FIZIOLOGIJA ŽIVALI

Laboratorijske vaje

FIZIOLOGIJA SKELETNIH PREČNO-PROGASTIH MIŠIC

doc. dr. Katja Adam

UP FAMNIT

VAJE DO KONCA, POMEMBNI DATUMI

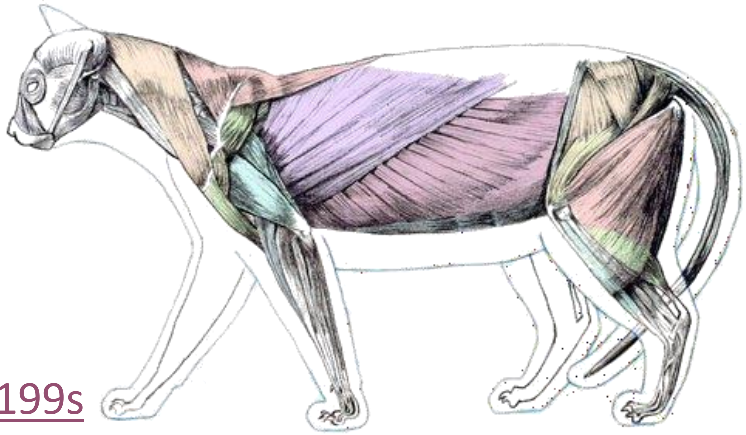
- **4.5**., 5.5. (2. skupina) – zadnje vaje
- **11.5. –** ponavljalne vaje - skupna vprašanja poslati do **9.5.**
- \- na ponavljalnih vajah poberem poročila praktičnih vaj

- SAMI DOMA NAREDITE:
  - manjkajoče vaje (1_5, izostanki)
  - negativno ocenjene vaje – PONOVNO REŠITE
  - ostali: po želji ponovite do 2 slabše ocenjeni vaji
  - oddate v mapico POPRAVKI VAJ do 12.5.

- **18.5. - 1. rok za** KOLOKVIJ **13:00** EPSILON LIVADE UP FAMNIT – prijave odprte en teden prej
- **pogoj: vse vaje opravljene in pozitivno ocenjene**

SKELETNE PREČNO PROGASTE MIŠICE VRETENČARJEV

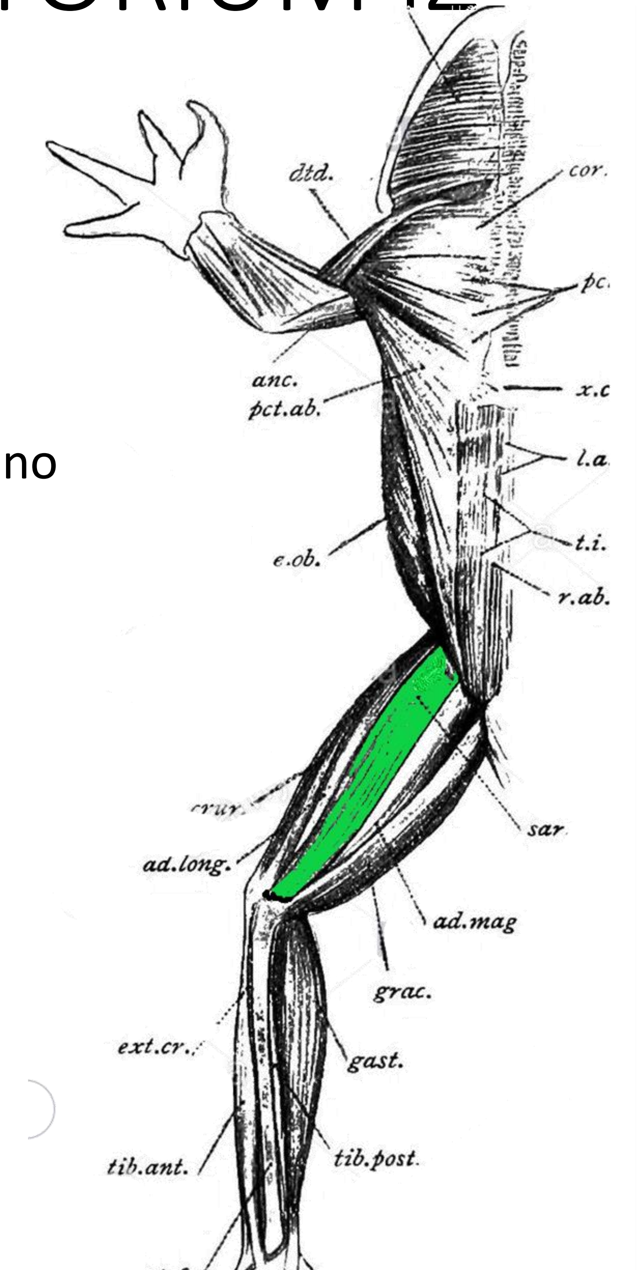
- s kito (tendon) povezane s kostmi
- mišično vlakno (m. fiber) – osnovna funkcionalna enota
  - debelo 10-nekaj 100 mm, dolgo nekaj mm do 1 dm ali več
- miofibrile – tvorijo krčljivi aparat, prečno-progaste mišične niti, ki izpolnjujejo 60-80% celice
  - iz proteinov, urejenih v niz sarkomer
  - aktin in miozin bistvena za krčenje



PONOVITE KRČENJE SKELETNE PREČNO PROGRASTE MIŠICE: https://www.youtube.com/watch?v=ousflrOzQHc&t=199s

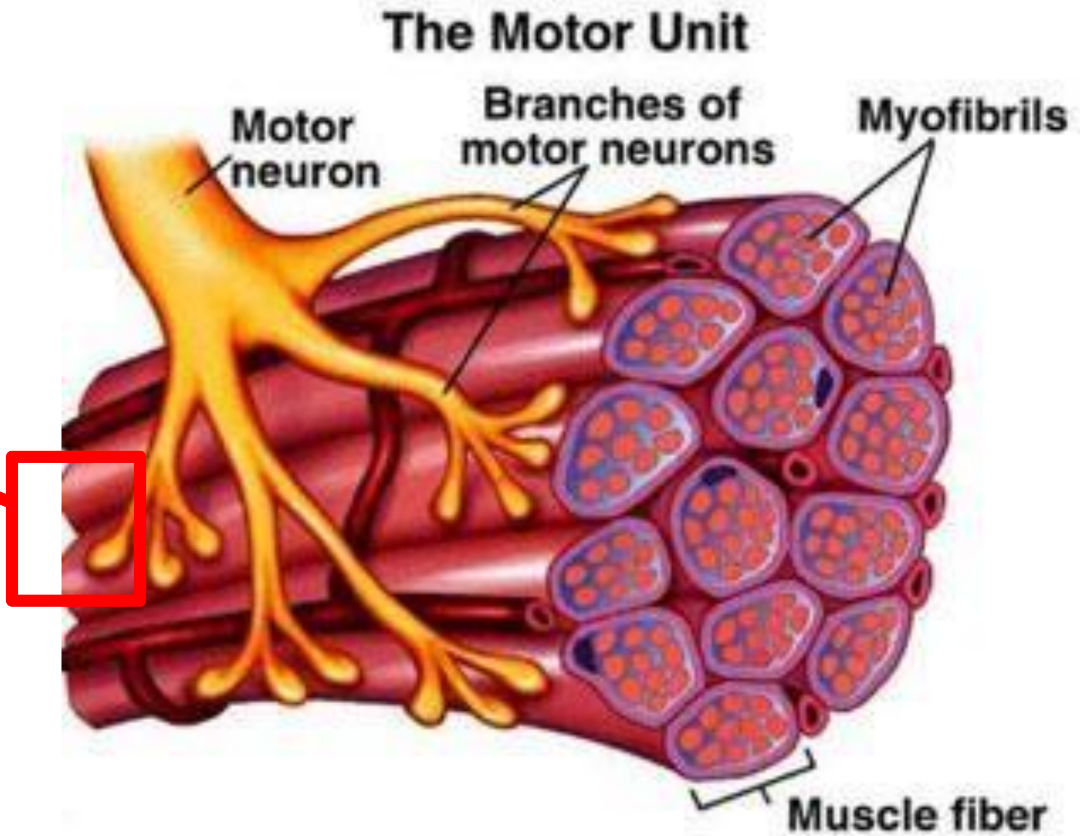
VAJE: KRČENJE M. SARTORIUM IZ ŽABJE NOGE

- celice = mišična vlakna proizvajajo mišično tenzijo (moč)
- izolacija mišice – z električnimi stimulacijami lahko izzovemo krčenje izolirane mišice - podobno kot v živi mišici (in vivo)



1. KRČENJE MIŠIC (m. twitch) in OBDOBJE LATENCE

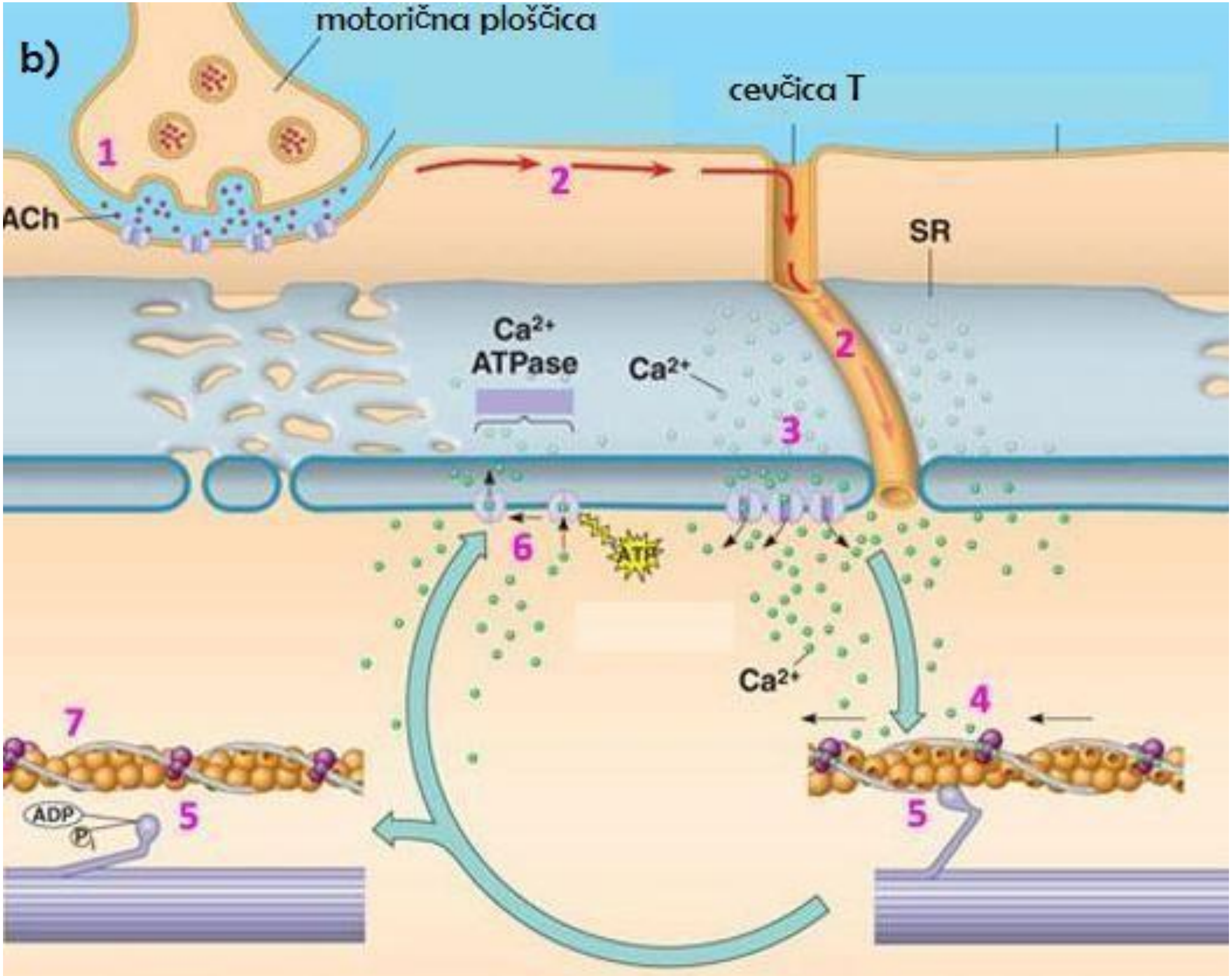
- motorična ploščica (neuromuscular junction) = stik med enim živčnim končičem enega motonevrona in mišičnim vlaknom
- MOTORIČNA ENOTA: motonevron + VSA mišična vlakna, ki jih oživčuje



motorična ploščica

MOTORIČNA PLOŠČICA (NEUROMUSCULAR JUNCTION)

- kjer se konec aksona motonevrona stika s specializiranim območjem membrane m. vlakna
    - tu pride do AP (end-plate potential)
    - AP v motonevronu spodbudi izločanje ACh iz končičev nevrona – difuzija in vezava Ach na receptorje membrane m. vlakna (sarkolemo) – sprememba v permeabilnosti za ione – depolarizacija membrane mišice (end plate potential)
    - ta potencial sproži serijo dogodkov, ki vodijo do kontrakcije mišične celice – exctitation-contraction coupling
- NA VAJAH – mišice celice stimuliramo z električnim stimulatorjem


b)
motorična ploščica
cevčica T
1
2
ACh
SR
Ca²⁺
ATPase
Ca²⁺
2
3
6
ATP
Ca²⁺
7
4
ADP
Pi
5
5

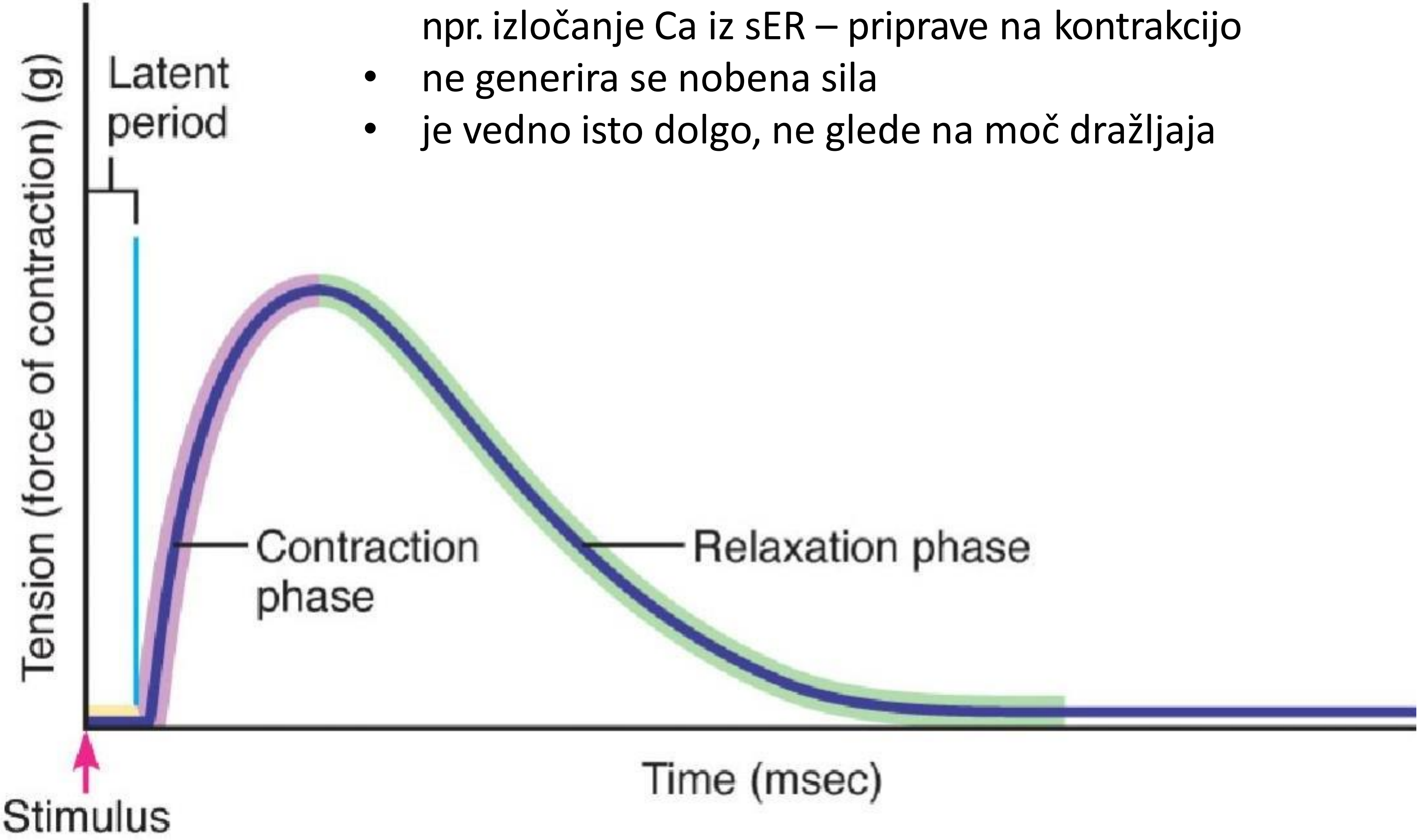
OBDOBJA KRČENJA MIŠICE

- MUSCLE TWITCH – TRZLJAJ MIŠIC – mehanski odziv na en AP živčne celice
- - 0.007 do 0.1 s

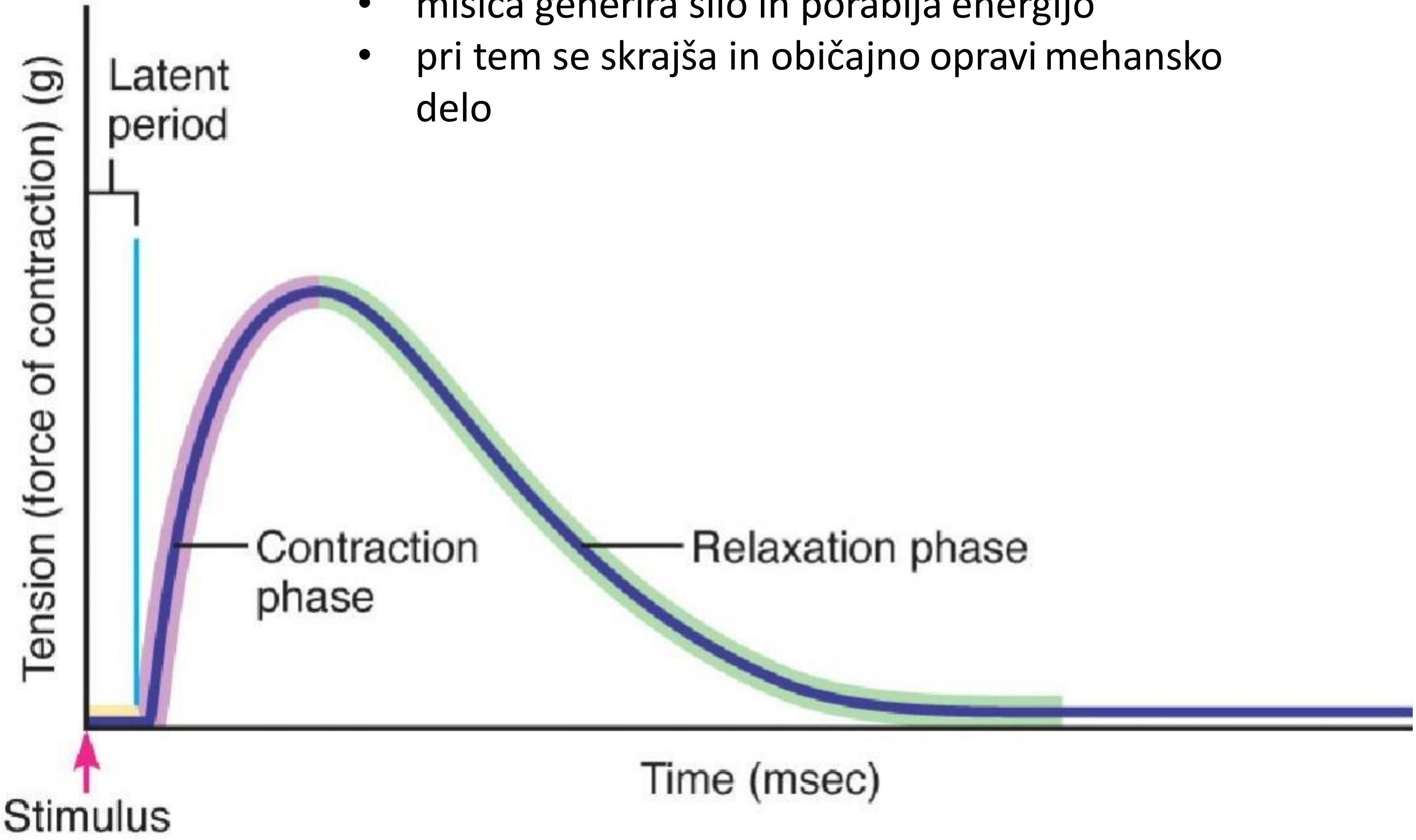
- obdobja trzljaja mišice so 3 – latentno obdobje, kontrakcija, relaksacija

LATENTNO OBDOBJE – čas, ki preteče med generiranjem enega AP v mišični celici in začetkom kontrakcije mišice

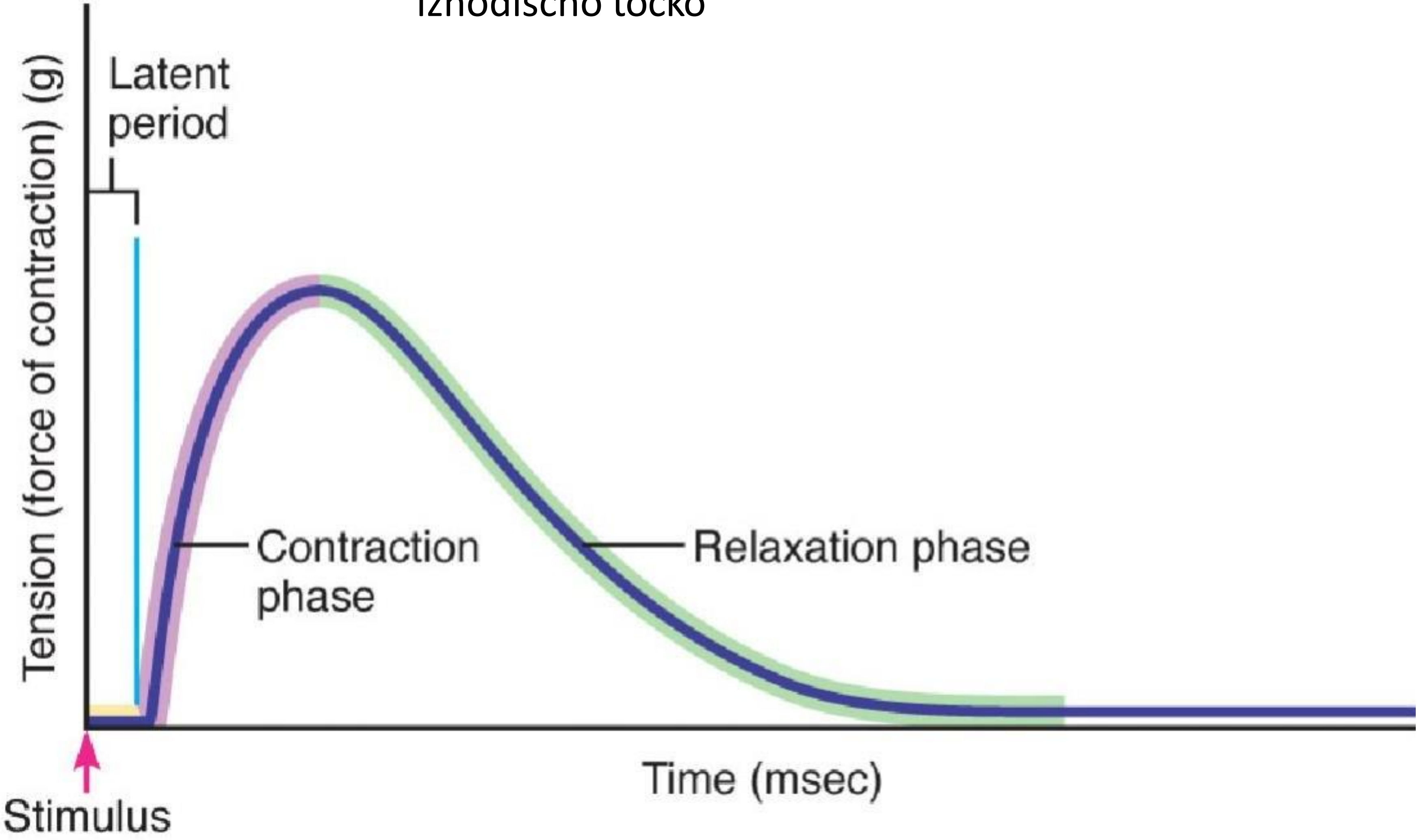
- prihaja do znotrajceličnih kemijskih sprememb – npr. izločanje Ca iz sER – priprave na kontrakcijo
- ne generira se nobena sila
- je vedno isto dolgo, ne glede na moč dražljaja



- KONTRAKCIJA – se začne po koncu latentne dobe in traja do takrat, ko je mišična tenzija največja
  - mišica generira silo in porablja energijo
  - pri tem se skrajša in običajno opravi mehansko delo



- RELAKSACIJA – od vrha tenzije do konca kontrakcije
  - pasivna faza, mišica se sprosti in iztegne na izhodiščno točko

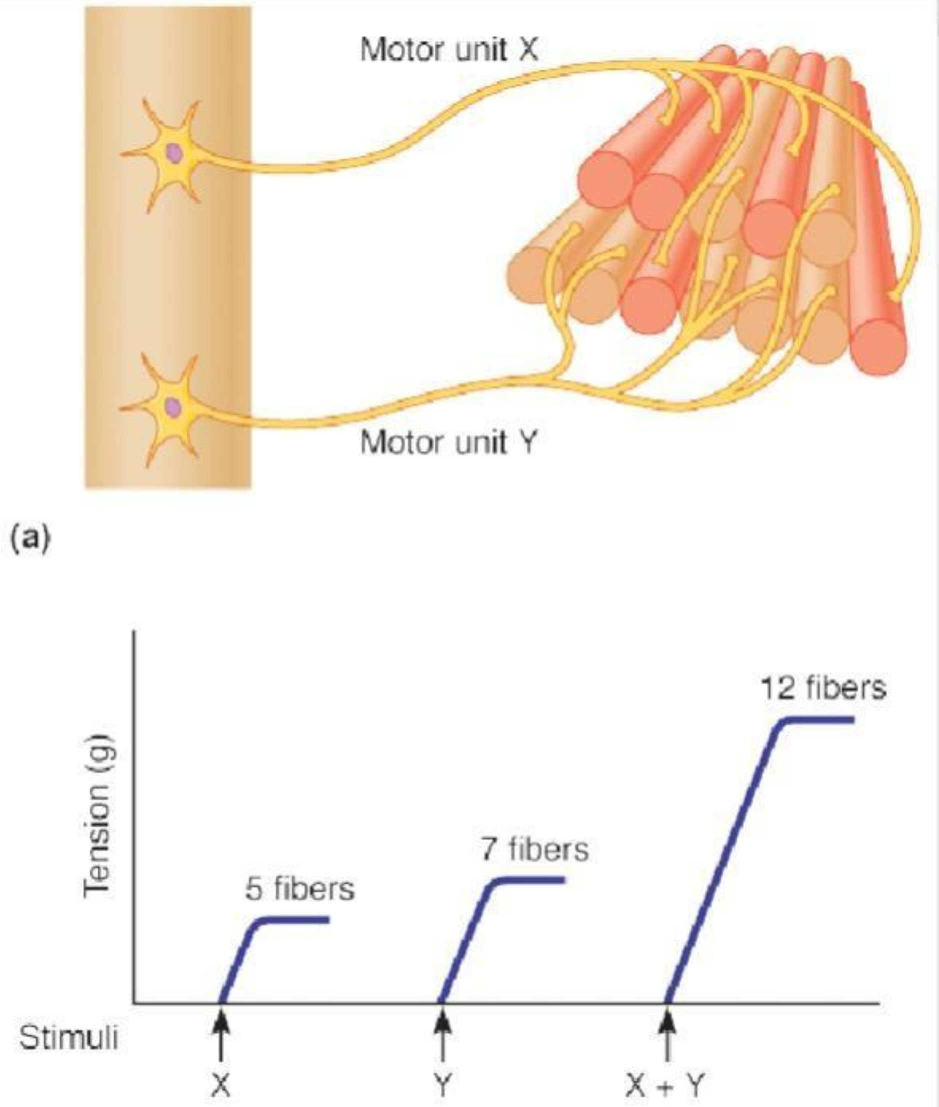


2. VPLIV NAPETOSTI DRAŽLJAJA NA KRČENJE MIŠICE

- med krčenjem mišica porablja E in opravlja TENZIJO (mišično delo) – ob živčnih ali električnih stimulacijah
- delo celotne mišice odvisno od števila aktivnih motoričnih enot v tistem času
  - <u>močna kontrakcija mišice</u> – veliko motoričnih enot je aktiviranih, vsaka enota proizvaja max tenzijo (silo)
  - <u>šibka kontrakcija</u> – manj aktiviranih enot, vendar še vedno vsaka proizvaja max tenzijo
  - razlika je v številu aktiviranih motoričnih enot

2. REKRUTACIJA motoričnih enot

- s povečanjem št. aktivnih motoričnih enot lahko povečamo mišično delo

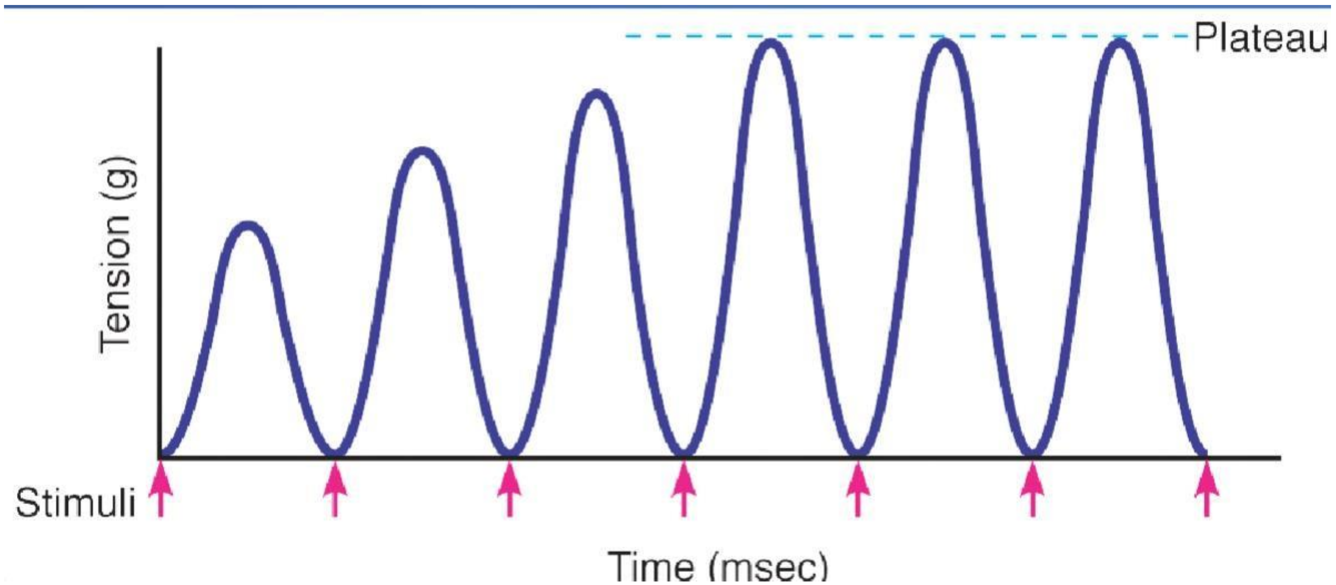


2. VPLIV NAPETOSTI DRAŽLJAJA NA KRČENJE MIŠICE

- enojna stimulirana kontrakcija celotne mišice – trzljaj mišice – 3 faze
- VAJA 2: vpliv moči električnega dražljaja na funkcijo celotne mišice
  - povečanje moči el. stimulacije podobno in vivo situaciji (ž. sistem poveča število aktivnih motoričnih enot)
- pražni dražljaj (threshold stimulus) – najmanjši dražljaj, ki inducira AP na sarkolemi mišičnega vlakna
- povečanje napetosti dražljaja nad pražno vrednostjo – več mišičnih vlaken se aktivira – povečanje moči, ki jo proizvede celotna mišica
- max tenzija **celotne** mišice – ko so aktivirana vsa m. vlakna, zadostno močan dražljaj maksimalne napetosti

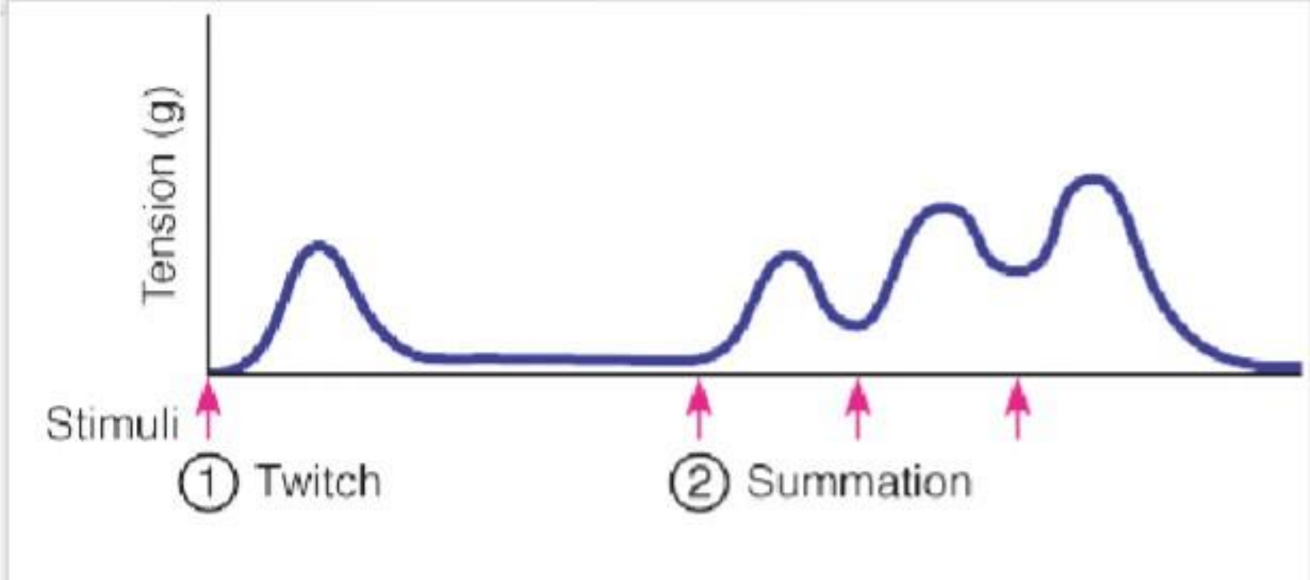
3. VPLIV FREKVENCE DRAŽENJA NA KRČENJE SKELETNE M.

- prvo krčenje mišice – ne proizvede max moči
- TREPPE – progresivno naraščanje moči, ko mišico zaporedno dražimo, vsak mišični trzljaj proizvede nekoliko več moči (efekt stopnic)
- POGOJI – mišica se relaksira med dražljaji, dražljaji morajo biti dovolj blizu (ampak ne preblizu)



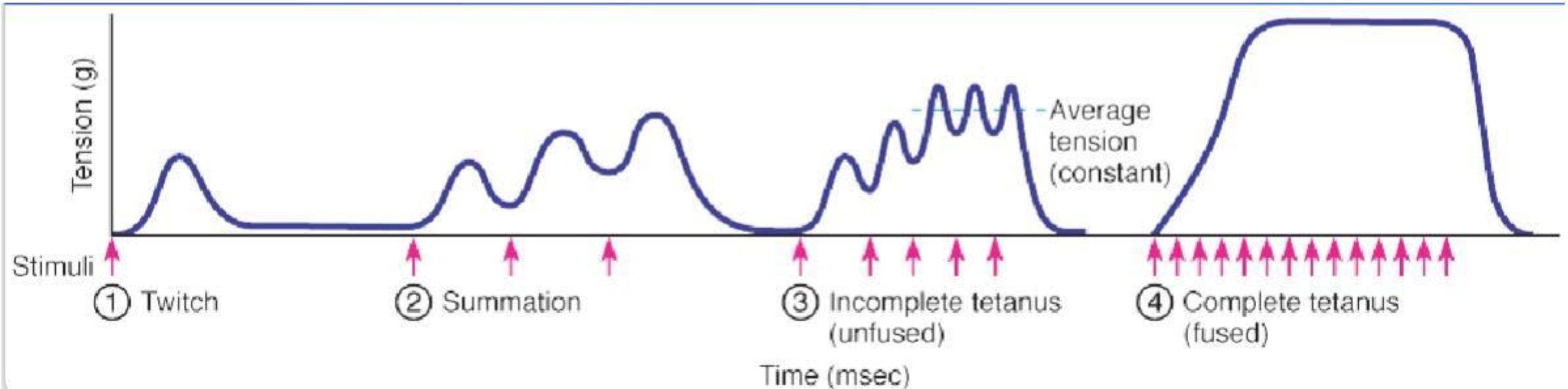
3. VPLIV FREKVENCE DRAŽENJA NA KRČENJE SKELETNE M.

- ko je skeletna mišica stimulirana zaporedno z več dražljaji (frekvenca draženja je večja kot pri treppe), se mišični trzljaji prekrivajo, mišica se ne relaksira popolnoma do novega dražljaja – to vodi v močnejšo kontrakcijo kot pri enojnem trzljaju
- SUMACIJA (SEŠTEVANJE) KONTRAKCIJ – mišična vlakna so stimulirana ponovno preden se popolnoma relaksirajo



4. TETANIČNA KONTRAKCIJA

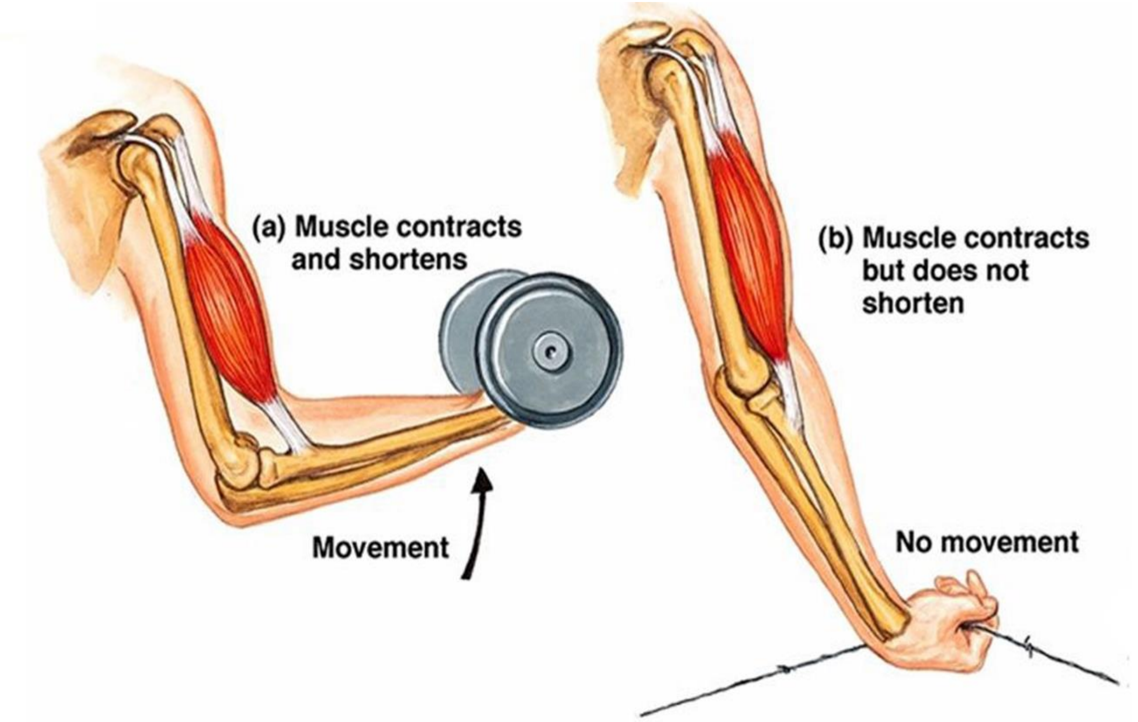
- s povečanjem frekvence draženja se kontrakcije mišice seštevajo kar vodi v večjo moč, ki jo mišica proizvede (do plato-ja)
- nižja frekv. dražljajev – posamezen drget mišice je viden, vendar se mišica ne relaksira vmes – nepopolna tetanična kontrakcija
- pri določeni frekvenci (stopitvena – fuzijska frekvenca) se m. med posameznimi dražljaji ne sprosti več popolnoma
  - popolnoma zlito gladko stanje, ne razločimo posameznega drgeta mišice – popolna tetanična kontrakcija
- maksimalna tetanična tenzija – ni več naraščanja v moči krčenja



6. KONTRAKCIJE SKELETNIH MIŠIC

izometrične ali izotonične

- IZOMETRIČNO – pomeni “iste dolžine” (**b** primer na sliki)
- IZOTONIČNO – pomeni “spremembe v dolžini, isto breme” (**a** primer na sliki)



6. RAZMERJE DOLŽINA - TENZIJA SKELETNE MIŠICE

IZOMETRIČNE KONTRAKCIJE

- ko mišica skuša prestaviti breme, ki je enako sili, ki jo proizvaja mišica
- mišica ostane iste dolžine, čeprav se aktivno krči
- primer – pritiskanje na okvir vrat – breme, ki ga poskušamo prestaviti, je enako sili, ki jo mišice generirajo – mišice se ne skrajšajo, čeprav se aktivno skrčijo

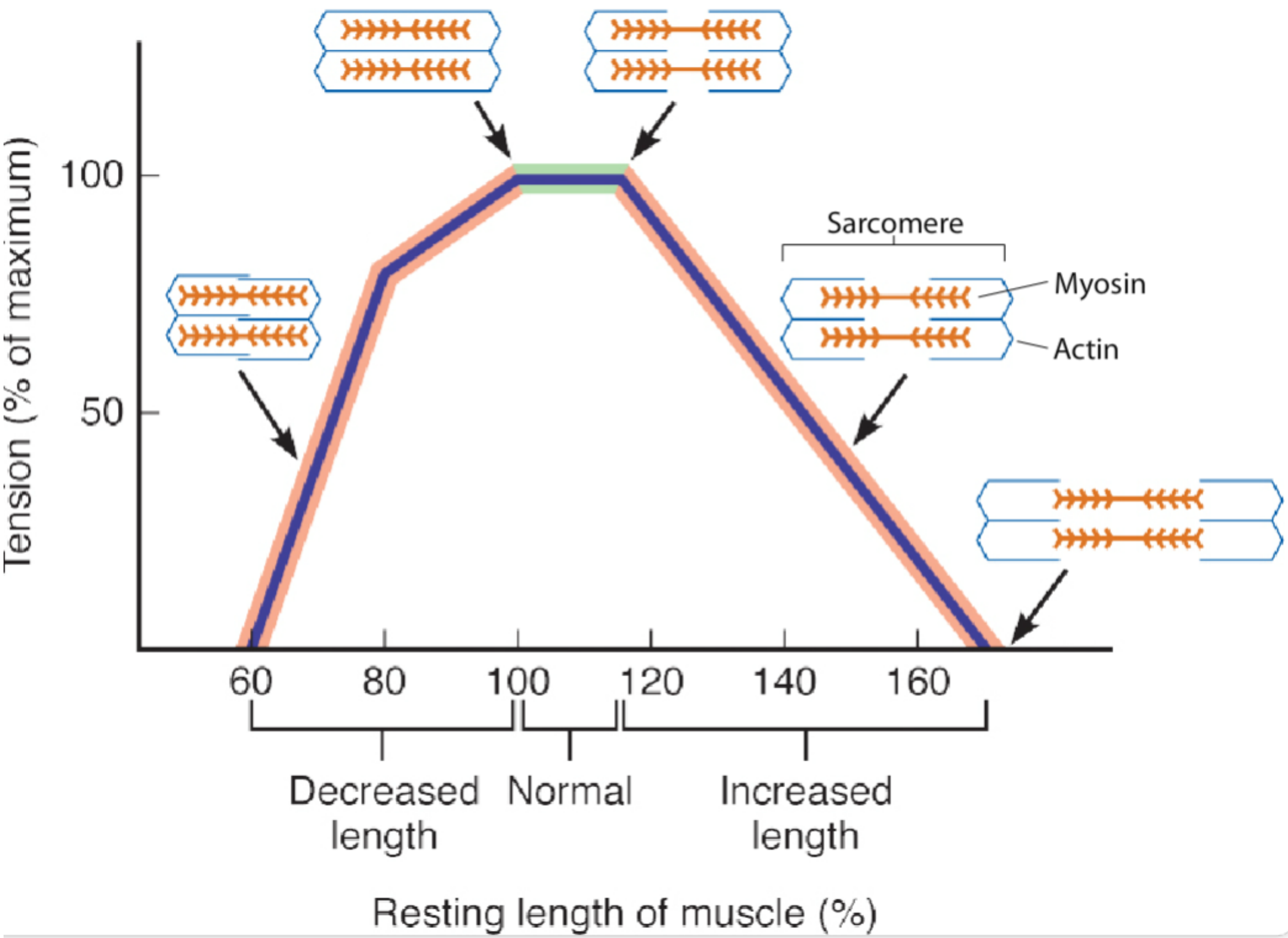
6. IZOMETRIČNE KONTRAKCIJE...

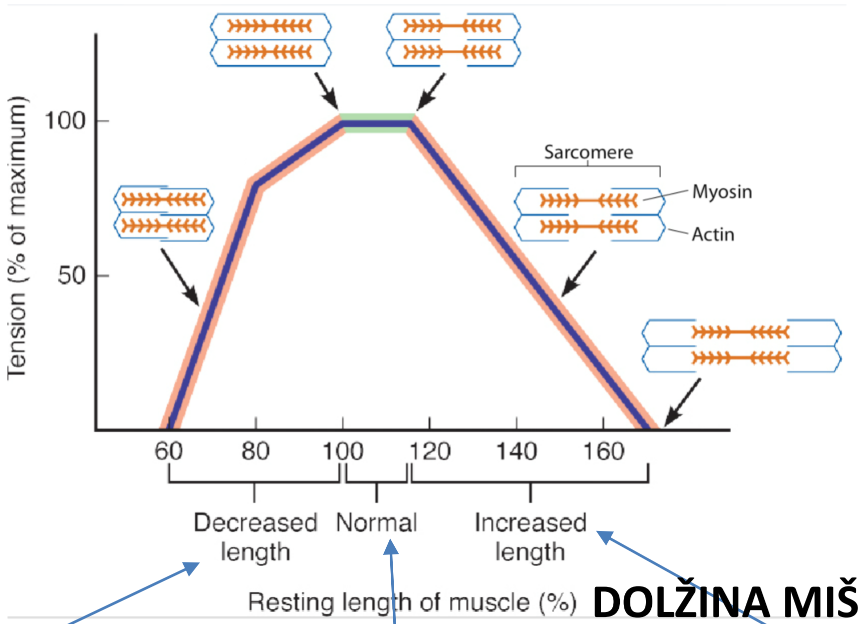
- eksperimentalno izometrične kontrakcije dosežemo tako, da oba konca mišice vpnemo na aparaturo, ki jo drži v fiksnem položaju med stimulacijo
- dolžina v mirovanju – pomembna pri določitvi količine moči, ki jo m. lahko proizvede med stimulacijo

- PASIVNA MOČ – generira se, ko mišico raztegujemo, posledica elastičnega proteina titin, ki povezuje miozinska vlakna na Z linijo, skrbi za elastičnost mišice
- AKTIVNA MOČ – generira se ob kontrakciji mišice, ko se miozin poveže z aktinom, ob tem se hidrolizira ATP
- SKUPNA MOČ – aktivna + pasivna

- **RAZMISLITE (POMAGAJTE SI Z GRAFOM NA NASLEDNJI STRANI)**

GRAF IZOMETRIČNEGA RAZMERJA MED DOLŽINO IN TENZIJO





DOLŽINA MIŠICE V MIROVANJU:

SKRČENA MIŠICA
sarkomera je skrčena bolj kot ponavadi, aktinska vlakna se prekrivajo, z večjim prekrivanjem (bolj skrčeno mišico) upada mišična tenzija

NORMALNA DOLŽINA
sarkomera je idealne dolžine, idealno prileganje med aktinom in miozinom, mišica lahko proizvede maksimalno tenzijo

RAZTEGNJENA MIŠICA
sarkomera je raztegnjena, miozinska vlakna se ne morejo popolnoma prilegati aktinskim, nekaj jih ostane prostih, z daljšim raztezom je možnost povezav med aktinom in miozinom manjša, s tem pa tudi upada mišična tenzija

- kdaj je pasivna moč mišice največja, kdaj je aktivna moč največja in kdaj je skupna moč največja???

optimalna dolžina mišice v mirovanju ima za posledico največjo moč, ki jo ta lahko proizvede

VAJE – Physioex 9.1. Exercise 2, Activity

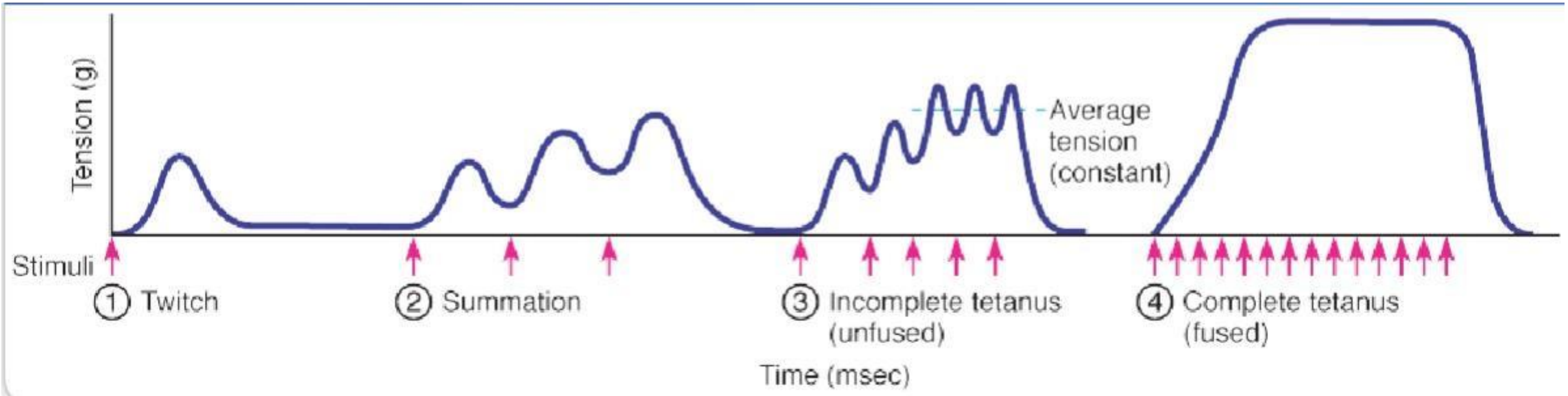
- ~~1_ latenca krčenja~~ – ne delamo, samo teorija v ppt
- 2_vpliv napetosti dražljaja na krčenje mišice
- 3_vpliv frekvence dražljajev na krčenje mišice
- 4_ tetanus
- ~~5_ utrujanje mišice~~ – ne delamo, delamo praktično vajo
- 6_izometrične kontrakcije

UTRUJANJE MIŠIC

MERJENJE Z ROČNIM DINAMOMETROM

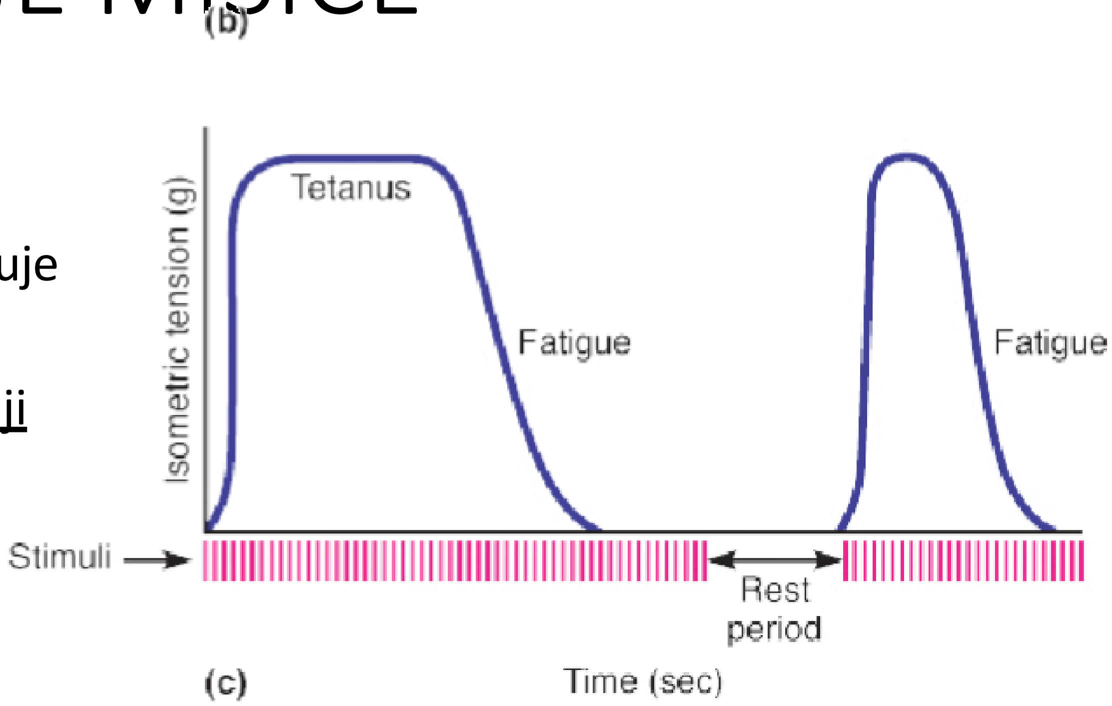
4. TETANIČNA KONTRAKCIJA

- pri določeni frekvenci (stopitvena – fuzijska frekvenca) se m. med posameznimi dražljaji ne sprosti več popolnoma
- nižja frekv. dražljajev – posamezen drget – nepopolna tetanična kontrakcija
- višja frekv dražlja – popolnoma zlito gladko stanje – popolna tetanična kontrakcija
- maksimalna tetanična tenzija – ni več naraščanja v moči krčenja



5. UTRUJANJE MIŠICE

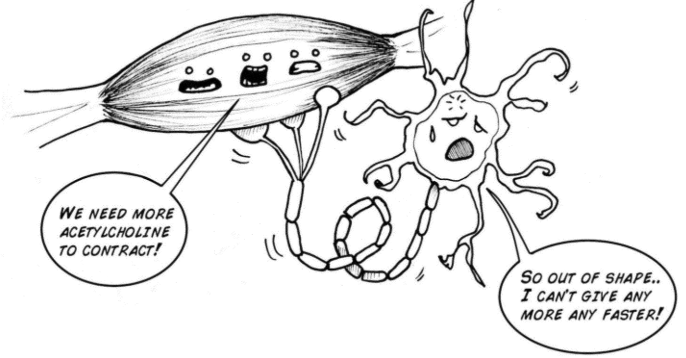
- zmanjšanje sposobnosti skeletne mišice, da vzdržuje konstanten nivo moči <u>po dolgi zaporedni stimulaciji</u>



- UTRUJENOST MIŠIC:
  - nesposobnost mišičnih vlaken, da proizvajajo tenzijo zaradi prejšnje aktivnosti
  - upad mišične sposobnosti da vzdržuje konstatno moč kontrakcije po dolgem zaporednem draženju

5. UTRUJANJE MIŠICE

- zapleten proces, v organizmu lahko zajame vrsto organskih sistemov
- npr. utrujanje živčnega centra, utrujanje živčno-mišične sinapse, utrujanje mišice
- utrujanje mišice lahko spremljamo s spremljanjem dinamike upadanja **amplitude, moči ali hitrosti mišične kontrakcije**
- zakaj pride do utrujenosti:
  - pomanjkanje snovi, ki so energetski vir delujoče mišice
  - kopičenje metabolitov, ki med delom nastajajo v mišici (mlečne kisline, ADP in Pi)



VAJE – UTRUJANJE MIŠIC

- utrujanje
- merjenje z ročnim dinamometrom

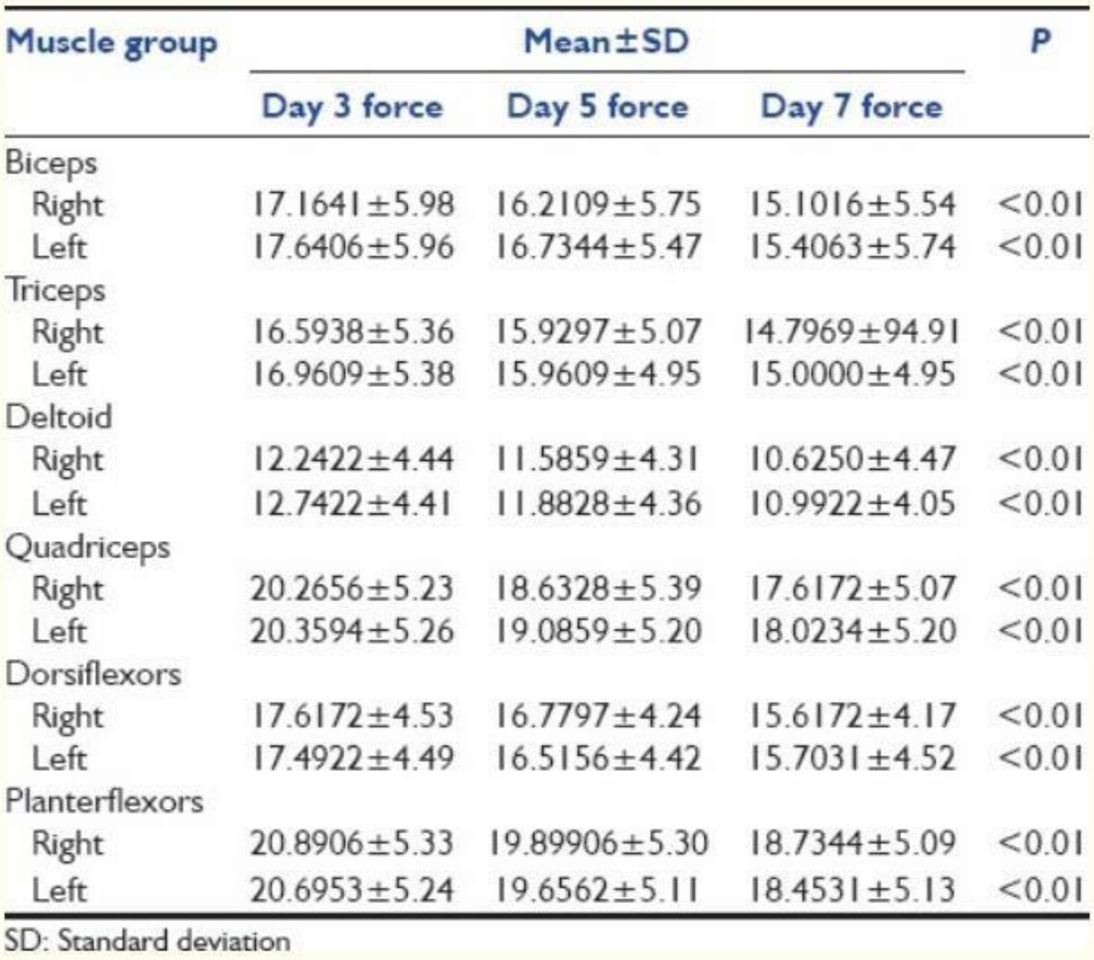
MERJENJE MOČI STISKA Z ROČNIM DINAMOMETROM

- validirana metoda, enostavna, poceni
- moč stiska roke = max moč, ki izhaja iz krčenja zunanjih in notranjih ročnih mišic, merjenje max izometrične kontrakcije

- razl. aplikacije, npr. v merjenju moči v športu, nekaterih poklicih (policija, vojska), zdravstvu (ICU)
- nizke vrednosti – znak za zdravstvene težave in prezgodnjo smrt (osteoporoza, kardiovaskularne boelzni in rak pri moških, šibkost in invalidnost...)

Table 2

Comparison of means of dynamometry values (in pounds) through day 3 to day 7



Muscle group	Mean±SD			P
	Day 3 force	Day 5 force	Day 7 force	
Biceps				
Right	17.1641±5.98	16.2109±5.75	15.1016±5.54	<0.01
Left	17.6406±5.96	16.7344±5.47	15.4063±5.74	<0.01
Triceps				
Right	16.5938±5.36	15.9297±5.07	14.7969±94.91	<0.01
Left	16.9609±5.38	15.9609±4.95	15.0000±4.95	<0.01
Deltoid				
Right	12.2422±4.44	11.5859±4.31	10.6250±4.47	<0.01
Left	12.7422±4.41	11.8828±4.36	10.9922±4.05	<0.01
Quadriceps				
Right	20.2656±5.23	18.6328±5.39	17.6172±5.07	<0.01
Left	20.3594±5.26	19.0859±5.20	18.0234±5.20	<0.01
Dorsiflexors				
Right	17.6172±4.53	16.7797±4.24	15.6172±4.17	<0.01
Left	17.4922±4.49	16.5156±4.42	15.7031±4.52	<0.01
Planterflexors				
Right	20.8906±5.33	19.89906±5.30	18.7344±5.09	<0.01
Left	20.6953±5.24	19.6562±5.11	18.4531±5.13	<0.01

SD: Standard deviation

The average reduction in peripheral muscle strength observed in the study was 11.8% during ICU stay. The percentage reduction was 13% in deltoid and quadriceps muscle groups. The minimum reduction in force was 10% in dorsiflexors and plantarflexors during 7 days of ICU stay [Figure 2].

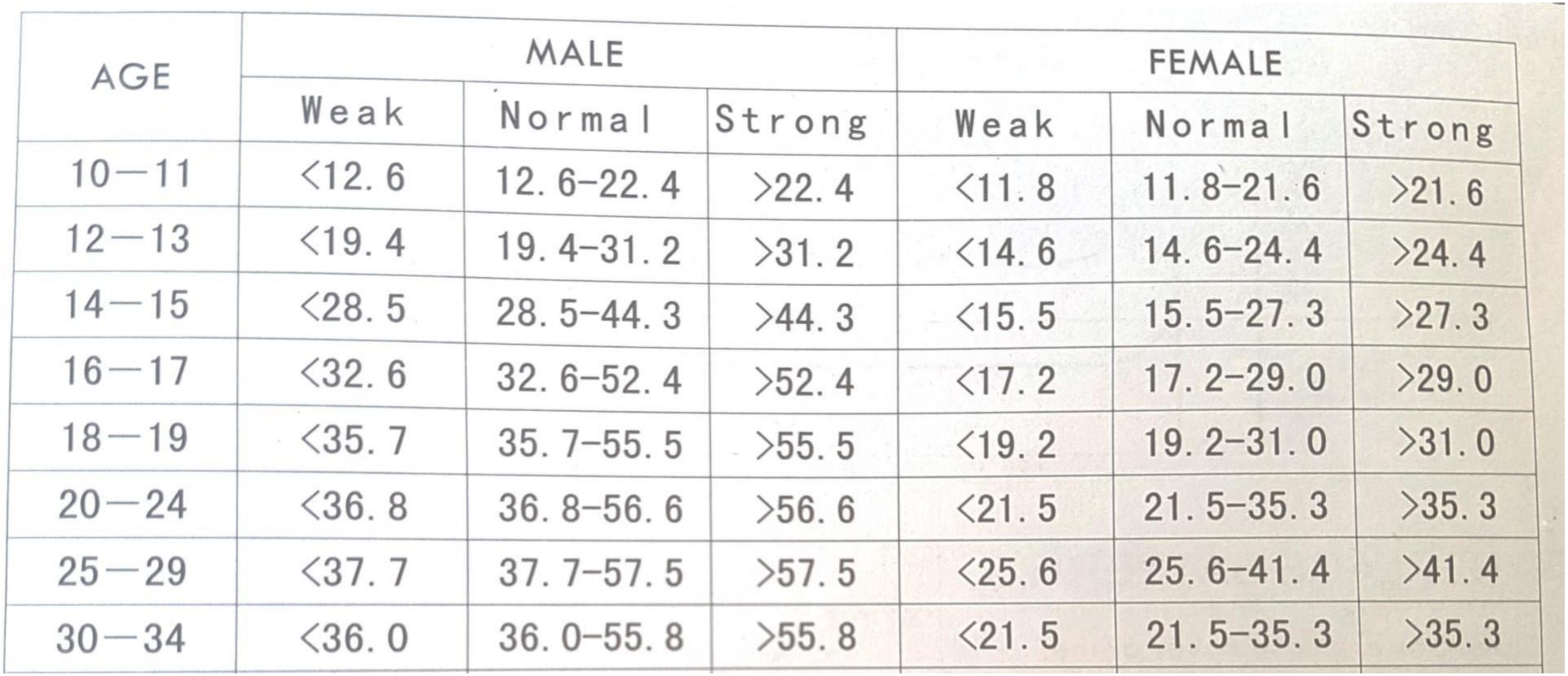
MERJENJE MOČI STISKA Z ROČNIM DINAMOMETROM

VAJA

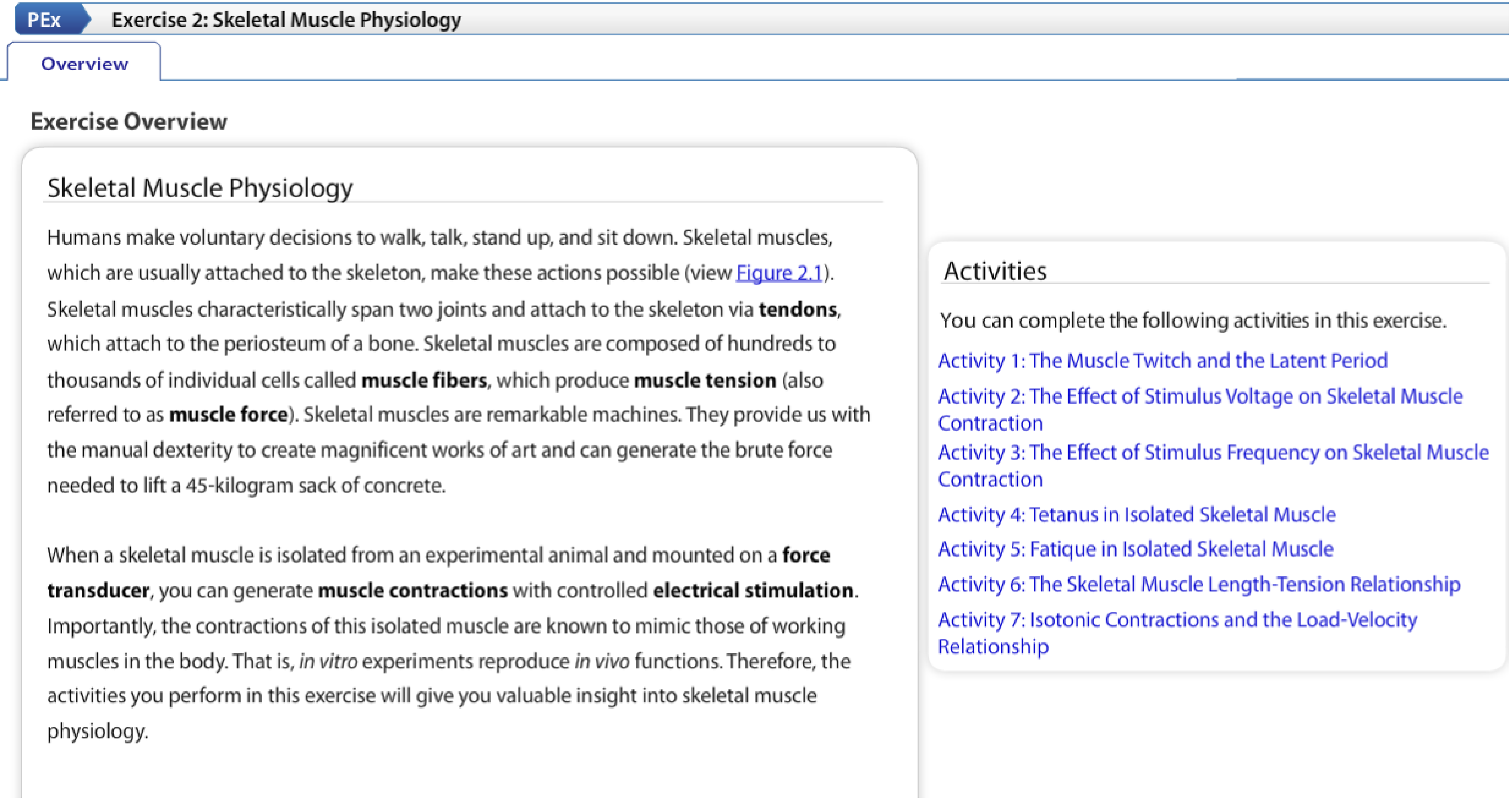
-dinamometer – z vijakom nastavite primeren položaj za optimalen oprijem roke

- nastavite spol, starost
- merjenje: pokonci, roka ob telo, 90st, ne premikati roke, spodbujati!
- 5 sek max stisk roke!

- meritve – razlike leva – desna roka
- meritve – utrujanje mišice
  - dominantna roka: 5 meritev, vmes 15 sek intervali



AGE	MALE			FEMALE		
	Weak	Normal	Strong	Weak	Normal	Strong
10—11	<12. 6	12. 6-22. 4	>22. 4	<11. 8	11. 8-21. 6	>21. 6
12—13	<19. 4	19. 4-31. 2	>31. 2	<14. 6	14. 6-24. 4	>24. 4
14—15	<28. 5	28. 5-44. 3	>44. 3	<15. 5	15. 5-27. 3	>27. 3
16—17	<32. 6	32. 6-52. 4	>52. 4	<17. 2	17. 2-29. 0	>29. 0
18—19	<35. 7	35. 7-55. 5	>55. 5	<19. 2	19. 2-31. 0	>31. 0
20—24	<36. 8	36. 8-56. 6	>56. 6	<21. 5	21. 5-35. 3	>35. 3
25—29	<37. 7	37. 7-57. 5	>57. 5	<25. 6	25. 6-41. 4	>41. 4
30—34	<36. 0	36. 0-55. 8	>55. 8	<21. 5	21. 5-35. 3	>35. 3



Exercise 2: Skeletal Muscle Physiology

Exercise Overview

Skeletal Muscle Physiology

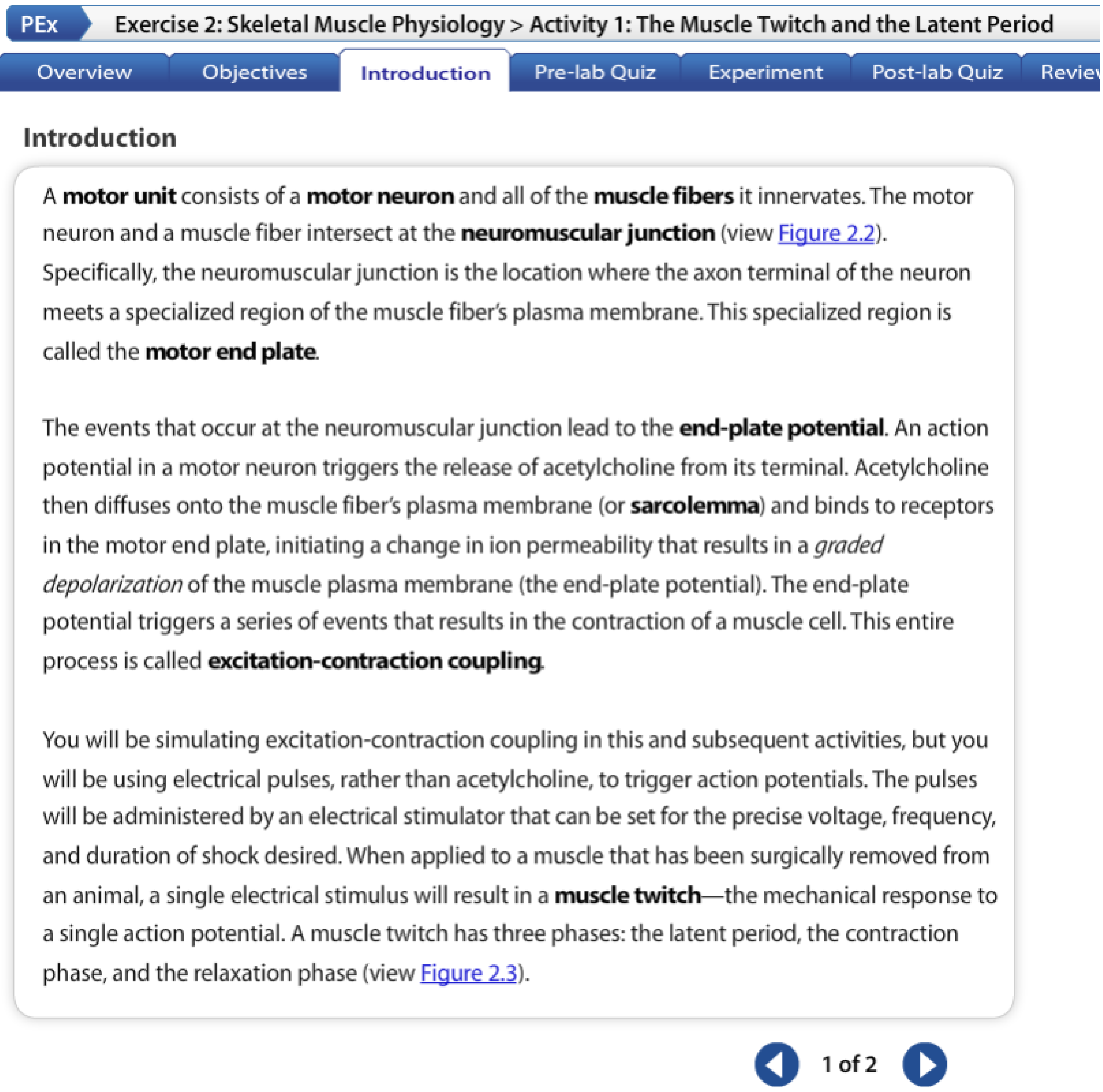
Humans make voluntary decisions to walk, talk, stand up, and sit down. Skeletal muscles, which are usually attached to the skeleton, make these actions possible (view Figure 2.1). Skeletal muscles characteristically span two joints and attach to the skeleton via **tendons**, which attach to the periosteum of a bone. Skeletal muscles are composed of hundreds to thousands of individual cells called **muscle fibers**, which produce **muscle tension** (also referred to as **muscle force**). Skeletal muscles are remarkable machines. They provide us with the manual dexterity to create magnificent works of art and can generate the brute force needed to lift a 45-kilogram sack of concrete.

When a skeletal muscle is isolated from an experimental animal and mounted on a **force transducer**, you can generate **muscle contractions** with controlled **electrical stimulation**. Importantly, the contractions of this isolated muscle are known to mimic those of working muscles in the body. That is, *in vitro* experiments reproduce *in vivo* functions. Therefore, the activities you perform in this exercise will give you valuable insight into skeletal muscle physiology.

Activities

You can complete the following activities in this exercise.

Activity 1: The Muscle Twitch and the Latent Period
Activity 2: The Effect of Stimulus Voltage on Skeletal Muscle Contraction
Activity 3: The Effect of Stimulus Frequency on Skeletal Muscle Contraction
Activity 4: Tetanus in Isolated Skeletal Muscle
Activity 5: Fatique in Isolated Skeletal Muscle
Activity 6: The Skeletal Muscle Length-Tension Relationship
Activity 7: Isotonic Contractions and the Load-Velocity Relationship



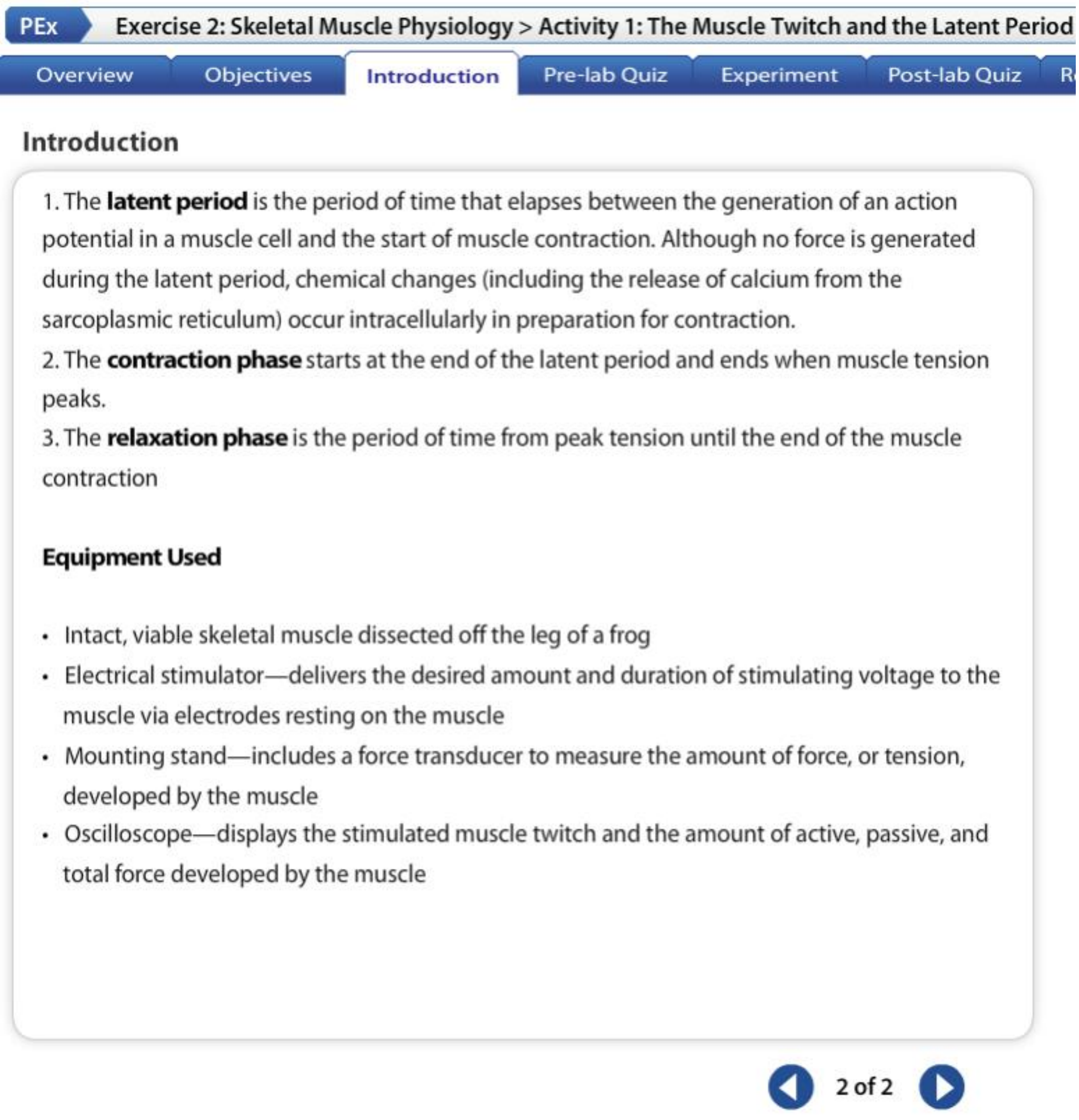
Exercise 2: Skeletal Muscle Physiology > Activity 1: The Muscle Twitch and the Latent Period

Introduction

A **motor unit** consists of a **motor neuron** and all of the **muscle fibers** it innervates. The motor neuron and a muscle fiber intersect at the **neuromuscular junction** (view Figure 2.2). Specifically, the neuromuscular junction is the location where the axon terminal of the neuron meets a specialized region of the muscle fiber's plasma membrane. This specialized region is called the **motor end plate**.

The events that occur at the neuromuscular junction lead to the **end-plate potential**. An action potential in a motor neuron triggers the release of acetylcholine from its terminal. Acetylcholine then diffuses onto the muscle fiber's plasma membrane (or **sarcolemma**) and binds to receptors in the motor end plate, initiating a change in ion permeability that results in a *graded depolarization* of the muscle plasma membrane (the end-plate potential). The end-plate potential triggers a series of events that results in the contraction of a muscle cell. This entire process is called **excitation-contraction coupling**.

You will be simulating excitation-contraction coupling in this and subsequent activities, but you will be using electrical pulses, rather than acetylcholine, to trigger action potentials. The pulses will be administered by an electrical stimulator that can be set for the precise voltage, frequency, and duration of shock desired. When applied to a muscle that has been surgically removed from an animal, a single electrical stimulus will result in a **muscle twitch**—the mechanical response to a single action potential. A muscle twitch has three phases: the latent period, the contraction phase, and the relaxation phase (view Figure 2.3).



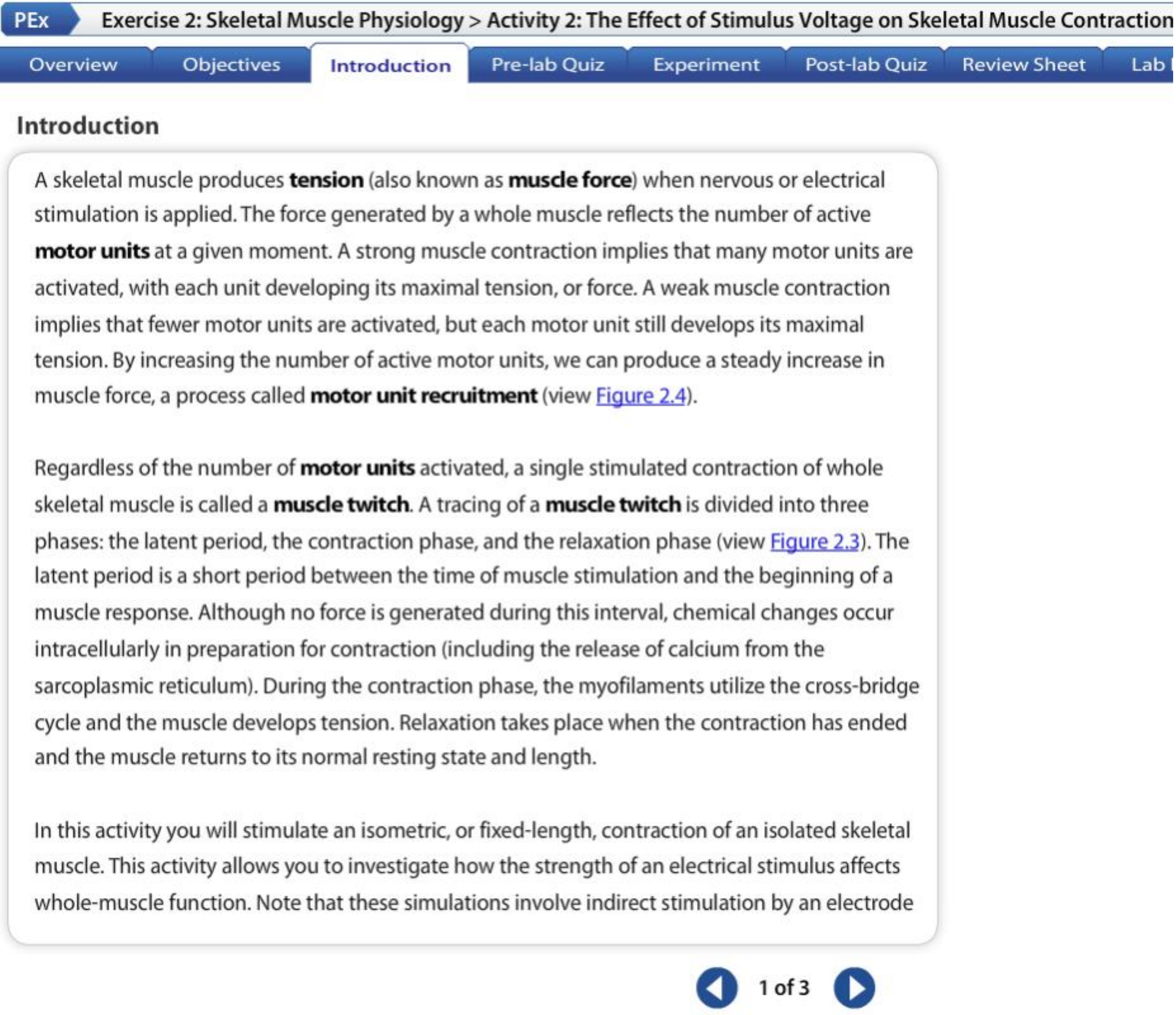
Exercise 2: Skeletal Muscle Physiology > Activity 1: The Muscle Twitch and the Latent Period

Introduction

1. The **latent period** is the period of time that elapses between the generation of an action potential in a muscle cell and the start of muscle contraction. Although no force is generated during the latent period, chemical changes (including the release of calcium from the sarcoplasmic reticulum) occur intracellularly in preparation for contraction.
2. The **contraction phase** starts at the end of the latent period and ends when muscle tension peaks.
3. The **relaxation phase** is the period of time from peak tension until the end of the muscle contraction

Equipment Used

- Intact, viable skeletal muscle dissected off the leg of a frog
- Electrical stimulator—delivers the desired amount and duration of stimulating voltage to the muscle via electrodes resting on the muscle
- Mounting stand—includes a force transducer to measure the amount of force, or tension, developed by the muscle
- Oscilloscope—displays the stimulated muscle twitch and the amount of active, passive, and total force developed by the muscle

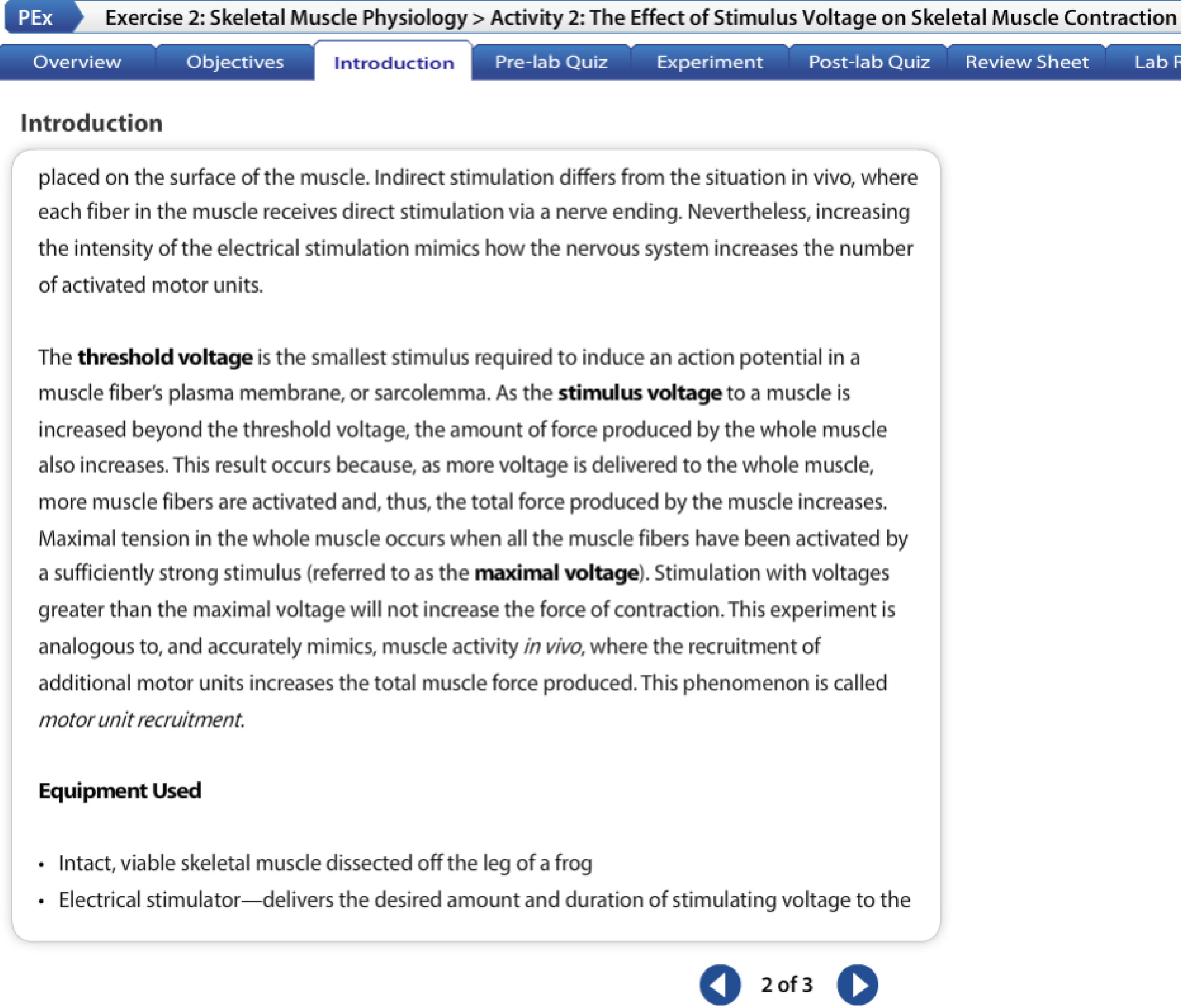


Introduction

A skeletal muscle produces **tension** (also known as **muscle force**) when nervous or electrical stimulation is applied. The force generated by a whole muscle reflects the number of active **motor units** at a given moment. A strong muscle contraction implies that many motor units are activated, with each unit developing its maximal tension, or force. A weak muscle contraction implies that fewer motor units are activated, but each motor unit still develops its maximal tension. By increasing the number of active motor units, we can produce a steady increase in muscle force, a process called **motor unit recruitment** (view Figure 2.4).

Regardless of the number of **motor units** activated, a single stimulated contraction of whole skeletal muscle is called a **muscle twitch**. A tracing of a **muscle twitch** is divided into three phases: the latent period, the contraction phase, and the relaxation phase (view Figure 2.3). The latent period is a short period between the time of muscle stimulation and the beginning of a muscle response. Although no force is generated during this interval, chemical changes occur intracellularly in preparation for contraction (including the release of calcium from the sarcoplasmic reticulum). During the contraction phase, the myofilaments utilize the cross-bridge cycle and the muscle develops tension. Relaxation takes place when the contraction has ended and the muscle returns to its normal resting state and length.

In this activity you will stimulate an isometric, or fixed-length, contraction of an isolated skeletal muscle. This activity allows you to investigate how the strength of an electrical stimulus affects whole-muscle function. Note that these simulations involve indirect stimulation by an electrode



Exercise 2: Skeletal Muscle Physiology > Activity 2: The Effect of Stimulus Voltage on Skeletal Muscle Contraction

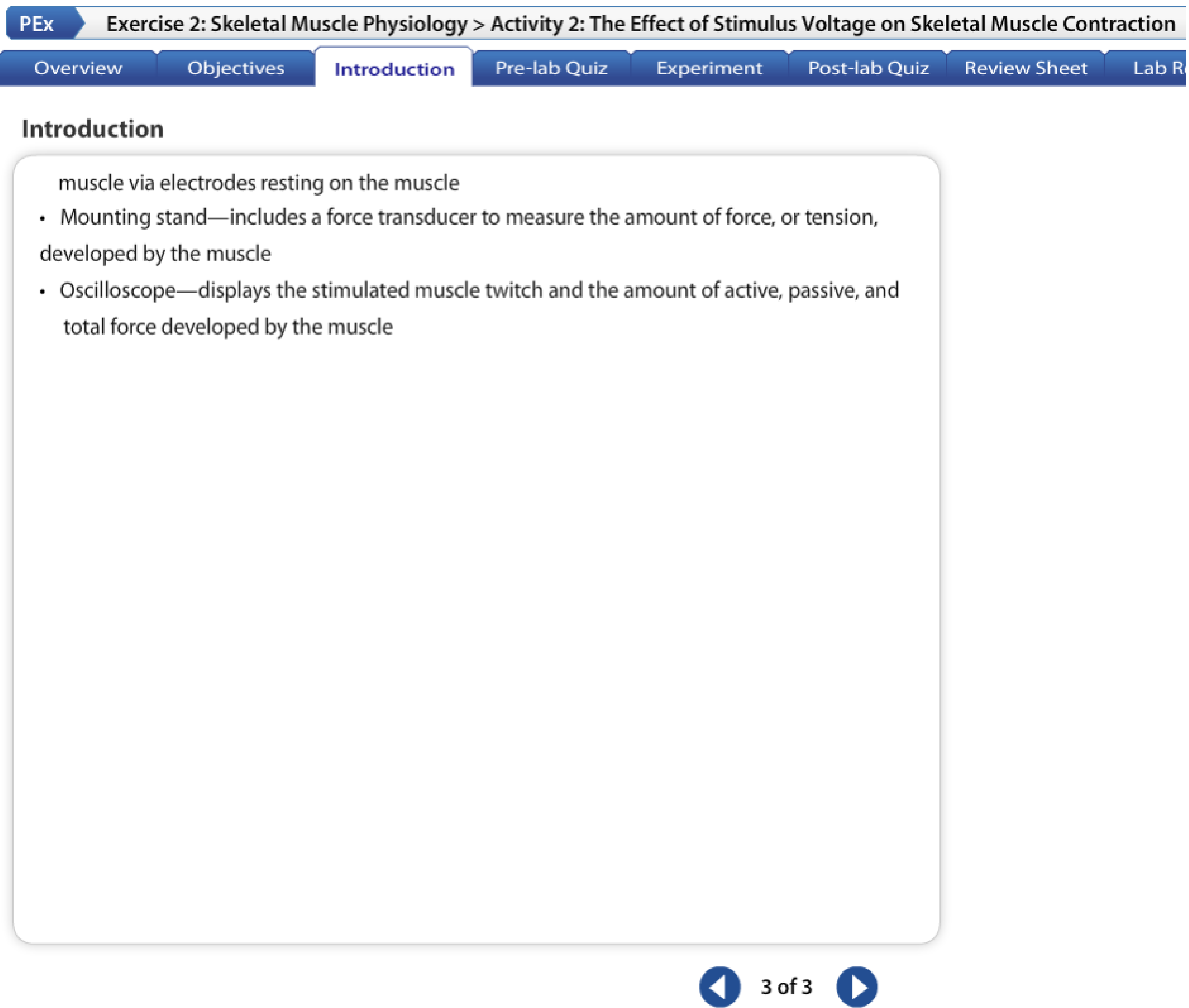
Introduction

placed on the surface of the muscle. Indirect stimulation differs from the situation in vivo, where each fiber in the muscle receives direct stimulation via a nerve ending. Nevertheless, increasing the intensity of the electrical stimulation mimics how the nervous system increases the number of activated motor units.

The **threshold voltage** is the smallest stimulus required to induce an action potential in a muscle fiber's plasma membrane, or sarcolemma. As the **stimulus voltage** to a muscle is increased beyond the threshold voltage, the amount of force produced by the whole muscle also increases. This result occurs because, as more voltage is delivered to the whole muscle, more muscle fibers are activated and, thus, the total force produced by the muscle increases. Maximal tension in the whole muscle occurs when all the muscle fibers have been activated by a sufficiently strong stimulus (referred to as the **maximal voltage**). Stimulation with voltages greater than the maximal voltage will not increase the force of contraction. This experiment is analogous to, and accurately mimics, muscle activity *in vivo*, where the recruitment of additional motor units increases the total muscle force produced. This phenomenon is called *motor unit recruitment*.

Equipment Used

- Intact, viable skeletal muscle dissected off the leg of a frog
- Electrical stimulator—delivers the desired amount and duration of stimulating voltage to the

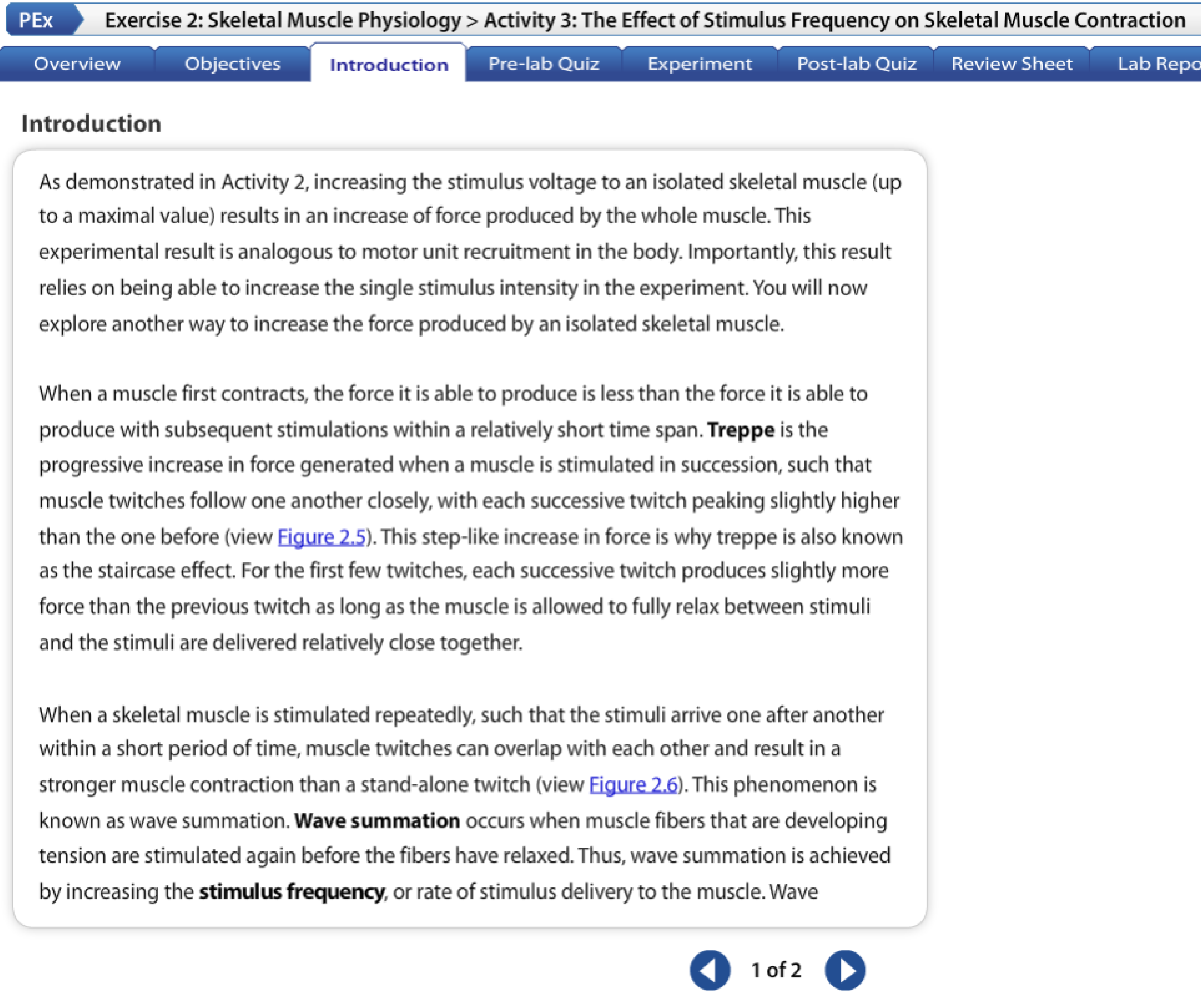


Exercise 2: Skeletal Muscle Physiology > Activity 2: The Effect of Stimulus Voltage on Skeletal Muscle Contraction

Introduction

muscle via electrodes resting on the muscle

- Mounting stand—includes a force transducer to measure the amount of force, or tension, developed by the muscle
- Oscilloscope—displays the stimulated muscle twitch and the amount of active, passive, and total force developed by the muscle



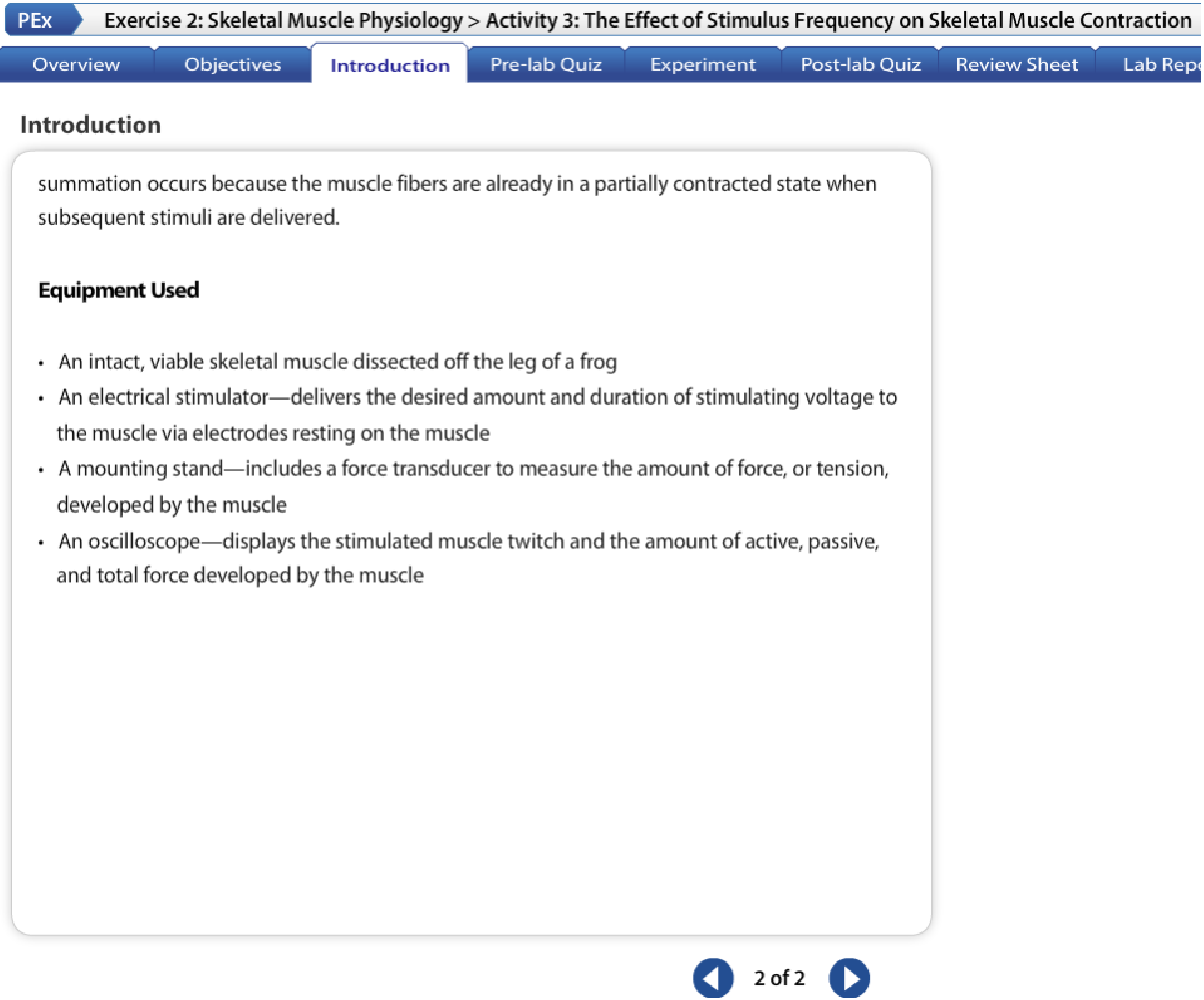
Exercise 2: Skeletal Muscle Physiology > Activity 3: The Effect of Stimulus Frequency on Skeletal Muscle Contraction

Introduction

As demonstrated in Activity 2, increasing the stimulus voltage to an isolated skeletal muscle (up to a maximal value) results in an increase of force produced by the whole muscle. This experimental result is analogous to motor unit recruitment in the body. Importantly, this result relies on being able to increase the single stimulus intensity in the experiment. You will now explore another way to increase the force produced by an isolated skeletal muscle.

When a muscle first contracts, the force it is able to produce is less than the force it is able to produce with subsequent stimulations within a relatively short time span. **Treppe** is the progressive increase in force generated when a muscle is stimulated in succession, such that muscle twitches follow one another closely, with each successive twitch peaking slightly higher than the one before (view Figure 2.5). This step-like increase in force is why treppe is also known as the staircase effect. For the first few twitches, each successive twitch produces slightly more force than the previous twitch as long as the muscle is allowed to fully relax between stimuli and the stimuli are delivered relatively close together.

When a skeletal muscle is stimulated repeatedly, such that the stimuli arrive one after another within a short period of time, muscle twitches can overlap with each other and result in a stronger muscle contraction than a stand-alone twitch (view Figure 2.6). This phenomenon is known as wave summation. **Wave summation** occurs when muscle fibers that are developing tension are stimulated again before the fibers have relaxed. Thus, wave summation is achieved by increasing the **stimulus frequency**, or rate of stimulus delivery to the muscle. Wave



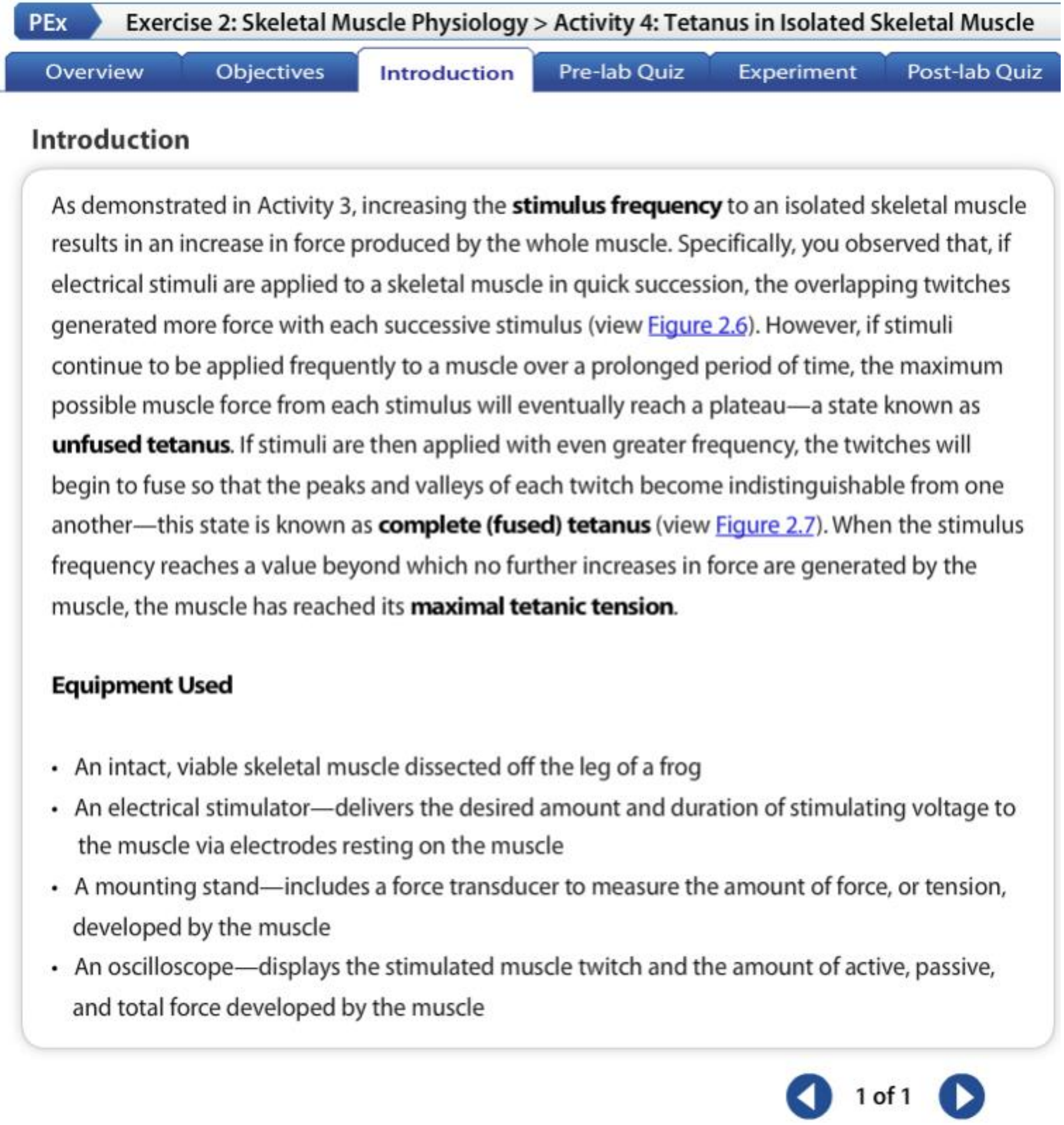
Exercise 2: Skeletal Muscle Physiology > Activity 3: The Effect of Stimulus Frequency on Skeletal Muscle Contraction

Introduction

summation occurs because the muscle fibers are already in a partially contracted state when subsequent stimuli are delivered.

Equipment Used

- An intact, viable skeletal muscle dissected off the leg of a frog
- An electrical stimulator—delivers the desired amount and duration of stimulating voltage to the muscle via electrodes resting on the muscle
- A mounting stand—includes a force transducer to measure the amount of force, or tension, developed by the muscle
- An oscilloscope—displays the stimulated muscle twitch and the amount of active, passive, and total force developed by the muscle



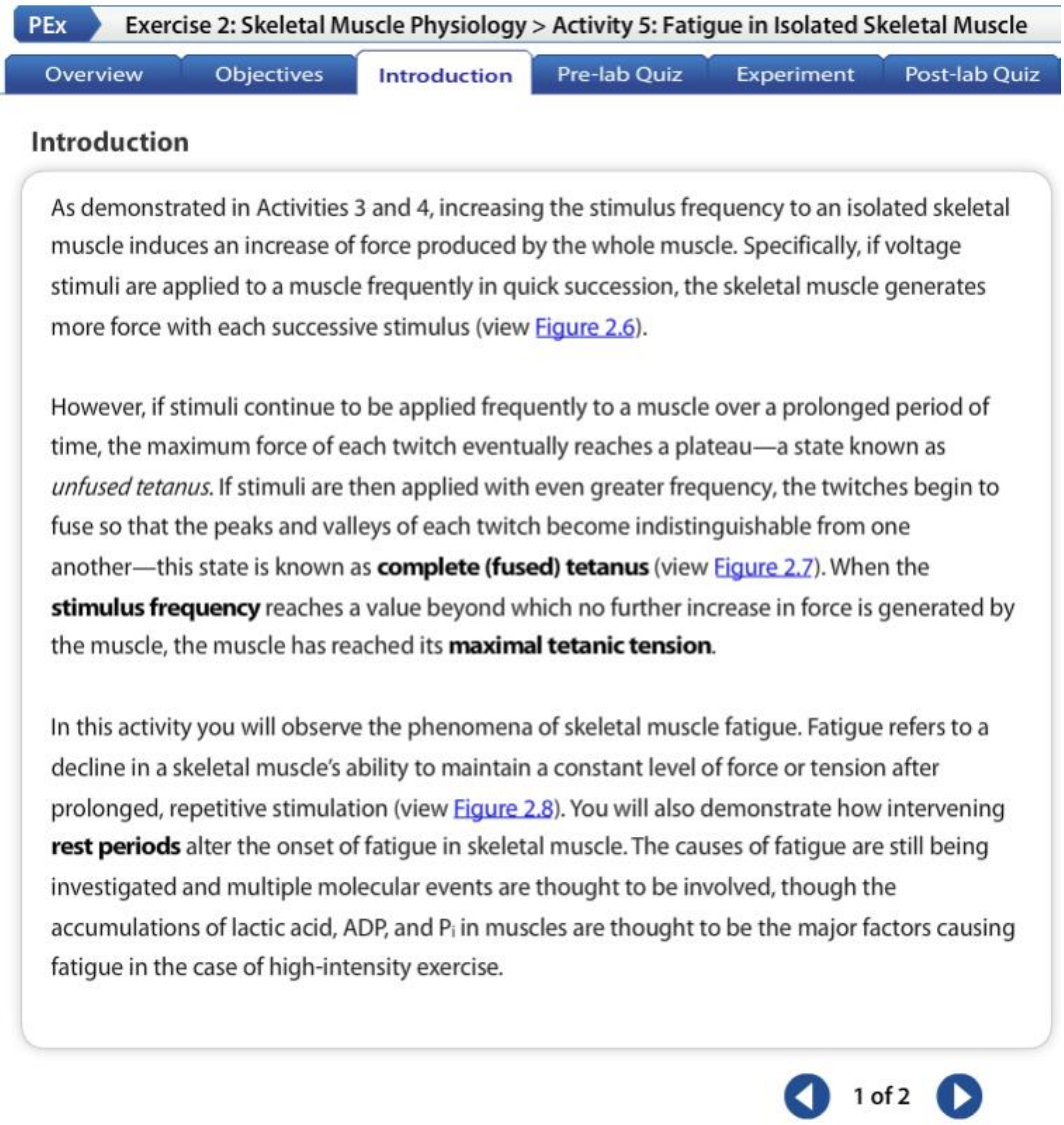
Exercise 2: Skeletal Muscle Physiology > Activity 4: Tetanus in Isolated Skeletal Muscle

Introduction

As demonstrated in Activity 3, increasing the **stimulus frequency** to an isolated skeletal muscle results in an increase in force produced by the whole muscle. Specifically, you observed that, if electrical stimuli are applied to a skeletal muscle in quick succession, the overlapping twitches generated more force with each successive stimulus (view Figure 2.6). However, if stimuli continue to be applied frequently to a muscle over a prolonged period of time, the maximum possible muscle force from each stimulus will eventually reach a plateau—a state known as **unfused tetanus**. If stimuli are then applied with even greater frequency, the twitches will begin to fuse so that the peaks and valleys of each twitch become indistinguishable from one another—this state is known as **complete (fused) tetanus** (view Figure 2.7). When the stimulus frequency reaches a value beyond which no further increases in force are generated by the muscle, the muscle has reached its **maximal tetanic tension**.

Equipment Used

- An intact, viable skeletal muscle dissected off the leg of a frog
- An electrical stimulator—delivers the desired amount and duration of stimulating voltage to the muscle via electrodes resting on the muscle
- A mounting stand—includes a force transducer to measure the amount of force, or tension, developed by the muscle
- An oscilloscope—displays the stimulated muscle twitch and the amount of active, passive, and total force developed by the muscle



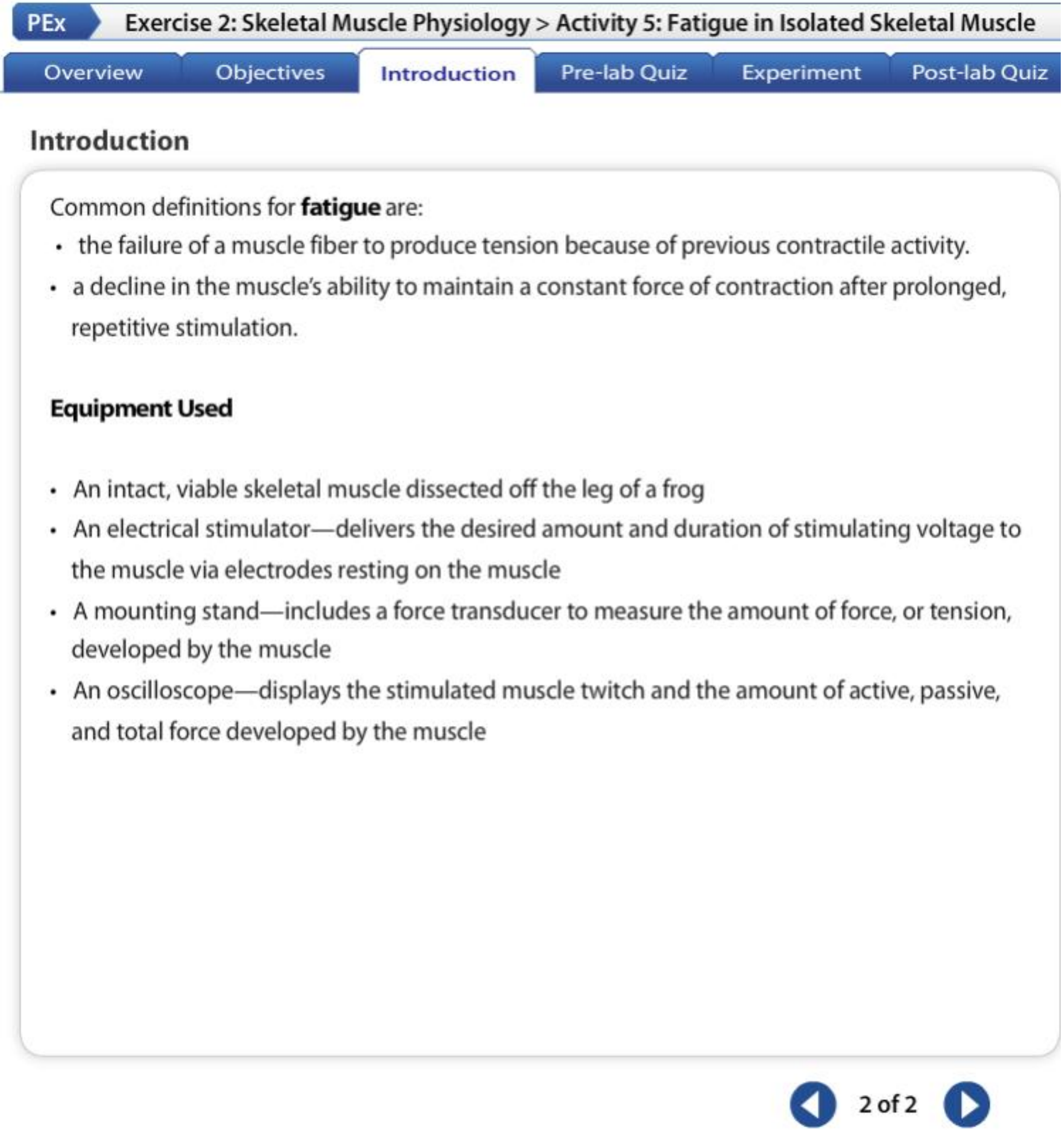
Exercise 2: Skeletal Muscle Physiology > Activity 5: Fatigue in Isolated Skeletal Muscle

Introduction

As demonstrated in Activities 3 and 4, increasing the stimulus frequency to an isolated skeletal muscle induces an increase of force produced by the whole muscle. Specifically, if voltage stimuli are applied to a muscle frequently in quick succession, the skeletal muscle generates more force with each successive stimulus (view Figure 2.6).

However, if stimuli continue to be applied frequently to a muscle over a prolonged period of time, the maximum force of each twitch eventually reaches a plateau—a state known as *unfused tetanus*. If stimuli are then applied with even greater frequency, the twitches begin to fuse so that the peaks and valleys of each twitch become indistinguishable from one another—this state is known as **complete (fused) tetanus** (view Figure 2.7). When the **stimulus frequency** reaches a value beyond which no further increase in force is generated by the muscle, the muscle has reached its **maximal tetanic tension**.

In this activity you will observe the phenomena of skeletal muscle fatigue. Fatigue refers to a decline in a skeletal muscle's ability to maintain a constant level of force or tension after prolonged, repetitive stimulation (view Figure 2.8). You will also demonstrate how intervening **rest periods** alter the onset of fatigue in skeletal muscle. The causes of fatigue are still being investigated and multiple molecular events are thought to be involved, though the accumulations of lactic acid, ADP, and P_i in muscles are thought to be the major factors causing fatigue in the case of high-intensity exercise.



Exercise 2: Skeletal Muscle Physiology > Activity 5: Fatigue in Isolated Skeletal Muscle

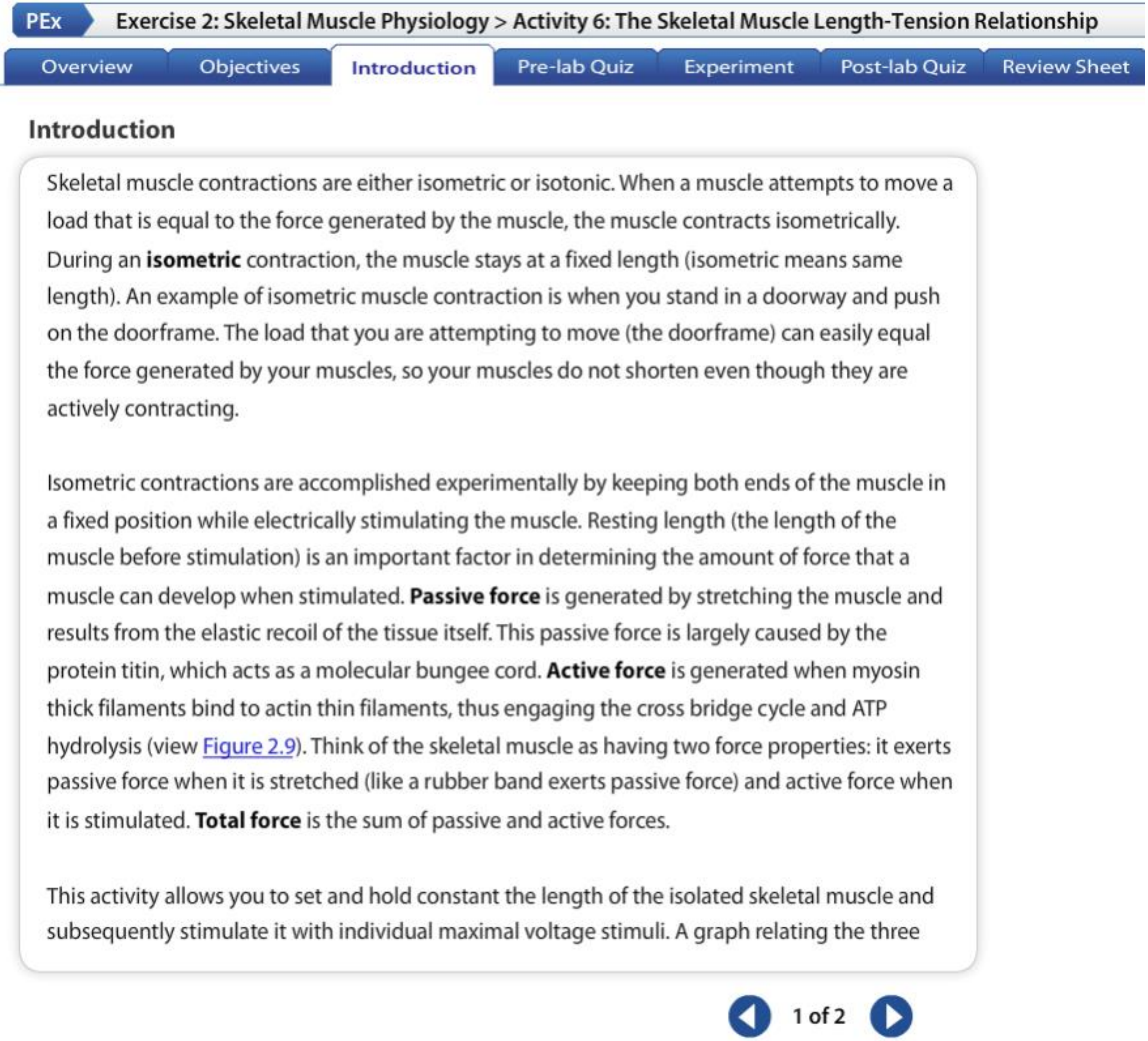
Introduction

Common definitions for **fatigue** are:

- the failure of a muscle fiber to produce tension because of previous contractile activity.
- a decline in the muscle's ability to maintain a constant force of contraction after prolonged, repetitive stimulation.

Equipment Used

- An intact, viable skeletal muscle dissected off the leg of a frog
- An electrical stimulator—delivers the desired amount and duration of stimulating voltage to the muscle via electrodes resting on the muscle
- A mounting stand—includes a force transducer to measure the amount of force, or tension, developed by the muscle
- An oscilloscope—displays the stimulated muscle twitch and the amount of active, passive, and total force developed by the muscle



Exercise 2: Skeletal Muscle Physiology > Activity 6: The Skeletal Muscle Length-Tension Relationship

Introduction

Skeletal muscle contractions are either isometric or isotonic. When a muscle attempts to move a load that is equal to the force generated by the muscle, the muscle contracts isometrically. During an **isometric** contraction, the muscle stays at a fixed length (isometric means same length). An example of isometric muscle contraction is when you stand in a doorway and push on the doorframe. The load that you are attempting to move (the doorframe) can easily equal the force generated by your muscles, so your muscles do not shorten even though they are actively contracting.

Isometric contractions are accomplished experimentally by keeping both ends of the muscle in a fixed position while electrically stimulating the muscle. Resting length (the length of the muscle before stimulation) is an important factor in determining the amount of force that a muscle can develop when stimulated. **Passive force** is generated by stretching the muscle and results from the elastic recoil of the tissue itself. This passive force is largely caused by the protein titin, which acts as a molecular bungee cord. **Active force** is generated when myosin thick filaments bind to actin thin filaments, thus engaging the cross bridge cycle and ATP hydrolysis (view Figure 2.9). Think of the skeletal muscle as having two force properties: it exerts passive force when it is stretched (like a rubber band exerts passive force) and active force when it is stimulated. **Total force** is the sum of passive and active forces.

This activity allows you to set and hold constant the length of the isolated skeletal muscle and subsequently stimulate it with individual maximal voltage stimuli. A graph relating the three

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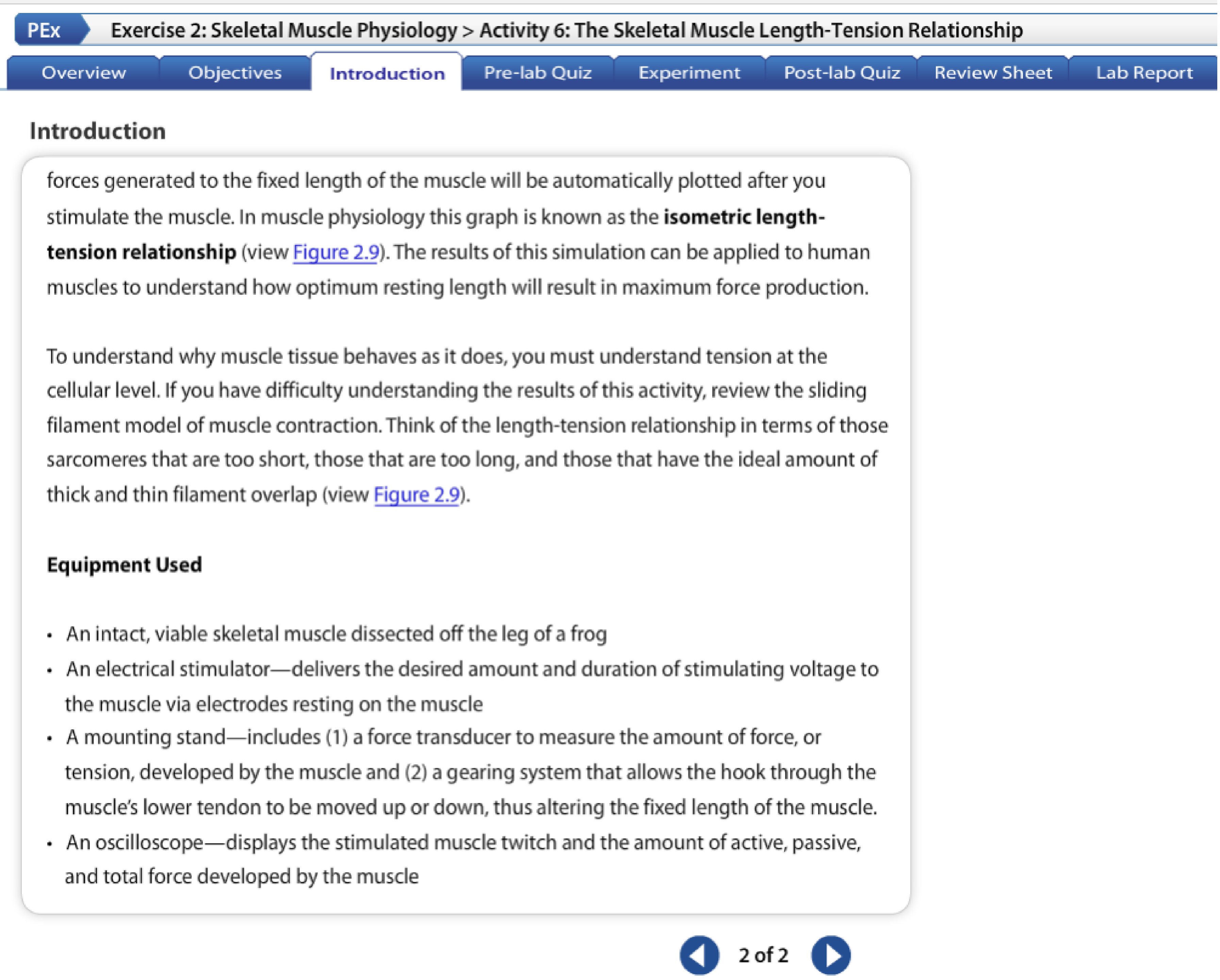

Exercise 2: Skeletal Muscle Physiology > Activity 6: The Skeletal Muscle Length-Tension Relationship

Introduction

forces generated to the fixed length of the muscle will be automatically plotted after you stimulate the muscle. In muscle physiology this graph is known as the **isometric length-tension relationship** (view Figure 2.9). The results of this simulation can be applied to human muscles to understand how optimum resting length will result in maximum force production.

To understand why muscle tissue behaves as it does, you must understand tension at the cellular level. If you have difficulty understanding the results of this activity, review the sliding filament model of muscle contraction. Think of the length-tension relationship in terms of those sarcomeres that are too short, those that are too long, and those that have the ideal amount of thick and thin filament overlap (view Figure 2.9).

Equipment Used

- An intact, viable skeletal muscle dissected off the leg of a frog
- An electrical stimulator—delivers the desired amount and duration of stimulating voltage to the muscle via electrodes resting on the muscle
- A mounting stand—includes (1) a force transducer to measure the amount of force, or tension, developed by the muscle and (2) a gearing system that allows the hook through the muscle's lower tendon to be moved up or down, thus altering the fixed length of the muscle.
- An oscilloscope—displays the stimulated muscle twitch and the amount of active, passive, and total force developed by the muscle