Characteristics of Skeletal Muscle Contraction

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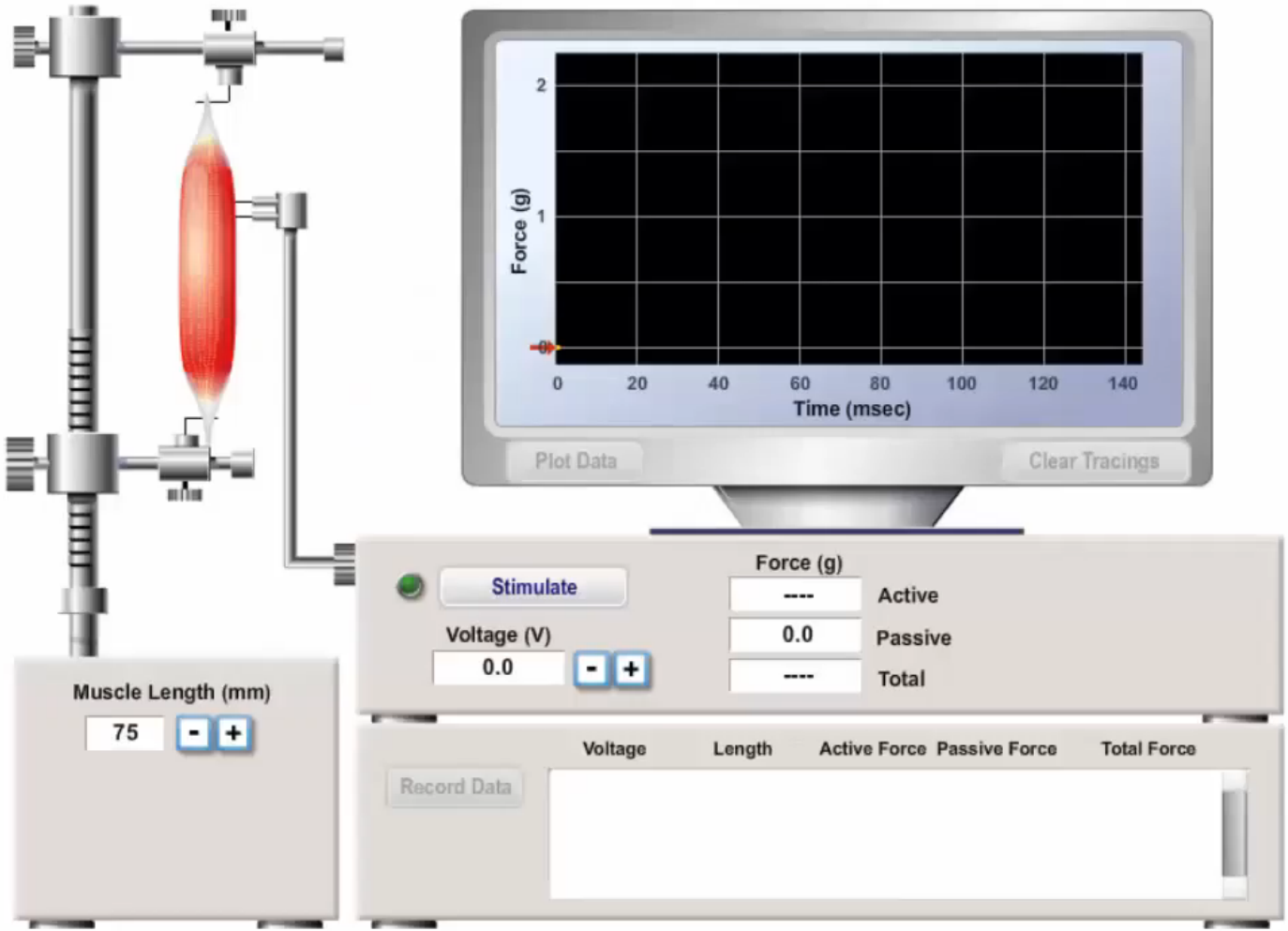
Aim of the experiment

Learn some of the characteristics of skeletal muscle contraction

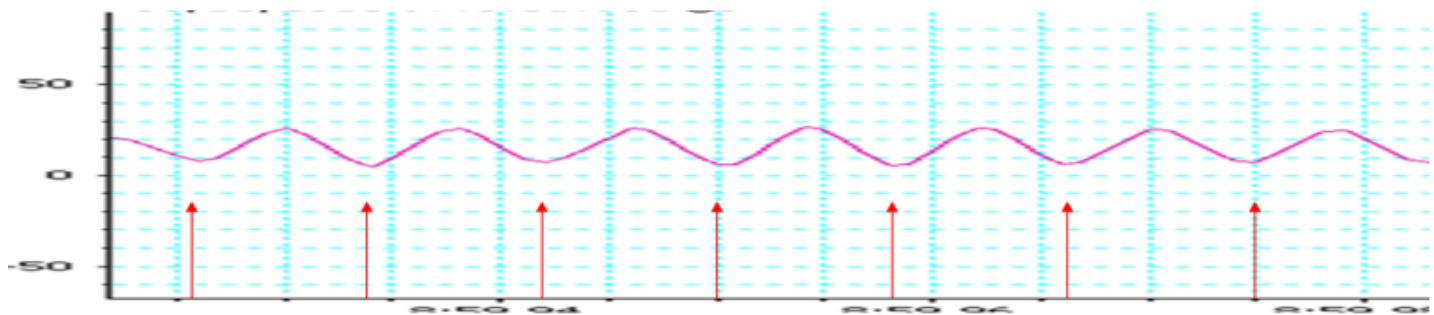
- Simple muscle twitch
- Summation
- Tetanization
- Fatigue
- Treppe phenomenon


2
1
0
Force (g)
0
20
40
60
80
100
120
140
Time (msec)
Plot Data
Clear Tracings
Stimulate
Force (g)
Voltage (V)
0.0
Active
0.0
Passive
Total
Muscle Length (mm)
75
Voltage
Length
Active Force
Passive Force
Total Force
Record Data

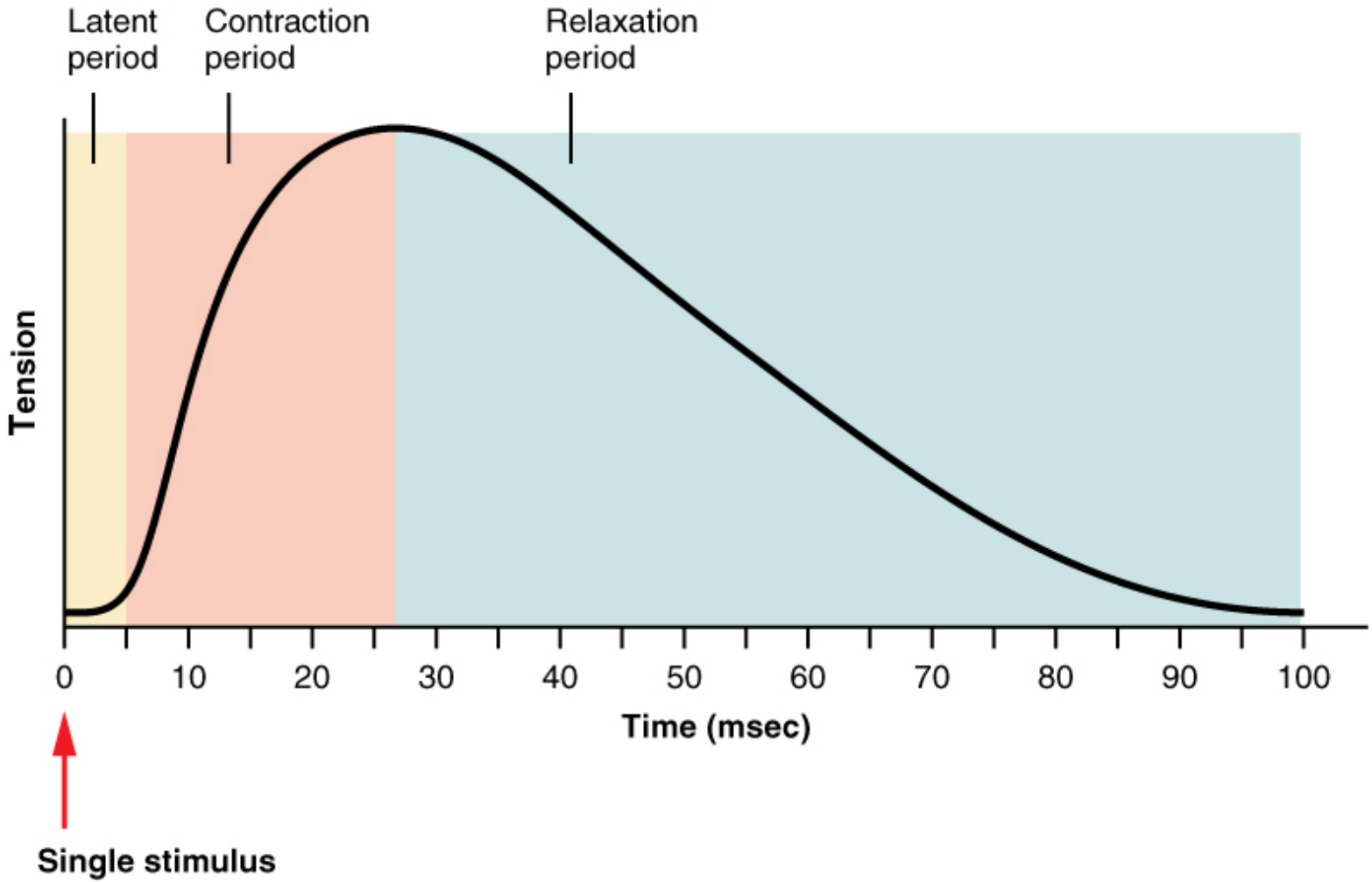
Simple Muscle Twitch

•Muscle twitch, is a brief muscle contraction followed by relaxation that occurs in response to a single stimulus.

• A **threshold stimulation** is the smallest amount of stimulation that will result in a contraction.



Give a stimulus above the threshold at low frequency


Latent period
Contraction period
Relaxation period
Tension
0
10
20
30
40
50
60
70
80
90
100
Time (msec)
Single stimulus

Components of muscle twitch

Latent period

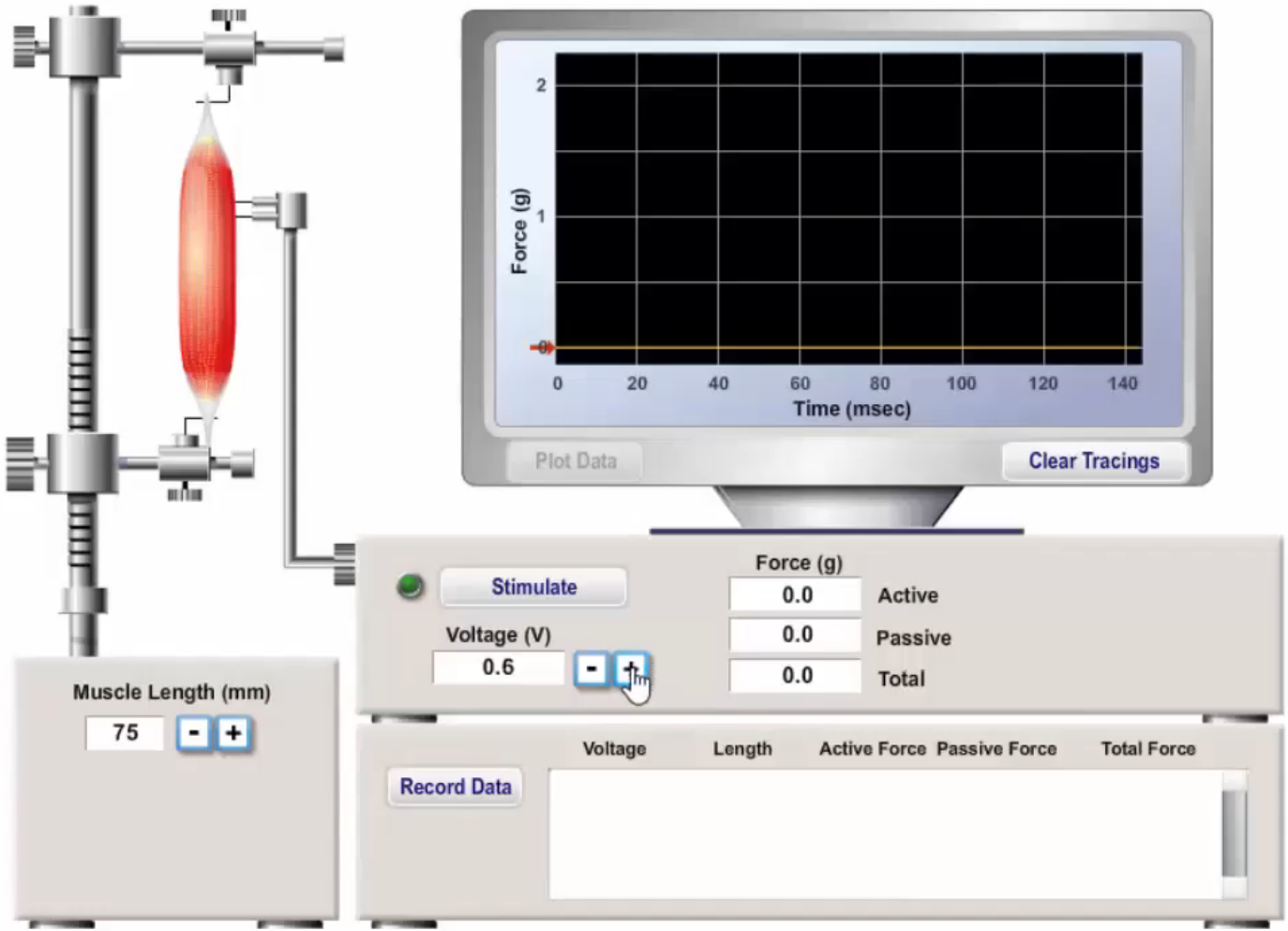
- The time between the application of the stimulus and the beginning of contraction.
- During the latent period, the action potential sweeps over the sarcolemma and calcium ions are released from the sarcoplasmic reticulum.

Contraction period:

- When the tension starts to increase till maximum tension is achieved.
- During this time, calcium ions bind to troponin, myosin-binding sites on actin are exposed, and cross-bridges form.

Relaxation period:

- When the tension starts to decrease till it returns to baseline.
- Calcium ions are actively transported back into the sarcoplasmic reticulum, myosin-binding sites are covered by tropomyosin, myosin heads detach from


2
1
0
Force (g)
0
20
40
60
80
100
120
140
Time (msec)
Plot Data
Clear Tracings
Stimulate
Force (g)
Voltage (V)
0.6
-
+
0.0
Active
0.0
Passive
0.0
Total
Muscle Length (mm)
75
-
+
Voltage
Length
Active Force
Passive Force
Total Force
Record Data

Summation

•Summation is used to increase the intensity of overall muscle contraction.

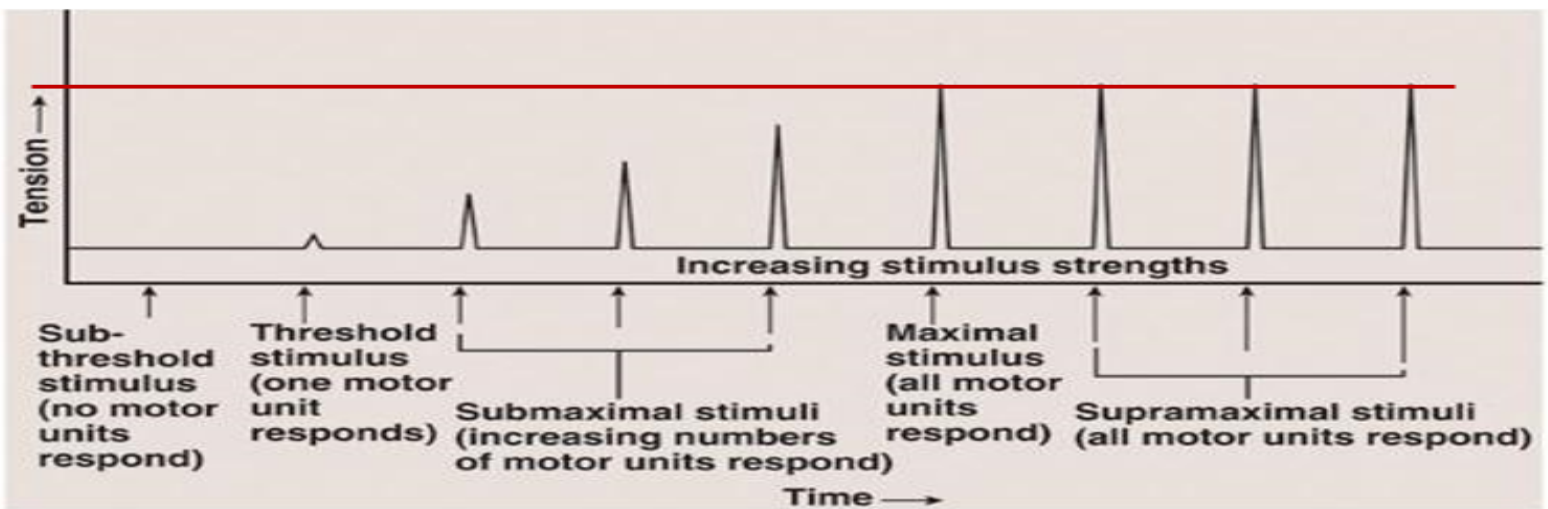
• Summation occurs in two ways:

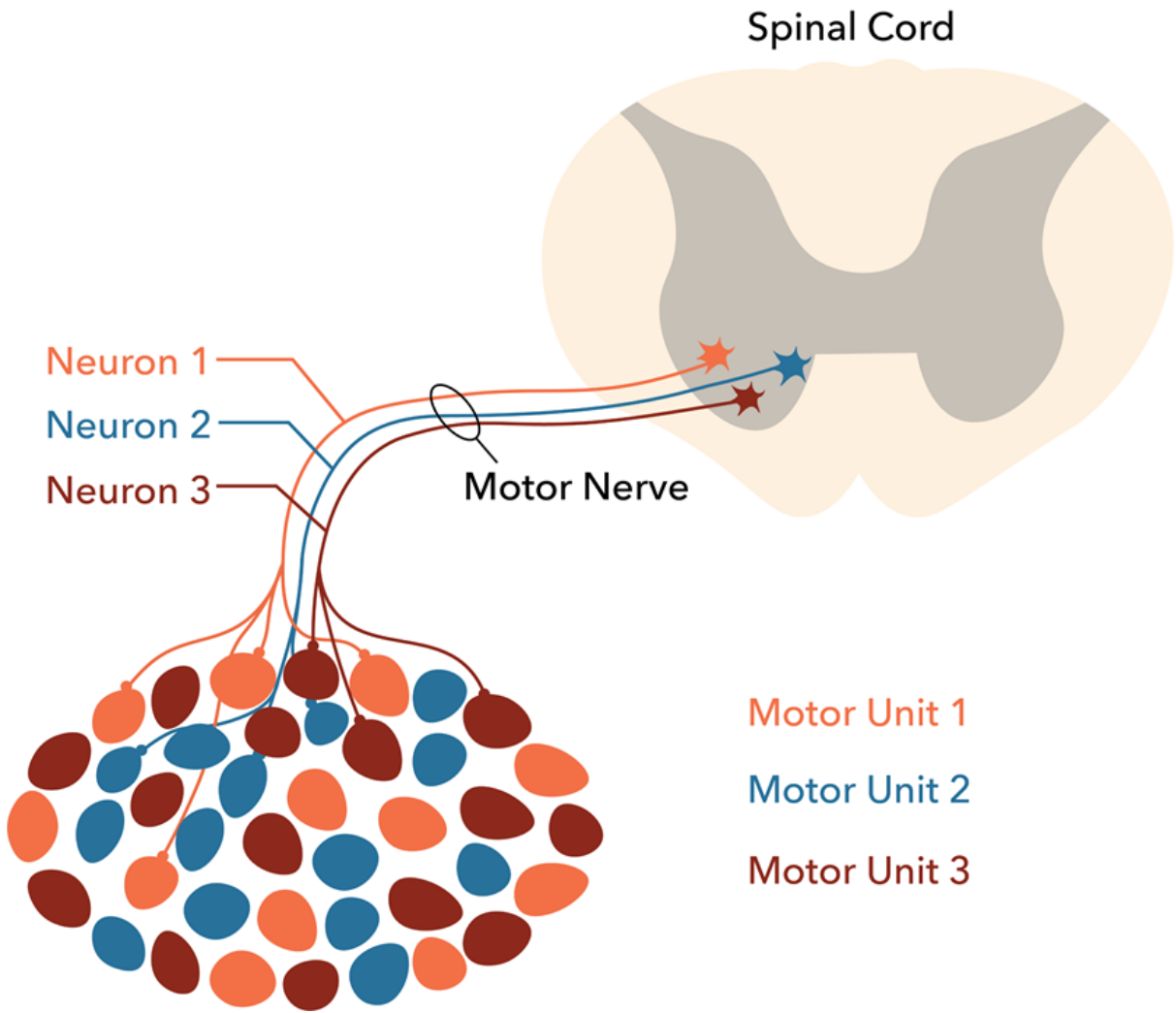
1. Multiple fiber summation: by increasing the number of motor units contracting simultaneously. It is achieved by increasing the stimulus strength
2. Frequency summation: by increasing the frequency of stimulation leading to an overlap between successive muscle twitches. It is achieved by increasing the frequency of stimulation
    - Can lead to tetanization

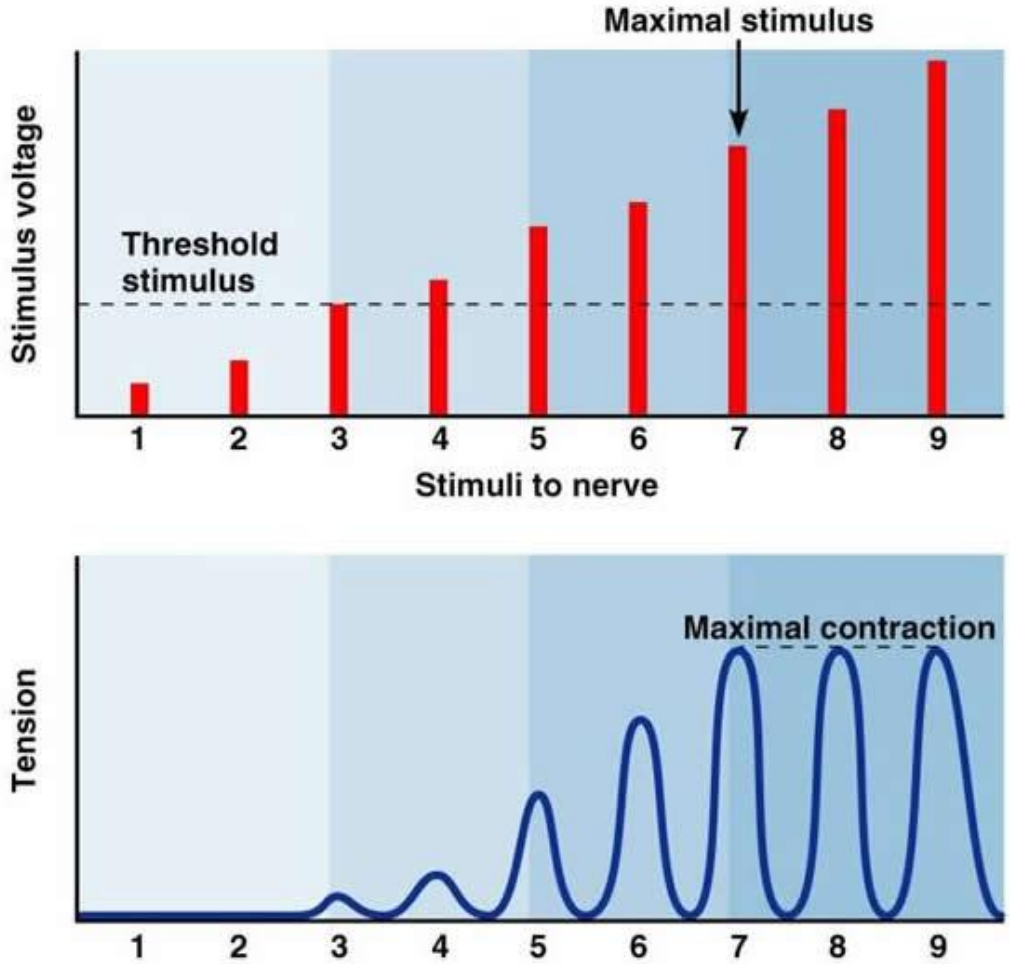
Multiple fiber summation(Recruitment)

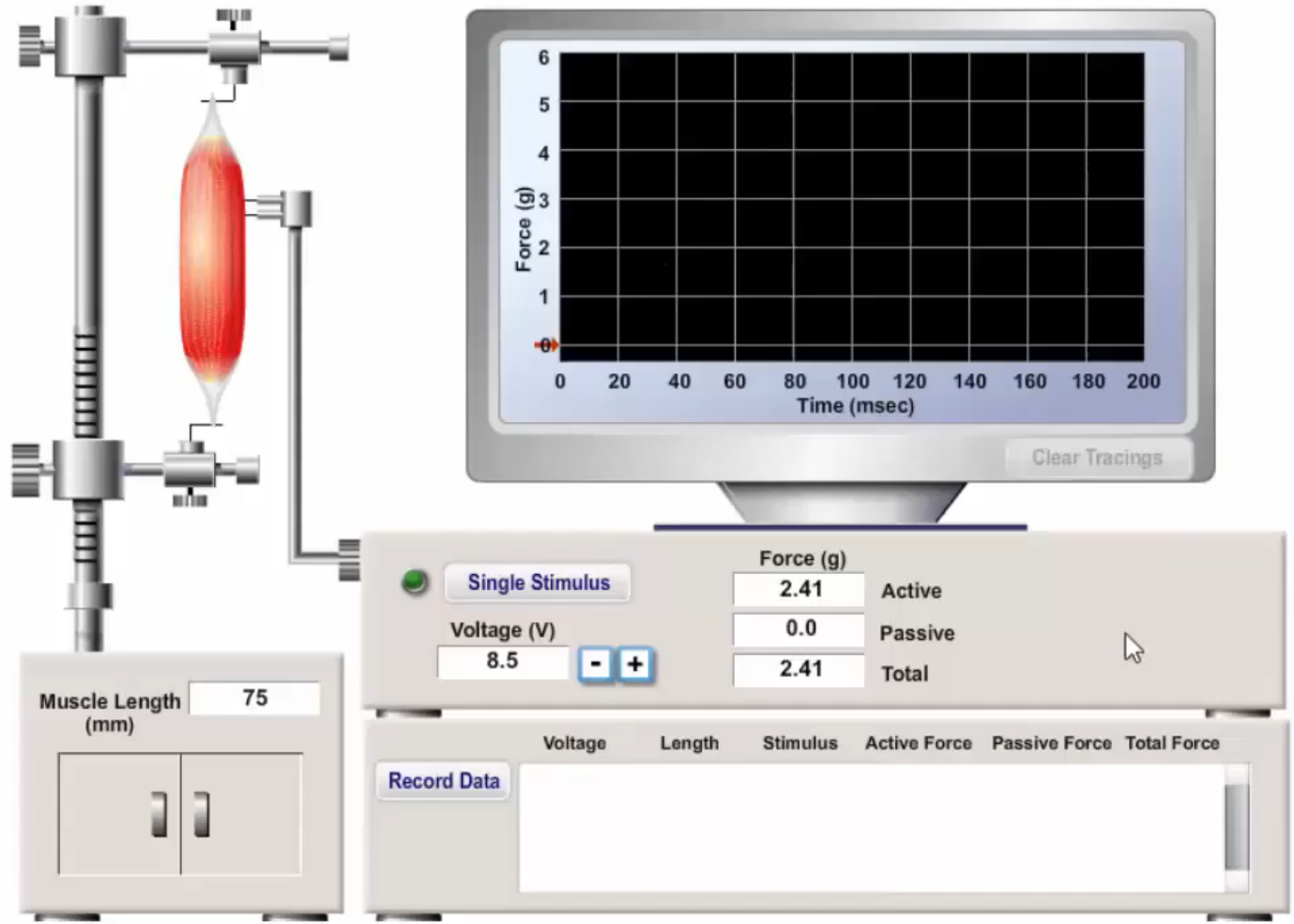
•Increasing the stimulus strength (voltage) will lead to Multiple fiber summation.

•Occurs by increasing the number of motor units contracting simultaneously

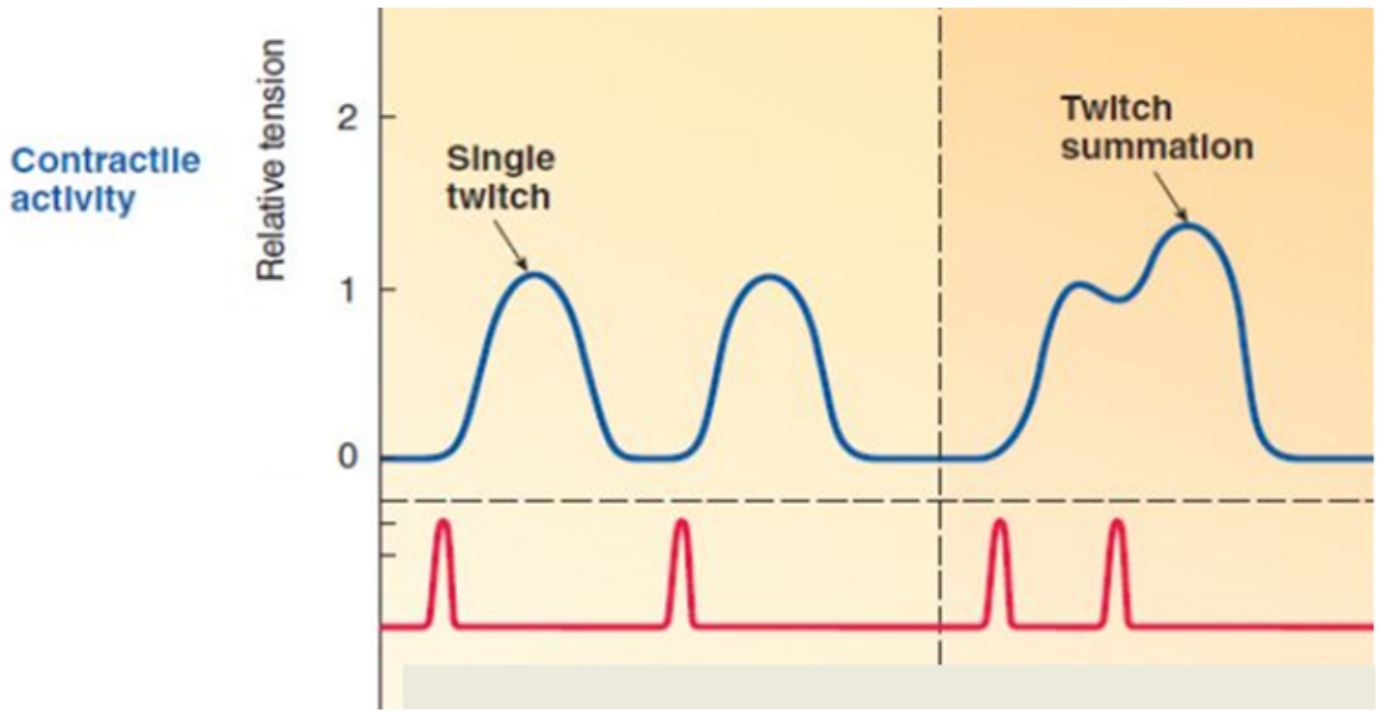



Spinal Cord
Neuron 1
Neuron 2
Neuron 3
Motor Nerve
Motor Unit 1
Motor Unit 2
Motor Unit 3


Maximal stimulus
Stimulus voltage
Threshold stimulus
1
2
3
4
5
6
7
8
9
Stimuli to nerve
Tension
Maximal contraction
1
2
3
4
5
6
7
8
9


6
5
4
3
2
1
0
Force (g)
0 20 40 60 80 100 120 140 160 180 200
Time (msec)
Clear Tracings
Single Stimulus
Force (g)
2.41
Active
Voltage (V)
0.0
Passive
8.5
-
+
2.41
Total
Muscle Length (mm)
75
Voltage
Length
Stimulus
Active Force
Passive Force
Total Force
Record Data

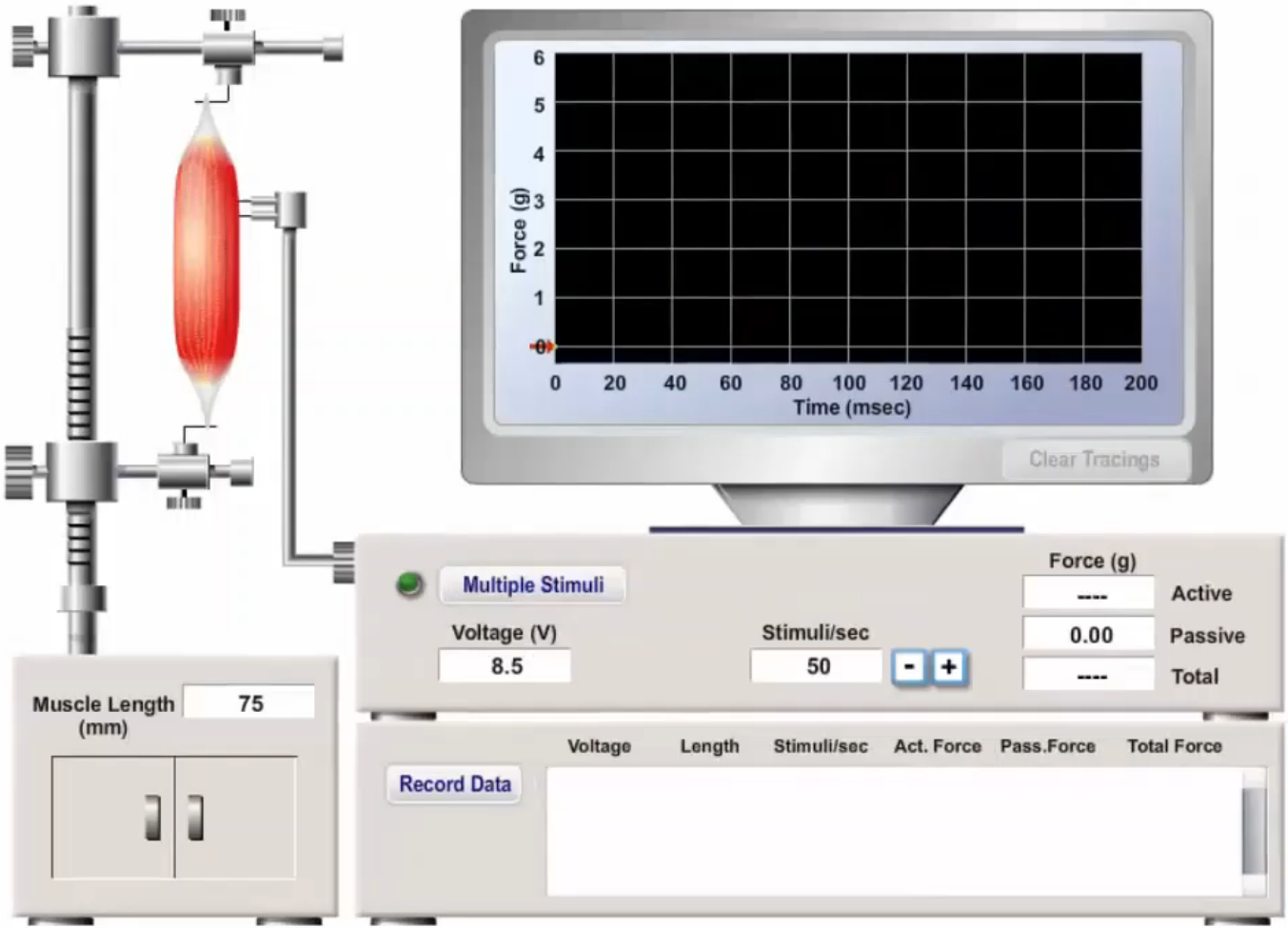
Frequency (Wave) Summation



If we fix the voltage and increase the frequency of stimulation

- The increase in tension observed in frequency summation happens because a muscle fiber is unable to fully relax between twitches, the new contraction is partially added to the previous one resulting in higher tension (stronger contraction)

- The concentration of Calcium in the cytosol becomes higher with each successive contraction


6
5
4
3
2
1
0
Force (g)
0 20 40 60 80 100 120 140 160 180 200
Time (msec)
Clear Tracings
Multiple Stimuli
Voltage (V)
8.5
Stimuli/sec
50
-
+
Force (g)

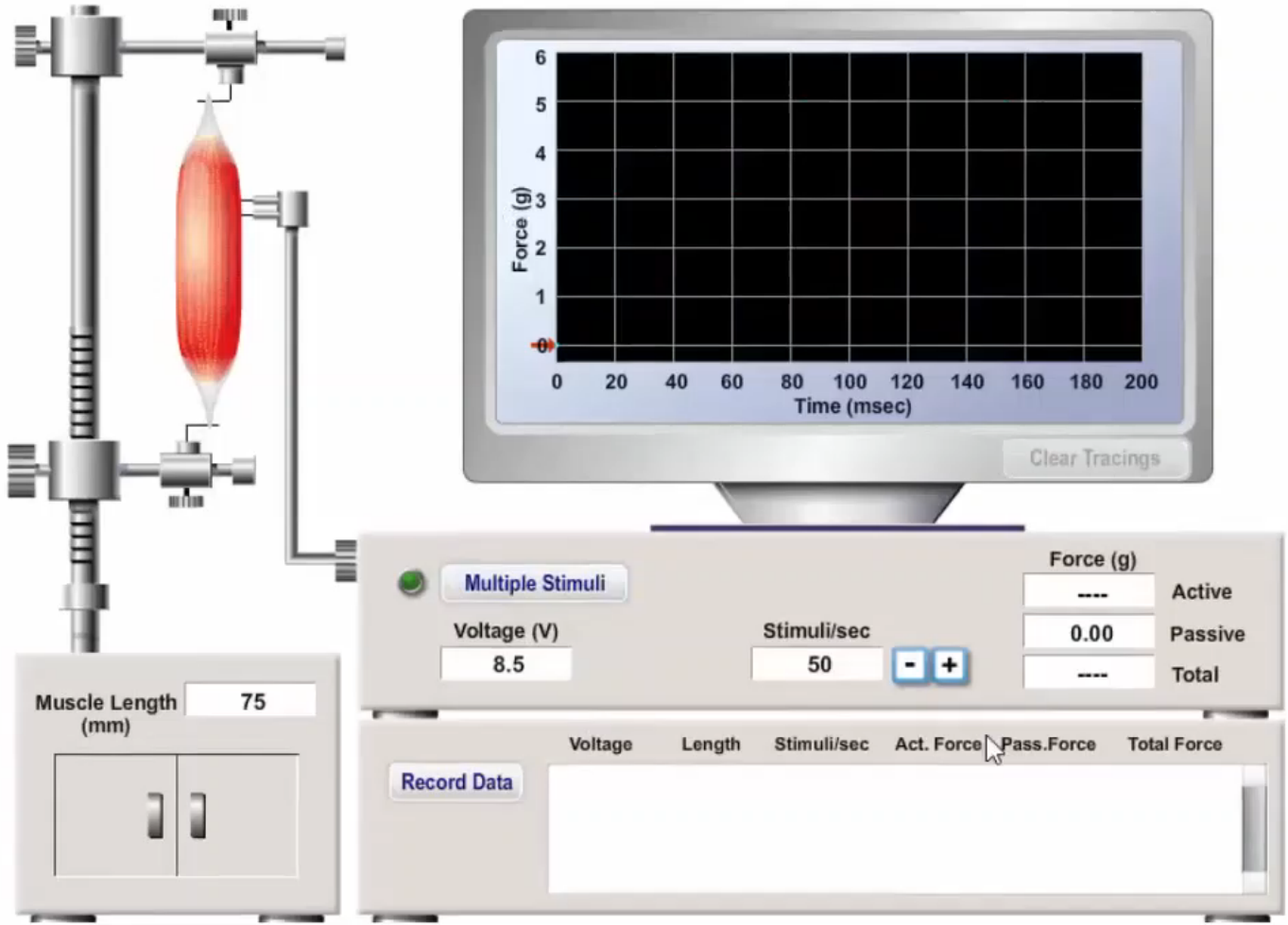
Active
0.00
Passive

Total
Muscle Length (mm)
75
Voltage
Length
Stimuli/sec
Act. Force
Pass.Force
Total Force
Record Data

Incomplete tetanization

- Unfused (incomplete) tetanization is a sustained but wavering contraction.

- Occurs When a skeletal muscle fiber is stimulated at a high rate, so it can only partially relax between stimuli.


Force (g)
6
5
4
3
2
1
0
0 20 40 60 80 100 120 140 160 180 200
Time (msec)
Clear Tracings
Multiple Stimuli
Voltage (V)
8.5
Stimuli/sec
50
-
+
Force (g)
Active

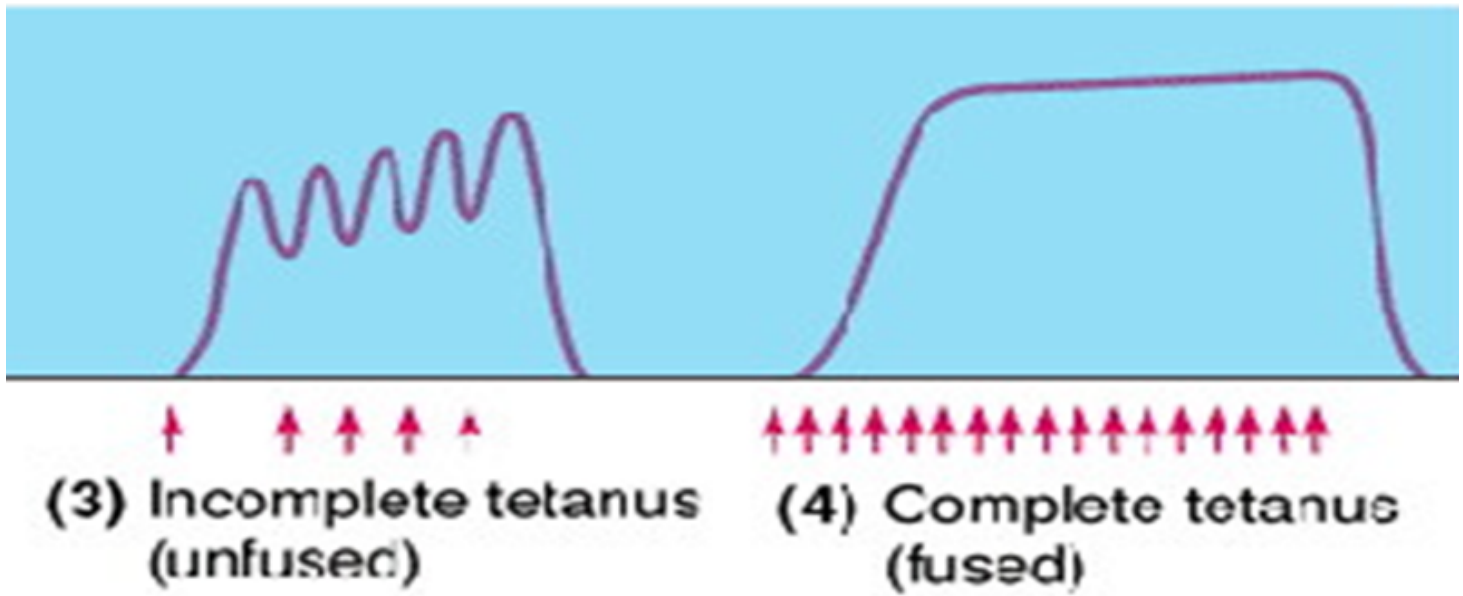
Passive
0.00
Total

Muscle Length (mm)
75
Record Data
Voltage
Length
Stimuli/sec
Act. Force
Pass.Force
Total Force

Complete tetanization

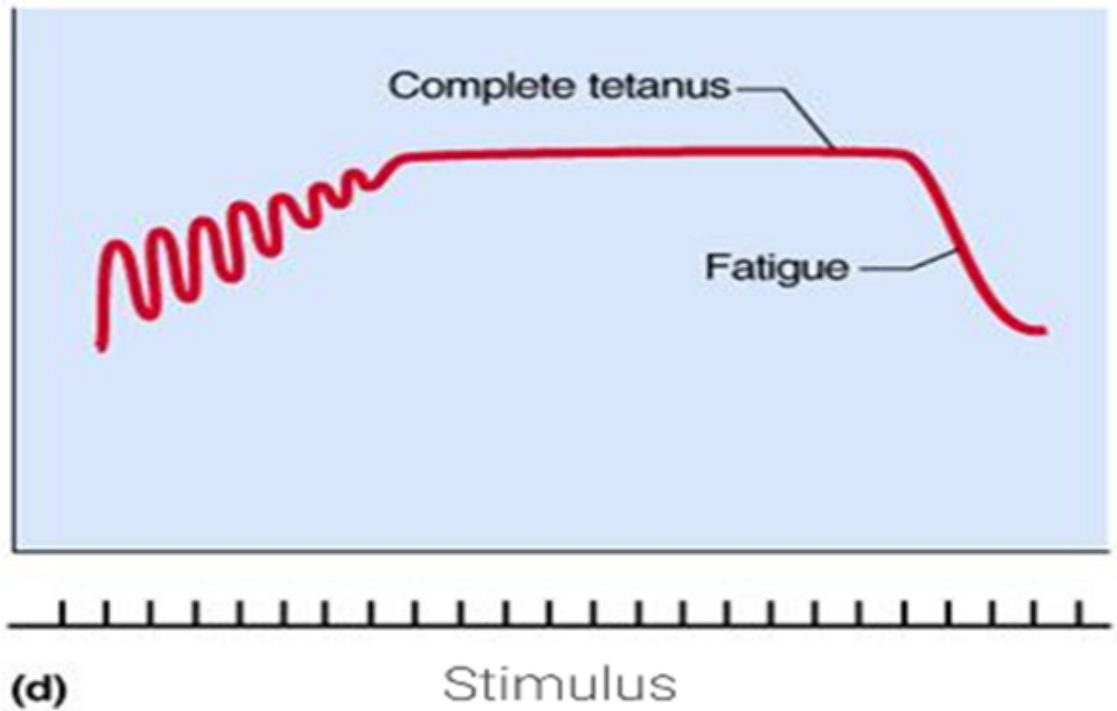
- Fused (complete) tetanization, a sustained contraction in which individual twitches can't be detected.
- Occurs when a skeletal muscle fiber is stimulated at a very high rate, so it does not relax at all between stimuli.
- The maximum tension a muscle can generate is reached.
- Any additional increase in frequency beyond that point has no further effect on increasing the muscle's tension.
- It occurs because enough calcium ions are maintained in the muscle sarcoplasm so that full contractile state is sustained.

Tetanization



If we fix the voltage and greatly increase the frequency of stimulation

Fatigue

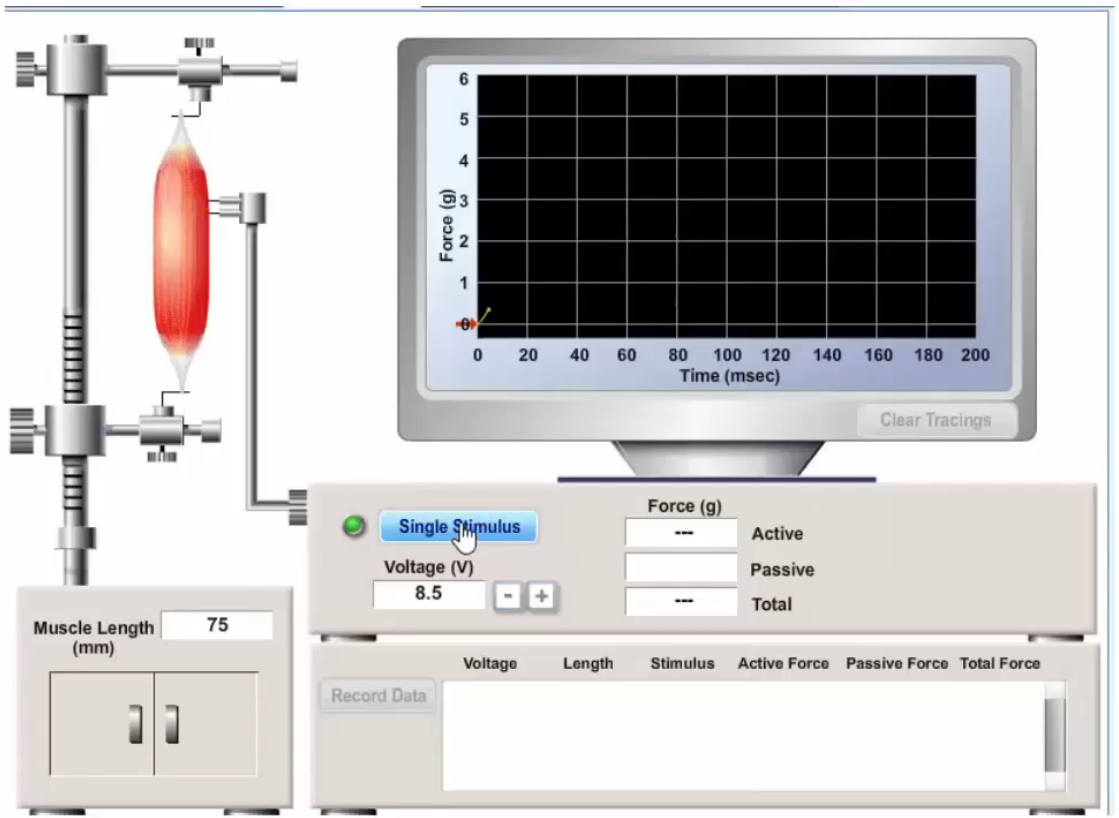


If we continue to give stimulation at a very high frequency for a long time

- Fatigue is a decline in the ability of the muscle to respond to stimulation, occurs after prolonged and strong contraction.
- On the graph it is depicted as a drop in tension **despite continued stimulation**

Why does fatigue happen?

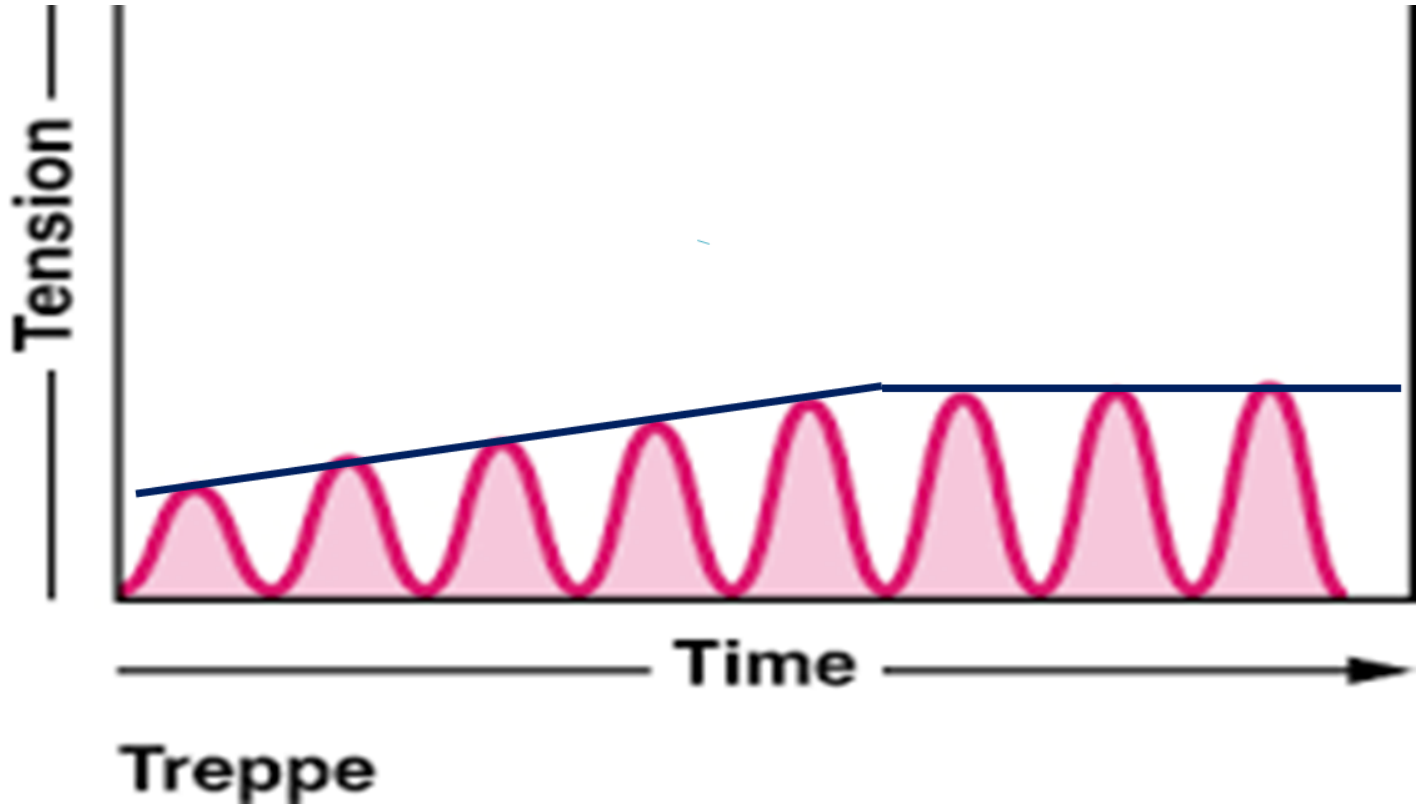
1. Inability of the contractile and metabolic processes of the muscle fibers to continue supplying the same work output. (Depletion of glycogen, accumulation of end products)
2. Diminished transmission at the neuromuscular junction. (Depletion of acetylcholine)
3. Interruption of blood flow which leads to loss of nutrient supply, especially loss of oxygen.

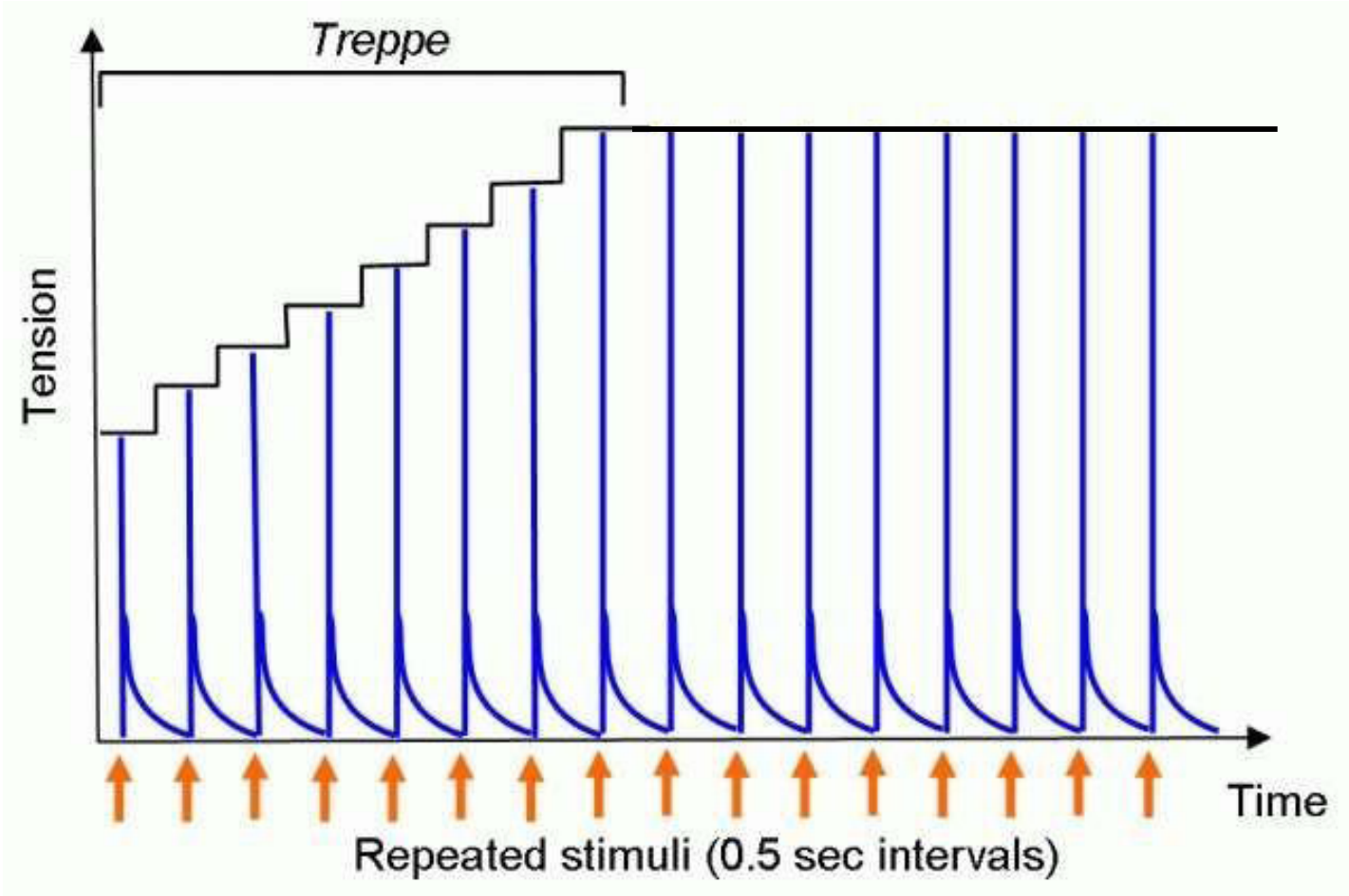

Force (g)
6
5
4
3
2
1
0
0 20 40 60 80 100 120 140 160 180 200
Time (msec)
Clear Tracings
Single Stimulus
Voltage (V)
8.5
Force (g)

Active
Passive

Total
Muscle Length (mm)
75
Voltage
Length
Stimulus
Active Force
Passive Force
Total Force
Record Data

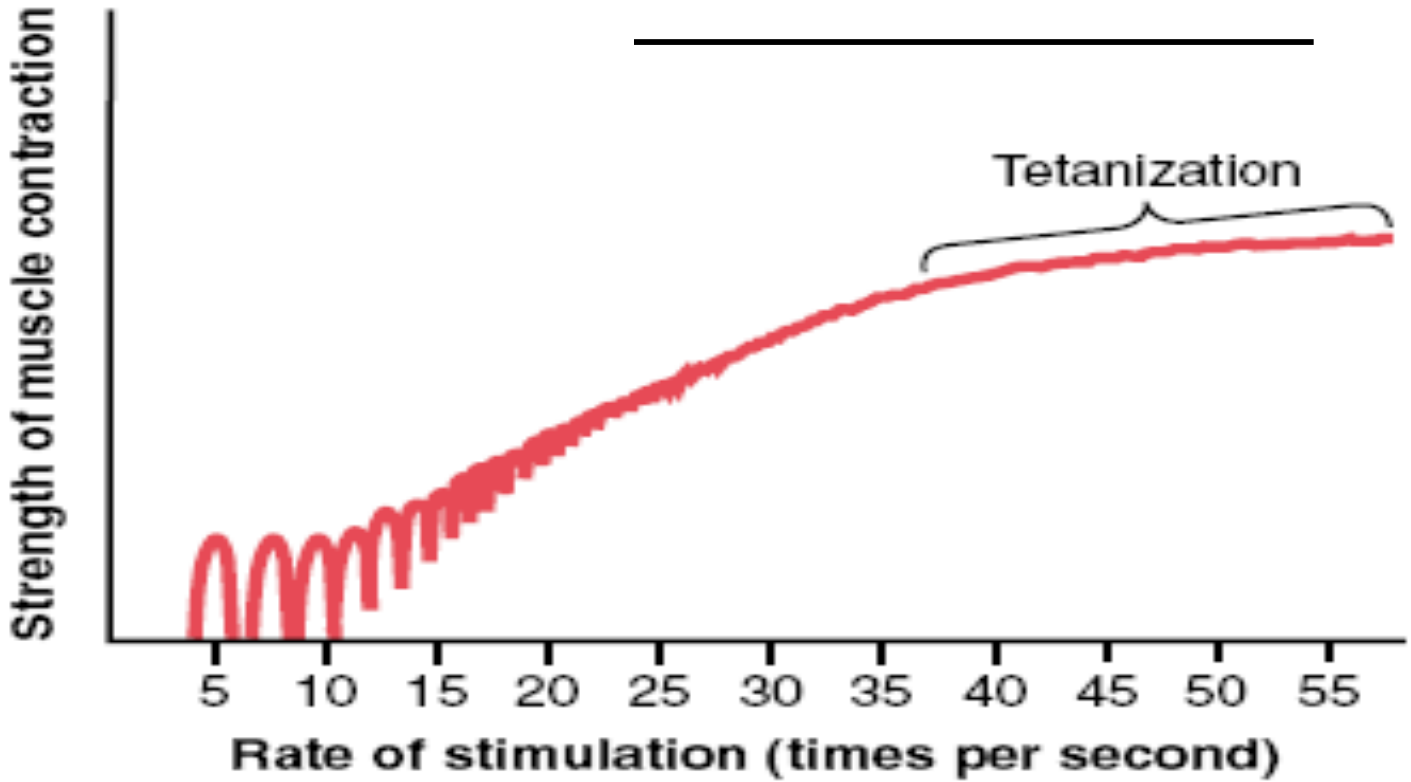
Treppe Effect




Treppe
Tension
Time
Repeated stimuli (0.5 sec intervals)

- Treppe effect happens when a muscle begins to contract after a long period of rest, its strength of contraction will gradually increase with every successive stimulus till a maximum response is reached.
- It is believed to be caused by:

1. The rise in muscle temperature.
2. Increased concentration of calcium ions in the cytosol
3. The enhanced blood flow


Strength of muscle contraction
Tetanization
5
10
15
20
25
30
35
40
45
50
55
Rate of stimulation (times per second)