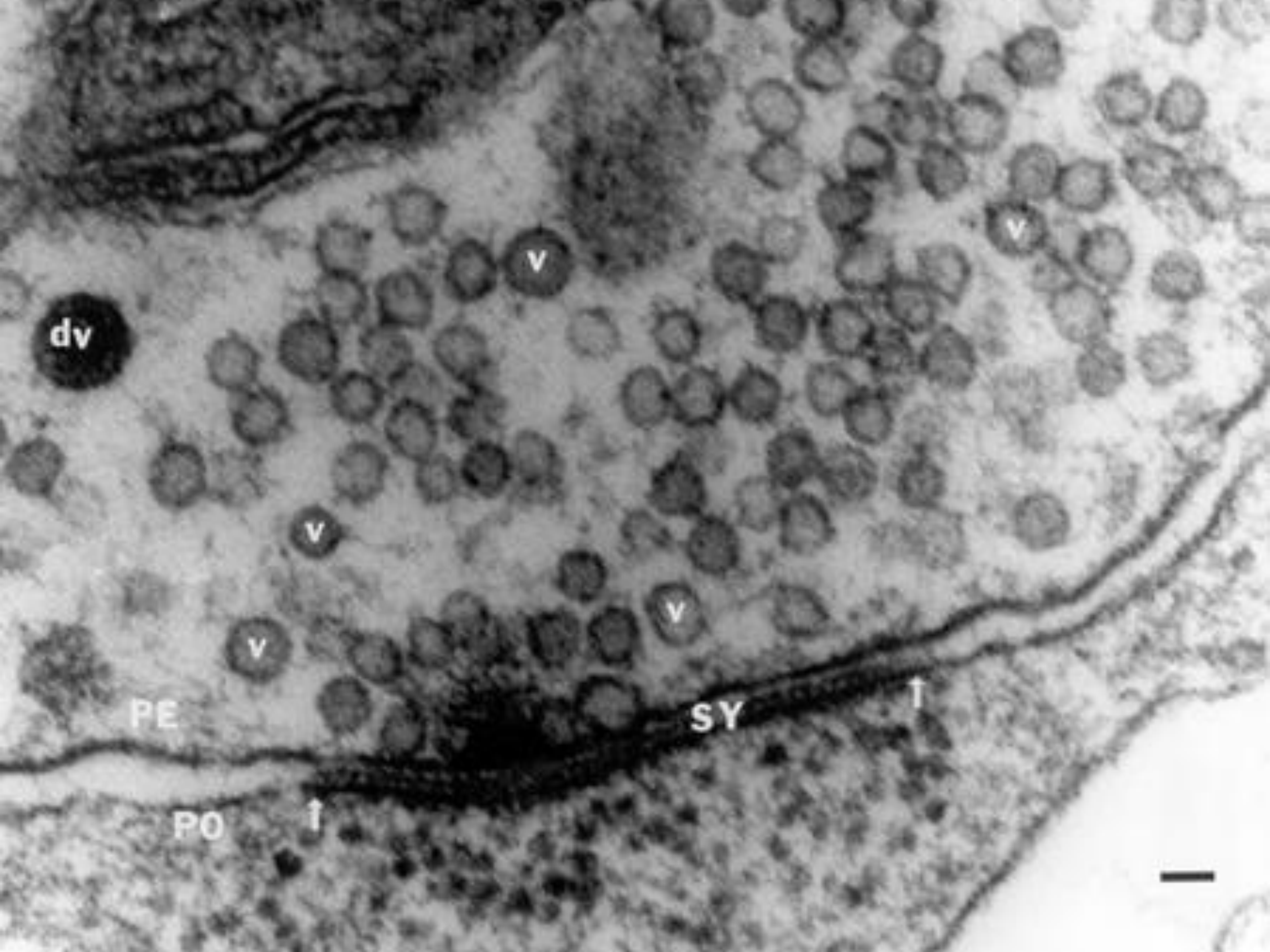
Sherman, R. G., & Atwood, H. L. Synaptic facilitation: Long term neuromuscular facilitation in crustaceans. Science. 171, 1248 - 1250 (1971).

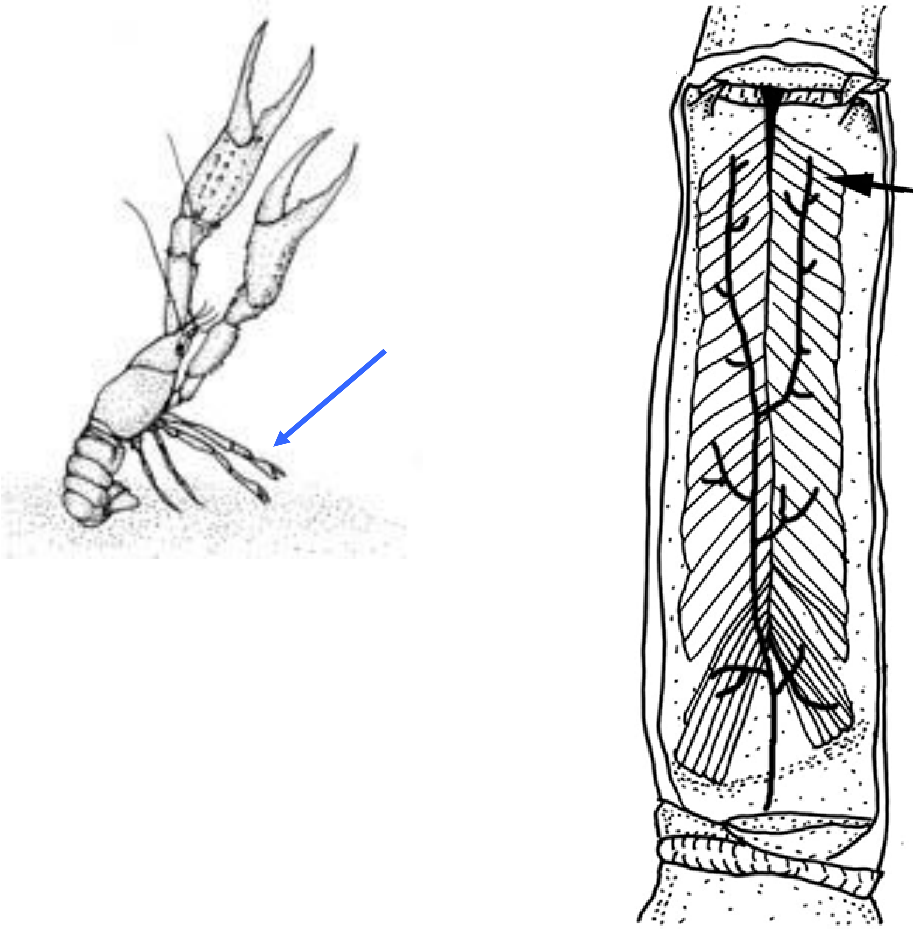
Bliss, T.V.P. & Lomo, T. Long-lasting potentiation of synaptic transmission in the dentate area of the anaesthetized rabbit following stimulation of the perforant path. J. Physiol. 232, 357 - 374 (1973).

Figure 5.9 Local recycling of synaptic ve t



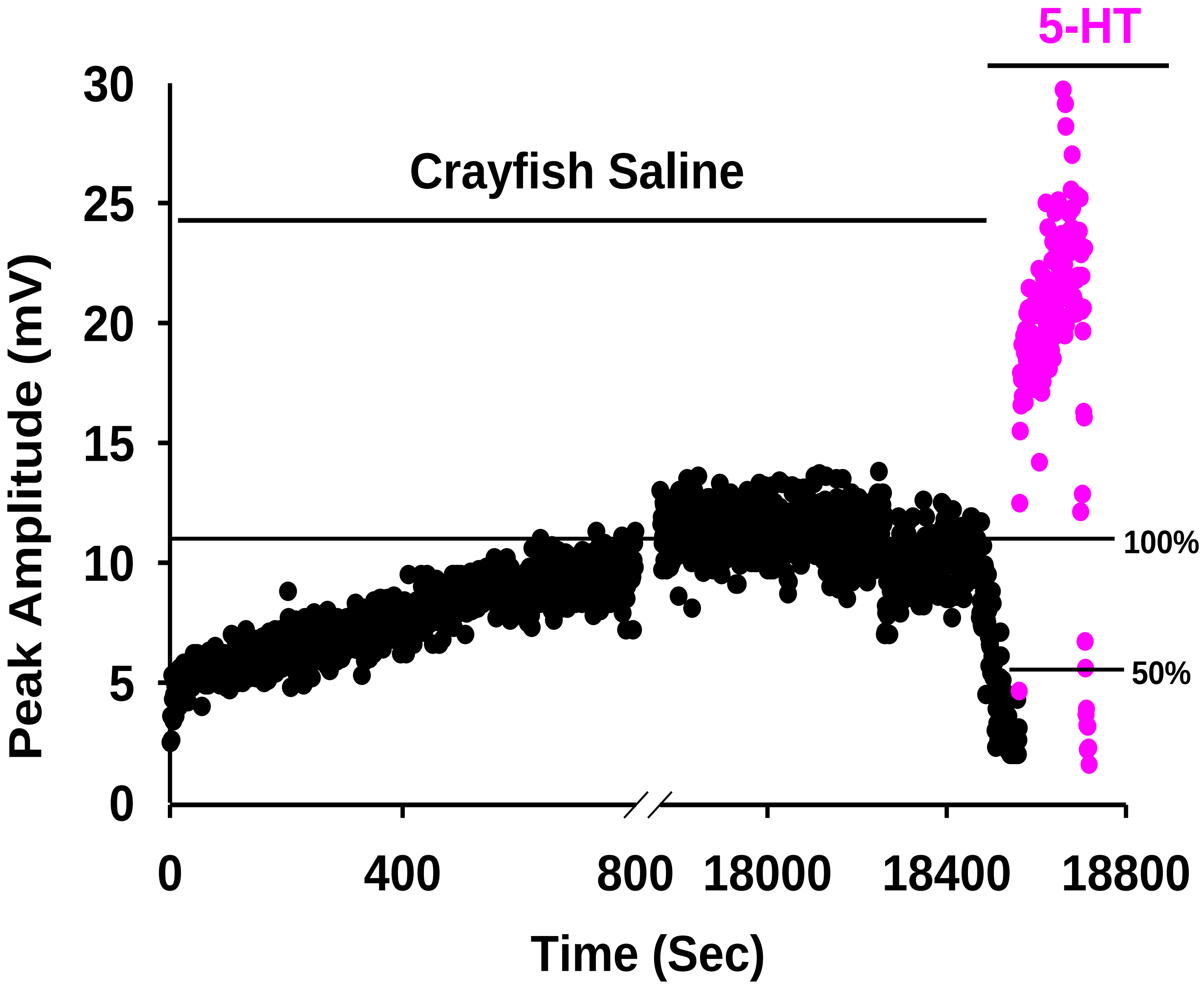
***NEUROSCIENCE 5e,* Figure 5.9 (Part 2)**


v
v
dv
v
v
v
PE
SY
PO



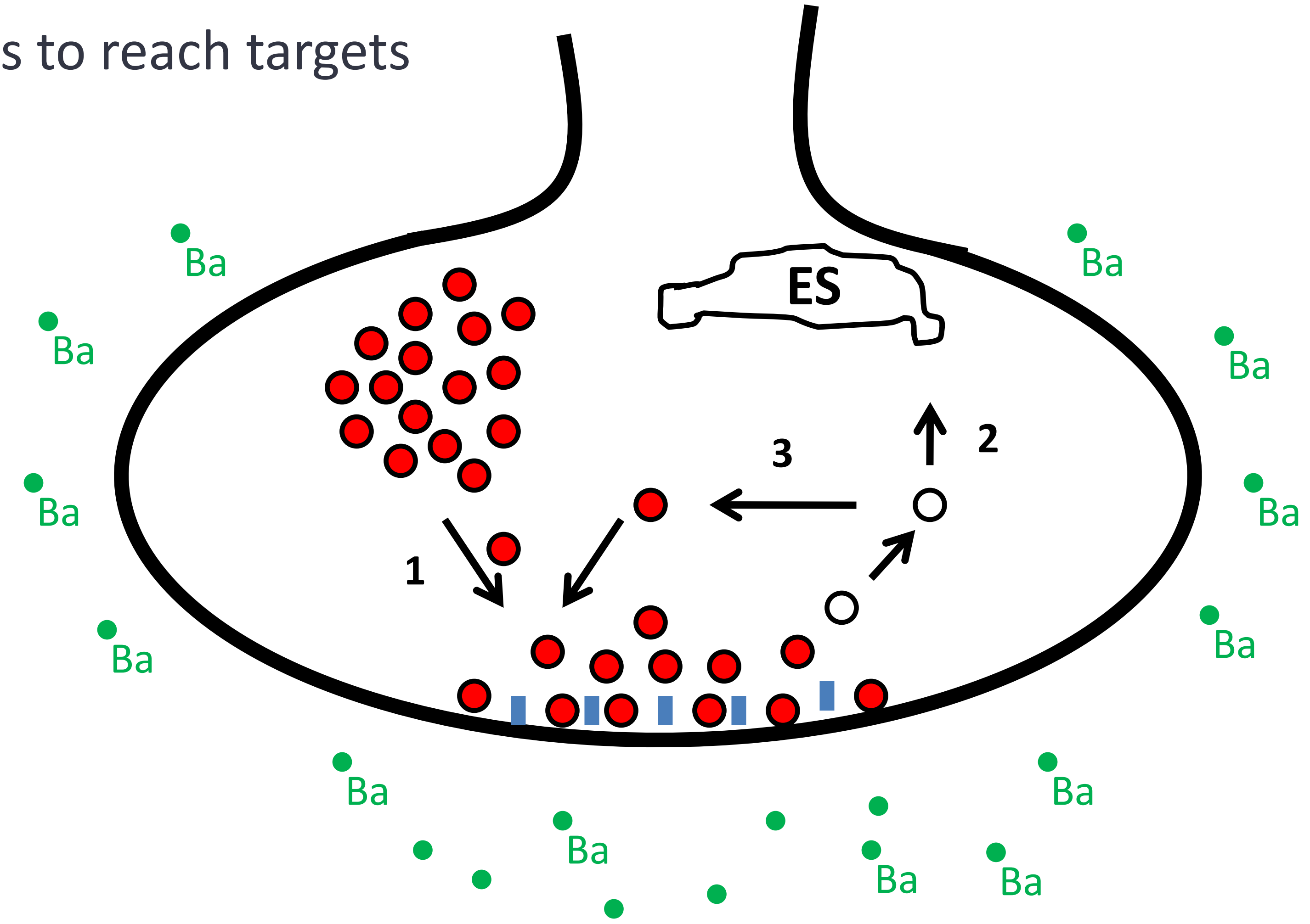
The schematic of the opener muscle in the crayfish walking leg in which the distal muscle fibers were recorded with an intracellular electrode.

40 Hz induced depression, but rejuvenated with 5-HT.
Depression is not due to a lack in vesicles.

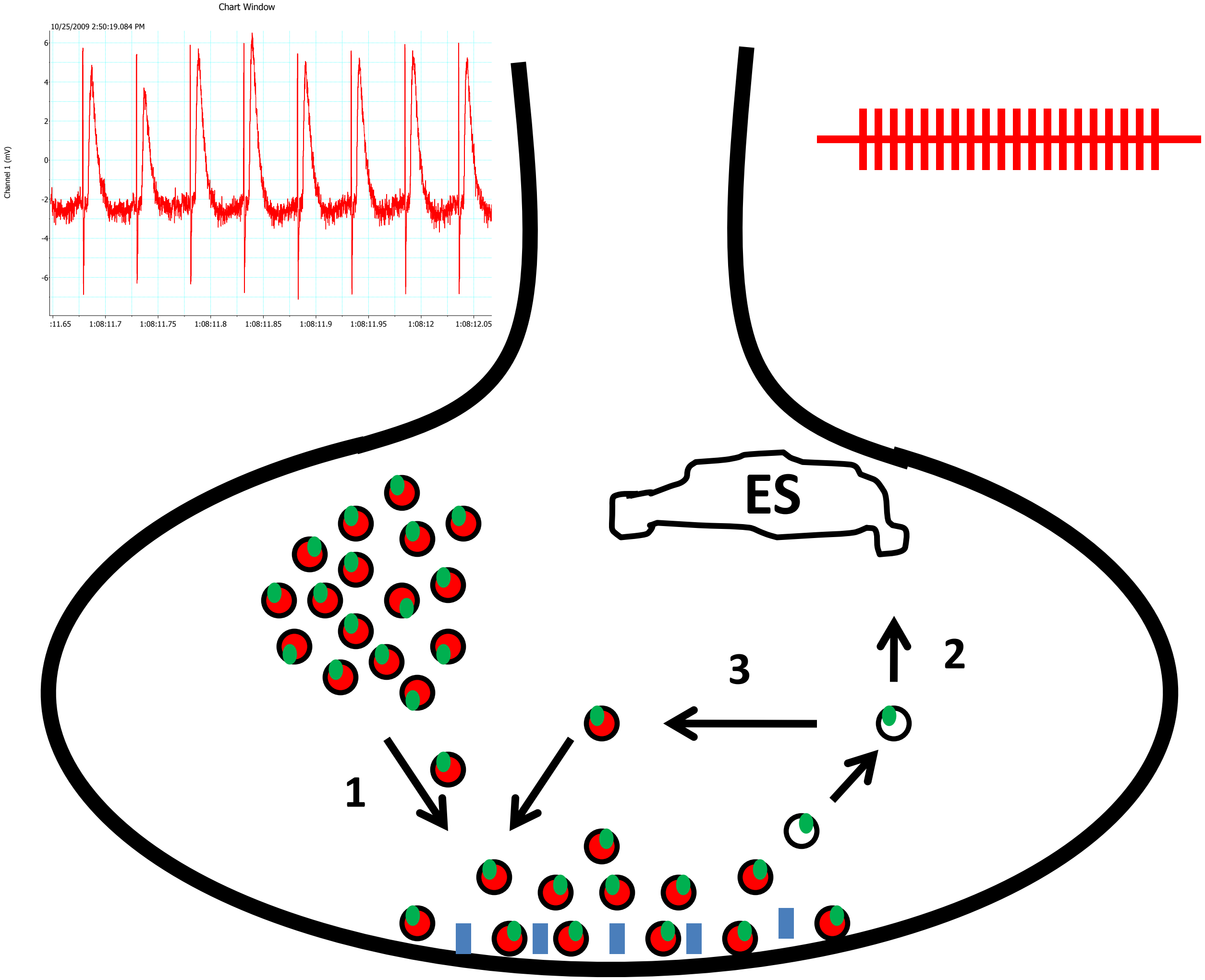


Working Model

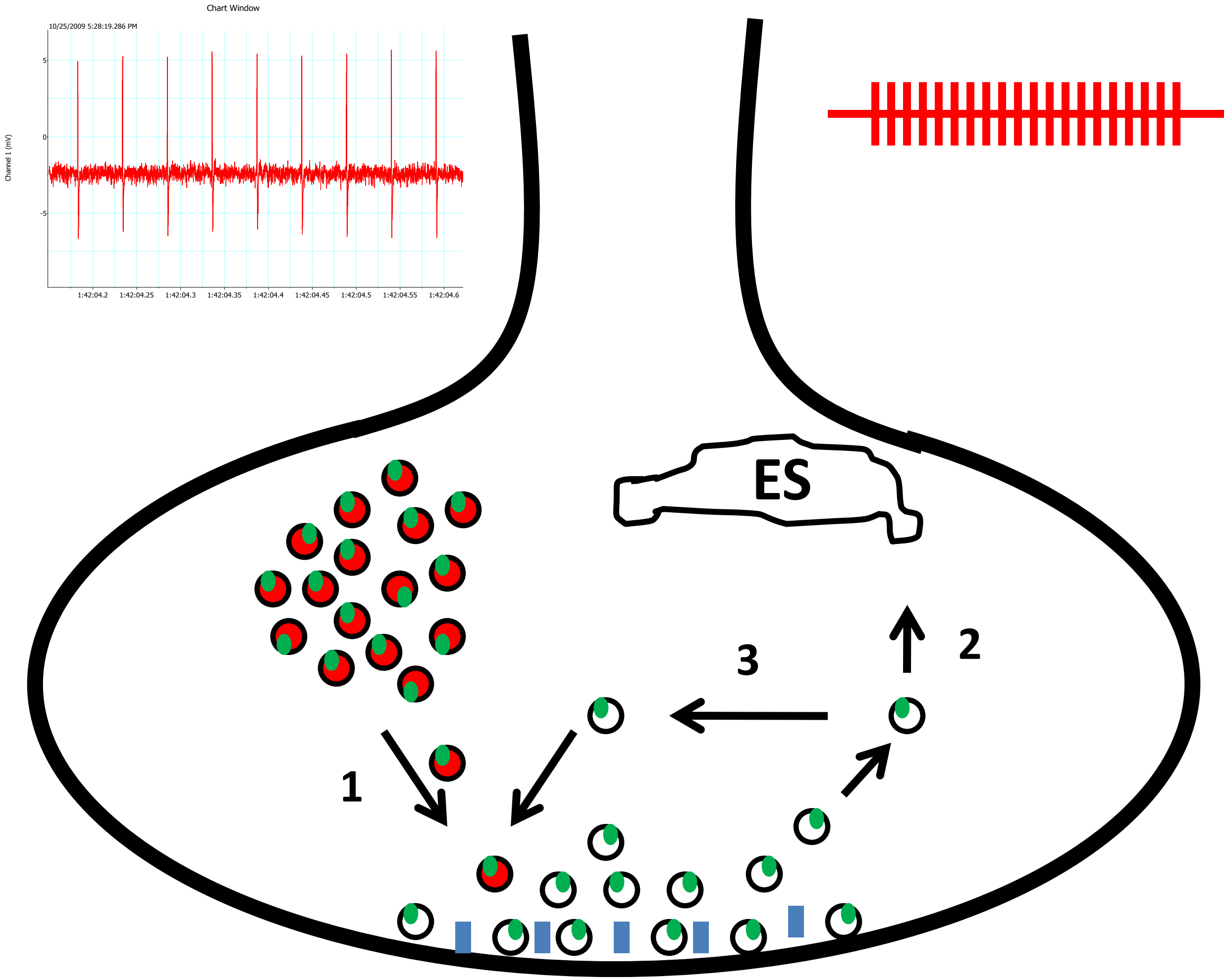
Two ways to reach targets



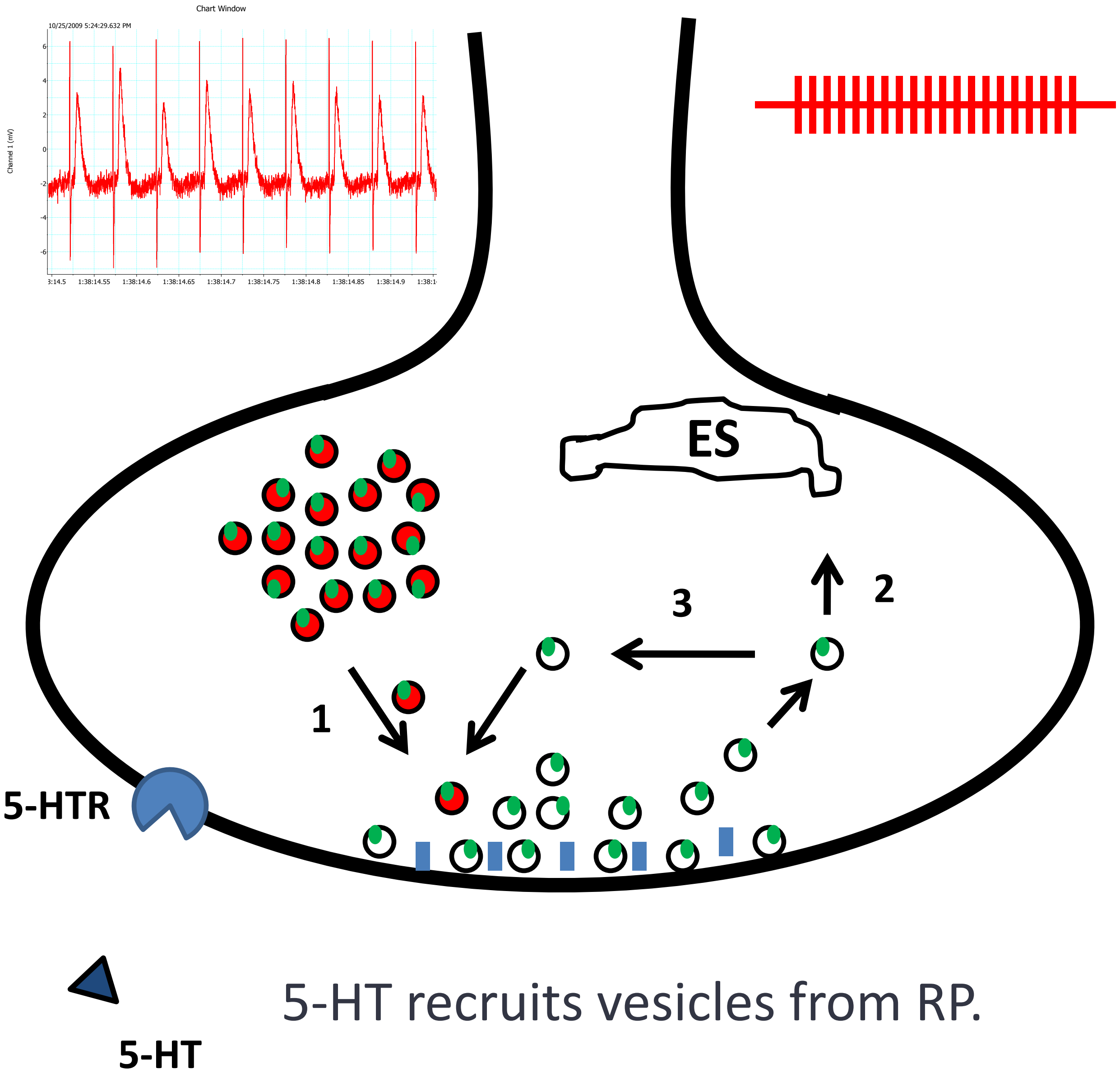
High Frequency



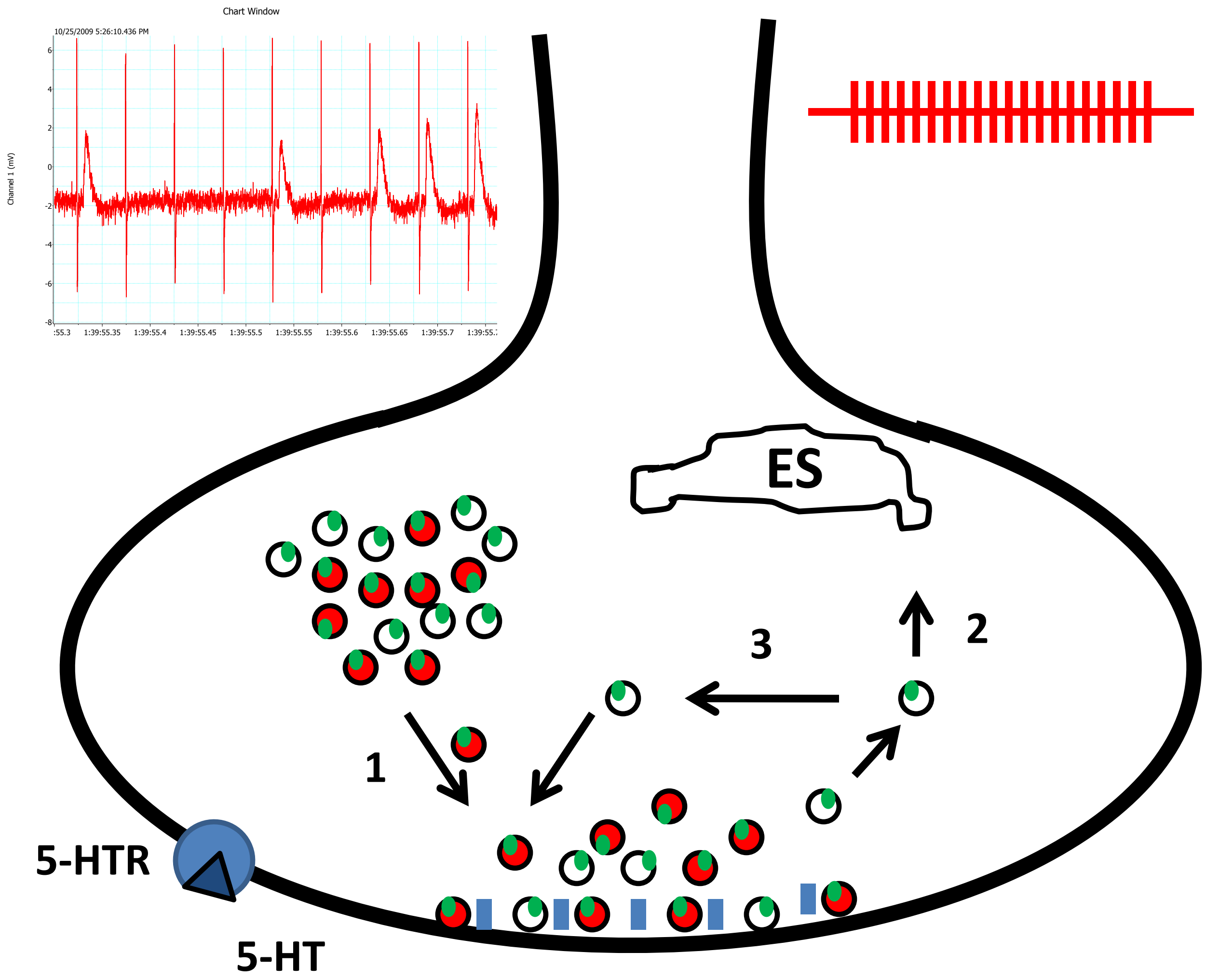
Recycled vesicles can not be refilled again.



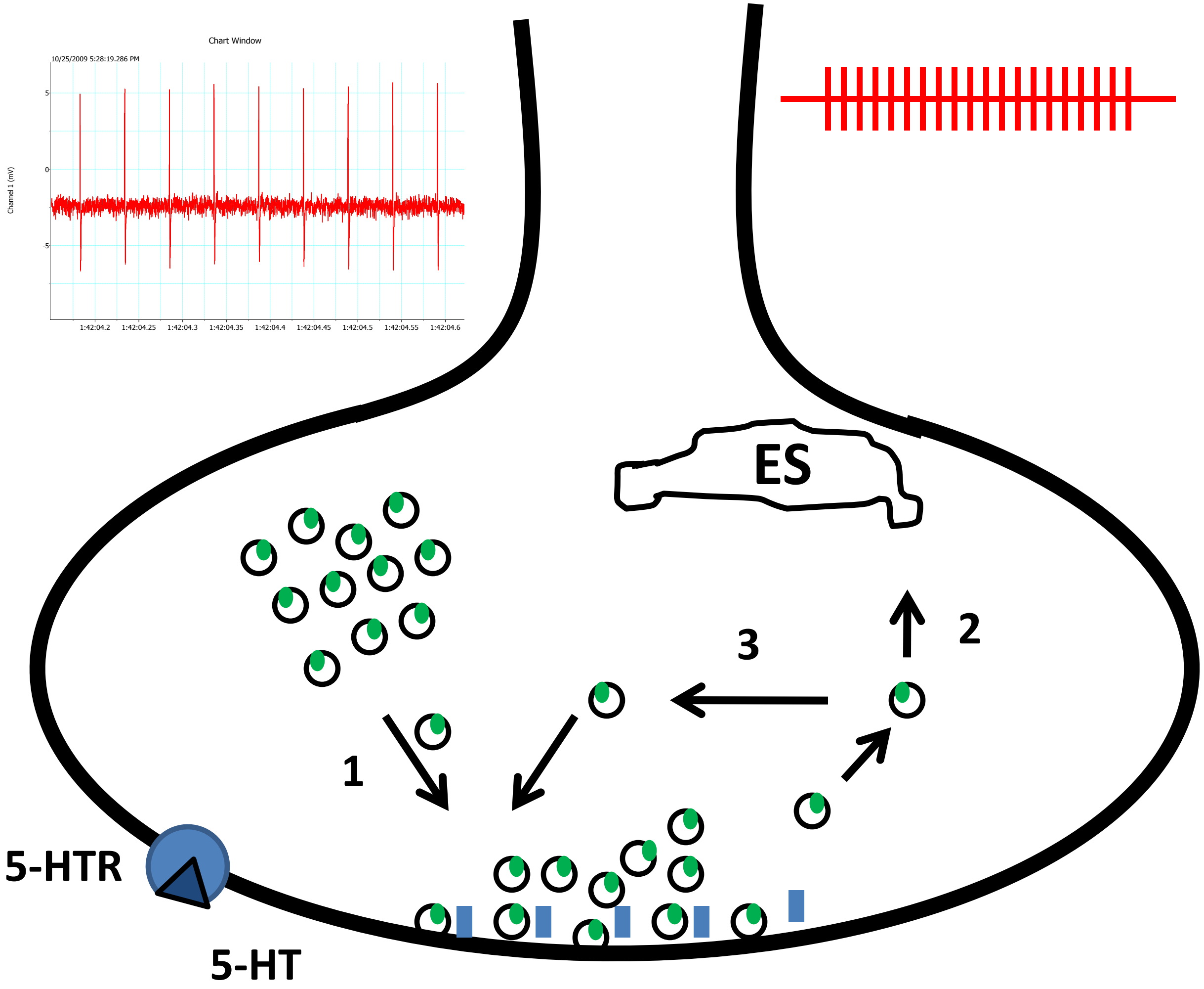
Vesicles in RRP are empty.



5-HT recruits vesicles from RP.

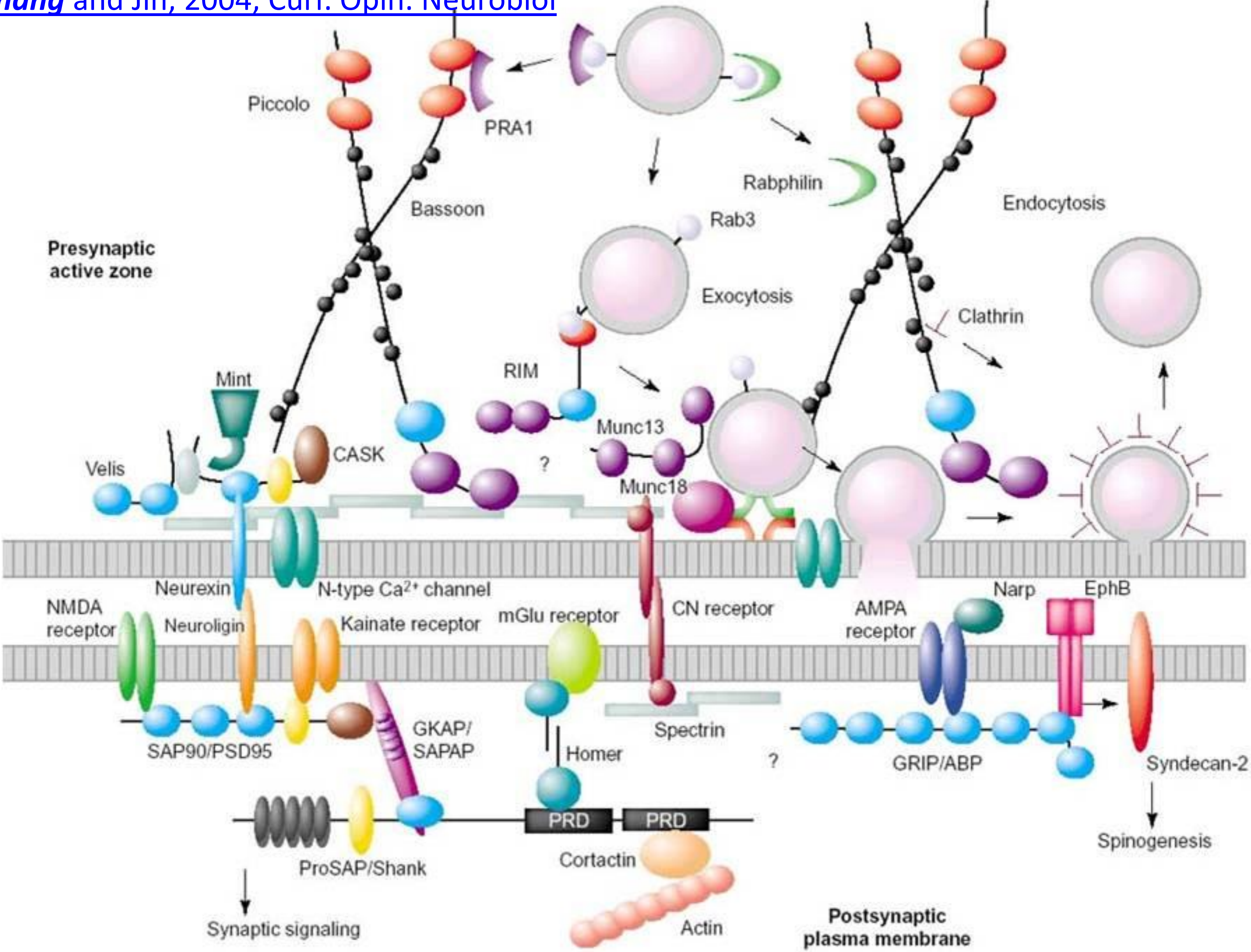


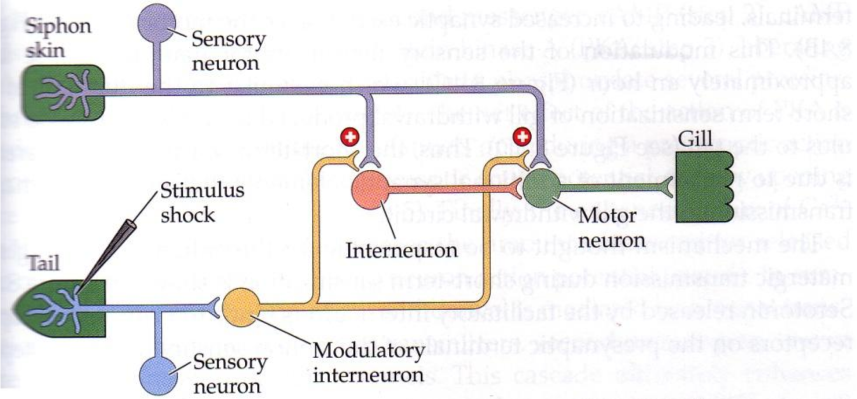
Fully packed vesicles in RP are decreased.

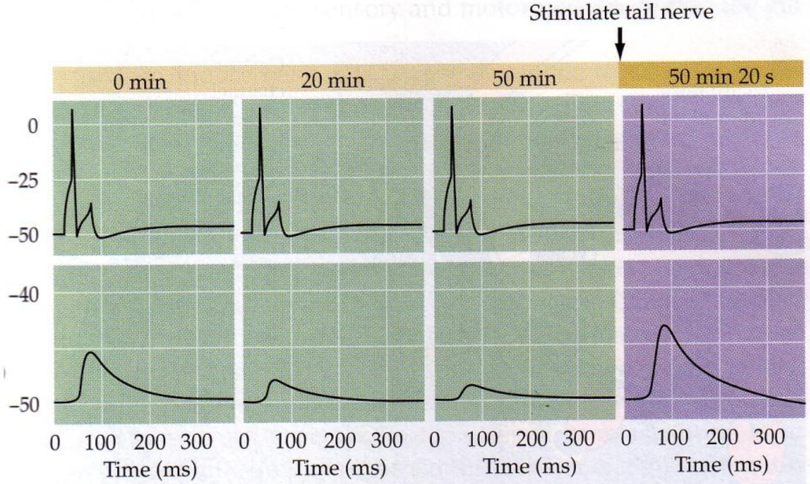


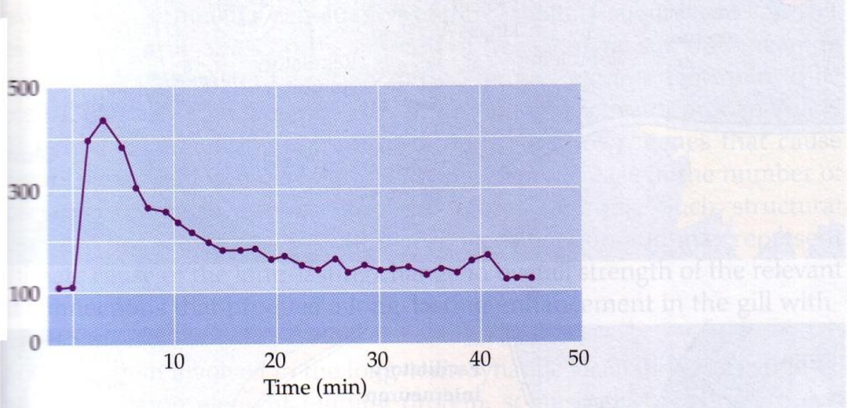
Vesicles in both RP and RRP are empty.

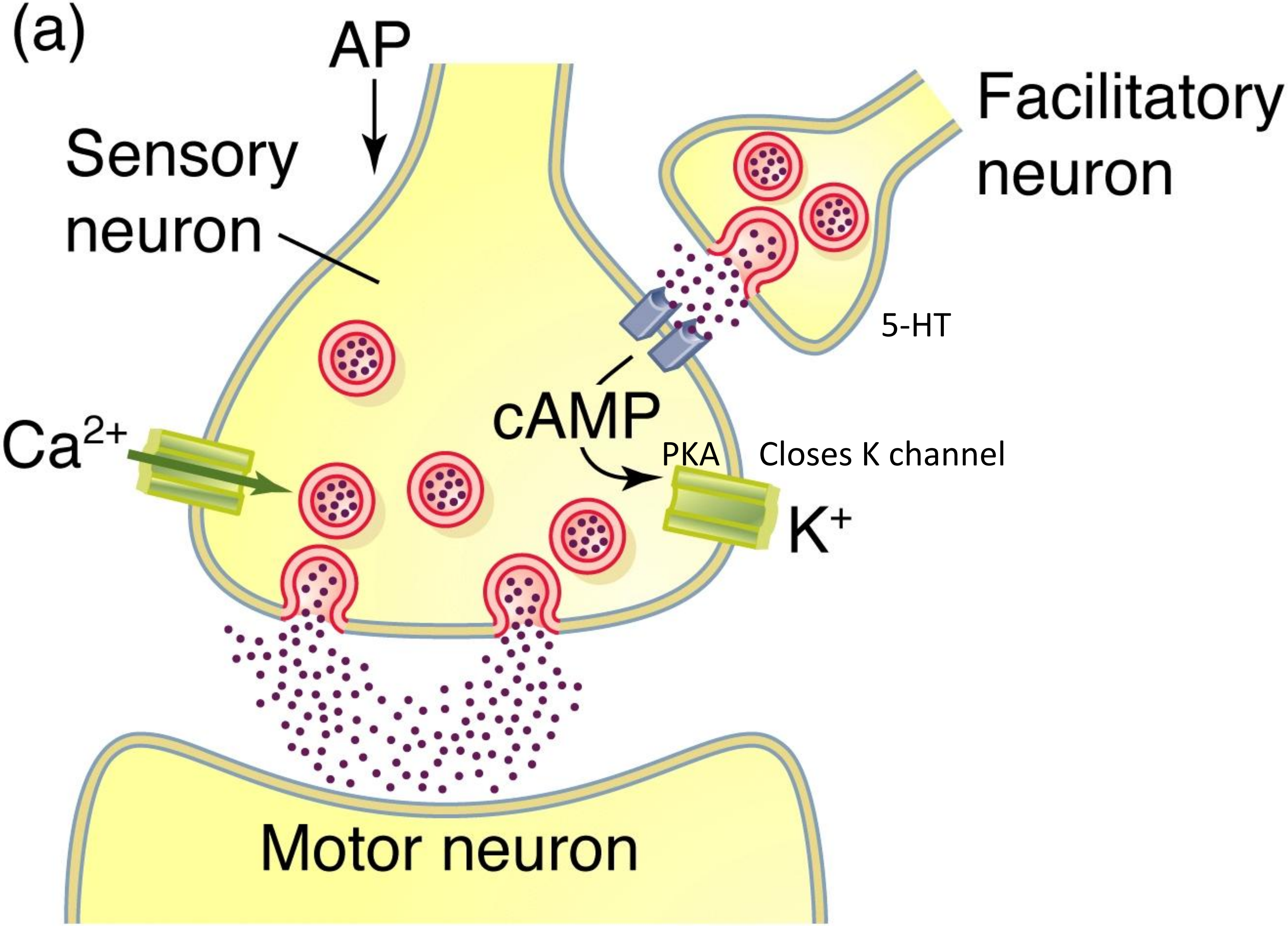
Zhang **and Jin, 2004, Curr. Opin. Neurobiol**

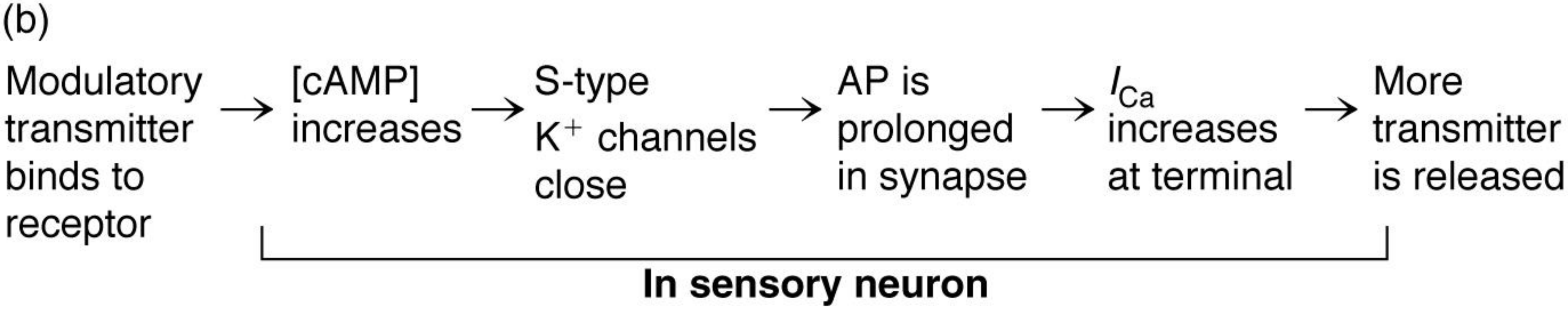



Siphon skin
Sensory neuron
Gill
Stimulus shock
Interneuron
Motor neuron
Tail
Sensory neuron
Modulatory interneuron


Stimulate tail nerve
0 min
20 min
50 min
50 min 20 s
0
–25
–50
–40
–50
0 100 200 300
Time (ms)
0 100 200 300
Time (ms)
0 100 200 300
Time (ms)
0 100 200 300
Time (ms)


500
300
100
0
10
20
30
40
50
Time (min)

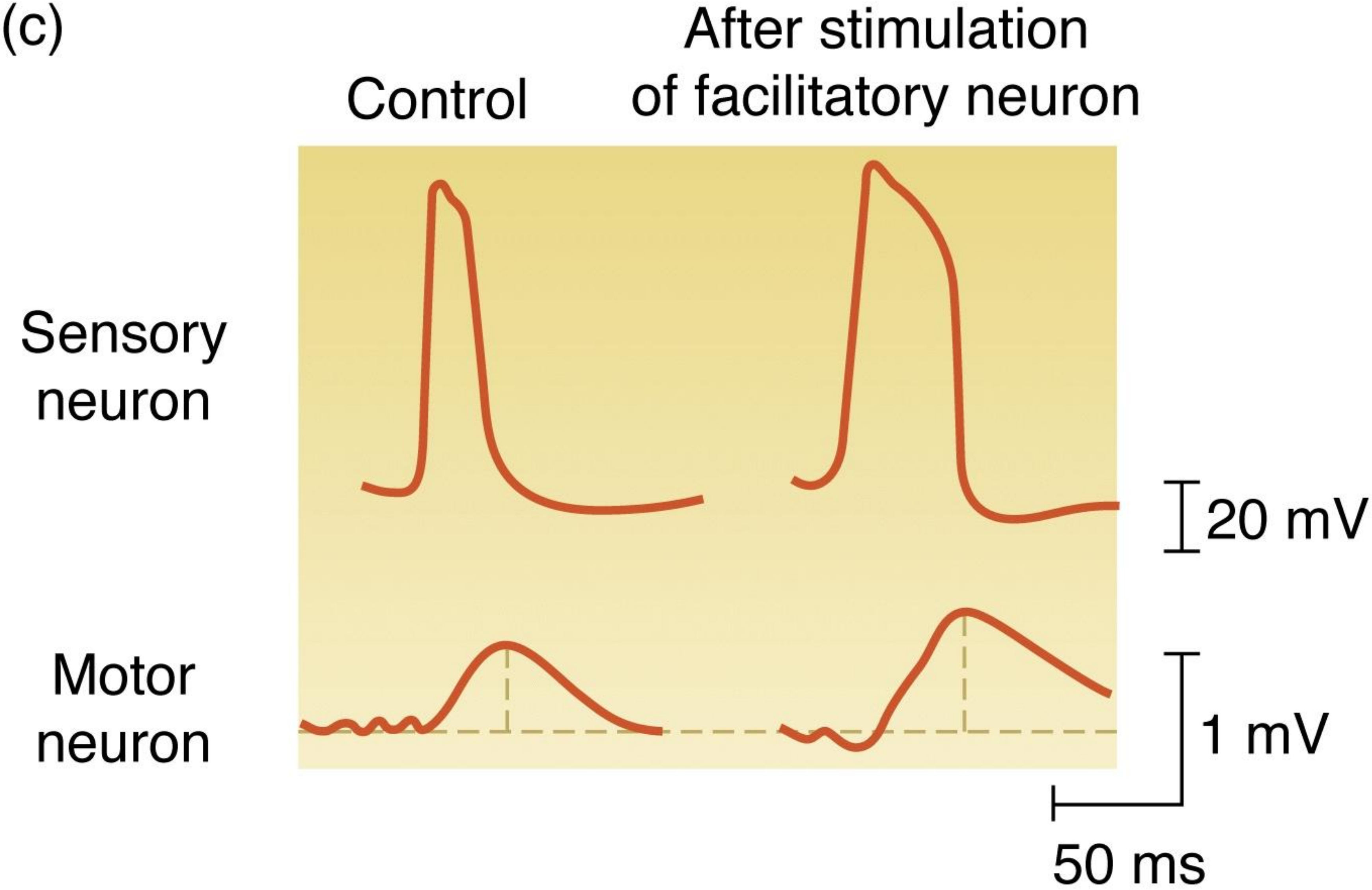

(a)
AP
Sensory neuron
Facilitatory neuron
5-HT
cAMP
PKA
Closes K channel
Ca^{2+}
K^+
Motor neuron

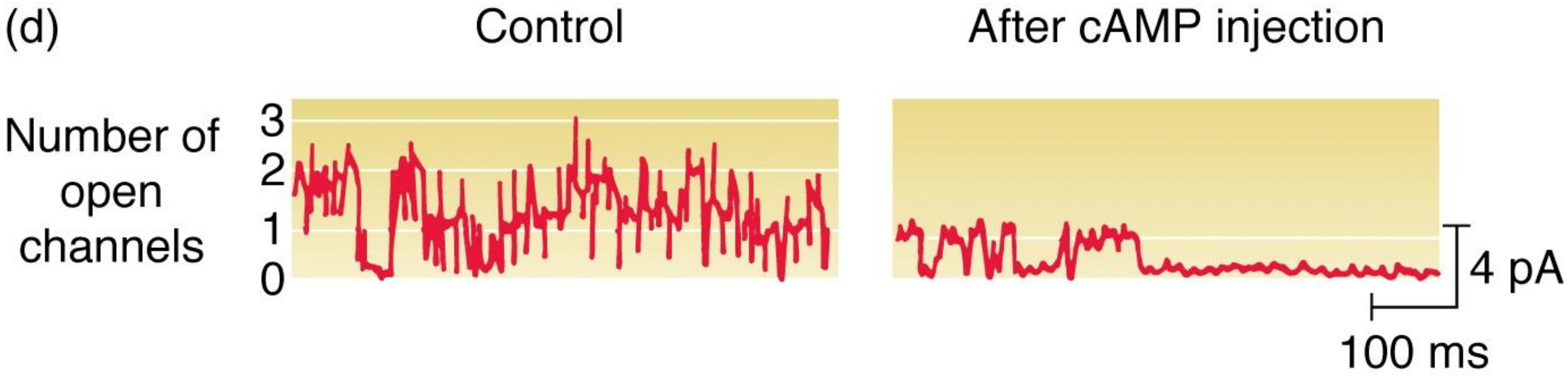


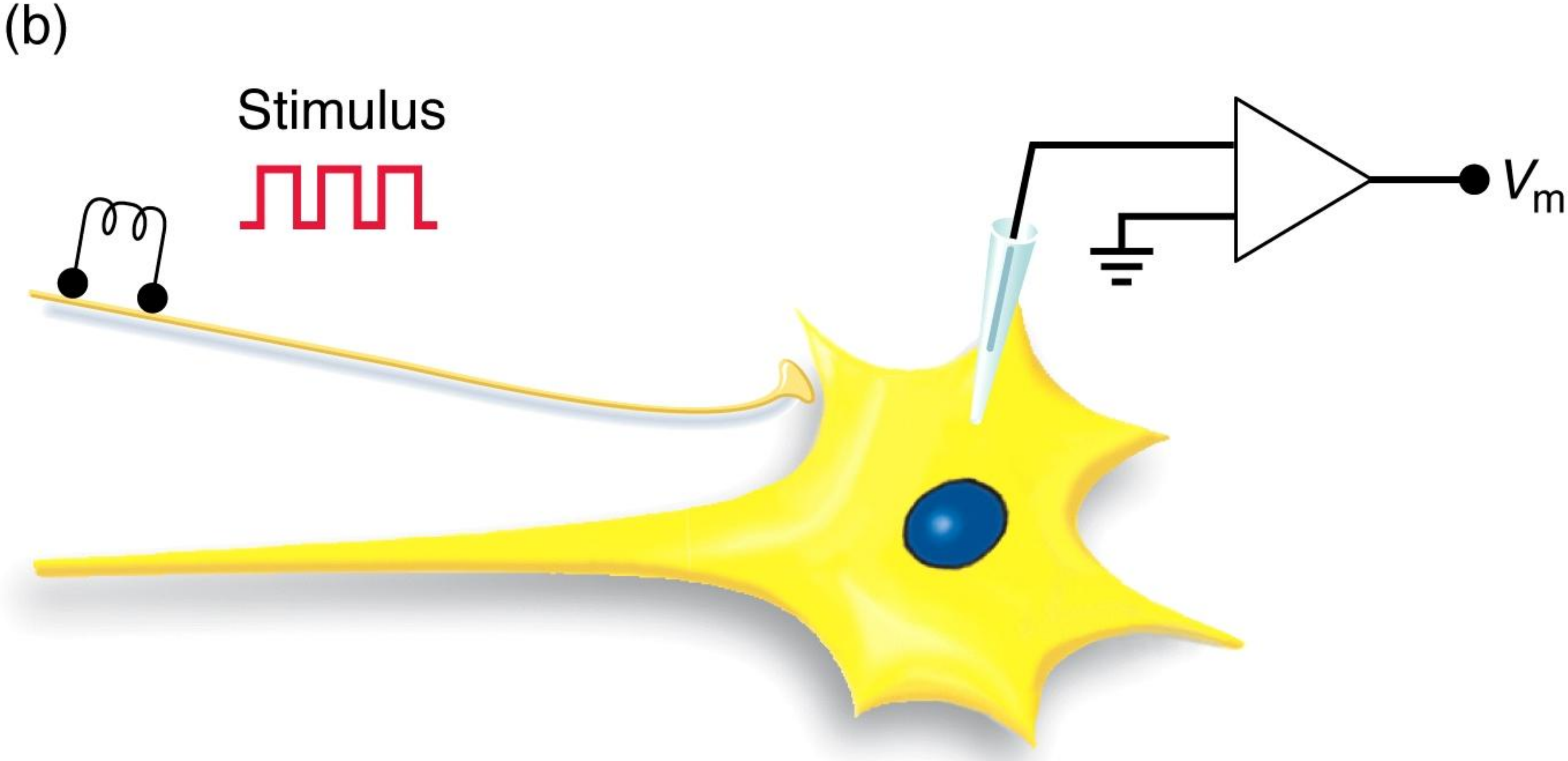
(b)

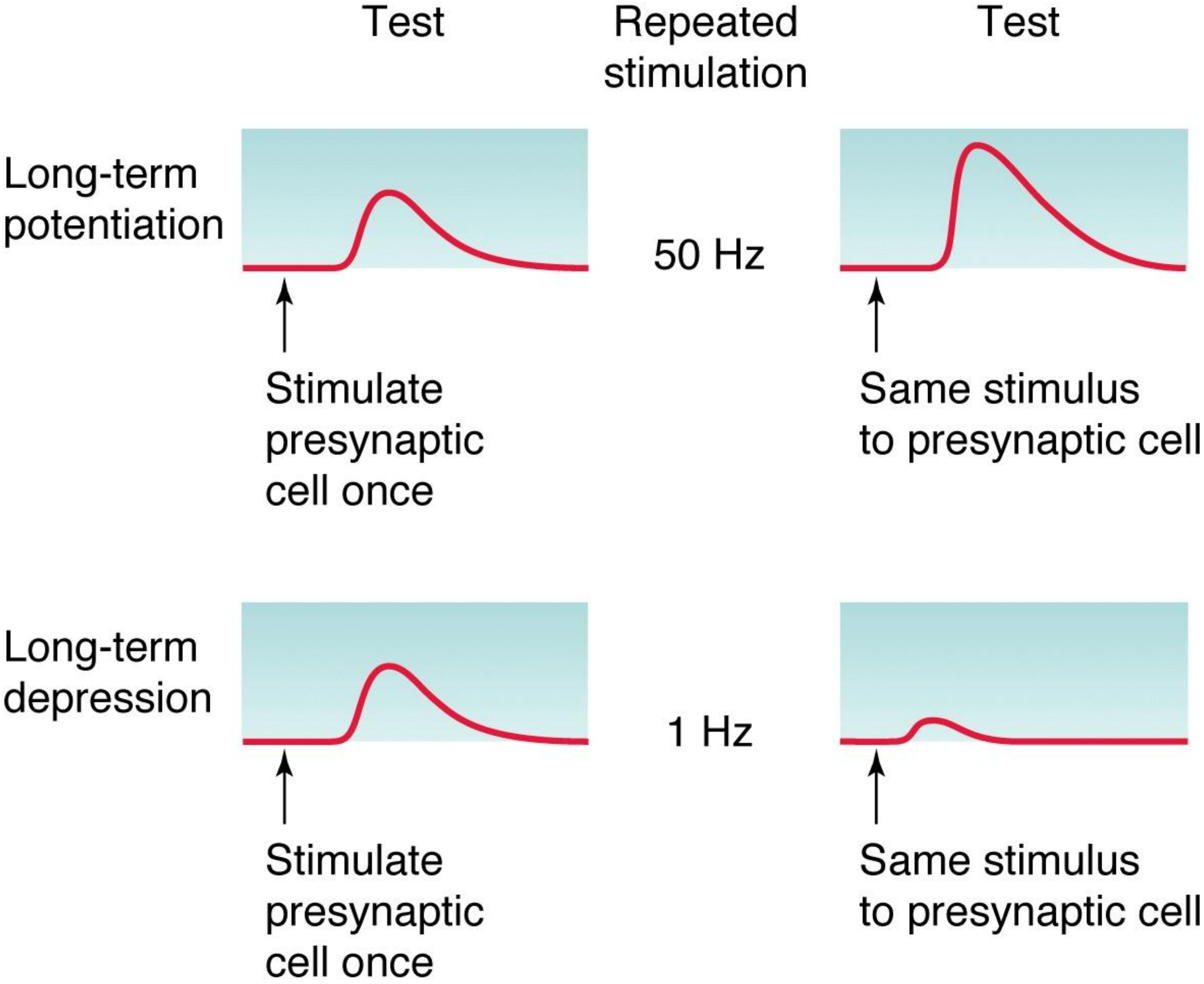
Modulatory transmitter binds to receptor → [cAMP] increases → S-type K^+ channels close → AP is prolonged in synapse → I_{Ca} increases at terminal → More transmitter is released

In sensory neuron


(c)
Control
After stimulation of facilitatory neuron
Sensory neuron
Motor neuron
20 mV
1 mV
50 ms


(d)
Control
After cAMP injection
Number of open channels
3
2
1
0
4 pA
100 ms


(b)
Stimulus
V_m



Test

Repeated stimulation

Test

Long-term potentiation

50 Hz

Stimulate presynaptic cell once

Same stimulus to presynaptic cell

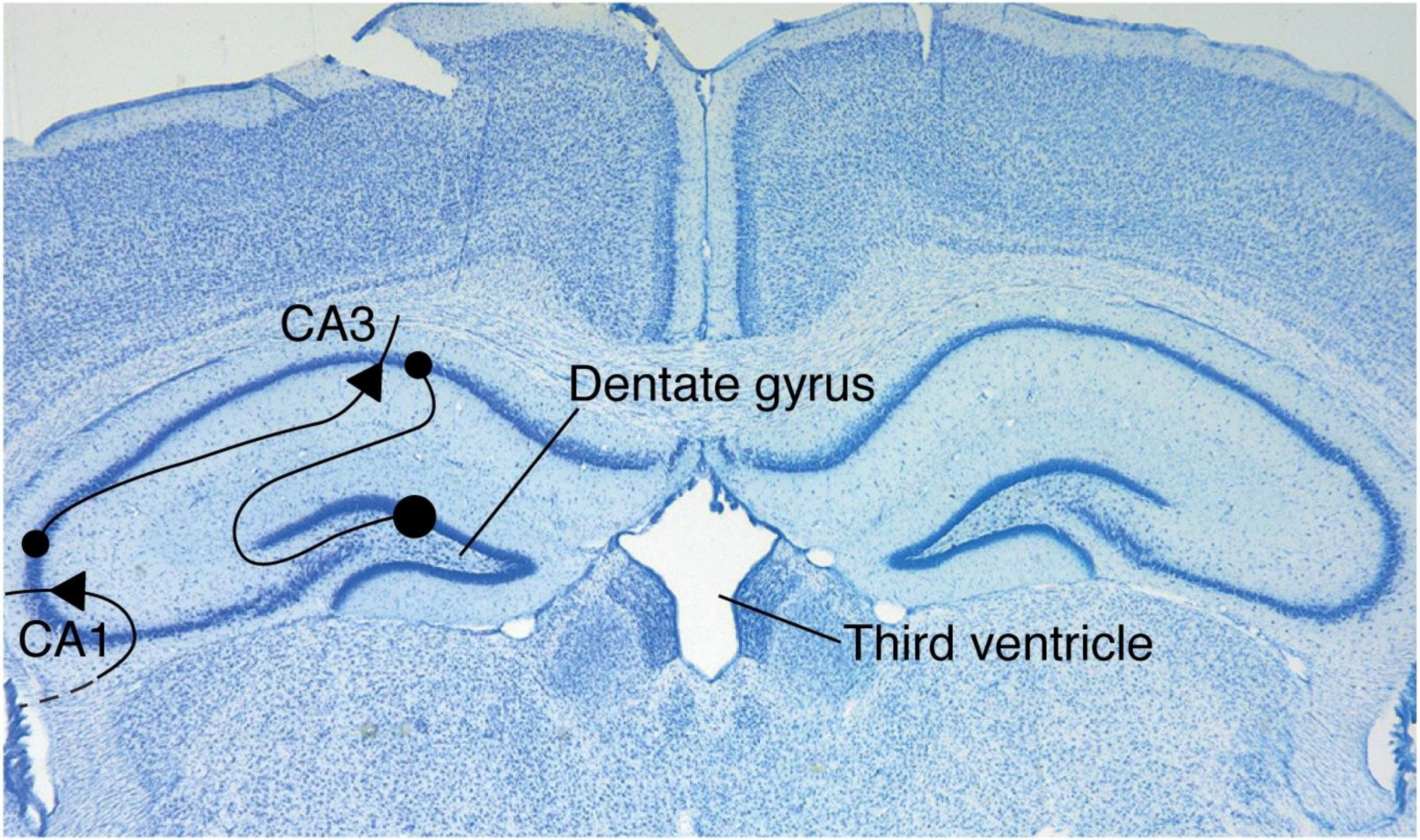
Long-term depression

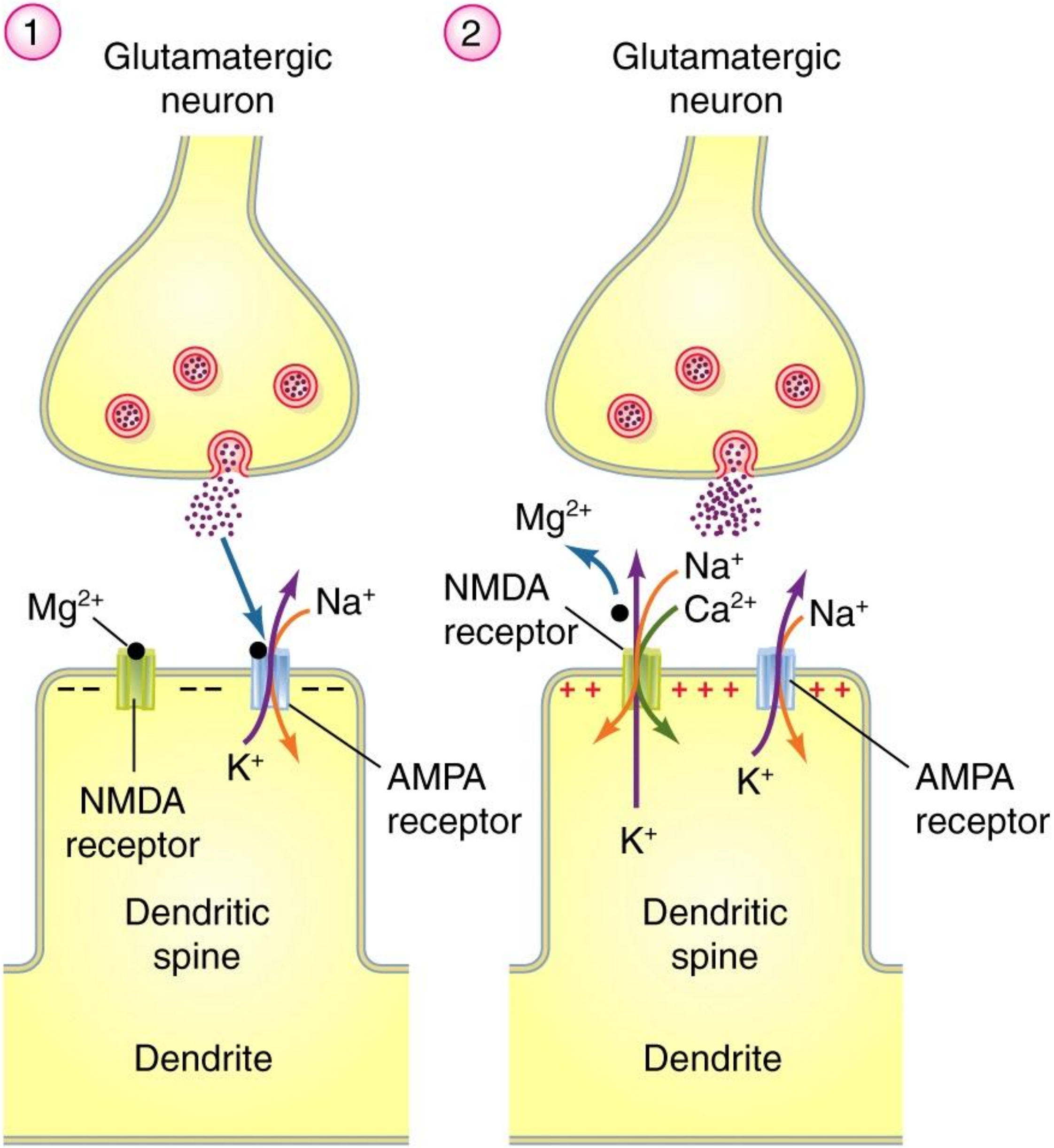
1 Hz

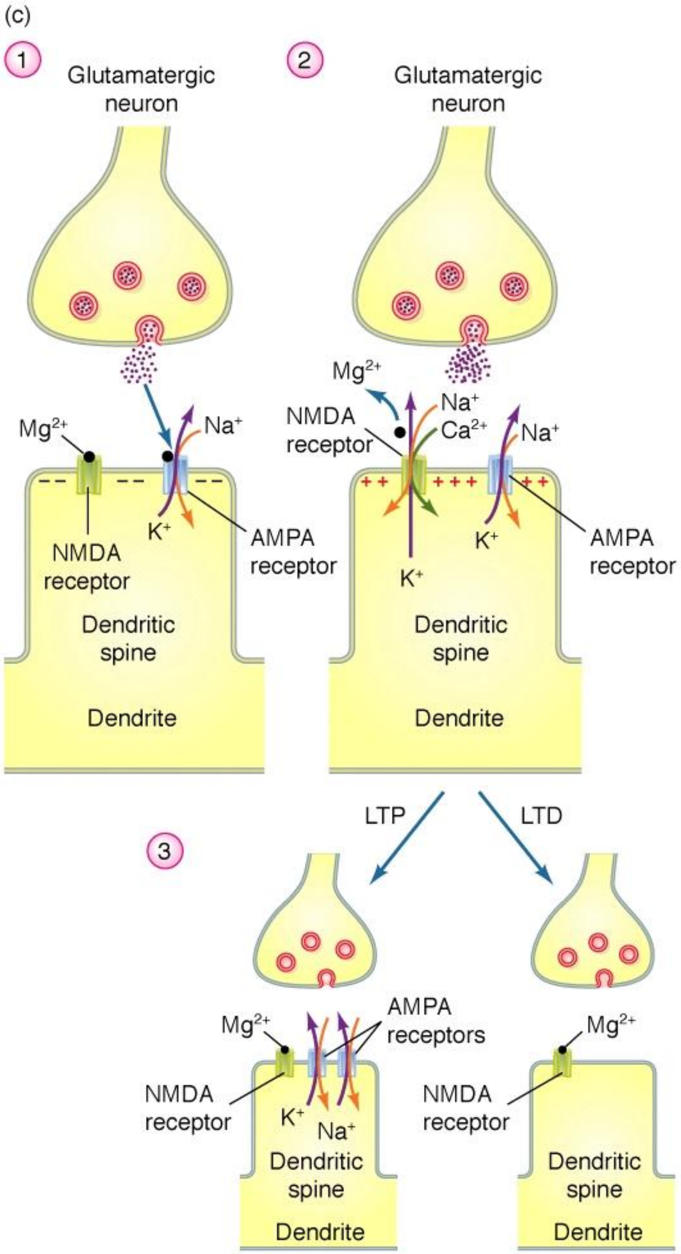
Stimulate presynaptic cell once

Same stimulus to presynaptic cell

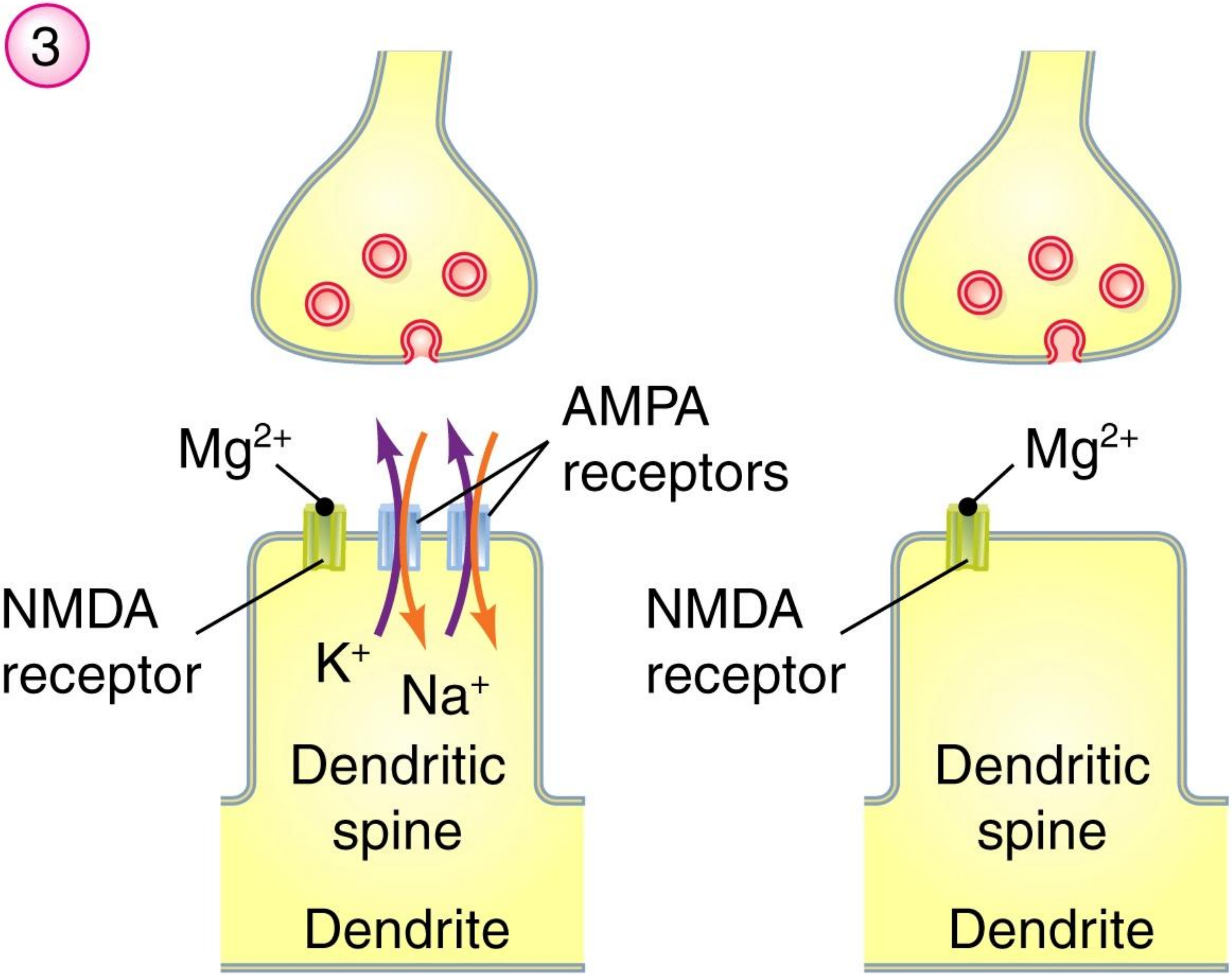
(a)

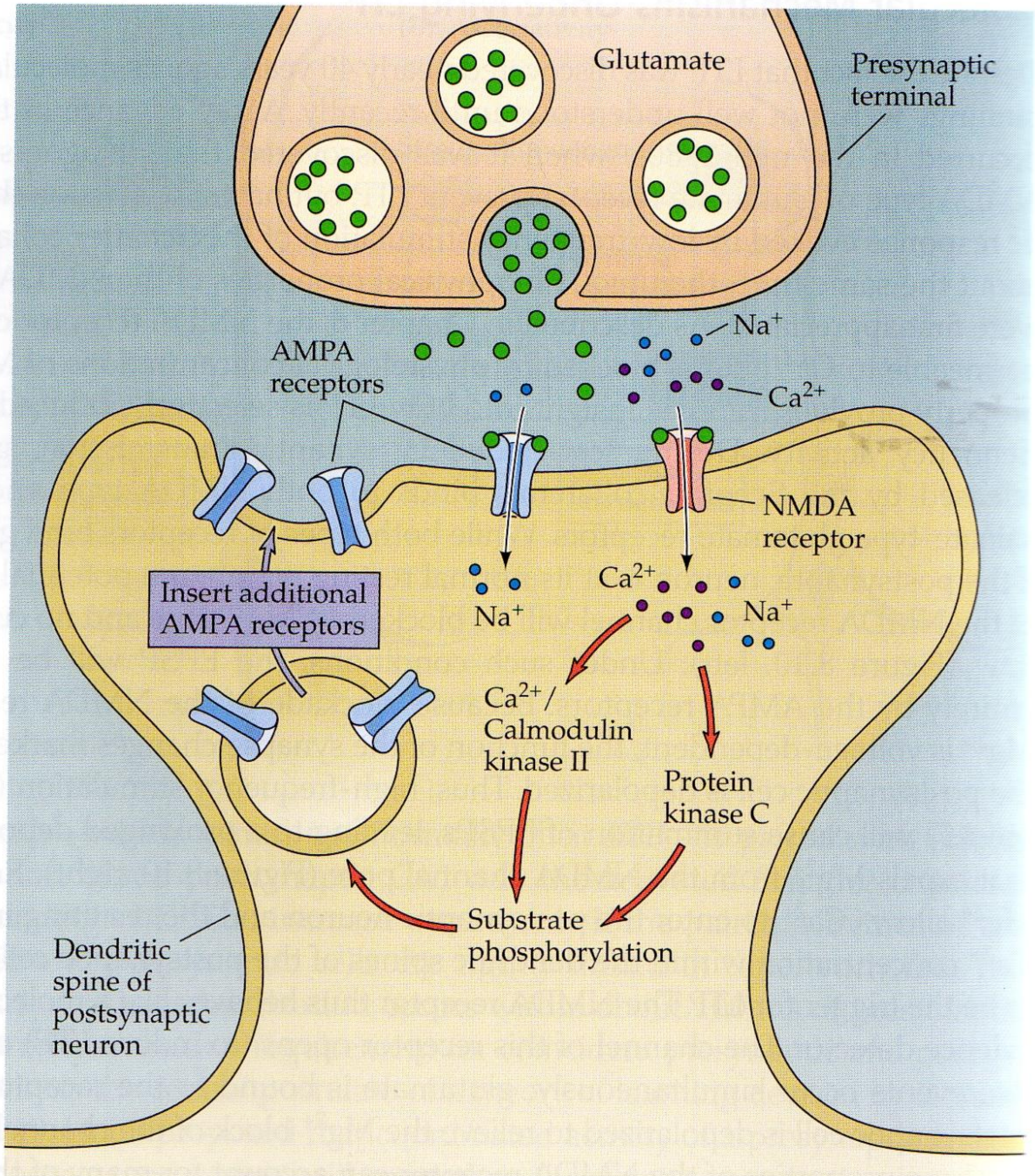


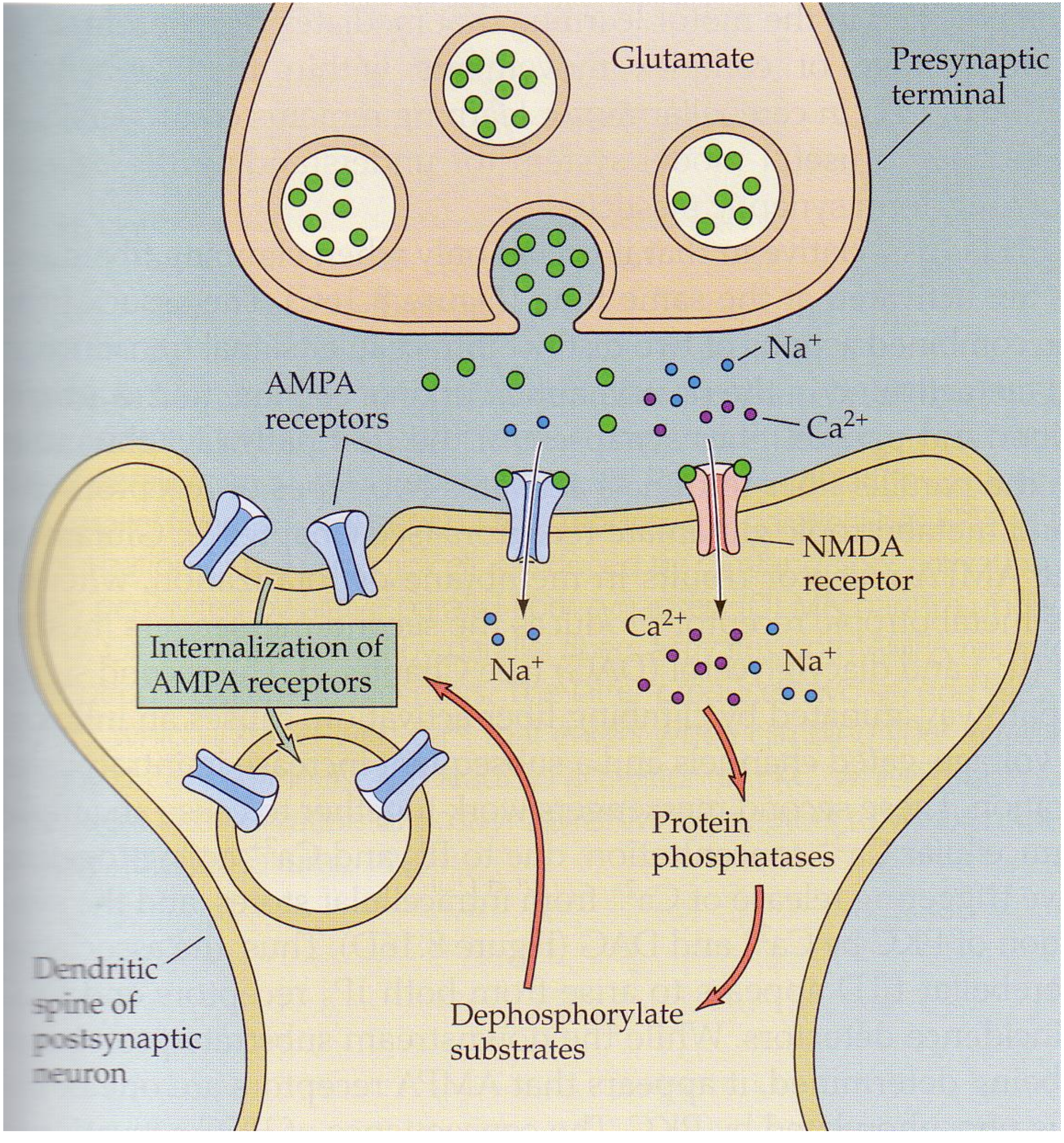
1
Glutamatergic neuron
Mg2+
Na+
K+
NMDA receptor
AMPA receptor
Dendritic spine
Dendrite
2
Glutamatergic neuron
Mg2+
NMDA receptor
Na+
Ca2+
Na+
K+
K+
AMPA receptor
Dendritic spine
Dendrite

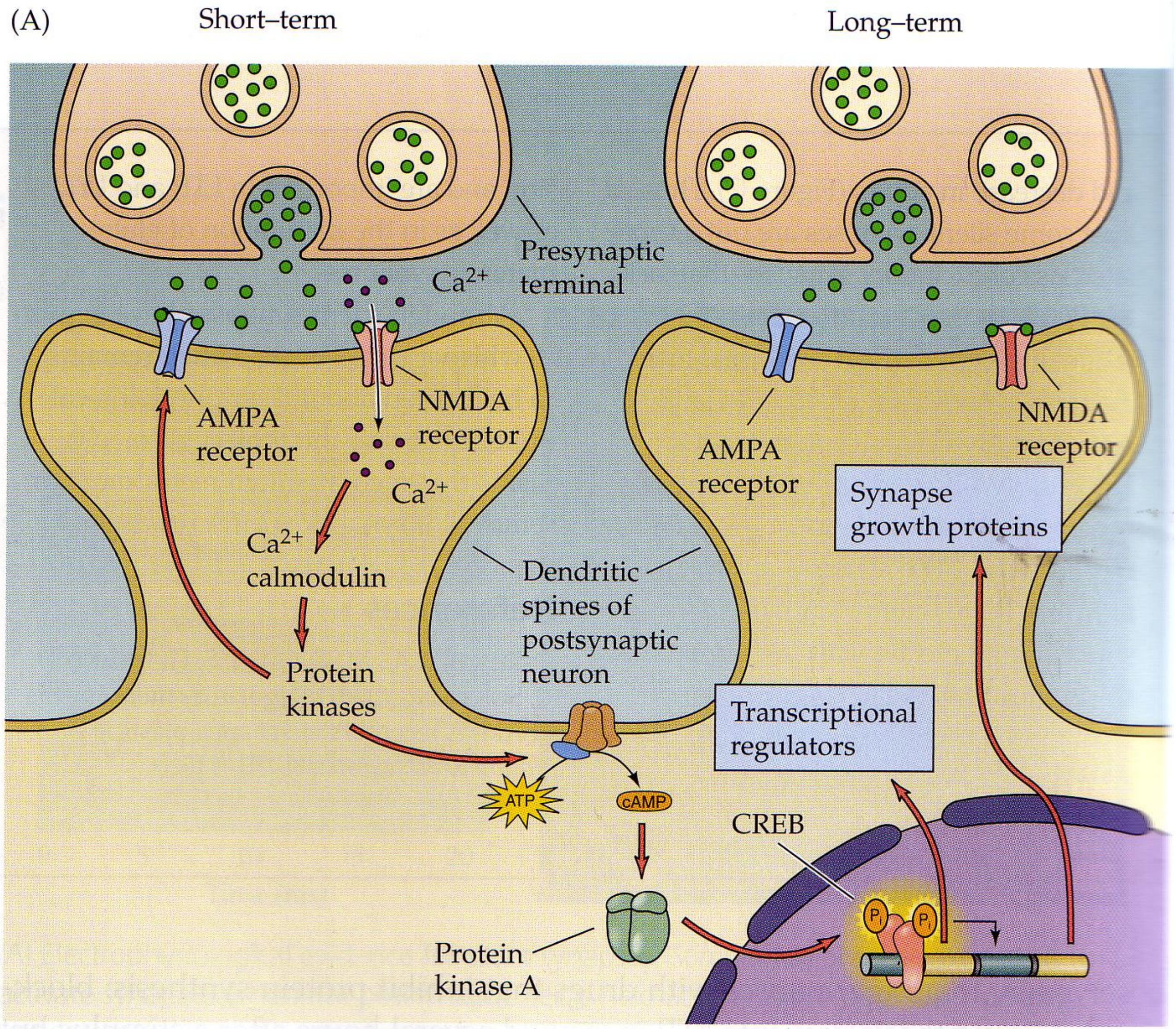


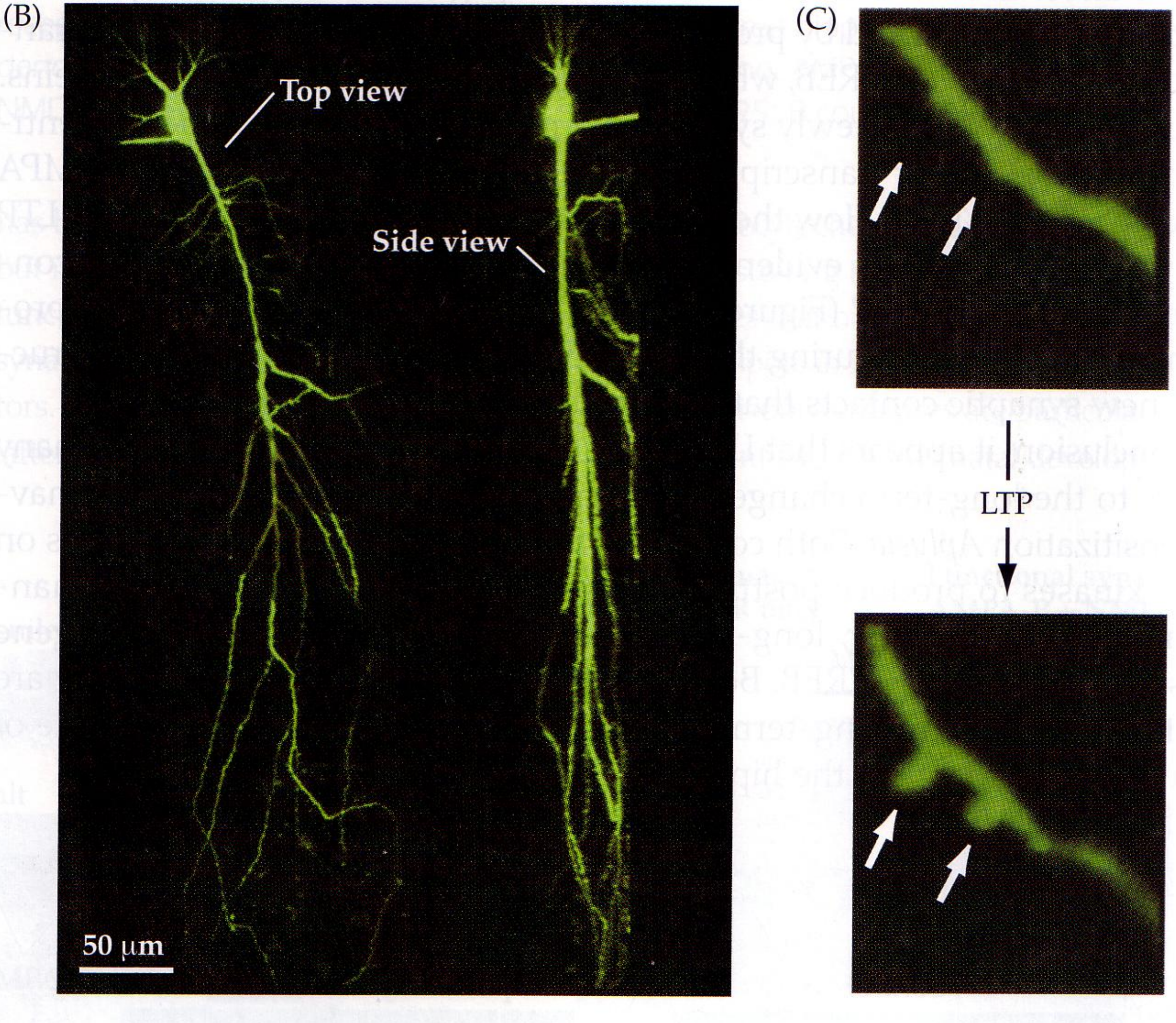
(c)
①
Glutamatergic neuron
Mg^{2+}
Na$^+$
NMDA receptor
K$^+$
AMPA receptor
Dendritic spine
Dendrite
②
Glutamatergic neuron
Mg^{2+}
NMDA receptor
Na$^+$
Ca^{2+}
Na$^+$
K$^+$
K$^+$
AMPA receptor
Dendritic spine
Dendrite
LTP
LTD
③
Mg^{2+}
AMPA receptors
NMDA receptor
K$^+$
Na$^+$
Dendritic spine
Dendrite
Mg^{2+}
NMDA receptor
Dendritic spine
Dendrite

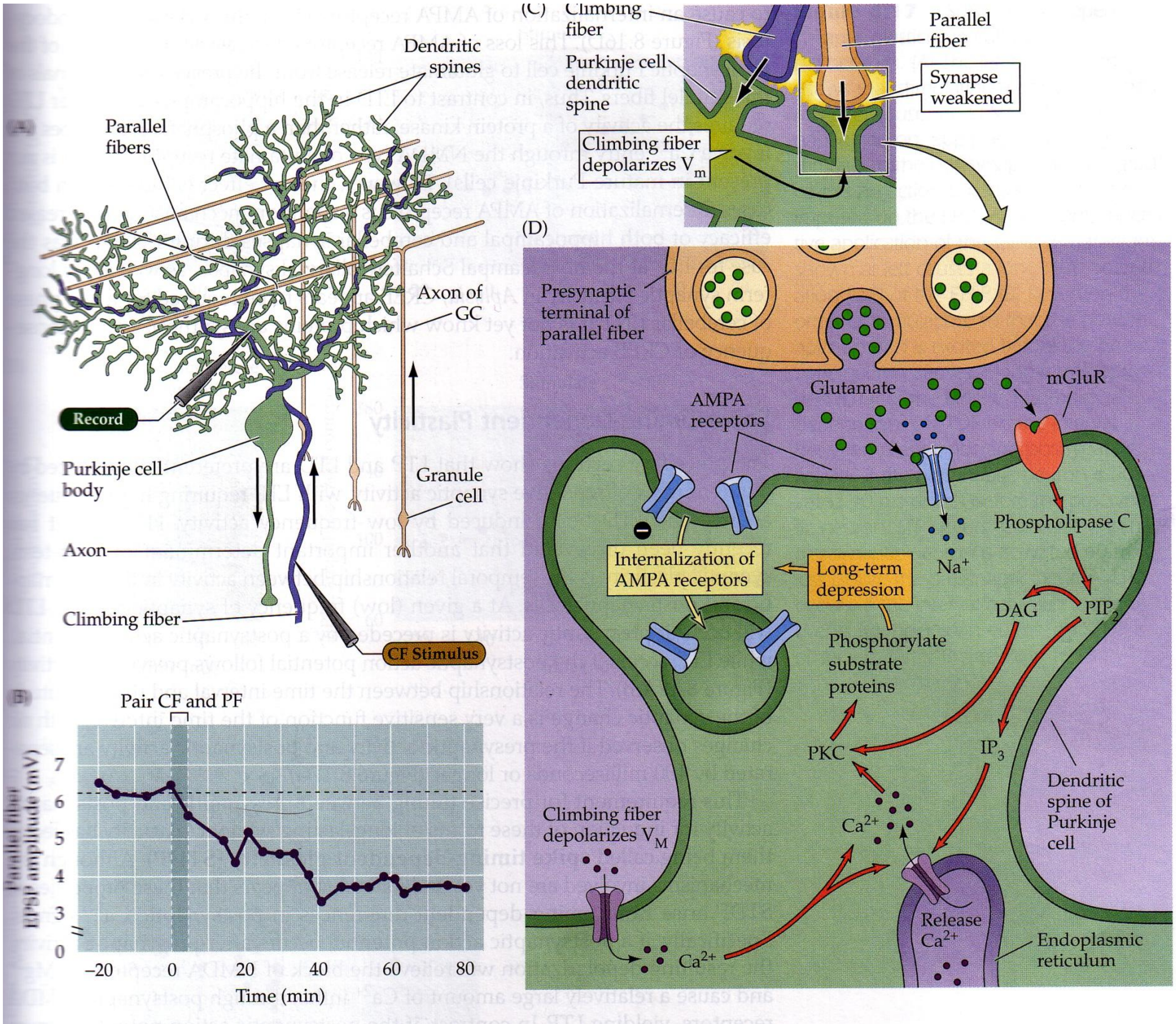
3
Mg2+
AMPA receptors
NMDA receptor
K+
Na+
Dendritic spine
Dendrite
Mg2+
NMDA receptor
Dendritic spine
Dendrite


Glutamate
Presynaptic terminal
Na+
AMPA receptors
Ca2+
NMDA receptor
Ca2+
Na+
Na+
Insert additional AMPA receptors
Ca2+/ Calmodulin kinase II
Protein kinase C
Substrate phosphorylation
Dendritic spine of postsynaptic neuron


Glutamate
Presynaptic terminal
Na+
AMPA receptors
Ca2+
NMDA receptor
Internalization of AMPA receptors
Na+
Ca2+
Na+
Protein phosphatases
Dephosphorylate substrates
Dendritic spine of postsynaptic neuron


(A)
Short–term
Long–term
Presynaptic terminal
Ca2+
AMPA receptor
NMDA receptor
Ca2+
Ca2+ calmodulin
Protein kinases
Dendritic spines of postsynaptic neuron
ATP
cAMP
Protein kinase A
CREB
Pi
Pi
Transcriptional regulators
AMPA receptor
NMDA receptor
Synapse growth proteins


(B)
Top view
Side view
50 μm
(C)
LTP


(A)
Dendritic spines
Parallel fibers
Axon of GC
Record
Purkinje cell body
Granule cell
Axon
Climbing fiber
CF Stimulus
(B)
Pair CF and PF
Parallel fiber EPSP amplitude (mV)
0
3
4
5
6
7
−20
0
20
40
60
80
Time (min)
(C)
Climbing fiber
Parallel fiber
Purkinje cell dendritic spine
Synapse weakened
Climbing fiber depolarizes V$_m$
(D)
Presynaptic terminal of parallel fiber
Glutamate
mGluR
AMPA receptors
Na$^+$
Phospholipase C
Internalization of AMPA receptors
Long-term depression
DAG
PIP$_2$
Phosphorylate substrate proteins
PKC
IP$_3$
Dendritic spine of Purkinje cell
Climbing fiber depolarizes V$_M$
Ca^{2+}
Release Ca^{2+}
Endoplasmic reticulum
Ca^{2+}