Problem 1: Auditory System (35 pts)

a) [5 points] Please label appropriately scala tympani, scala vestibuli, basilar membrane, the inner and outer hair cells in the following schematic drawing of a cross section of the cochlea:

![Cochlea Diagram]

b) [2 points] A complex periodic sound is synthesized as a sum of three sinusoids with frequencies of 1800, 2000, and 2200 Hz. What is the pitch of this complex sound, as determined by the following method: A listener is asked to adjust the frequency of a reference tone, a single sinewave, within the frequency range 50–800 Hz, until the pitch of the reference tone is the same as the pitch of the complex test sound.

( ) 100 Hz  ( ) 200 Hz  ( ) 500 Hz  ( ) 1800 Hz  ( ) 2000 Hz or ( ) 2200 Hz

c) [8 points] The graphs below show a tuning curve and an input-output function of a normal cochlea, please indicate which is the tuning curve and which is the input-output function (remember to label the x- and y-axis appropriately), and draw schematically what the tuning curve and the input-output function would look like if the outer hair cells are damaged in the cochlea:

![Tuning Curve and Input-Output Function]

- Tuning curve (1 pt)
- Cochlear or Basilar membrane output (1 pt)
- Input-output function (1 pt)
- Stimulus level or intensity or input (1 pt)
d) [10 points] Determine whether the following statements are true (T) or false (F):

(F) stapes is connected to round window
(T) “active mechanism” or “cochlear amplifier” refers to outer-hair-cell function
(T) tono-topic organization refers to the place code
(T) inner hair cells are the true transducers that convert mechanical energy into electrical signals
(F) the amplitude compression effect of outer hair cells reduces the usable range of sound pressure levels.
(F) a cochlear implant is different from a hearing aid because it can acoustically amplify sound more than a hearing aid.
(F) functioning of a cochlear implant requires residual inner hair cells.
(T) a cochlear implant stimulates the auditory nerve directly with electric currents.
(T) high frequency (>1000 Hz) information is critical to speech recognition.
(T) demyelination reduces nerve transduction speed.

e) [6 pts] In a cochlear implant, mark the following events in the order in which they occur with #1 being the first:

6) Electrodes stimulate auditory nerve fibers
1) Microphone picks up sound
3) Speech processor changes acoustic signal into coded electrical signal
2) Signal travels down the cable to the speech processor
5) Radio Frequency (RF) signal is carried across the skin to the receiver
4) Electrical signal travels up the cable to the transmitter

f) [4 pts] Briefly describe two ways that you might improve pitch perception in cochlear implant users.

- “built-in” automatic pitch extraction as a front-end of the speech processor;
- a biological model for realistic stimulation in the electrode-to-nerve interface.
- deeper electrode array that goes all the way to the apex
- miniaturized robot that can pull the electrode to the apex
- double electrode arrays with one being inserted from the base and the other from apex
- bilateral implants
- more electrode contacts for better pitch resolution
- different processing for low- and high-frequency pitches
- stem cells to regenerate the cochlea
- transplantation
Problem 2: Bone and Skeletal Mechanics (35 pts)
a. Fill in the blanks using the words or phrases listed below. Note that some may be used more than once and some may not be used at all.

Words to select from, unless otherwise indicated:
osteoblasts  osteocytes  osteoclasts  resorb bone
form bone  osteons  modeling  homeostasis
remodeling  reduced strain  increased strain

A “centrifuge” has been created to study the effects of hypergravity (gravitational forces greater than those on Earth). A person in the centrifuge experiences twice the gravitational force that he/she normally experiences on Earth. The person is aligned so that this force is from head to toe (the same as if he/she were standing on Earth). The person is in the centrifuge for 2 hours per day. The following occurs in this order:

Osteocytes sense changes in strain. In this case, they sense _increased strain_.

Osteoclasts (a type of cell) _resorb bone_ (an action).

Osteoblasts (a type of cell) _form bone_ (an action).

Osteoclasts are _less_ active than osteoblasts. (pick one: less or more)

Net result is that bone density _increases_. (pick one: increases or decreases)

The person stops going in the centrifuge. Over the next few months, the following occurs in this order:

Osteocytes sense _reduced strain_.

Osteoclasts (a type of cell) _resorb bone_ (an action).

Osteoblasts (a type of cell) _form bone_ (an action).

Osteoclasts are _more_ active than osteoblasts. (pick one: less or more)

Net result is that bone density _decreases_. (pick one: increases or decreases)

This process is known as bone _remodeling_.

The person is 80 kg. When standing on the left foot on Earth outside the centrifuge, the person’s left femoral head experiences a force of about (circle one):

i) 400 N  ii) 800 N  iii) 2400 N  iv) 8000 N

When standing on the left foot while in the centrifuge, the person’s left femoral head experiences a force of about (circle one):

i) 400 N  ii) 800 N  iii) 2400 N  iv) 4800 N  v) 8000 N  vi) 16,000 N

The person’s femur breaks while standing on one leg inside the centrifuge. Therefore, the strength of the person’s femur is approximately between _2400_ N and _4800_ N.

True False (circle one): The person’s femur broke because the stress on the bone in the femur exceeded the strength of the bone in the femur.

True False (circle one): The person probably experienced a great deal of pain after breaking his/her femur.
True/False (circle one): The greater trochanter is medial to the femoral head.
True/False (circle answer): Trabecular bone is best described as orthotropic.
True/False (circle answer): An orthotropic material behaves the same in all directions.

b. Your grandmother was in the circus. She wants to lift her grandchildren and carry them on her shoulders. She weighs 80 kg. Her grandson weighs 15 kg.
i) What is the approximate increase in force on your grandmother’s thoracic spine when a child is on her shoulders?

\[ 150 \text{ N. Give } \frac{1}{2} \text{ credit for } 15 \text{ kg} \]

ii) Someone puts a child on your grandmother’s shoulders. The trabecular bone in your grandmother’s weakest thoracic vertebra can withstand a stress of 1 MPa.
Assume the following:
• the stress is uniformly distributed across the trabecular bone of the vertebral body
• the vertebral body is a cylinder of radius=2.5 cm and height=2.5 cm
• the force on the entire vertebra when she is not carrying the child is 1600 N
• the trabecular bone carries 50% of the force on the entire vertebra

What is the total force on the trabecular bone of the vertebral body? 875 N. Give \frac{1}{2} \text{ credit for } 1750 \text{ N}
What is the stress on the trabecular bone of the vertebral body? 446 \text{ MPa or } 446 \text{ kPa}
Will the vertebral body break when she carries the child on her shoulders? No

iii) Your grandmother decides to pick up the child with her arms in front of her. Assume that the distance from the center of the vertebral body to the center of mass of the child is 35 cm, and the distance from the center of the vertebral body to the center of the extensor muscles is 3 cm.
Use the same assumptions as for the questions above.

What is the force on the trabecular bone of the vertebral body due only to the child? 950 N. Give \frac{1}{2} \text{ credit for } 1900 \text{ N}
What is the total force on the trabecular bone of the vertebral body? 1750 \text{ N - } \frac{1}{2} \text{ credit for } 3500 \text{ N}
What is the stress on the trabecular bone of the vertebral body? 0.892 \text{ MPa or } 892 \text{ kPa}
Will her vertebral body break? No (but full credit if above answer was 1.78 MPa)

iv) True/False (circle answer): The intervertebral disk consists of trabecular and cortical bone.
v) True/False (circle answer): Adequate calcium intake is important for the prevention of osteoporosis.
vi) True/False (circle answer): There are no drugs that can be taken to increase bone density.
Problem 3: Motor Systems (15 pts)

a. Shown below is a tangled block diagram of a feedback controller, with some arrows either missing or incomplete. Please connect the blocks to make the feedback controller work.

b. Shown below are the electromyograms from elbow muscles as someone else lifts a load off of a person's hand (imposed unloading), or as the person lifts the load (voluntary unloading). Label on the EMG the precise moments when you can detect evidence of feedforward control and feedback control. Use the label FF for feedforward and FB for feedback.

-A-

-B-  Imposed unloading  Voluntary unloading

Elbow rotation

Force

- Manual arm:
  - Biceps brachii
  - Postural forearm:
    - Biceps brachii
    - Triceps brachii
  - Brachial radius

0.6 mV

0.5 mV

0.4 mV

0.3 mV

0.2 mV

0.1 mV

0.0 mV

-200 0 200 400 ms

400g

10°
c. List the advantages and disadvantages of feedback and feedforward control

<table>
<thead>
<tr>
<th></th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feedback control</td>
<td>1, 10</td>
<td>1, 9, 11</td>
</tr>
<tr>
<td>Feedforward control</td>
<td>2, 7</td>
<td>3, 8, 12, 13</td>
</tr>
<tr>
<td>Impedance control</td>
<td>4, 10</td>
<td>6</td>
</tr>
</tbody>
</table>

1. It only starts working once an error develops, so there is always an error.
2. Robust to delays
3. To design this type of controller, you must develop an internal model of the plant
4. To design this type of controller, all you have to know is what direction to push the plant in order to make the error smaller
5. Only works for biological systems
6. Requires a lot of energy
7. Theoretically, the performance can be perfect
8. Cannot compensate for unpredictable disturbances
9. Requires a sensor
10. Can compensate for unpredictable disturbances
11. Delay causes instability
12. Requires a lot of time

Problem 4: Muscle and Neuron (15 pts)
True or False?

<table>
<thead>
<tr>
<th></th>
<th>The primary way the nervous system can get muscles to produce more force is recruitment</th>
</tr>
</thead>
<tbody>
<tr>
<td>F</td>
<td></td>
</tr>
<tr>
<td>T</td>
<td>A muscle with a linear force-velocity curve would generate maximal power at a</td>
</tr>
<tr>
<td></td>
<td>velocity higher than the velocity for a muscle that obeys the Hill curve</td>
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<tr>
<td>T</td>
<td>The Hill curve arises because of crossbridge binding dynamics</td>
</tr>
<tr>
<td>F</td>
<td>A muscle twitch is the movement produced by an isometric muscle in response to</td>
</tr>
<tr>
<td></td>
<td>an action potential in one or more motor units</td>
</tr>
<tr>
<td>F</td>
<td>The fused tetanus stimulation frequency for a muscle is one divided by the total</td>
</tr>
<tr>
<td></td>
<td>twitch time</td>
</tr>
<tr>
<td>F</td>
<td>The passive force-length curve is due to cross-bridge binding</td>
</tr>
<tr>
<td>T</td>
<td>The series elastic element is needed to model muscle behavior when muscle is</td>
</tr>
<tr>
<td></td>
<td>stretched quickly</td>
</tr>
<tr>
<td>F</td>
<td>The Huxley model of muscle is more useful for biomechanical simulations than</td>
</tr>
<tr>
<td></td>
<td>the Hill model</td>
</tr>
<tr>
<td>T</td>
<td>The resting potential of a neuron is usually around –60 mV</td>
</tr>
<tr>
<td>T</td>
<td>The size of an action potential can vary slightly with the stimulus current</td>
</tr>
<tr>
<td>T</td>
<td>Neurons have a high internal concentration of potassium</td>
</tr>
<tr>
<td>T</td>
<td>A passive dendrite with a high resistance will charge more slowly in response to</td>
</tr>
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<td></td>
<td>a current input than dendrite with a low resistance, given equal capacitance.</td>
</tr>
<tr>
<td>F</td>
<td>The stretch reflex involves two neuron-neuron synapses</td>
</tr>
<tr>
<td>F</td>
<td>Action potentials propagate at a maximal speed of about 300 m/s</td>
</tr>
<tr>
<td>F</td>
<td>Nodes of Ranvier behave electrically like the transatlantic telephone cable</td>
</tr>
</tbody>
</table>