Central Nervous System
Brain & Spinal Cord

1874 – 1st experiments on electrical stimulation of the brain
early 50’s – Hess: pioneering studies on electrode stimulation of cat brain
1953 – Olds: discovery of rat’s pleasure center

CNS
begins as a fold in epidermis of embryo in 1st few weeks of development
this develops into brain and spinal cord
brain develops very rapidly during 1st few years of life
growth due mainly to:
1. increase in size of neurons cells already present
2. proliferation and growth of neuroglial cells
also get development and refinement of synaptic contacts
myelination of various fiber tracts

Brain
one of largest organs in body:
men: 1,600 g (3.5 lbs)
women: 1,450g (3.2 lbs)
[brain size is proportional to body size not intelligence
→ Neanderthals had larger brains than us!!]
early thoughts on function of brain:
ancient Greeks weren’t particularly impressed with the brain
where snot was generated
cooling device for blood
most neurons divide only during prenatal development and a few months after birth

Some General Terminology for CNS:
one of the most obvious feature of the surface of the brain are the folds:
gyri = raised areas
sulci = fissures between the gyri
-found in the cerebrum and the cerebellum
gray matter = thin myelin; mostly cell bodies
dendrites & synapses
-outer layer of brain = cortex
-inner layer of spinal cord
-nuclei: small areas of gray matter deeper inside the brain
white matter = thick insulation; mostly axons
-inner layers of brain: nerve tracts = bundles of axons that interconnect various parts of the brain
-outner layer of spinal cord

The Brain is Subdivided Into:
1. Cerebral Hemispheres (60% of brain mass)
   - “human” part: thought, creativity, communication
2. Diencephalon moods, memory, manages internal environment
epithalamus
thalamus
hypothalamus
after that they increase in size, but not numbers
one of most metabolically active organs in body
comprises only 2% of total body weight it yet
→ gets 15% of blood
→ consumes 20% of our oxygen need at rest
   (more when mentally active)
   blood flow and O₂ increase to active brain areas
1-2 min interruption of blood flow may impair brain cells
>4 min w/o oxygen → permanent damage
besides O₂ must get continuous supply of glucose
very little in reserve
decrease in glucose:
dizziness
convulsions
unconsciousness
one of the brain’s most impressive features is it’s ability to store information:
compared to computer memory one estimate of the brain’s storage capacity based in number of neurons and number of synapses is 1 Million Gigabytes
→ the equivalent of ~3 million hours of DVD images

3. Cerebellum – coordinating movement and balance
4. Brain Stem – oldest and smallest region, basic bodily functions = vegetative functions
midbrain
pons
medulla

Brain Stem
1. Medulla
lowest portion of brainstem
continuous with the spinal cord
all ascending and descending tracts from spinal cord and brain = white matter
most tracts cross over as they pass through the medulla
helps control several vital functions
→ contains important autonomic reflex centers
cardiac reflex center
rate and force of heartbeat
vasomotor control center
controls diameter of blood vessels
controls the distribution of blood to specific organs
controls blood pressure
respiratory center
regulates the rate and depth of breathing
polio especially affects this center in medulla → resp failure (iron lungs)

also contains many nonvital reflex centers (nuclei):
speech
swallowing
vomiting
coughing
sneezing
hiccuping
sudden contractions of diaphragm
often caused by overeating and carbonated beverages
babies hiccup in womb
may be a reminder that ancient ancestors had gills (primitive reflex) → useful to many amphibians because it stops water getting into their lungs
also the process of movements during suckling is very similar to hiccups

several pairs of cranial nerves have nuclei in medulla:
VIII – vestibulocochlear
IX – glossopharyngeal
X – vagus
XI – accessory (head and shoulder movements)
XII – hypoglossal (tongue movements)

2. Pons
just above medulla
bridge connecting spinal cord with brain and parts of brain with each other
contains 2 centers that help to regulate breathing → pneumotaxic center

→ apneustic center
also contains nuclei that affect sleep and bladder control
contains nuclei for several cranial nerves:
V. Trigeminal - chewing and head and face sensations
VI. Abducens - eyeball movements
VII. Facial - taste, salivation, facial expression
VIII. VC nerves - equilibrium

3. Midbrain
in the form of 4 lobes above and behind pons = Corpora Quadrigemina

upper 2 lobes = Superior Colliculi
control center for some visual reflexes:
  a. pupillary reflex
  b. reflex centers for coordinating eye movement with head and neck movement in response to visual stimuli

lower two lobes = Inferior Colliculi
control center for some auditory reflexes:
  a. reflex centers for movements of head and trunk in response to auditory stimuli to locate sound

also contains:
red nuclei → helps with fine motor control
substantia nigra → suppresses unwanted muscle contractions

Parkinsons Disease
progressive loss of motor function
begins in 50's or 60's
can be hereditary
due to degeneration of dopamine releasing neurons in substantia nigra (inhibitory neurons)
leads to hyperactivity of basal nuclei and involuntary muscle contractions
results in shaking hands, facial muscles become rigid, range of motion decreases
develops smaller steps, slow shuffling gait with forward bent posture and a tendency to fall forward
speech becomes slurred, handwriting illegible

diffuse system of interconnecting fibers extending through several areas of brain including brain stem
- comprises a large portion of entire brainstem
- extends into spinal cord and diencephalon
- interlacing of gray and white matter

Functions of RAS - both sensory and motor

1. Sleep and consciousness
maintains consciousness and awakens from sleep → alarm clock
barbiturates depress RAS, decrease alertness & produce sleep
amphetamines stimulate RAS producing wakefulness
general anesthetics may produce unconsciousness by depressing RAS
falling asleep may be caused by specific neurotransmitters that inhibit RAS

2. helps control muscle tone, balance and posture during body movements

3. filters flood of sensory input (=habituation)
highlights unusual signals; disregards rest (99%)
LSD interferes → get flood of sensory stimuli
**Diencephalon**

1. **Epithalamus**
   - includes roof of 3rd ventricle
   - mainly pineal gland

2. **Thalamus**
   - 4/5ths of diencephalon
   - 1.2” long
   - forms lateral walls of 3rd ventricle
   - mainly a sensory relay center
     - “Rome of the Nervous System” or “gateway to cerebral cortex”
     - main relay station for sensory impulses that reach cerebral cortex from spinal cord, brain stem and cerebellum
     - eg. taste, touch, heat, cold, pain, some smell
     - the only sensory signals that can reach the cortex without going through the thalamus are for sense of smell

3. **Hypothalamus**
   - part of the brain most involved in regulating internal environment
   - no blood brain barrier
   - forms floor and part of lateral walls of 3rd ventricle
   - a. link between “mind” and “body”
     - controls and integrates activities of autonomic NS
     - means by which emotions express themselves by altering body functions
     - role in psychosomatic illnesses
   - b. relays reflexes related to smell
   - c. manufactures and transports releasing hormones that control the “Master Gland”
     - anterior pituitary
   - e. regulates body temperature
     - has receptors that monitor blood temperature
   - f. regulates food and water intake
     - has receptors that monitor osmotic pressure
     - thirst center
   - other receptors monitor some hormone concentrations in blood

4. **Limbic System**
   - diencephalon is a main part of a diffuse group of structures called the Limbic System
   - includes thalamus, hypothalamus, hippocampus, midbrain, amygdala (cerebrum), mammillary body (relay center from limbic system to thalamus), fornix (connects hippocampus to mammillary body of hypothalamus)
   - = the emotional brain
   - limbic system perception & output is geared mainly toward the experience and expression of emotions
     - eg. pain, anger, fear, pleasure
   - continuous back & forth communication between limbic system and frontal lobes of cerebrum
   - much of the richness of your emotional life depends on these interactions
   - outward expression of these emotions requires participation of the hypothalamus

   all sensory impulses are shunted through the limbic system
   - smell is directly wired to limbic system
     - goes straight to amygdala (“the gateway to the limbic system”)
     - in lower animals smell is closely tied to territorial behaviors, aggression, sexuality
   - produces a crude appreciation of some sensations; eg. pleasure, fear, anger, pain
     - but can’t distinguish their location or intensity
   - eg. contains pleasure center
     - -rats pressing bar for stimulation of pleasure center
       - ignore sleep, food, water, sexual partners
       - continue until exhausted (50-100x’s/min)
       - willing to cross electrified grid to seek reward (420 µamps vs 60-180 µamps for food)
     - in humans stimulates erotic feelings
   - opioids and endorphins are concentrated in limbic pathways
   - is site of action of many addictive drugs
a few who lack the amygdala, part of the limbic system have no sense of fear

Cerebellum
2nd largest part of brain
just below and posterior to cerebrum
only other part of brain that is highly folded
consists of 2 hemispheres
grey matter outside
white matter inside

= **arbor vitae** (tree of life)

**Functions of Cerebellum:**
helps to coordinate voluntary muscles:
but does not send impulses directly to muscles
1. acts with cerebrum to **coordinate different groups of muscles**
   smooths and coordinates complex sequences of muscular activity needed for body movements
2. controls skeletal muscles to **maintain balance**
   receives input from proprioceptors in muscles, tendons and joints and equilibrium receptors and eyes

3. **learning and storing motor skills**
   eg. playing musical instrument, riding a bike, typing, etc
4. recent research indicates that the cerebellum also has roles in awareness, emotion and judging the passage of time
diseases of cerebellum produce **Ataxia**
   eg. tremors
   speech problems
difficulty with equilibrium
   NOT paralysis

Cerebral Hemispheres
largest portion of brain (~60% of brain mass)
two hemispheres joined by tracts = **corpus callosum**
heavily convoluted: **gyri** and **sulci**
folding allows greater area of cortex in smaller space (area = 2,500 cm² = area of 4.5 textbook pages or 1 keg of beer)
also has larger grooves (= **fissures**) that divide each hemisphere into 4 main regions named after the bones they lie under:
1. **frontal**
2. **parietal**
3. **occipital**
4. **temporal**
each hemisphere:

a. **outer gray matter** = cerebral cortex (2-4mm)
b. **inner white matter** = **tracts**
   → bundles of myelinated axons
c. **nuclei** = islands of gray matter in interior of brain
   → cell bodies and sometimes dendrites
   eg. basal nuclei (=basal ganglia)
clusters of gray matter around thalamus (5) help direct movements
overactivity due to lack of dopamine produces Parkinson’s disease
hemispheres connected by nerve tracts in corpus callosum

Function of Cerebral Cortex:

neurons of cortex are arranged into a highly organized, radial array of 6 cellular layers (=neocortex)

→ differ in composition
→ functional properties
→ sets of connections

cortex has been systematically subdivided into >40 functionally distinct areas

cortex is responsible for our most “human” traits

conscious mind
abstract thought
memory
awareness

→ most of these will be discussed later under integration

A. on simplest functional level, the cerebral cortex contains:

→ repository of language
→ processes many aspects of language: syntax, semantics, etc
→ also analytical skills, math, logic

Right Hemisphere:

1. mainly concerned with visuospatial tasks
2. nonverbal communication: interprets more subtle aspects of language - metaphor, allegory, ambiguity
3. also concerned with emotions, intuition
4. global holistic aspects of sensory processing

eg. does reality checks of new information
eg. holistic aspects of vision

→ “reading” facial expressions
→ recognize faces

there appears to be a gender difference in brain lateralization

males process spatial tasks in right hemisphere by 6 yrs of age
females spatial function is equally developed in both hemispheres until age of 13

→ damage to rt hemisphere in childhood impairs language devel in male more than females

Hemispheric Dominance:
lateralization as described is true for 97% of all people

for ~90% of these people

→ traits characteristic of the left hemisphere are dominant
→ more verbal, analytical
→ all are right handed

for 7% of these people

→ traits characteristic of right hemisphere are dominant
→ visuospatial tasks
→ these are left handed
→ more likely to be males

for 3% of population functions are shared = bilateral (no dominance)
lateralization is reversed or reduced in bilateral folks
→ often ambidextrous
→ sometimes leads to confusion and dyslexia

C. Lobes of the cerebrum

fissures divide each hemisphere into 4 regions, each with a specific set of functions:

1. frontal personality
control of voluntary movement
2. **parietal**
   touch, stretch
   perception of somatic sensations

3. **occipital**
   processing of vision

4. **temporal**
   processing of sound and speech
   awareness of equilibrium

1. **Frontal (=& prefrontal)**
   **Prefrontal:**
   elaboration of thought
   intelligence
   motivation
   personality
   abstract ideas
   judgement
   planning
   "civilizing behaviors"
   **damage:**
   wide mood swings
   loss of attentiveness
   become oblivious to social constraints
   careless about personal appearances
   **prefrontal lobotomy**
   reduced anxiety
   but lost initiative
   had mood swings

   **Frontal**
   motor processing areas:

   a. **Somatic Motor Cortex**
      (Primary Motor Area)
      contralateral control
      directs conscious individual muscle contractions
      large body zones → homunculus
      within each zone: neurons that control specific movements are scattered as combinations of muscles are arranged in useful ways
      damage causes paralysis
      but: cats can walk when cerebral cortex has been removed
      monkeys w/o primary motor cortex can be trained to make many types of movement

   b. **premotor cortex**
      coordinates groups of muscles
      not individual muscles
      if damaged person has trouble eg typing, tying shoes
      loose learned series of movements eg typing

   c. **Olfactory Cortex**
      conscious awareness of taste stimuli

2. **Parietal Lobe**
   sensory processing areas
   a. **primary sensory (somatosensory) cortex**
      receives information from skin sensors
      when stimulated patient reports "feeling" in some part of body
      muscle, tendon and joint sensations, and touch provides feedback to motor cortex
      spatial discrimination
      motor and sensory cortex, like other areas are malleable
      eg. learning Braille
      the area representing touch in the finger used in somatosensory cortex expands into areas previously devoted to neighboring fingers
   b. **somatosensory association**
      integrates and analysis of skin sensors:
      touch, pressure, pain, temperature
      relates sensations to past experiences
   c. **Gustatory Cortex**
      conscious awareness of taste stimuli

3. **Occipital Lobe**
   visual processing areas
   a. **Primary Visual Cortex**
      image is 1st mapped onto PVC
      receives info from retinas of eyes
      analyzes image in terms of its elementary features
      orientation
      color
      texture
      depth
      presence of movement
   b. **Visual Association Areas**
      interprets and associates with past visual experiences → recognize people, flowers, etc

4. **Temporal Lobe**
   a. **Auditory Cortex & Association Area**
      interprets sounds: pitch, rhythm, loudness
   b. **Vestibular (equilibrium) Cortex**
      awareness of balance

   **Basal Nuclei**
masses of gray matter buried deep in white matter of cerebrum
made up of at least 3 groups
all are involved in motor control

Spinal Cord
located in the spinal canal of the vertebral column
17 – 18 inches long
extends from foramen magnum to lower border of 1^{st} lumbar vertebrae
subdivided into cervical, thoracic, lumbar, sacral regions
cord widens at 2 places along its length:
  - **cervical enlargement**
    - gives rise to nerves of upper limbs
  - **lumbar enlargement**
    - gives rise to nerves of pelvic region and lower limbs
spinal cord terminates in a bundle of nerves
  = cauda equina
associated with cord in spinal canal are:
  - meninges
  - adipose cushion
  - CSF
  - blood vessels
space between vertebrae and dura mater

  = epidural space
  - is occupied by blood vessels, adipose tissue
  - and loose connective tissue

Cross Section of Spinal Cord:

white matter: myelinated, divided into columns and tracts; "highways"
gray matter: unmyelinated, cell bodies & dendrites, synapses

Nerve Tracts
numerous tracts can be identified in the spinal cord
spinal cord tracts serve as 2-way conduction paths between peripheral nerves and brain
each tract is composed of bundles of axons
ascending tracts & descending tracts

each tract is a structural and functional unit:
  1. all axons of a tract originate in same structure
  2. all axons of a tract terminate in same structure
  3. all axons of a tract serve the same general function
  eg. spinothalamic tract
    - all axons originate from cell bodies in spinal cord and terminate in thalamus of brain
    - all are sensory (ascending)
**Protection of CNS**
both brain and spinal cord are heavily protected:

1. **bone**: skull and vertebral column
2. **adipose cushion** around spinal cord
3. **meninges**: tough flexible covering
4. **liquid cushion**: cerebrospinal fluid

**Meninges**
composed of 3 layers:

1. **dura mater**
   - strong fibrous connective tissue
   - outer layer in skull is periosteum of cranial bones
2. **arachnoid layer**
   - delicate cobwebby layer
   - **subdural space** = between dura mater and arachnoid membrane
   - **subarachnoid space** = between arachnoid layer and pia mater
3. **pia mater**
   - transparent

CSF provides buoyancy and protection to delicate brain tissues also produces chemical stability

CSF mainly in:
- a. **brain ventricles and ducts**
- b. **central canal** of spinal cord
- c. in **subarachnoid space** of the meninges
  → space between arachnoid layer and pia mater

**Ventricles**
ventricles are fluid filled cavities inside brain:

1. **1st & 2nd**: in side cerebral hemispheres
   = lateral ventricles
2. **3rd**: small slit at base of brain
   inside diencephalon (thalamus)
3. **4th**: diamond shaped expansion of central spinal canal in brainstem

capillary beds in pia mater of meninges extend into the
4. ventricles of the brain where they form choroid plexi

adheres to outer surface of brain and cord contains blood vessels

3 extensions of the meninges form partitions between various parts of the brain:

- **falx cerebri**
  - largest partition between cerebral hemispheres
- **falx cerebelli**
  - separates cerebellar hemispheres
  - not in sheep brain
- **tentorium cerebelli**
  - separates cerebrum from cerebellum

meninges continues around spinal cord and extends beyond the end of the spinal cord
  → safer site for lumbar puncture to get CSF

**Meningitis** = inflammation of arachnoid, pia and CSF usually bacterial or viral; may lead to encephalitis

**Encephalitis** = inflammation of brain tissue itself

**Cerebro Spinal Fluid**
as further protection against damage the brain and spinal cord have a cushion of fluid around and within
  → brain actually “floats” in CSF (~140 ml of CSF)

surrounded by **astrocytes** (blood brain barrier)
each **choroid plexus** secretes CSF into ventricles
  → produces ~500ml of CSF/day
  → only 100-160ml at a time in circulation

isolated by **“Blood Brain Barrier”**
capillaries are much less leaky than normal capillaries
  → tight junctions
  → astrocytes help regulate flow into CSF

some substances easily, rapidly passed:
- glucose, O₂, CO₂, alcohol, caffeine, nicotine, heroin, anesthetics

others cross more slowly; creatinine, urea, most ions (Na⁺, K⁺, Cl⁻)
larger molecules cannot cross at all; proteins, antibodies
  → difficulty getting drugs to brain tissue
  → any trauma to head may damage BBB

**Circulation of CSF**

**Choroid plexus** in each ventricle
  → fluid moves from lateral ventricles through duct to 3rd ventricle
another duct moves fluid to 4th ventricle
fluid moves to central canal of spinal cord
fluid moves out to subarachnoid space around cord and brain
reabsorbed from subarachnoid space into arachnoid granulations
if circulation is blocked by tumor or other means during fetal development may cause hydrocephalus
→ fluid is still produced but can’t circulate and be reabsorbed

CNS Neurotransmitters

most of the diversity is in the CNS, esp the brain
several hundred neurotransmitters have been identified so far
a variety of different chemicals have been found to act as neurotransmitters in the CNS:

1. acetylcholine

2. protein & amino acid derivatives
   biogenic amines
   amino acids
   peptides
   proteins

3. Inorganic gasses

4. ATP

1. Acetylcholine (ACh)
   also at all NM jcts
   in CNS:
   1. inadequate amt ACh → correlated with Alzheimer’s
   2. ACh receptors destroyed in Myasthenia gravis

2. Protein & Amino Acid Derivatives
   broadly distributed in brain
   affect behavior, moods, sleep, thought
   some examples:
   eg. dopamine
      a catecholamine
      synthesized from tyrosine
      esp in substantia nigra of basal ganglia
      (midbrain)
      affects coordination of skeletal muscles
      also a “feel good” NT
      1. Parkinson’s Disease
deficiency
     →tremors (no inhibition of basal nuclei)
      2. schizophrenia
correlated with excess of dopamine
      3. amphetamines
     enhance its feel good effects
      4. cocaine
     blocks its uptake
   eg. norepinephrin

3. Inorganic gasses
   esp in brain stem
   another “feel good” NT
   affects mood: arousal, dreaming
   also released by some neurons in autonomic NS (sympathetic branch)
   1. generally excess → mania
deficiency → depression
   2. Cocaine & amphetamines
     prevents inactivation of norepinephrin
     →enhances its effect
     amphetamines and cocaine have similar effect as on dopamine
     eg. serotonin
      indolamine
      syn from tryptophan or histidine
      in brain stem (reticular system)
      induces sleep, temp regulation, appetite,
affects mood and aggression
      1. LSD
     binds to serotonin receptors
     →prevents its effect or counteracts its function in brainstem (RAS)
      2. Prozac
     prevents its uptake
3. linked to migraine headaches

**eg. histamine**
- produced in hypothalamus
- immune system is powerful vasodilator

**eg. aspartate**
- amino acid
- only in CNS
- excitatory

**eg. glutamate**
- amino acid
- only in CNS
- excitatory
  - important in learning and memory
  - released in large quantities after stroke
    - increases damage to nervous tissue

**eg. glycine**
- amino acid
  - in spinal cord
  - inhibitory
  - strychnine blocks receptors
    - causes convulsions

**eg. GABA**
- modified amino acid
- most abundant inhibitory NT in brain (~1/3 of all)
- inhibits skeletal movements
  - deficiency: Huntington’s disease
    - jerky movements
  - alcohol
    - enhances its inhibitory effects
      - slowed reflexes
      - reduced coordination
  - tetanus toxin blocks CNS synapses that release inhibitory NT such as GABA and glycine
    - results in overstimulation of muscles
- also affects mood
  - excess: less anxiety
  - deficiency: more anxiety
  - Valium
    - binds to GABA receptors
    - mimics or enhances its effects
      - less anxiety

**eg. Substance P**
- peptide (chain of amino acids)
- mediates pain transmission in PNS
  - in CNS affects mood

4. **ATP**
- now recognized as a major neurotransmitter in both CNS and PNS
- produces fast excitatory response at certain receptors

3. **Inorganic Gasses**

**eg. NO (nitric oxide)**
- toxic gas
- short lived
- is synthesized on demand
- not stored in axonal vesicles
- in CNS may be involved in learning and memory
- in PNS causes relaxation of smooth muscle

**eg. CO (carbon monoxide)**
- in CNS
- similar physiology as NO

- may be related to feeding disorders
Aging Central Nervous System

reaches peak development ~30
by age 75 average brain weighs slightly half its 30 yr weight

- gyri are narrower
- sulci are wider
- cortex is thinner
- more space between brain and meninges

neurons show signs of slower metabolism, accumulate neurofibrillary tangles and lipofuscin pigment

less efficient signal conduction and transmission

myelin sheath degenerates

fewer synapses

less NT produced, fewer receptor proteins

language skills and long term memory hold up better than motor coordination, intellectual function and short term memory

Brain Anatomy and Function

insula → sustains gut feelings and is part of networks of addictive behavior

cerebrum
- frontal lobe
- parietal lobe
- occipital lobe
- occipitotemporal cortex - monitors and reflects how other areas of the brain react to food
- temporal lobe
cerebellum
diencephalon
epithalamum
thalamus
hypothalamus
- suprachiasmatic nucleus → mammalian body clock

Disorders of the Central Nervous System

migraine headaches:
- often debilitating and excruciating headaches
- 10-12% of US → 28M in US suffer;
- ~70% are women
- 92 M workdays lost/yr; $11 B/yr (AAS 97)

2 kinds:
- Classic (with aura)
  - some or all of symptoms:
    - seeing zigzagging lines
    - tingling or numbness in face, arm, leg
    - seeing blind spots and tunnel vision

- Common (without aura)
  - pain on one or both sides of head
  - nausea
  - sometimes vomiting
  - sensitivity to light, smell or noise
  - throbbing, intense pain

may be due to:
  - a. fluctuations in levels of serotonin
  - b. excessive levels of dopamine
  - c. may be a genetic component

Alzheimer's Disease

- affect 11% in us over 65; 47% by 85
- ~half of all nursing home admissions
- leading cause of death among elderly
- AD may begin before 50 with very mild, undiagnosed symptoms
- one of 1st symptoms is memory loss, esp of recent events
- progresses with reduced attention span, disorientation, moody, confused, paranoid, combative or hallucinatory
- may lose ability to read, write, talk, walk, and eat
- death usually from pneumonia or other complications of confinement and immobility

Parkinson’s Disease

- progressive loss of motor function
- begins in 50’s or 60’s
- can be hereditary
due to degeneration of dopamine releasing neurons in substantia nigra (inhibitory neurons)
leads to hyperactivity of basal nuclei and involuntary muscle contractions
results in shaking hands, facial muscles become rigid, range of motion decreases
develops smaller steps, slow shuffling gait with forward bent posture and a tendency to fall forward
speech becomes slurred, handwriting illegible

Tourette’s Syndrome

- recurrent involuntary muscle contractions = tics
- eg: eyeblinking, nose twitching, facial grimacing, head shaking, shoulder shrugging
- usually begins in childhood between ages of 2 – 15
- worldwide, all races; males more than females
- may affect 1 in 2000, worldwide; US ~100,000 affected
- may be due to chemical abnormality in basal ganglia