

Index

Locators in **bold** refer to figures

Locators for main headings with subheadings refer to general aspects of that topic only

- abduction, finger 180
- ablation *see* lesion studies
- accuracy parameter 21
- action phase control 143–145
- Action Research Arm Test (ARAT) 304
- action tremor 383–385, **384**, **386**, 464–466
- active skin markers 24
- adaptation 120, 241–244; *see also* plasticity
 - pathological *see* hypo-activation; maladaptive plasticity
- ADDS (Arm Dystonia Disability Scale) 473, 477
- adduction, finger 180
- adolescents *see* children; *see also* development
- adult learning 119
- afferents 146–148, 150–151, 155, 180, 259
- aging effects 250–252, 262; *see also* development
 - behavioral slowing 252–253
 - bimanual coordination 261–262
 - control over external moments 256–258, **257**, 262
 - dependency 250
 - fast-adapting tactile afferents 259
 - force variability 261, 262
 - intervention strategies 251–252, 262
 - manual dexterity 250–251
 - other than slowing 253–256, **254**, **255**
 - sensory function of hand **254**, 258–261, 262, 000
 - tactile deterioration 259
- AHA (Assisting Hand Assessment) 447
 - AIP *see* anterior intraparietal area
- akinesia 327, 459–461, **461**, 483
 - deep brain stimulation 462–464, **463**, **464**
 - Parkinson's disease 459
- Alpha-Omega Engineering 53
- amphetamines 430
- amphibian studies 131
- anesthesia 10, 179–180, 242, 286
 - transient 269, 270; *see also* somatosensory disorders
- anatomy
 - cerebellum 361–364, **362**
 - hand 161
 - lesions 435
- animal models 131, 184, 355, 435; *see also* lesion studies;
 - macaques; monkeys; primates
- anterior intraparietal area (AIP) 72, 112; *see also* intraparietal
 - sulcus
 - fMRI studies 89, 91, **91**
 - grasp planning/execution 112
 - human 73, 106, 112
 - monkey 72, 106, 112, 116
 - primate studies 89
 - virtual lesions 74–77, **76**
- anticipation *see* grip force scaling; *see* internal models;
 - object representations; prediction/predictive mechanisms
- anticipatory postural adjustment (APA) 207, 208–209
- antipsychotic medication, side effects 390, 391
 - awareness of action impairment 396–397
 - bradykinesia 395
 - kinematic motion analysis 392–396, **395**, **396**
 - neurological soft signs 392
 - Parkinson's disease-like effects 391–396
- APA (anticipatory postural adjustment) 207, 208–209
- aperture path ratios 303; *see also* grip apertures
- aphasia 425
- apraxia 138, 483
- ARAT (Action Research Arm Test) 304
- arbitrary grasps 41
- arm controller model 118
- Arm Dystonia Disability Scale (ADDS) 473, 477
- arm movements 87, 88, 89, 205
- Assisting Hand Assessment (AHA) 447
- asymmetric
 - movements 205, 206, 209, 212, 214, 223
 - shape 199
- ataxia 367
- attention/attention deficits 230, 336–337, 343
- auditory signals 142, 155

ballistic
 grip forces 105
 strategies, development of 114

basal ganglia 363

bimanual coordination 209

 development of grasping 111, 114–115

 duration/rate/amplitude of force **101**, 103–106, **104**

 dysfunction 311, 312, 318, 320, 391; *see also* Parkinson's disease

 FARS model 113

 focal hand dystonia (FHD) 355

 gait 229

 grasping control 99, 103

 grip-force output selection 100–103, **101**, **102**

 hand motor control 408

 Huntington's disease 326

 motor changes following stroke 427

 movement velocity/frequency 105–106

 precision grip 99–100, 103, 106–107

battered infant syndrome 333, 336–339, **339**, 340–342; *see also* traumatic brain injury

BCI (brain–computer interfaces) 120, 433

behavioral slowing *see* bradykinesia

bell-shaped distribution
 force rates trajectories/velocity profiles 235, 242, 243–244, 246

 reach-to-grasp movements 314, 315–316

bend sensing technology 25

bilateral coupling, arm movements 205

bilateral training, stroke therapy 411, 412

bimanual coordination 204–205, 214

 aging effects 261–262

 crosstalk model 205–207, 208, 210, 212, 214

 functional specialization/handedness 209–210, **212**, 213, 214

 lateralization at cortical level 210

 lateralized differences theory 209–210

 manipulative role 209, 213

 mirror neurons 213–214

 neural substrates 206–207

 object manipulation 210–213, **211**, **212**

 postural role 207, 209, 213

 predictive mechanisms/object representations 207–208, **207**

 subcortical structures 208–209

 subgoals for each hand 209–210

 symmetric/asymmetric movements 205, 206, 209, 212, 214, 223

biological realism 111

biological force constraints 33, 43–45; *see also* finger enslaving; force deficit

biomechanical control mechanisms 166–171

biphasic profile of finger movements 134–136

birds, gape aperture 136

blepharospasm (BSP) 350, 355–356

blindfold studies 80

BOLD (blood-oxygenation level dependent) signals 86–87, 93, 100–101, 104, 433; *see also* fMRI studies

Bobath concept 409

botulinum toxin 471, 472

bradykinesia; *see also* aging effects
 Huntington's disease 327

 Parkinson's disease 315–316

 schizophrenia 391, 393, 395

 traumatic brain injury 336

Braille reading 473–474, **474**

brain circuits
 action/perception 173

 anticipatory grip-force adjustments 166–171, **170**

 bimanual coordination 206–207

 dexterity 438

 force pulses 100

 grasping *see* grasping brain circuits

 hand motor control 408

 monkey 110

 reach-to-grasp movements 77–78

brain–computer interfaces (BCI) 120, 433

brain imaging *see* neuroimaging

brain injury 297; *see also* traumatic brain injury

Brandeis University 131–132

Bruininks–Oseretsky Test of Motor Proficiency 447, **449**

Brunnstrom Stages of Recovery 343

BSP (blepharospasm) 350, 355–356

carpal tunnel syndrome 272–273, 285–287, 292–293

 anticipatory grip force scaling 290–291

 degrees of freedom of movement 287

 disease characteristics 287–288

 grasp control effects 288–289

 multi-digit grasping 289–291, **289**, **291**, **292**

 sensorimotor memory 285–286

 somatosensory feedback 285

caudal cingulate cortex 206, 407–408

caudate 100, 101

 gait 229

 grip-force amplitude 103

 Huntington's disease 326

 movement selection 103

 role in grasping 99

 transcranial magnetic stimulation 431

CD (cervical dystonia) 350

central oscillations 377; *see also* physiological tremor

center of mass (CoM) 198

cerebellar disorders 361

 ataxia 367

 isometric grip forces 371

 lesions 362, 367

 motor changes following stroke 426, 427

 nuclear activity and task function 364–365

 pathophysiology of grasping 369–371, **370**

- symptoms relevant to grasping 367–369
- tremor 371, 380, 381–385
- cerebellum; *see also* cerebellar disorders
 - anatomy 361–364, **362**
 - anticipatory role 365
 - bimanual coordination 208–209
 - daily functioning/grasping ability 367
 - error correction 362
 - fMRI studies 87
 - forward model 366
 - function 365–367
 - grip-force planning 228–229
 - hand movements 184–185
 - internal models 366–367, 371
 - inverse model 367
 - lift-and-release actions 93
 - mammals 184
 - monkeys 118, 184, 364
 - motor control 408
 - motor learning 363
 - movement planning **363**
 - neurohaptic control 184–185
 - positron emission tomography 86
 - sensorimotor coupling 365–366
 - sensorimotor integration 365
 - transcranial magnetic stimulation 431
- cerebral cortex 112
- cerebral palsy 269, 297; *see also* somatosensory disorders
 - disease characteristics 438–439
 - excessive grip forces 343
 - forced use of affected limbs; *see also* constraint-induced movement therapy; hand function training
 - grip-force scaling 280
 - grip-force variation 343
 - transcranial magnetic stimulation study 439
- cerebrospinal fluid (CSF) shunting 483, 486–488, **487**
- cervical dystonia (CD) 350
- chains 181
 - kinematic 209
- children; *see also* development
 - battered 333, 336–339, **339**, 340–342, **342**; *see also* traumatic brain injury
 - feedback correction 244
 - hand pre-shaping 238
 - infant reaching, kinematic studies 236
 - internal models 244
- chorea 327
- chronic electrode implants 54; *see also* EMG activity, monkeys
- CIM/CIMT *see* constraint-induced movement therapy
- cinematographic method 132, **133**, **137**; *see also* video-based systems
- cingulate motor area (CMA) 407–408, 427
- clinical studies 5–6, 9, 10
- clumps 181
- clumsiness 286, 293, 367, 399
- CMAv (ventral cingulate sulcus) 184
- cognitive
 - decline 482, 483
 - deficits 344
- CoM (center of mass) 198
- compensatory mechanisms, neural 428; *see also* functional neuromodulation; plasticity
- complementary action 213–214; *see also* mirror neurons
- computational modeling 119; *see also* grasping control models
- computational movement neuroscience 95
- computer-aided video analysis 22; *see also* video-based systems
- computerized tomography (CT) scanning 334–335
- connectivity analysis
 - fMRI studies 84, 92
 - interhemispheric interactions 79
 - motor system post stroke 428–429, **430**
 - neural connectivity, cerebral palsy 439, 445, 446–449, **448**
 - synaptic 246; *see also* neuronal group selection
- constant force maintenance 5
- constraint-induced movement therapy (CIM)
 - cerebral palsy 438, 442–443, **443**, **444**, 449, 450–451
 - historical perspectives 441–442
 - limitations 443–444
 - musician's cramp 476
 - stroke therapy 409–410
- contact 33
- context-specific learning 164
- contextual factors 29, 99
- control, hand xiii; *see also* dynamic grasp control; grip-force control; neurohaptic control; sensorimotor control; sensory control of object manipulation
 - aging effects 256–258, **257**, 262
 - anticipatory *see* grip-force scaling; internal models; object representations; prediction/predictive mechanisms
 - biomechanical mechanisms 166–171
 - grasp 99, 103, 142, 288–289, 316–317; *see also* grasping control models
 - motor 227–229, **228**, 235, 408
 - neurological 61, 63–64
 - predictive/reactive 394, 395
 - sensorimotor control mechanisms 93–95
 - transport, Parkinson's disease 315–316, **315**
- cooling, hand 10, 270; *see also* anesthesia
- coordination; *see also* bimanual coordination; carpal tunnel syndrome
 - bodily/gait 219–220
 - grasping control models 117
 - joints 369–371
 - prehension components 117, 136–138, **137**, **138**, 235
- Coriolis forces 10
- corollary discharge 398
- corpus callosum 206
- corrective action *see* feedback correction

494

correlation
 analysis 251, 326
 mechanisms 136–138

cortical activity recording, monkeys 52, 58
 LFP (local field potentials) 54, 55–57
 MUA (multi-unit activity) 54, 57
 precision grip 55
 recording methodology 52–54
 signals, decoding 54–58, **56**
 SUA (single neuron spiking activity) 54–55
 synchronous firing 57–58

cortical substrates *see* brain circuits

cortico-motoneuronal (CM) projections 52, 54–55, 105, 407
 cerebral palsy 439, 450
 connectivity in motor system following stroke 428
 macaques 62, 65
 neurohaptic control 178, 183

corticospinal tract (CST)
 integrity 428, 434, 438
 reorganization 450

Coulomb law 35, **35**, 195
 coupling; *see also* grip-force coupling
 bilateral 205
 grip–inertial force 219, 223–228, 230
 grip–load force 118–119, 168–171
 intrinsic 429
 sensorimotor 365–366
 temporal 301, **301**
 thalamo-cortical 378

critical flicker frequency 379

critical period, developmental 444

cross-talk, EMG signals 65

crosstalk model, bimanual coordination 205–207, 208, 210, 212, 214

CSF (cerebrospinal fluid) shunting 483, 486–488, **487**

CST *see* corticospinal tract

CT (computerized tomography) scanning 334–335

CTS *see* carpal tunnel syndrome

cuboid precision grip points **194**

cues
 effects on grasping 466
 precision grip points selection 198–200
 visual *see* visual cues/feedback

cutaneo-muscular reflexes 245

cutaneous afferents 180

cutaneous receptors 141–143, **144–145**, 178, 181–183, 270

daily functioning
 cerebral palsy 438
 Parkinson's disease 311
 role of cerebellum 367
 stroke 304–305, **305**, 405
 traumatic brain injury 337

Index

DataGloves 25

deafferentation *see* sensory neuropathy

deep brain stimulation 458, 462–464, **463**, **464**, 466

definitions
 kinematic assessment of grasping 21
 precision grip points 194
 prehension 235

degrees of freedom of movement 128, 132–134, 161, 239, 287; *see also* six-degrees-of-freedom sensors

delusions, motor control 398

dementia 482, 483

dependency 250; *see also* aging effects; daily functioning

de-sensitization 462

development 235–236
 ballistic strategies 114
 basal ganglia, fMRI studies 114–115
 cerebral palsy impairment 441
 control 145
 friction, tactile adjustments 241–242
 grasping control models 114–115, 119–120
 grip forces analysis 5, 8
 hand movement description, historical perspective 138
 independent finger movements 236, 238–239
 kinematic assessment of grasping 27, **28**
 neuronal group selection 235, 240, 246
 precision grip 114–115, 238
 prehension 131, 236–238, **237**
 probing strategy, infant 242, 243
 sensory control mechanisms 241–246, **243**, **245**
 stable object manipulation/lifting 239–240, **241**
 triggered corrections/manipulation reflexes 244–246, **245**
 unstable object manipulation 239, **240**
 visually guided reach-to-grasp 114
 weight adaptation/predictive parameterization of force 242–244

Developmental Hand Function Test 333, 336, 341, 343

developmental non-use 438, 439, 444, 449

dexterity, human xiii, 61–62
 aging effects 250–251, 261
 cerebral palsy 280
 impairment 390
 neural correlates 438
 sensorimotor control mechanisms 93–95

diadochokinesia 392

diffusion tensor imaging (DTI) 428, 434

diffusion weighted imaging (DWI) 433

digit forces 33; *see also* multi-digit grasping
 hard-finger contact 34
 modeling digit contacts 33–34
 point contact model 34
 single-digit contacts 33–36
 slip prevention 34–36
 soft-finger contact 34, **35**

- digitization 22
 directionality, precision grip points 201
 dominance, hand 209–210, **212**, 213, 214
 dopamine 355, 429
 dopaminergic medication 458; *see also* levodopa-induced dyskinesias
 dopaminergic systems 251, 262, 430
 prehension 312, 320
 schizophrenia 391, 392
 tremor 379, 383, 385
 dorsal premotor cortex (PMd) 72, 81, 184
 early imaging studies 85
 parallel distributed model 407–408
 reach-to-grasp studies 77–81, **80**
 dorsal visual pathway 131–132, 134
 DTI (diffusion tensor imaging) 428, 434
 dynamic grasp control (during gait) 219–220,
 229–230
 coordination, bodily 219–220
 grip–inertial force coupling 219, 223–228, 230
 impairment *see* hypokinetic gait disorder
 initiation 225–227, **226**
 methodology 222–223
 neuro-motor control processes
 227–229, **228**
 regular rhythmic gait 220–222, **220**
 variable gait 223–225, **224**
 velocity 219, 230
 dysdiadochokinesia 367, 392
 dysmetria 367, **368**
 dystonia 100, 327

 Eckhorn system 53
 efference copy 398
 electroencephalography (EEG) 380, 471
 electronic force measurement methods 3; *see also* strain gauges
 electrophysiological recording 30, 471
 EMG (electromyogram) 4
 control of grasp 63–64
 feedback-based training 411
 focal hand dystonia (FHD) 354
 functional electrical stimulation 414
 grip-force responses 245
 precision grip 4
 stroke 299
 EMG activity, monkeys 61–62, 69
 data collection/analysis 64–65
 methodology 62–64, **64**
 object-specific grasp analysis 65–67,
 66, 67–69, **68**
 encephalopathy *see* metabolic tremor
 end-state comfort strategy 201
 enslaving, finger 43, 44–45, 238

 error correction *see* feedback correction
 essential, tremor (ET) 377, 379–381
 cerebellar disorders 380, 381–385
 clinical characteristics 379
 grasping movement interference 380–381, **381**
 pathophysiology 379
 Euclidian distance 67–69
 evolution
 of hand 127–128
 of nervous system 128
 precision grip 179
 prehension 179
 primates 179
 excessive grip forces 395; *see also* grip-force scaling
 antipsychotic medication side effects 395
 carpal tunnel syndrome 286, 288–289, 292–293
 cerebellum 371
 cerebral palsy 343
 complete deafferentation/sensory neuropathy
 275–276
 fingertip 256–258, 261, 262
 hydrocephalus 343, 487
 Parkinson's disease 320, 460–461, 462–464
 schizophrenia 394, 395
 somatosensory disorders 280–281
 stroke 278–279, 280–281, 301, 411
 transient somatosensory afferent perturbation 270–271
 traumatic brain injury (TBI) 343
 exercise therapy 409
 experience, grip force 198; *see also* internal models; object representations
 experimental bias 138
 exploratory movements 179, 200, 279–280; *see also* haptic cues
 exteroceptors 141–143, **144–145**, 178, 181–183, 270
 eye
 /hand analogy 127
 movements 142, 153–155

 familiar loads, internal models 164–165
 FARS grasping control model 111, 112–113, **113**
 fast-adapting tactile afferents 259
 fatigability 367
 feedback based training, stroke therapy 411
 feedback correction 152, 204, 362, 365
 children 244
 modulating fingertip forces 286
 reflexes 244–246, **245**
 somatosensory 285, 286, 302
 tactile 162
 visual *see* visual cues/feedback
 feedforward mechanism 271, 273, 281
 FHD *see* focal hand dystonia
 fiber-optic transducers 89

finger
 abduction/adduction 180
 enslaving 43, 44–45, 238
 grip *see* prehension components
 independent movements 236, 238–239
 interdependence 43
 fingertip forces 86, 142
 fMRI studies 89
 misapplication 256–258, 261, 262
 modulating 286
 sensorimotor control mechanisms 95
 stroke 301–302
 fingertip mechanics 171
 flip-flop effect 382
 fMRI studies 84, 86–89, **88, 90**
 advantages of fMRI 85
 anterior intraparietal area 89, 91, **91**
 anticipatory grip-force scaling 84
 brain–computer interfaces 433
 connectivity analysis 84
 connectivity in motor system following stroke 428, 429, **430**
 development of grasping 111, 114–115
 duration/rate/amplitude of force **101**, 103–106, **104**
 early imaging studies 84–86
 fingertip forces 89
 frontoparietal circuits 89–93
 functional neuromodulation/reorganization 425, 426
 grip-force output selection 100–103, **101, 102**
 head-coil tilting 87–88
 idiopathic normal pressure hydrocephalus 483
 inferior parietal cortex 86
 intraparietal sulcus 84, 85, 86, 89
 isometric grip-forces analysis 86
 kinematics 30
 motor changes following stroke 426, 427
 physiological basis of BOLD signal 86–87
 power grip 86
 precision grip 84, 85–86, 99–100, 103, 106–107
 predicting functional outcomes 434–435
 premotor area 91
 primate studies 87
 reach-to-grasp studies 84, 89–93, **92**
 rehabilitation 416–417
 sensorimotor control mechanisms 93–95, **94**
 stroke therapy 413
 supramarginal gyrus 86
 tactile shape exploration paradigm 84–86
 technical challenges 87–89, **88, 90**
 traumatic brain injury 344
 ventral premotor cortex (PMv) 84, 85, 86, 89–91
 focal hand dystonia (FHD) 348, 356–357, 469; *see also* focal
 hand dystonia therapy
 animal models 355
 clinical characteristics 469–470

disease characteristics 348–350, **349**
 electroencephalography (EEG) 471
 EMG studies 354
 GABA 355
 genetic abnormality 348, 350
 homeostasis mechanisms 348, 354
 imaging studies 350–352, **351**, 355
 inhibitory circuits, impaired 348, 352, 354–356, 471–472
 pathophysiology 470–472
 plasticity, maladaptive 348, 352–354, **353**, 469, 471, 476
 sensorimotor integration, abnormal 348, 350–352, **351**
 sensory disorder 348
 sensory processing abnormalities 470–471
 surround inhibition 350, 356
 task-specificity 349
 focal hand dystonia therapy 476
 Braille reading 473–474, **474**
 immobilization 473
 modified pen grip 475, **475**
 neurostimulation 472–473
 pharmacological interventions 472
 sensory/motor training programs 473–477, **476**
 foot, tactile sensibility 142
 force
 constraints 33, 43–45; *see also* finger enslaving
 coordination *see* carpal tunnel syndrome and force
 coordination
 deficit 43
 duration 106
 output, anticipatory 244; *see also* grip-force scaling
 predictive parameterization 242–244
 pulses 4, 100, 103; *see also* grip-forces analysis
 variability, aging effects 261, 262; *see also* variable grip
 force
 forced use 441–442; *see also* constraint-induced movement
 therapy
 forward models 118–119, 163, 164; *see also* internal models
 cerebellum 366, **366**
 gait 227
 schizophrenia 398, **399**
 sensory neuropathy 275
 fragility 241; *see also* object properties
 free moments 34
 friction 148, 151, 165, 179, 180; *see also* Coulomb law
 adaptation/tactile adjustments 241–242
 aging effects 259
 development of grasping/object manipulation 241–242
 grasping and lifting 8
 grip 195–196
 precision grip points 194, **194**, 195–196, **196**
 tangential forces 188, **188**
 frontal lobes *see* cortical activity recording
 frontoparietal circuits 89–93
 functional electrical stimulation 414

- functional flexibility xiii
- functional magnetic resonance imaging *see* fMRI
- functional neuromodulation 425–426, 434–435; *see also*
 - plasticity; stroke therapy
 - brain–computer interfaces (BCI) 433
 - compensatory mechanisms, neural 428
 - connectivity in motor system following stroke 428–429, **430**
 - hypo-activation 427, 429, 434
 - motor changes following stroke 426–428
 - neuroimaging 425, 426, 433–434
 - pharmacological interventions 425, 429–431, **431**
 - plasticity, brain 426, 431
 - transcranial magnetic stimulation 425, 431–433, **432**
- functional specialization 209–210, **212**, 213, 214
- GABA 355, 356
- gait
 - disorders, hypokinetic 482, 483; *see also* idiopathic normal pressure hydrocephalus
 - grasp control *see* dynamic grasp control
- gaze fixations 142
- genetics
 - focal hand dystonia 348, 350
 - nature–nurture debate 246, 348; *see also* neuronal group selection
 - schizophrenia 399
- Glasgow Coma Scale (GCS) 333–334
- globus pallidus (GPi/GPe) 99, 101, 104–106
 - connectivity in motor system following stroke 429
 - force duration 106
 - force pulse amplitude 103
 - gait 229
 - grip forces analysis 100, 103
 - movement velocity/frequency 105–106
 - Parkinson's disease 312, 383
 - pinch grip force amplitude 106
- gloves 270
- GMFM (Gross Motor Function Measure) 336, 342
- goal-directed reaching 236, 369; *see also* grasping
- GPi/GPe *see* globus pallidus
- grasp/grasping; *see also* dynamic grasp control; fMRI
 - studies; kinematic assessment of grasping; lifting and grasping
 - control 99, 103, 142, 288–289, 316–317; *see also* grasping control models
 - and daily functioning 304–305, **305**, 311
 - definition 194
 - evaluation/generation module 114–115
 - force 42
 - initiation 328
 - matrix 38–39
 - neural correlates *see* grasping brain circuits
 - object-specific grasp analysis, monkeys 65–67, **66**, 67–69, **68**
 - pathophysiology *see* pathophysiology of grasping
 - physiology *see* physiological basis of grasping
 - planning/execution 112, 114–115
 - stability control points 148–150, **149**
 - /transport decoupling 200–201
 - and tremor 377, 385, 464–466, **465**
- grasping brain circuits 99, 100
 - anterior intraparietal area (AIP) 112
 - basal ganglia 99, 103
 - cerebellum 361–364, **362**
 - intraparietal sulcus 112
 - monkeys 106
 - motor cortex 112
 - multimodal representations 116–117, 156
 - premotor cortex 106, 112
 - reach-to-grasp movements 77–78
 - somatosensory cortex 186–187
- grasping control models 110–111, 114–115, 117, 119–120
 - coordination, reaching/grasping 117
 - development of grasping 114–115, 119–120
 - dynamic *see* dynamic grasp control
 - FARS model 112–113, **113**
 - grip-force coupling 111, 118–119, 120
 - hand pre-shaping, learning 115–117; *see also* internal models
- grip; *see also* power grip; precision grip
 - apertures 205, 316–317, 318, 319–320
 - definition 194
 - and friction 195–196
- grip force/grip force analysis 3, 86, 168–171, 371; *see also*
 - lifting and grasping
 - aging/development studies 5, 8
 - amplitude 103
 - coordination **23**, 220–222, 223–227, **226**
 - control *see* grip-force control
 - coupling *see* grip-force coupling
 - during locomotion *see* dynamic grasp control
 - Huntington's disease 327–329, **328**, 329–331, **330**
 - idiopathic normal pressure hydrocephalus 482, 486–488, **487**
 - impairment, Huntington's disease 327–329, **328**
 - /load force coupling 118–119, 168–171
 - memory representations 166; *see also* object representations
 - model 227
 - neural correlates 100, 103
 - neurological diseases 5–6, 9, 10
 - object movements 9–12
 - output selection 100–103
 - overshoot *see* excessive grip forces
 - planning 228–229
 - prediction 162, 163; *see also* internal models
 - production, sensory neuropathy 274
 - reflex responses 245
 - six-degrees-of-freedom sensors 9
 - variable *see* variable grip forces
 - writing 12–13, **14**

grip-force control 3–6, **6**, 7–8, **26**; *see also* kinematic assessment of grasping
 feedforward mechanism 271
 grip-forces analysis 3–6, **6**, 7–8, **7**
 neurological control of hand 61, 63–64
 object movement 8, 9–12
 schizophrenia 393–396
 somatosensory disorders 272–273

grip-force coupling
 grasping control models 111, 118–119, 120
 grip–inertial force coupling 219, 223–228, 230
 PET imaging 118

grip-force scaling 286; *see also* excessive grip forces
 carpal tunnel syndrome 290–291
 cerebral palsy 280
 fMRI studies 84
 force output 244
 Huntington's disease 329
 idiopathic normal pressure hydrocephalus 484–486
 object weight 93
 Parkinson's disease 320, 484–486
 rehabilitation 416
 schizophrenia 393–396
 sensorimotor control mechanisms 93
 sensory neuropathy 275, 276
 stroke 302
 transcranial magnetic stimulation study 73–74, 76–77

grip–lift
 synergy 239–240, 241, 242, **243**
 task 484–486, **485**

Grooved Pegboard Test 251, 253, 256

Gross Motor Function Measure (GMFM) 336, 342

group selection, neuronal 235, 240, 246

guitarist's cramp 349; *see also* focal hand dystonia

HABIT (hand–arm bimanual intensive training) 438, 445, 446–449, **448**, 449–451, **449**; *see also* hand function training

hand cooling 10, 270; *see also* anesthesia

hand dominance 209–210, **212**, 213, 214

hand function testing 334–335, 336–337, **337**

hand function training, cerebral palsy 438–439, 449–452; *see also* constraint-induced movement therapy
 grasping impairment, underlying mechanisms 439–441, **440**
 hand–arm bimanual intensive training 438, 445, 446–449, **448**, 449–451, **449**
 intensity of treatment 451
 part task practice 447
 rationale for bimanual intensive training with children 444–446
 whole task practice 447

hand motor control 408

hand motor organization 406–409, **406**, **408**

hand motor rehabilitation *see* stroke therapy

hand movements 110, 179, 183–185, 186

hand movement description, historical perspective 127, 138
 Brandeis University meeting (1978) 131–132
 coordination/timing of prehension components 136–138, **137**, **138**
 degrees of freedom of movement, reducing 132–134
 kinematic description of grasping 134–136, **135**
 pre 1980 127–131

hand pre-shaping 110; *see also* object shape
 anterior intraparietal area virtual lesions 75–77

children 238

grasping control models 115–117

Infant Learning to Grasp Model 117

intentional/contextual factors 29

kinematic assessment of grasping 25–27, **26**, 27, 29

monkeys 64–65; *see also* EMG activity

prehension 134

primate studies 29

SUA (single neuron spiking activity) 55

hand sensorimotor dysfunction therapy, Parkinson's disease 458–459

cues 466

deep brain stimulation 458, 462–464, **463**, **464**, 466

grasping in tremor-dominant symptomatology 464–466, **465**

levodopa effects 459–461, **461**, 466

hand tactile sensibility 142; *see also* cutaneous receptors;
 sensory function of hand

handedness 209–210, **212**, 213, 214

handles, rough textured 196

handwriting training 474–475; *see also* writer's cramp

haptic cues 165; *see also* neurohaptic control
 exploratory movements 179, 200
 object properties 200
 precision grip points 194
 stroke victims 279–280

tactile cues 200

weight 200

haptic grasping 114, 115

hard-finger contact 34

HD *see* Huntington's disease

head-coil tilting 87–88

head movement induced artefacts 87, 88, 89

Hebbian learning 116

hemiparesis *see* paresis/hemiparesis

hepatic encephalopathy *see* metabolic tremor

hierarchical model of motor planning/executive 407

Hoff–Arbib model 111, 117

homeostasis mechanisms 348, 354

homologous brain circuits, primate 72, 112, 120

how questions 119

Huntington's disease (HD) 100, 326–327
 correlation analysis 326
 disease characteristics 326–327
 grip-force variation 329, 331

- grip-forces analysis to assess disease progression 329–331, **330**
- grip-forces impairment and disease severity 327–329, **328**
- neurophysiological analysis 326
- hydraulic force measurement 4
- hydrocephalus 343; *see also* idiopathic normal pressure hydrocephalus
- hypermetria 367, **368**
- hypo-activation 426, 427, **427**, 429, 434
- hypokinetic gait disorder 482, 483; *see also* idiopathic normal pressure hydrocephalus
- hypometria 317, 367
- hypotonia 369
- idiopathic normal pressure hydrocephalus (INPH) 482–484
 - cerebrospinal fluid shunting 486–488, **487**
 - disease characteristics 482
 - fMRI studies 483
 - Parkinsonism 483
 - upper limb hypokinetic deficits 484–486, **485**
- ILGM *see* Infant Learning to Grasp Model
- imagery, motor 412
- imaging *see* neuroimaging
- imitation 213–214; *see also* mirror neurons
- immobilization, focal hand dystonia therapy 473
- independent finger movements 236, 238–239
- inertial loads 371
- Infant Learning to Grasp Model (ILGM) **113**, 114–115, 117
- infant reaching, kinematic studies 236
- inferior parietal cortex (IPS) 86, 93
- inhibition
 - sensorimotor 469
 - surround 350, 356, 471
- inhibitory circuits, focal hand dystonia (FHD) 348, 352, 354–356, 471–472
- injury, brain/spinal cord 297; *see also* traumatic brain injury
- integration, sensorimotor *see* sensorimotor integration
- intentional factors 29, 99
- inter-finger connection matrices 44–45
- interhemispheric interactions 79; *see also* connectivity analysis
- internal models 118–119, 178, 205, 450; *see also* forward models; object representations; sensorimotor memory
 - carpal tunnel syndrome and force coordination 285–286
 - cerebellum 366–367, 371
 - children 244
 - complete deafferentation/sensory neuropathy 275
 - familiar loads 164–165
 - gait 221, 223, 227, 228, 230
 - grip-force coupling 118–119
 - object dynamics 163
 - predictive mechanisms 162–166, **167**
 - schizophrenia 390
 - sensory control of object manipulation 153, 156
 - transient somatosensory afferent perturbation 271
 - weight 73, 242, 244
- intersection 24
- intervention strategies, aging effects 251–252, 262; *see also*
 - focal hand dystonia therapy; functional neuromodulation; hand function training; hand sensorimotor dysfunction therapy; idiopathic normal pressure hydrocephalus; stroke therapy
- intracortical recording *see* cortical activity recording
- intraparietal sulcus 72
 - early imaging studies 85
 - fMRI studies 84, 85, 86, 89
 - grasp planning/execution 112
 - humans 112
 - macaques 112
- intrinsic coupling 429
- intrinsic optimality 120
- inverse model 163–164, 367; *see also* grasping control models
- IPS (inferior parietal cortex) 86, 93
- ipsilateral pathway 450
- isometric force pulses 4; *see also* grip forces analysis
- Jebsen–Taylor Test of Hand Function 442, 443, **443**, **444**
- Johansson and Westling grasping and lifting paradigm 6–9, 7
- joint coordination 369–371
- Kelvin rule 21
- Kennard principle 344
- kinematic/s; *see also* kinematic assessment of grasping
 - analysis 21–25
 - chains 209
 - constraints, precision grip points 201–202
 - electrophysiological recording 30
 - functional magnetic resonance imaging (*see* fMRI) 30
 - historical perspective 134–136, **135**
 - infant reaching 236
 - motion analysis 392–396
 - precision grip 340–342, **342**
 - prehension 271–272
 - reach-to-grasp movements 337–339
 - rehabilitation 416–417
 - transcranial magnetic stimulation 29
 - transient somatosensory afferent perturbation 271–272
 - traumatic brain injury 337–342, **339**, 342, **342**, 343
- kinematic assessment of grasping 20
 - absolute/relative reference systems 24
 - active markers 24
 - bimanual coordination 205–206
 - combining with other techniques 29, 30
 - DataGloves 25
 - definitions/conceptualizations 21
 - development of grasping 5, 8, 27, **28**
 - errors in marker-based systems 24
 - future research directions 29–30
 - hand pre-shaping 25–27, **26**, 27, 29
 - intentional/contextual factors 29

kinematic assessment of grasping (cont.)
 kinematic analysis systems 21–25
 kinematic studies review 25–29
 macaques 65–67, **66**; *see also* EMG activity, monkeys
 neuropsychology 27–29, **28**
 normal adults 25–27
 object properties 25, **26**, 99
 object size **26**
 optoelectronic techniques 22, **23**, 25
 passive markers 23–24
 primate studies 29
 sensors/detected variables 21
 social interactions 29
 stroke 299–302, **300**, **301**
 traumatic brain injury 333
 video-based systems 22
 kinesthesia, abnormal 350
 Klein–Vogelbach functional kinetics 409

 lateral sclerosis 280–281, 297
 lateralized dominance/lateralization 209–210, **212**, 213, 214
 learned non-use 443
 learning 119, 198, 363; *see also* development; internal models;
 memory; object representations
 LEDs (light emitting diodes) 24
 lesions 131–132, 185; *see also* somatosensory disorders; stroke
 anatomy 435
 cerebellum 362, 367
 idiopathic normal pressure hydrocephalus 483
 location 435
 peripheral sensory system 272–277
 plasticity, brain 426
 pyramidal tract 369
 size and functional outcomes 433
 somatosensory disorders 277–280
 traumatic brain injury 335
 virtual 74–77, **76**, 146, 185; *see also* TMS
 lesion studies, animal 269, 273, 355
 prehension characteristics 312
 primate 72–73, 106, 129–131, **130**, 186, 269
 levodopa-induced dyskinesias (LID) 458, 459–461,
461; *see also* Parkinson's disease
 deep brain stimulation 462–464, **463**, **464**
 hand sensorimotor dysfunction therapy 459–461,
461, 466
 levodopa test 458
 LFP (local field potentials) 54, 55–57
 LICI (long intracortical inhibition) 355
 lift-and-release actions
 BOLD signal 93
 neural correlates 93
 lifting and grasping 6–9
 aging/development studies 8; *see also* development
 friction 8

grip-force control 7–8, **7**
 load forces **7**, 8
 measuring device 6, **7**
 neurological diseases 9
 object movement 8, 9–12, **11**; *see also* sensory control of
 object manipulation
 shape 8
 light emitting diodes (LEDs) 24
 lips, tactile sensibility 142
 liver cirrhosis *see* metabolic tremor
 load force
 control, traumatic brain injury 343
 grasping and lifting **7**, 8
 /grip force coupling 118–119, 168–171
 memory representations 166
 local field potentials 54, 55–57
 locomotion, grip-forces analysis *see* dynamic grasp control
 long intracortical inhibition (LICI) 355
 lower motor neurons 406

 macaques **28**, 29; *see also* EMG activity monkeys
 anterior intraparietal area 72, 112, 120
 biphasic profile of finger movements 135–136
 intraparietal sulcus 112
 kinematic assessment of grasping 65–67, **66**
 M1 (primary motor cortex) 67–69
 reach-to-grasp studies 72–73
 ventral premotor cortex (PMv) 72
 magnetic fields 87
 magnetic gait disorder 483
 magnetic resonance imaging (MRI) scanning 334–335
 magnetic resonance spectroscopy 350–352, **351**, 355
 magnetoencephalography (MEG) 470
 maladaptation
 neural 426, 427, **427**, 429, 434
 plasticity 348, 352–354, **353**, 469, 471, 476
 manipulandum equipment 11–12
 manipulation; *see also* sensory control of object manipulation
 bimanual coordination 209, 213
 force 42, 43
 tasks 143–145, **144–145**
 Mann–Whitney U-tests 336
 manual dexterity *see* dexterity
 marker-based systems 23–24
 matrix of moment arms 38
 maximum grip aperture (MGA) 127–131, 132, 134–136
 measurement
 grasping and lifting 6, **7**
 impairment 405
 mechanical/hydraulic force 4
 mechanical digit force constraints 33, 43–45; *see also* finger
 enslaving; force deficit
 mechanical-reflex oscillations 377; *see also* physiological
 tremor

- mechanoreceptors 178
 medication 425, 429–431, **431**, 472; *see also* antipsychotic medication; dopaminergic medication; levodopa-induced dyskinesias
 MEG (magnetoencephalography) 470
 Meissner corpuscles 181–182, **182**
 memory 152, 161, 166, 198, 200; *see also* internal models; learning; object representations; sensorimotor memory
 MEPs *see* motor-evoked potentials
 Merkel ending complexes 181–182
 metabolic tremor 377–379
 clinical characteristics 377–378
 grasping movement interference 379
 pathophysiology 378–379
 meta-model 111, **111**; *see also* grasping control models
 methodology *see* cortical activity recording; digit forces; EMG activity; fMRI studies; grasping control models; grip forces; analysis; kinematic assessment of grasping
 methylphenidate 430
 MGA (maximum grip aperture) 127–131, 132, 134–136
 micro slips 241–242, 244
 micrographia 100
 microgravity 10
 Mini Mental Status examination 486, 487, 488
 mini-asterix *see* metabolic tremor
 minimum-jerk model 117
 minimum variance model 117
 mirror movements 206, 209
 mirror neurons 213–214
 mirror reflection training, stroke therapy 412
 mirrors 87
 mismatches, sensory 143, 151, 152–153, 156, 162; *see also* size–weight illusion
 models, digit contact 33–34; *see also* grasping control models; internal models
 Modular Selection and Identification for Control (MOSAIC model) 119
 monkeys **28**, 29; *see also* cortical activity recording; EMG activity; macaques
 anterior intraparietal area (AIP) 106, 116
 biphasic profile of finger movements 135–136
 brain circuits 110
 cerebellum 118, 364
 forced use of affected limbs 441
 grasping brain circuits 106
 hand pre-shaping 64–65
 lesion studies 106, 129–131, **130**, 186, 269
 motor cortex 106, 183
 muscimol 186
 object-specific grasp analysis 65–67, **66**, 67–69, **68**
 parallel distributed model of motor planning/execution 408
 plasticity, brain 353–354
 premotor cortex 106
 primary motor cortex 67–69, 106, 183
 reach-to-grasp studies 64–65
 rhesus 29
 skin/skin receptors 181–182
 ventral premotor cortex 89–91
 MOSAIC (Modular Selection and Identification for Control) model 119
 motor
 changes following stroke 426–428
 control 227–229, **228**, 235, 408
 cortex *see* primary motor cortex
 functions of hand 127
 imagery 412
 learning 363
 organization, hand 406–409, **406**, **408**
 programming 4
 reorganization 405, 406–409, **406**, **408**; *see also* functional neuromodulation; stroke therapy
 training 409, 473–477, **476**
 motor-evoked potentials 78
 focal hand dystonia 352, 354, 356
 predicting functional outcomes 434
 movement; *see also* dynamic grasp control; object movement;
 reach-to-grasp movements; transport
 bilateral 205
 execution module 115
 hand 110, 179, 183–185, 186; *see also* hand movement description, historical perspective
 induced artefacts 87, 88, 89
 observation, stroke therapy 412–413
 planning 363, **363**
 pointing 138
 preparation/execution 103
 selection 103
 training, stroke therapy 410
 velocity/frequency 105–106
 MRI (magnetic resonance imaging) scanning 334–335
 MUA (multi-unit activity) 54, 57
 multi-digit grasping 36–37
 arbitrary grasps 41
 biological/mechanical digit force constraints 33, 43–45
 carpal tunnel syndrome and force coordination 289–291, **289**, **291**, **292**
 grasp matrix 38–39
 internal forces 42–43
 non-vertical prismatic grasps 39–41, **39**
 prehension synergies 45–47, **46**
 vertically oriented prismatic grasp 37–38, **37**
 virtual finger 41–42
 multi-electrode recording techniques 53–54
 multimodal representations 116–117, 156
 multiple sclerosis 297
 multi-unit activity (MUA) 54, 57
 muscimol 185, **185**, 186

502

muscles, hand/arm
 aging effects 259
 antagonistic muscle contraction 180–181
 carpal tunnel syndrome and force coordination 287–288
 functional electrical stimulation 414
 Parkinson's disease, prehension characteristics 321
 precision grip 180–181
 stroke 298–299
 traumatic brain injury 343
 tremor *see* tremor
 musician's cramp 469, 470, 476, 477; *see also* focal hand dystonia
 myelination 120, 181

N dimensional muscle vectors (NDMV) 67
 nature–nurture debate 246, 348; *see also* neuronal group selection
 NDMV (N dimensional muscle vectors) 67
 nerve compression 10
 nervous system evolution 128
 neural connectivity, cerebral palsy 439, 445, 446–449, **448**
 neural correlates *see* brain circuits; grasping brain circuits
 neural networks, artificial 116
 neural noise hypothesis 311, 312, 321
 neural plasticity *see* plasticity
 neurocognitive rehabilitation 409
 neurohaptic control 178–179
 cerebellum 184–185
 motor cortex 183
 precision grip/antagonistic muscle contraction 180–181, 184–185
 prehension/exploratory hand movements 179–180
 premotor cortex 183–184
 skin/skin receptors 181–183
 somatosensory cortex 186–187, **187**
 tactile exploration 188–189, **188**
 neuroimaging 110, 434–435; *see also* diffusion tensor imaging; diffusion weighted imaging; fMRI studies; MRI; PET; SPECT
 focal hand dystonia 350–352, **351**, 355, 471
 grip-force coupling 118
 predicting functional outcomes 433–434
 stroke 303
 traumatic brain injury 334–335
 neurological control of hand 61, 63–64; *see also* grip force control
 neurological diseases 5–6, 9, 10; *see also* cerebral palsy; Huntington's disease; Parkinson's disease
 neurological soft signs (NSS) 390, 391, 399
 antipsychotic medication side effects 392
 kinematic motion analysis 392–396, **395**, **396**
 neuromodulation *see* functional neuromodulation
 neuro-motor control processes 227–229, **228**

Index

neuronal
 activation 187, **187**
 firing rate 87
 group selection 235, 240, 246
 shear-force sensitivity 187
 neuropathy
 artificially induced 288–289
 sensory 273–277, **274**, **276**
 neuroprosthetics 54; *see also* brain–computer interfaces
 neuropsychology 27–29, **28**
 neurostimulation 472–473; *see also* TENS; TMS
 neurotransmitters 429
 non-vertical prismatic grasps 39–41, **39**
 noradrenaline 429, 430
 NSS *see* neurological soft signs
 nuclear activity, cerebellar disorders 364–365
 null space 42

object affordances 113
 object dynamics 163
 object information/input module 115
 object manipulation, bimanual 210–213, **211**, **212**; *see also* development; sensory control of object manipulation
 object motion/movement 9–12
 control points 152–153
 grasping and lifting 8, 9–12, **11**
 grip-force control 8, 9–12
 neurological diseases 10
 object properties 134–136, 142, 151, 156, 165; *see also* fragility; shape; size; texture; unstable objects; weight
 haptic cues 200
 kinematic assessment of grasping 25, **26**, 99
 object representations 161; *see also* internal models; sensorimotor memory
 action/perception independence 171–174, **172**
 internal models 162–166, **167**
 memory 161
 neural basis of anticipatory grip-force adjustments 166–171, **170**
 object dynamics 163
 tactile feedback 162
 object-specific grasp analysis, monkeys 65–69, **66**, **68**
 occipital area 85
 occipito-parietal visual pathway 131–132, 134
 occipito-temporal visual pathway 131–132
 oculomotor deficits 367
 opposability/opposition xiii, 115–116, 134, 180
 optic ataxia 27, 138
 optoelectronic techniques
 kinematic assessment of grasping 22, **23**, 25
 primate studies 29
 traumatic brain injury 333
 orientational detection 260–261
 orthonormal basis vectors 42

- paired associative stimulation technique (PAS) 352
- paired pulse studies 78–81, **80**
- palmar grasp 136, 303
- parallel distributed model of motor planning/execution 407–409
- paresis/hemiparesis 296–297, 407
 - stroke 296–299, 413, 425
 - traumatic brain injury 343
- parietal cortex 229, 408, 426; *see also* cortical activity
 - recording
- Parkinsonism 392–396, **395**, **396**, 483; *see also* antipsychotic medication
- Parkinson's disease 27, 138, 229, 293
 - akinesia 459
 - bimanual coordination 209
 - fMRI studies 99, 100, 105
 - grip-force scaling 484–486
 - hand sensorimotor dysfunction therapy *see* hand sensorimotor dysfunction therapy
 - prehension characteristics *see* prehension characteristics
 - tremor *see* tremor in Parkinson's disease
- paroxetine 430
- PAS (paired associative stimulation technique) 352
- passive markers 23–24
- pathological adaptation *see* hypo-activation; maladaptive plasticity
- pathophysiology of grasping 136, 138, 206, 272; *see also*
 - carpal tunnel syndrome; cerebellar disorders; focal hand dystonia; Huntington's disease; Parkinson's disease; somatosensory disorders; schizophrenia; stroke; traumatic brain injury; tremor
- pen grip modification 475, **475**
- perceptive hand function *see* sensory function of hand
- perceptual impairment 470–471
- perceptual suppression 87
- PET (positron emission tomography) 85–86, 118, 350–352, **351**, 355
 - functional neuromodulation/reorganization 425, 426
 - motor changes following stroke 426
 - movement velocity/frequency 105–106
 - schizophrenia 392
 - supplementary motor area 86
- perturbations 136
- pharmacological interventions 425, 429–431, **431**, 472; *see also* antipsychotic medication; dopaminergic medication; levodopa-induced dyskinesias
- physiological basis of grasping xiii–xiv; *see also* aging effects;
 - bimanual coordination; development; dynamic grasp control; hand movement description; neurohaptic control; object representations; precision grip points; sensory control of object manipulation
- physiological tremor 375–377, **376**
 - clinical characteristics 375
 - grasping movement interference 377
 - pathophysiology 375–377, **376**
- physiotherapy, stroke 409
- pianist's cramp 349; *see also* focal hand dystonia
- pill rolling rest tremor 464
- pinch grip force amplitude 106
- plane of grasp 37
- plasticity 287, 344, 426, 431; *see also* functional neuromodulation
 - hand–arm bimanual intensive training 449
 - maladaptive 348, 352–354, **353**, 469, 471, 476
 - monkeys 353–354
 - primary motor cortex 407, 408
 - stroke 426
 - stroke therapy 413
 - synaptic 116
- plegia 296–297; *see also* stroke
- Plexon 53
- PMd *see* dorsal premotor cortex
- PMv *see* ventral premotor cortex
- point contact model 34
- pointing movements 138
- polyneuropathy 272–273
- positron emission tomography *see* PET
- posterior parietal cortex (PPC) 72, 74, 80, 81
 - early imaging studies 85
 - gait 229
 - mirror neurons 213
 - stroke 305–306
- postural/action tremor 383–385, **384**, **386**, 464–466
- power grip 4, 86, 128
- PPC *see* posterior parietal cortex
- practice effects 440–441, 444, 450
- precentral sulcus 431
- precision grip 4–5, 33, 128, 333; *see also* digit forces; precision grip points
 - antagonistic muscle contraction 180–181
 - cerebral activity 4–5
 - complete deafferentation/sensory neuropathy 274
 - cortical activity recording, monkeys 55
 - development 111, 114–115, 238
 - duration/rate/amplitude of force **101**, 103–106, **104**
 - EMG studies 4
 - evolution 179
 - fMRI studies 84, 85–86, 99–100, 103, 106–107
 - grip-force output selection 100–103, **101**, **102**
 - grip-load force decoupling 168–171
 - kinematic analysis 340–342, **342**
 - motor cortex 183
 - muscles, hand/arm 180–181
 - neuronal group selection 246
- precision-grip–lift paradigm 93–95
- precision grip points 193–195, 202
 - center of mass (CoM) 198
 - choosing/selection 193–194, **194**
 - cuboid **194**

- precision grip points (cont.)
 - cues, selection 198–200
 - definitions 194
 - directionality 201
 - and friction 194, **194**, 195–196, **196**
 - grasp/transport decoupling/independence 200–201
 - gripping 194–195
 - kinematic constraints 201–202
 - neurohaptic control 180–181, 184–185
 - object shape **194**
 - reach-to-grasp studies 200
 - sensorimotor memory 200
 - shape 194, 196–198, **197**
 - slip 189
 - stroke 201–202
 - torques (twist forces) 194, 198
 - weight distribution 198, **199**
- precision parameter 21
- prediction/predictive mechanisms 162–166, **167**; *see also* grip-
 - force scaling; internal models; object representations
 - bimanual coordination 207–208, **207**
 - control 244, 365, 394, 395
 - error 398
 - functional outcomes 433–434
 - object weight 152, 165
 - sensorimotor 145, 151, 155
- prehension 99–100, 128, 180; *see also* grasp/grasping; grip
 - apertures; prehension characteristics; prehension components; reach-to-grasp movements; transport
 - cerebral palsy 439–440
 - complete deafferentation/sensory neuropathy 274–275
 - definition 235
 - development 27, 236–238, **237**
 - evolution 179
 - hand pre-shaping 134
 - kinematics 271–272
 - neurohaptic control 179–180
 - synergies 45–47, **46**
 - transient somatosensory afferent perturbation 271–272
 - visual cues 274–275
 - visual feedback **135**
 - visuomotor channels 131–132
- prehension characteristics, Parkinson's disease 311–313, 320–321
 - basal ganglia dysfunction 311, 312, 318, 320
 - daily functioning and grasping ability 311
 - grasp control 316–317
 - lesion studies, animal 312
 - neural noise hypothesis 311, 312, 321
 - off medication state 314
 - prehension components 313–314, **313**
 - transport control 315–316, **315**
 - transport/grasp coordination, temporal/spatial measures 315–316, 317–320, **318, 319**

- prehension components **129**, 179, 205, 235
 - development 131
 - historical perspectives 128, 131–132
 - Parkinson's disease 313–314, **313**
 - temporal/spatial measures 314
- premotor cortex 105
 - fMRI studies 91
 - grasp planning/execution 112
 - grasping behaviors 106
 - hand movements 183–184
 - monkeys 106
 - motor changes following stroke 426, 427
 - neurohaptic control 183–184
- primary motor cortex 105, 184; *see also* transcranial magnetic stimulation study
 - bimanual coordination 206–207
 - connectivity in motor system following stroke 428
 - focal hand dystonia 355
 - grasp planning/execution 112
 - hand function, motor organization 406–409, **406, 408**
 - hand movements 183
 - hypo-activation 434
 - idiopathic normal pressure hydrocephalus 483
 - lift-and-release actions 93
 - monkeys 67–69, 106, 183
 - motor changes following stroke 426, 427
 - neurohaptic control 183
 - plasticity 407, 408
 - positron emission tomography 86
 - precision grip 183
 - rest tremor 382–383
 - shear forces 183
 - stroke 297
 - transcranial magnetic stimulation 73–74, 431
- primary motor cortex
- primates; *see also* macaques; monkeys
 - adaptations 178–179
 - anterior intraparietal area (AIP) 89
 - evolution 179
 - fMRI studies 87
 - focal hand dystonia (FHD) 469, 471
 - hand pre-shaping 29
 - kinematic assessment of grasping 29
 - lesion studies 72–73
 - optoelectronic techniques 29
 - reach-to-grasp studies 72–73, 85
- principle of superposition 46
- prismatic pinch grasps 36, **37**; *see also* multi-digit grasping
- probing strategy, infant 242, 243
- procedural memory 152
- prognostic factors 433–434
- proprioceptive neuromuscular facilitation 409
- proprioceptors 141, 142–143, 155, 180, 270
- prosthetics 120; *see also* brain–computer interfaces

- psychophysics of force perception 4
 psychosocial deficits, traumatic brain injury 344
 PTNs (pyramidal tract neurons) 67–69, **68**
 Purdue Pegboard Test 251, 333, 336, 341, 342
 putamen 101, 104, 229
 connectivity in motor system following stroke 429
 force duration 106
 force pulse amplitude 103
 gait 229
 grip-forces analysis 100, 103
 movement preparation/execution 103
 movement velocity/frequency 105–106
 role in grasping 99
 pyramidal tract lesions 369
 pyramidal tract neurons (PTNs) 67–69, **68**

 radio-frequency noise 87
 rat studies 355
 rCBF (regional cerebral blood flow) 85, 86, 105–106
 reach-to-grasp movements 25, 99–100; *see also* kinematic
 assessment of grasping; prehension
 adults 236
 bell-shaped distribution 314
 dorsal premotor cortex 78–81, **80**
 fMRI studies 84, 89–93, **92**
 humans 72
 infant reaching, kinematic studies 236
 kinematic analysis 337–339, **339**, **340**
 macaques 72–73
 monkeys 64–65; *see also* EMG activity, monkeys
 motor control 235
 neural correlates 74–81, **76**, **80**
 paired pulse studies 78–81, **80**
 postural/action tremor 383
 precision grip points 200
 primate studies 72–73, 85
 stroke 305–306
 temporal coupling 301, **301**
 transcranial magnetic stimulation study 77–78
 virtual lesions 74–77, **76**
 visual cues 238
 reactive control 394, 395
 reboxetine 429–430
 recording methodology, cortical activity recording, monkeys
 52–54
 recovery 302–303, 344–345; *see also* therapy
 re-entry signaling 246
 reference points, absolute/relative 24
 reflexes 165, 169
 grasp 236
 grip-force responses 245
 manipulation 244–246
 oscillations 377; *see also* physiological tremor
 smart 143

 regional cerebral blood flow (rCBF) 85, 86, 105–106
 rehabilitation; *see also* functional neuromodulation;
 intervention strategies; stroke therapy; therapy
 fMRI studies 416–417
 kinetic aspects of grasping 416–417
 neurocognitive 409
 release movements 303
 reorganization, corticospinal tract 450; *see also* functional
 neuromodulation
 repetitive
 motor training 409
 movements 348; *see also* focal hand dystonia
 peripheral nerve stimulation 415–417, **415**, **417**, **418**
 transcranial magnetic stimulation (rTMS), stroke therapy
 415–417, **415**, **417**, **418**, 428; *see also* TMS
 representations, internal *see* object representations; *see also*
 internal models
 resection 24
 resolution parameter 21
 resting tremor 382–383, 464
 rhesus monkeys 29
 rigidity 483
 robotic-assisted training 413
 robotics 46, 114, 161, 163, 207
 rodent studies 131
 roll, object 259–260
 rostro-caudal gradient 102–103
 rough surfaces 242; *see also* friction; texture
 rTMS (repetitive transcranial magnetic stimulation) 415–417,
 415, **417**, **418**, 428; *see also* TMS

 saccades 153
 saccadic suppression 74
 safety margins 35–36, 135, 242, 273, 460
 sarcopenia 250
 schema model of grasp planning 112, 117, 136; *see also* FARS
 model
 schizophrenia 390, 399; *see also* antipsychotic medication
 awareness of action impairment 396–397, 398
 dopaminergic systems 391, 392
 grip-force control/scaling 393–396
 internal models 390, 398
 kinematic motion analysis 392–396, **395**, **396**
 positron emission tomography (PET) 392
 theoretical considerations 398
 tremor 391
 secondary normal pressure hydrocephalus 482
 self care *see* daily functioning
 self-monitoring, voluntary action 396–397, 398
 sensor matrices 13, **14**
 sensorimotor control; *see also* sensory control of object
 manipulation
 anticipatory grip-force scaling 93
 dexterity, human 93–95

sensorimotor control (cont.)
 fingertip forces 95
 fMRI studies 93–95, **94**
 loop delays 145, 150, 152, 155
 points 143
 precision-grip–lift paradigm 93–95
Sensorimotor Control of Grasping, structure of book xiv
 sensorimotor cortex 427
 sensorimotor coupling 365–366
 sensorimotor discrimination training 413–414
 sensorimotor dysfunction therapy *see* hand sensorimotor dysfunction therapy
 sensorimotor integration
 cerebellum 365
 and focal hand dystonia 348, 350–352, **351**, 469, 470–471
 sensorimotor memory 152, 165–166, 200, 285–286, 293; *see also* internal models; object representations
 sensorimotor predictions 145, 151, 155
 sensorimotor representations *see* object representations; *see also* internal models
 sensors (detected variables) 21
 sensory control of object manipulation 141, 155–156; *see also* sensorimotor control; visual cues/feedback
 accidental slips 151–152
 development 241–246, **243**, **245**
 grasp stability control points 148–150, **149**
 manipulation tasks, contact events/action goals 143–145, **144–145**
 object motion control points 152–153
 object shape 150
 sensorimotor control loop delays 145, 150, 152, 155
 sensory systems 141–143, **144–145**
 tactile contact responses 146–148, **147**, 150–151
 tactile control points 145–146, 155
 visual predictions/control points 153–155, **154**
 sensory cortex (SI) 74, 85, 365
 sensory disorders 348; *see also* focal hand dystonia; somatosensory disorders
 sensory function of hand xiii, 61, 127, 161, **254**
 effects of aging 258–261, 262
 tactile sensibility 142; *see also* skin receptors
 sensory neuropathy 273–277, **274**, **276**
 sensory plans 143
 sensory processing abnormalities 470–471
 sensory systems 141–143, **144–145**
 sensory training programs 473–477, **476**
 SEP (somatosensory evoked potentials) 350
 serotonin 429
 Shannon–Nyquist theorem 21
 shape 142, 148–150, 156, 165; *see also* object properties
 exploration paradigm 84–86
 and grasping and lifting 8
 precision grip points 194, **194**, 196–198, **197**
 non-symmetric 199

 sensory control of object manipulation 150–151
 shear forces 183, 187, **187**
 short intracortical inhibition (SICI) 355
 shuffling 483
 S1 (sensory cortex) 74, 85, 365
 SICI (short intracortical inhibition) 355
 side effects, medication *see* antipsychotic medication; dopaminergic medication; levodopa-induced dyskinesias
 signals, decoding 54–58, **56**
 single-digit contacts forces 33–36
 single electrode recording techniques 4–5, 53
 single neuron spiking activity (SUA) 54–55
 single-photon emission computerized tomography (SPECT) 344
 six-degrees-of-freedom sensors 9, **252**, 253–256
 size **26**, 134–136, 142, 165; *see also* object properties
 size–weight illusion 171–174
 skin
 markers 24
 movement artefacts 24
 receptors 141–143, **144–145**, 178, 181–183, 270
 slips
 accidental 151–152
 micro slips 241–242, 244
 neuronal activation 187, **187**
 precision handling 189
 prevention, digit forces 34–36
 surface 179, 242; *see also* friction, texture
 slowing *see* bradykinesia; *see also* aging effects
 SMA *see* supplementary medial area
 smart reflexes 143
 social interactions 29
 soft-finger contact 34, **35**
 somatosensory cortex 186–187, **187**
 somatosensory disorders 269–270, 280–281; *see also* carpal tunnel syndrome; cerebral palsy; stroke
 central lesions 277–280
 complete deafferentation/sensory neuropathy 273–277, **274**, **276**
 grip-force control 272–273
 pathology 272
 peripheral sensory system lesions 272–277
 polyneuropathy/carpal-tunnel syndrome 272–273
 transient somatosensory afferent perturbation 270–272, **272**
 traumatic nerve injury 273
 somatosensory evoked potentials (SEP) 350
 somatosensory feedback 162, 285, 286, 302
 somatotopy 407
 spatial discrimination 348; *see also* sensorimotor integration
 SPECT (single-photon emission computerized tomography) 344
 spinal cord injury 297; *see also* traumatic brain injury
 spiral dynamics concept 409
 spring compression measures 3, 239

- SSRIs (selective serotonin reuptake inhibitors) 430
- stable object manipulation/lifting 239–240, **241**
- stereophotogrammetry 21, 24
- stereotyped movements 348; *see also* focal hand dystonia
- stick diagrams 22
- stick-slip stretching 182, 183
- strain gauges 3
- strength–dexterity test 239
- strength training 410–411
- stroke 27, 199, 269, 296, 306; *see also* lesions; somatosensory disorders; stroke therapy
 - cingulate motor area (CMA) 427
 - daily functioning and grasping ability 304–305, **305**
 - general information 296–297
 - kinematic assessment of grasping 299–302, **300, 301**
 - paresis/hemiparesis 296–299, **298**
 - posterior parietal lobe damage 305–306
 - precision grip points 201–202
 - recovery of grasping 302–303
- stroke therapy 405–406, 417–419; *see also* functional neuromodulation
 - bilateral training 411, 412
 - constraint-induced movement therapy 409–410
 - feedback-based training 411
 - functional electrical stimulation 414
 - mirror reflection training 412
 - motor imagery 412
 - motor reorganization/recovery 405, 406–409, **406, 408**
 - movement observation 412–413
 - movement training 410
 - physiotherapy concepts 409
 - repetitive motor training 409
 - repetitive peripheral nerve stimulation 415–417, **415, 417, 418**
 - repetitive transcranial magnetic stimulation **415, 417, 418**
 - robotic-assisted training 413
 - sensorimotor discrimination training 413–414
 - strength training 410–411
 - telerehabilitation 412
 - transcranial direct current stimulation 415–417, **415, 417, 418**
 - virtual reality training 411–412
 - visual feedback 412
- stuttering phase transitions 145, 156
- SUA (single neuron spiking activity) 54–55
- subcortical structures 208–209
- subgoals, hand 209–210
- substantia nigra 229, 251, 312
- subthalamic nucleus (STN) 99, 100, 101, 104–106
 - grip-forces analysis 103
 - movement velocity/frequency 105
 - pinch grip force amplitude 106
- superior parietal cortex 229
- superior temporal gyrus 413
- supplementary medial area (SMA) 184
 - bimanual coordination 206, 209
 - connectivity in motor system following stroke 428
 - motor changes following stroke 426, 427
 - parallel distributed model of motor planning/execution 407–408
 - stroke therapy 413
 - transcranial magnetic stimulation 431
- supplementary motor area 86
- supramarginal gyrus 86, 413
- surface slip 179
- surround inhibition 350, 356, 471
- symmetric/asymmetric movements 205, 206, 209, 212, 214, 223
- synaptic
 - activity levels 86
 - connectivity 246; *see also* neuronal group selection
 - plasticity 116; *see also* plasticity
- synchronous firing 57–58
- synergy
 - grip–lift 239–240, 241, 242, **243**
 - prehension 45–47, **46**
- tactile
 - afferents 146–148, 150–151, 155, 259
 - contact responses 146–148, **147**, 150–151
 - control points 145–146, 155
 - cues 200; *see also* haptic cues
 - exploration 179, 188–189, **188**
 - feedback 162; *see also* somatosensory feedback
 - sensation loss 186
 - sensibility 142
 - shape exploration paradigm 84–86
- tangential forces 186
 - aging effects 260
 - detecting 183
 - friction 188, **188**
 - neuronal activation 187
 - /normal force ratio 35
- tangential loads 148
- task-related motor behavior 239
- task-specificity 65, 349
- TBI *see* traumatic brain injury
- tDCS (transcranial direct current stimulation) 415–417, **415, 417, 418**
- telemetry systems, wire-free 63
- telerehabilitation 412
- temporal
 - coupling 301
 - discrimination, disordered 348; *see also* sensorimotor integration
- TENS (transcutaneous electrical stimulation) 472–473
- texture, surface 156, 180, 183, 242; *see also* friction; object properties

thalamo-cortical coupling 378
 thalamus 105, 365, 427, 431
 therapy of impaired grasping *see* focal hand dystonia therapy;
 functional neuromodulation; hand function training; hand
 sensorimotor dysfunction therapy; idiopathic normal
 pressure hydrocephalus; stroke therapy
 Thomas Recording 53
 threshold position control paradigm 227
 thrombolysis 425
 TMS (transcranial magnetic stimulation) 72–73; *see also* rTMS
 anterior intraparietal area virtual lesions 74–77, **76**
 bimanual coordination 206
 cerebral palsy 439
 focal hand dystonia 352, 353, 354, 356
 focal hand dystonia therapy 471, 473
 grip-force scaling 73–74, 76–77
 kinematics 29
 M1 (primary motor cortex) 73–74
 paired pulse studies, PMd involvement 78–81, **80**
 predicting functional outcomes 434
 reach-to-grasp premotor involvement 77–78
 supplementary medial area/thalamus 431
 virtual lesions 146
 tongue 142
 tool use xiii
 torques (twist forces) 148, 198, **199**
 precision grip points 194, 198
 sensors 9
 tracking studies 5–6
 training/practice effects 250, 251–252
 trans-cortical loop 246
 transcranial direct current stimulation (tDCS) 415–417, **415**,
 417, **418**
 transcranial magnetic stimulation *see* TMS; *see also* TMS
 transcutaneous electrical stimulation (TENS) 472–473
 transient anesthesia 269, 270; *see also* somatosensory disorders
 transient somatosensory afferent perturbation 270–272,
 272; *see also* sensory control of object manipulation
 transport; *see also* dynamic grasp control; movement
 Parkinson's disease 315–316, **315**, 317–320, **318**, **319**
 prehension components 314
 traumatic brain injury (TBI) 297, 333, 342–345
 Brunnstrom Stages of Recovery 343
 children/adolescents 333
 cognitive/psychosocial deficits 344
 computerized tomography scanning 334–335
 Developmental Hand Function Test 336
 disease incidence/severity 333–335, **335**
 fMRI studies 344
 hand function testing 334–335, 336–337, **337**
 imaging studies 334–335
 kinematic analysis 337–342, **339**, **340**, **342**
 kinematic analysis limitations/advantages 342, 343
 load force control 343

Mann–Whitney U-tests 336
 muscles of arm/hand 343
 paresis/hemiparesis 343
 precision grip, kinematic analysis 340–342, **342**
 Purdue Pegboard Test 336
 reach-to-grasp movements, kinematic analysis 337–339,
 339, **340**
 recovery 344–345
 single-photon emission computerized tomography 344
 slowing 336
 Wilcoxon tests 336
 traumatic nerve injury 273
 tremor 367–369, 375, 385–387
 action 383–385, **384**, **386**, 464–466
 cerebellar disorders 371
 essential *see* essential tremor
 idiopathic normal pressure hydrocephalus 483
 metabolic *see* metabolic tremor
 Parkinson's disease 459; *see* tremor in Parkinson's disease
 physiological *see* physiological tremor
 resting 382–383, 464
 schizophrenia 391
 tremor in Parkinson's disease 380, 381–385, 459
 clinical characteristics 381–382
 grasping movement interference 385, 464–466, **465**
 hand sensorimotor dysfunction therapy 464–466, **465**
 pathophysiology 382–385
 postural/action tremor 383–385, **384**, **386**
 rest tremor 382–383
 trial and error learning 115; *see also* development of grasping
 triggered corrections 244–246, **245**
 Turing machine 119
 twist forces *see* torques
 two-visual systems model 131
 ultrasound motion analysis 392
 Unified Huntington's Disease Rating Scale (UHDRS) 326,
 329, 394, 466
 limitations 326–327
 unstable objects, manipulation 236, 239, **240**
 upper limb hypokinetic deficits 484–486, **485**
 upper motor neurons 406
 urinary incontinence 482, 483
 variable grip forces
 aging effects 261, 262
 attention deficits 343
 carpal tunnel syndrome 293
 cerebellar disorders 371
 cerebral palsy 343
 Huntington's disease 329, 331
 hydrocephalus 343
 Parkinson's disease 316, 321
 schizophrenia 394

- stroke 299, 411
- traumatic brain injury 343
- velocity, gait 219, 230
- velocity profiles 235, 242, 243–244, 246
- ventral cingulate sulcus (CMAv) 184
- ventral premotor cortex (PMv) 72, 184
 - early imaging studies 85
 - fMRI studies 84, 85, 86, 89–91
 - macaque homolog 72
 - mirror neurons 213
 - monkeys 89–91
 - parallel distributed model of motor planning/execution 407–408
 - reach-to-grasp premotor involvement 77–78
 - stroke therapy 413
- ventral visual pathway 131–132
- vertically oriented prismatic grasp 37–38, **37**; *see also* multi-digit grasping
- video-based systems 22, 99; *see also* cinematographic method
- virtual finger 41–42, 116
- virtual lesions 74–77, **76**, 146, 185; *see also* TMS
- virtual reality training 411–412
- visual cues/feedback
 - anticipatory control 244
 - carpal tunnel syndrome 285
 - complete deafferentation/sensory neuropathy 274–275
 - development 114
 - grip–inertial force coupling 225
 - memory representations 200
 - object weight 165
 - Parkinson's disease 317, 318
 - precision grip points 194
 - prehension **135**, 274–275
 - reach-to-grasp movements 114, 238, 338, 339
 - sensory control of object manipulation 141, 153–155, **154**
 - stroke 277, 302, 305–306, 412
- visual suppression 135
- visuomotor
 - behavior studies 138
 - channels 131–132
 - transformation 134
- walking *see* dynamic grasp control
- weight 142, 143; *see also* object properties; size–weight illusion
 - adaptation 242–244
 - anticipatory grip–force scaling 93
 - fMRI studies 86
 - haptic cues 200
 - internal representations 73, 242, 244; *see also* internal models; object representations
 - precision grip points 198, **199**
 - predicting 152, 165
 - visual cues 165
- Wheatstone Bridge circuit 3
- Wilcoxon tests 336
- Wolf Motor Function Test 304
- wrench 41
- writer's cramp 13, **349**, 469–470, 476–477; *see also* focal hand dystonia (FHD)
- writing analysis 12–13, **14**, 393