A	Drosophila studies, 71–72
Acetylcholine, corticohippocampal circuit tuning	Hermissenda studies, 72
during learning and memory, 140–141	honeybee studies, 72
Activity-based genetics	Limax studies, 73
biochemical and cellular studies in active circuits,	overview, 15, 65–66, 83
358–359	pond snail, 72–73
immediate early genes for activity mapping	principles
	environmental relationships, 83–84
circuit function manipulation, 354–358	learning-performance distinction, 84
principles, 350–351	procedure–process mechanism distinction, 84
transgenic mice, 351–354	shared features in invertebrates, 76–77
memory allocation studies, 360–361	•
overview, 349–350	
prospects, 361–362	В
Addiction	Basal ganglia. See Striatum
habit learning, 55	BAX, 119
reconsolidation targeting in treatment, 254, 256	BDNF. See Brain-derived neurotrophic factor
AMPA receptor	Beta-blockers, reconsolidation targeting, 25, 255
activity-based genetics, 359–360	Brain-derived neurotrophic factor (BDNF)
CPEB3 and translation, 239–240	long-term potentiation roles
Hebbian long-term potentiation role, 143–144	explicit memory consolidation, 185
reconsolidation role, 250	overview, 116
structural plasticity role in long-term	transcriptional regulation, 170
potentiation, 192	1 0
Amygdala	
activity-based genetics, 358	С
fear conditioning role, 8, 97–99, 146, 246–247	Calcium/calmodulin-dependent protein kinase II
reconsolidation role, 253	(CaMKII)
Aplysia. See Associative learning; Consolidation;	Hebbian long-term potentiation role, 144
Nonassociative learning; Synaptic capture	intermediate-term facilitation role in Aplysia, 20
Appetitive conditioning. See Associative learning;	knockout mouse, 111-112
Pavlovian conditioning	long-term potentiation role, 145
ARNT2, consolidation role, 162	pond snail classical conditioning role, 72
Associative learning. See also Classic conditioning; Fear	promoter, 113
conditioning; Pavlovian conditioning	promoter use for calcium indicator expression, 326
Aplysia studies	tetracycline transactivator system studies, 116-117
feeding behavior classical and operant	Calcium imaging
conditioning	cell expression of calcium indicators, 326-327
appetitive operant conditioning, 74–76	instrumentation for awake behaving animals,
overview, 73–74	327-331
gill- and siphon-withdrawal reflex	large-scale imaging overview, 322
behavioral sensitization, 66-67	long-term memory study advantages, 331-338
higher-order features, 70–71	neuronal spiking dynamics, 322-325
neurotransmitters, 67–68	prospects for memory studies, 338-340
postsynaptic mechanisms and trans-synaptic	CaMKII. See Calcium/calmodulin-dependent protein
signaling, 69–70	kinase II
presynaptic mechanisms, 69	Cannabinoid receptor, memory studies, 147
protein kinase role A, 68	C/EBP, consolidation role, 160, 163–165

c-Fos, consolidation role, 161	reconsolidation
Channelrhodopsin-2 (ChR2), optogenetics, 122, 124,	behavioral evidence, 246-248
265-268, 356-357	cellular evidence, 249-250
ChR2. See Channelrhodopsin-2	clinical implications, 254-256
Chromatin, structural changes in consolidation,	constraints, 251–253
163-166	experimental paradigms, 248-249
Classic conditioning. See also Associative learning;	presynaptic plasticity-mediated mechanisms,
Nondeclarative memory; Pavlovian	250-251
conditioning	prospects for study, 257
Aplysia studies	recapitulation of consolidation view, 253-254
feeding behavior classical and operant	retrograde amnesia studies in humans, 206-209
conditioning	structural plasticity during long-term potentiation
appetitive operant conditioning, 74–76	in mature and immature brain, 189-192
overview, 73-74	synapse growth, metaplasticity, and advantage of
gill- and siphon-withdrawal reflex	spaced learning, 192-193
behavioral sensitization, 66-67	transcription role
higher-order features, 70-71	evidence, 159–160
neurotransmitters, 67–68	microRNA regulation, 166-168
postsynaptic mechanisms and trans-synaptic	phases, 159
signaling, 69–70	prospects for study, 168–170
presynaptic mechanisms, 69	transcription factor classes, 160–163
protein kinase role A, 68	Corticohippocampal circuit
delay eyeblink conditioning, 8	CA1 pyramidal neuron heterogeneity, 136-138
Hermissenda studies, 72	genetic manipulation in mouse
honeybee studies, 72	Cre/loxP system, 114–116
Limax studies, 73	dominant-negative inhibition, 113-114
pond snail, 72–73	overview, 220–221
shared features in invertebrates, 76-77	pharmacokinetics, 119-120
Consolidation	prospects, 124–126
animal studies, 211–214	spatially restricted promoters, 112-113
Aplysia studies of synaptic plasticity	tetracycline transactivator system, 116-119
implicit memory reconstitution in cultured	viral/optogenetic approaches, 120-124,
neurons, 179	220-221
new synapse formation during long-term	heterosynaptic plasticity, 148-150
facilitation	hippocampal outputs, 135
initial steps of learning-related synaptic	information flow
growth, 181–183	classical pathways, 132-134
overview, 180	neoclassical pathways, 134-135
stabilization of new synapses, 183	overview, 132
silent synapse remodeling and activation during	parallel stream functions, 135-136
long-term facilitation, 179-180	inhibitory circuits in plasticity, learning, and
structural changes, 176–179	memory, 147-150
behavioral measures and cognitive factor	lesion studies
interpretation in animal studies, 214-217	CA1, 138-140
chromatin structural changes, 163-166	dentate gyrus, 139
dendritic spine studies, 186–189	entorhinal cortex, 139
fear memory, 246	long-term synaptic plasticity
long-term potentiation in explicit memory	Hebbian long-term potentiation, 143-144
consolidation, 184-186	homosynaptic plasticity, 141, 143
memory retrieval in mouse, 266–268	long-term depression, 144-145
metabolic and immediate early gene signatures	overview, 141–142
at various times after training, 217-221	prospects for study, 150
neuroimaging studies, 209-211	spike-timing-dependent plasticity, 145
overview, 158-160, 205-206, 246	memory retrieval. See Retrieval
place cell role, 293	relationship between memory systems, 10
prospects for study, 193-194	tuning during learning and memory, 140-141

CPEB. See Cytoplasmic polyadenylation	tasks in impairment identification, 4
element-binding protein	Dendritic spine
Cre/loxP system, corticohippocampal circuit genetic	consolidation studies, 186-187
manipulation in mouse, 114–116 CREB	structural plasticity in long-term potentiation, 188–192
activity-based genetics, 360–361	Dentate gyrus. See Corticohippocampal circuit
Aplysia studies	Dopamine Dopamine
consolidation, 182	addiction and habit learning, 55
feedback loops, 22–23	corticohippocampal circuit tuning during learning
long-term facilitation induction, 21–22,	and memory, 140
229–231	reward-predication error, 100–101
Caenorhabditis elegans nonassociative learning	subcortical dopaminergic working memory
role, 26	updating system, 312–313
consolidation role, 160, 161, 163–167, 169–170	
genetic manipulation in mouse, 112, 122	E
synaptic capture. See Synaptic capture	
Cytoplasmic polyadenylation element-binding protein	ECT. See Electroconvulsive therapy
(CPEB)	EEG. See Electroencephalography Electroconvulsive therapy (ECT), reconsolidation
long-term facilitation role in <i>Aplysia</i> , 24, 183	
synaptic capture	targeting, 255
CPEB3 studies	Electroencephalography (EEG)
aggregates in local protein synthesis, 238–242 AMPA receptor synthesis induction,	medial temporal lobe studies of episodic memory, 368–369
239-240	memory retrieval studies in humans, 278
explicit memory storage in mammals,	Episodic memory, neuroimaging studies in animals
237–238	encoding
SUMOylation and inactivation, 240-241	functional differentiation theory testing, 370
ubiquitination and activation, 240–241	memory paradigm, 368-370
molecular mechanisms	multivariate functional magnetic resonance
cytoplasmic polyadenylation element-	imaging analysis, 370-372
binding protein control of local protein	retrieval, multivariate functional magnetic
synthesis at marked synapse, 231–233	resonance imaging and connectivity
Drosophila cytoplasmic polyadenylation	analysis, 372–374
element-binding protein homolog Orb2	ERK. See Extracellular signal-regulated kinase
and prion-like state in memory	Explicit memory. See Declarative memory
persistence, 235–237	Extracellular signal-regulated kinase (ERK),
functional prion structure, 241–242	reconsolidation role, 230
inhibitor studies, 231	
microRNA presynaptic regulation of	_
cytoplasmic polyadenylation	F
element-binding protein, 233–235	Fear conditioning
modeling of Aplysia CPEB aggregation and	amygdala role, 8
protein synthesis, 242–243	descending fear circuit, 97-98
	history of study, 96–97
_	mechanistic models, 99
D	negative feedback and error correction, 98-99
Declarative knowledge, definition, 2	Fluorescence imaging. See Calcium imaging;
Declarative memory. See also Episodic memory	Optogenetics
amygdala role, 8	fMRI. See Functional magnetic resonance imaging
CPEB3 and explicit memory storage in mammals,	FOXP2, habit learning role, 54
237-238	Functional magnetic resonance imaging (fMRI)
discovery, 1–3	medial temporal lobe studies of episodic memory
hippocampus role, 6	memory paradigms, 369-370
long-term potentiation in consolidation, 184-186	multivariate functional magnetic resonance
medial temporal lobe system, 4-5	imaging analysis, 370-372
place cell remapping, 296-299	retrieval studies, 372-374

Functional magnetic resonance imaging (fMRI)	maintenance and expression mechanisms, 23-24
(Continued)	new synapse formation
memory retrieval studies in humans, 271–272, 275–278	initial steps of learning-related synaptic growth, 181–183
spatial memory studies, 378	overview, 180
working memory studies, 308, 310	stabilization of new synapses, 183
	postsynaptic mechanisms of intermediate-term
G	facilitation and long-term facilitation, 20–21
Gill-withdrawal reflex. See Classic conditioning	shared mechanisms in facilitation types, 25
Grid cell	short-term facilitation relationship, 17-19
place cell interactions, 294–296	silent synapse remodeling and activation,
prospects for study, 299–300	179-180
remapping and declarative memory, 296–299	Long-term potentiation (LTP)
	activity-based genetics, 359
Н	calcium/calmodulin-dependent protein kinase II
Habit learning. See Striatum	knockout mouse, 112
Habit memory. See Nondeclarative memory	Cre/loxP system studies of corticohippocampal
HDAC. See Histone deacetylase	circuit, 116
Hippocampus. See Corticohippocampal circuit; Grid	explicit memory consolidation, 184-186
cell; Place cell; Retrieval	fear conditioning, 97, 99
Histone deacetylase (HDAC), consolidation role, 162,	Hebbian long-term potentiation, 143–144
164, 166	learning and memory role, 145–147
101, 100	spatially restricted promoters, 112–113
	structural plasticity during long-term
I	potentiation in mature and immature
IEGs. See Immediate early genes	brain, 189–192
Immediate early genes (IEGs)	synapse growth, metaplasticity, and advantage of
expression in consolidation, 217-219	spaced learning, 192–193
memory retrieval studies, 262	Long-term sensitization (LTS), neural correlates in
Implicit memory. See Nondeclarative memory	Aplysia, 21
Infralimbic cortex, storage of habit memory, 60	LRRTM2, structural plasticity role in long-term
Intermediate-term facilitation (ITF), Aplysia studies	potentiation, 192 LTD. See Long-term depression
discovery, 19	LTF. See Long-term depression LTF. See Long-term facilitation
induction, maintenance, and expression, 19–20	LTP. See Long-term potentiation
postsynaptic mechanisms of intermediate-term	LTS. See Long-term sensitization
facilitation and long-term facilitation, 20–21	210. 660 26 ng term sensulation
shared mechanisms in facilitation types, 25	M
ITF. See Intermediate-term facilitation	
	Magnetic resonance imaging (MRI)
K	functional magnetic resonance imaging. See Functional magnetic resonance imaging
••	voxel-based morphometry studies of spatial
KHC. See Kinesin heavy chain	memory, 374–378
Kinesin heavy chain (KHC), consolidation role in	Magnetoencephalography (MEG), working memory
Aplysia, 183	studies, 309
L	MAPK. See Mitogen-activated protein kinase
	Medial temporal lobe (MTL)
Long-term depression (LTD)	declarative memory system, 4–5
activity-based genetics, 359	magnetic resonance imaging voxel-based
corticohippocampal circuit, 144–145	morphometry studies of spatial memory,
learning and memory role, 145–147	374–378
Long-term facilitation (LTF), Aplysia studies	neuroimaging studies in animals
feedback loops, 22–23	episodic memory encoding
induction mechanisms, 21–22, 229–231	functional differentiation theory testing, 370

memory paradigm, 368-370	maintenance and expression mechanisms,
multivariate functional magnetic resonance	23–24
imaging analysis, 370-372	long-term sensitization neural correlates, 21
retrieval, multivariate functional magnetic	nervous system features, 16
resonance imaging and connectivity	postsynaptic mechanisms of intermediate-term
analysis, 372–374	facilitation and long-term facilitation,
retrieval role, 270–272	20-21
working memory studies, 6-7, 310	shared mechanisms in facilitation types, 25
MEF2, corticohippocampal circuit genetic	short-term facilitation relationship with
manipulation in mouse, 120-121	long-term facilitation, 17–19
MEG. See Magnetoencephalography	short-term sensitization mechanisms, 16-18
Memory consolidation. See Consolidation	Caenorhabditis elegans, 26
Memory retrieval. See Retrieval	overview, 15–16, 65
MicroRNA	Nondeclarative memory. See also Classic conditioning
consolidation role, 166-168	amygdala role, 8
presynaptic regulation of cytoplasmic	Aplysia studies of synaptic plasticity
polyadenylation element-binding	implicit memory reconstitution in cultured
protein, 233–235	neurons, 179
Mitogen-activated protein kinase (MAPK),	structural changes, 176-179
consolidation role in <i>Aplysia</i> , 182	discovery, 3–4
MRI. See Magnetic resonance imaging	habit memory, 8–9
MTL. See Medial temporal lobe	priming, 7
•	relationship with declarative memory, 9–10
	reward-based learning, 9
N	NPAS4, consolidation role, 161-162
NCAM. See Neural cell adhesion molecule	Nuclear factor-κB (NF-κB), consolidation role,
Neural cell adhesion molecule (NCAM)	161-162
consolidation role in Aplysia, 181-182	Nucleus reuniens (NuRe), corticohippocampal circuit
long-term facilitation role in Aplysia, 23	tuning during learning and memory, 141
long-term potentiation role, 116	NuRe. See Nucleus reuniens
Neurexin-1β, structural plasticity role in long-term	
potentiation, 192	
Neuroglin-1, structural plasticity role in long-term	O
potentiation, 192	Obsessive-compulsive disorder (OCD), reconsolidation
NF-κB. See Nuclear factor-κB	targeting, 254–255
NMDA receptor	OCD. See Obsessive-compulsive disorder
<i>Aplysia</i> classical conditioning role, 69–70	OFC. See Orbitofrontal cortex
Cre/loxP system studies of corticohippocampal	Optogenetics
circuits, 114-116, 118	corticohippocampal circuit genetic manipulation in
fear conditioning role, 97	mouse, 122-124, 220-221
Hebbian long-term potentiation role, 143	memory retrieval studies, 264-266
long-term potentiation role, 145-146	Orb2, prion-like state in memory persistence, 235–237
place cells, 292	Orbitofrontal cortex (OFC), appetitive conditioning,
reconsolidation role, 252-253	101-102
structural plasticity role in long-term	
potentiation, 192	Р
Nonassociative learning	•
Aplysia studies	Parietal cortex, posterior parietal cortex role in memory
comparison with other invertebrates, 25-26	retrieval, 274–275
intermediate-term facilitation	Parvalbumin interneuron, inhibitory circuits in
discovery, 19	plasticity, learning, and memory, 148
induction, maintenance, and expression,	Pavlovian conditioning. See also Fear conditioning
19-20	appetitive conditioning
long-term facilitation	dopamine and reward-predication error,
feedback loops, 22-23	100-101
induction mechanisms, 21-22	motivation circuitry, 101

Pavlovian conditioning. See also Fear conditioning (Continued)	dominant-negative inhibition, 113 Drosophila classical conditioning role, 71
outcome representation circuitry, 101-102	Hermissenda classical conditioning role, 72
overview, 99–100	honeybee classical conditioning role, 72
associative structure and diagnosis	pond snail classical conditioning role, 72
conditioned response deliberateness, 93–94	tetracycline transactivator system studies, 117
inflation and devaluation, 90-91	Protein kinase C (PKC), intermediate-term facilitation
outcomes representation, 91–93	role in <i>Aplysia</i> , 19
overview, 89–90	PTSD. See Posttraumatic stress disorder
conditioned response topography, 94-96	
definition, 84–85, 96	R
evolutionary function	
adaptation, 95	Reconsolidation. See Consolidation
functional behavior systems approach to	Rescoria – Wagner model. See Pavlovian conditioning
conditioned response topography, 95-96	Retrieval
pairing versus contingency, 85–86	human studies
Pavlovian instrumental transfer, 92–93, 99, 101	default mode network, 272-273
prospects for study, 103	distributed interactions, 276
Rescoria-Wagner model	hippocampus role, 270–272
error correction and neural instantantiation,	medial temporal lobe role, 270-272
87-88	phenomenological analysis, 268-270
limitations	posterior parietal cortex role, 274-275
attention, 88–89	prefrontal cortex role, 273–274
extinction, 89	reinstatement of encoded processes,
time, 88	276-279
overview, 86–87	thalamus role, 275
PFC. See Prefrontal cortex	medial temporal lobe multivariate functional
PKA. See Protein kinase A	magnetic resonance imaging and
PKC. See Protein kinase C	connectivity analysis in episodic memory,
Place cell	372-374
consolidation, 293	mouse studies
grid cell interactions, 294–296	consolidated memory retrieval, 266-268
history of study, 290-292	optogenetic manipulation, 264-266
memory encoding, 292–293	patterned activity, 262-264
prospects for study, 299-300	overview, 263-264
remapping and declarative memory, 296-299	place cell role, 293-294
retrieval, 293–294	prospects for study, 279
synaptic plasticity in place map formation, 292	Rubinstein-Taybi syndrome, 166
Posttraumatic stress disorder (PTSD), reconsolidation	
targeting, 251–252, 254–256	
Prefrontal cortex (PFC), retrieval role, 273-274	S
Priming, nondeclarative memory, 7	Serotonin, Aplysia studies
Prion proteins. See also Cytoplasmic polyadenylation	classical conditioning role, 67-69
element-binding protein	consolidation role, 181
conformations, 227–228	long-term facilitation induction, 21-23
functional prion structure, 241-242	release and postsynaptic mechanisms of
nonpathogenic prions, 227-228	intermediate-term facilitation and
synaptic capture. See Synaptic capture	long-term facilitation, 20-21
Procedural knowledge, definition, 2	short-term sensitization role, 17
Protein kinase A (PKA)	Serum response factor (SRF), consolidation role,
Aplysia studies	161-162
classical conditioning role, 68-70	Short-term facilitation (STF), Aplysia studies
consolidation, 181	long-term facilitation relationship, 17-19
intermediate-term facilitation, 19-20	shared mechanisms in facilitation types, 25
long-term facilitation induction, 21-22	Short-term sensitization (STS), mechanisms in Aplysia,
short-term sensitization, 17–18	16-18

Spatial memory, medial temporal lobe magnetic resonance imaging voxel-based	microRNA presynaptic regulation of cytoplasmic polyadenylation element-binding
morphometry studies, 374–378	protein, 233–235
SRF. See Serum response factor	modeling of <i>Aplysia</i> CPEB aggregation and
STF. See Short-term facilitation	protein synthesis, 242–243
Striatum	overview, 230–231
addictions as habits, 55	010111011, 250 251
emotional and cognitive habits/skills circuitry, 61	
habit learning	T
behavioral optimization by striatum-based	Tetracycline transactivator system
circuits, 52–53	corticohippocampal circuit genetic manipulation
behavioral plasticity modeling, 53–55	in mouse, 116–119
chunks of neuronal bracketing activity,	transgenic mice in genetic activity-based genetics,
58-61	353
degrees of freedom problem and optimal	Thalamus role, 275
performance, 52, 60–61	TMS. See Transcranial magnetic stimulation
functional magnetic resonance imaging, 53	Transcranial magnetic stimulation (TMS), working
motor-motor association formation,	memory studies, 308
55-56	
task-bracketing patterns, 56-58	W
relationship between memory systems, 10	Working memory
STS. See Short-term sensitization	intention maintenance and realization, 313–314
Synaptic capture	long-term memory differentiation, 6
CPEB3 studies	maintenance
aggregates in local protein synthesis,	brain areas, 307-308
238-242	long-term memory formation promotion, 310
AMPA receptor synthesis induction, 239-240	mechanisms, 309–310
explicit memory storage in mammals,	manipulation
237–238	frontal cortex, 310–312
SUMOylation and inactivation, 240–241	subcortical dopaminergic updating system,
ubiquitination and activation, 240–241	312-313
molecular mechanisms	medial temporal lobe studies, 6–7
cytoplasmic polyadenylation element-binding	network modeling, 314-315
protein control of local protein synthesis	nondeclarative memory relationships, 9-10
at marked synapse, 231–233	overview, 5-6, 305-307
Drosophila cytoplasmic polyadenylation	prospects for study, 315
element-binding protein homolog Orb2	scene-location task, 6
and prion-like state in memory persistence, 235–237	
functional prion structure, 241–242	Z
inhibitor studies, 231	Zif268, consolidation role, 161
minoriol studies, 231	ZiiZoo, consolidation foic, 101