MSS

physiology

LEC no.5

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Aim of the experiment

Learn some of the characteristics of skeletal muscle contraction

- ✓Simple muscle twitch
- ✓Summation (motor unit "recruitment" vs frequency)
- ✓Tetanization (complete vs incomplete)
- ✓Fatigue
- ✓Treppe phenomenon

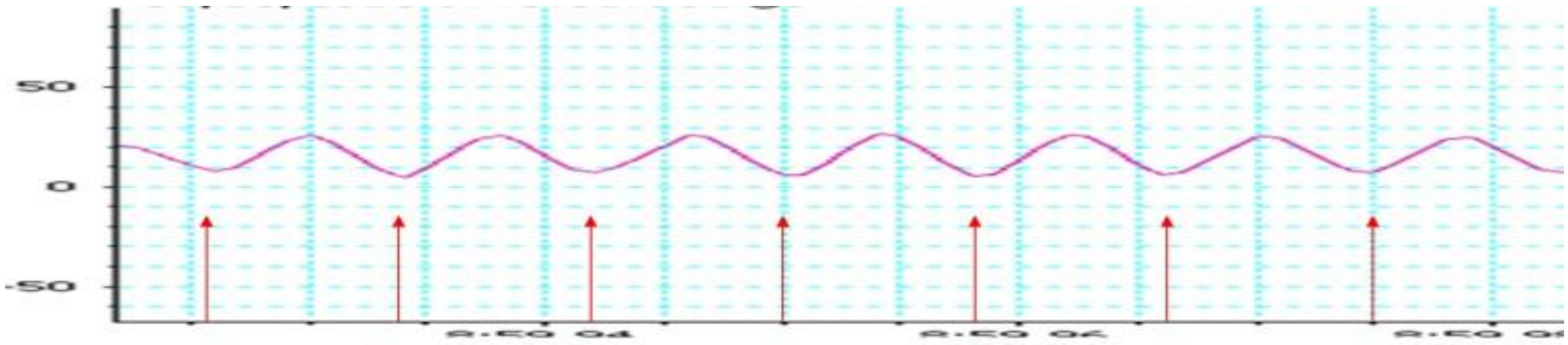
As we learned in previous lectures about the different types of contractions, isometric and isotonic especially , we found out that isometric contractions involve contractions that don't result in an overall change of the muscle's length and on the opposite, isotonic contractions that involve changes of the length (shortening or lengthening). When a muscle is stimulated to contract (either isotonic or isometric), this stimulus can lead to some characteristics that were mentioned in the previous slide.

When we want to study these characteristics we study the muscle in an **isometric session**, by placing the muscle in a position that its length remains unchanged. This is done by attaching a very heavy load to the muscle so that even if it contracts, there won't be an overall change in its length.

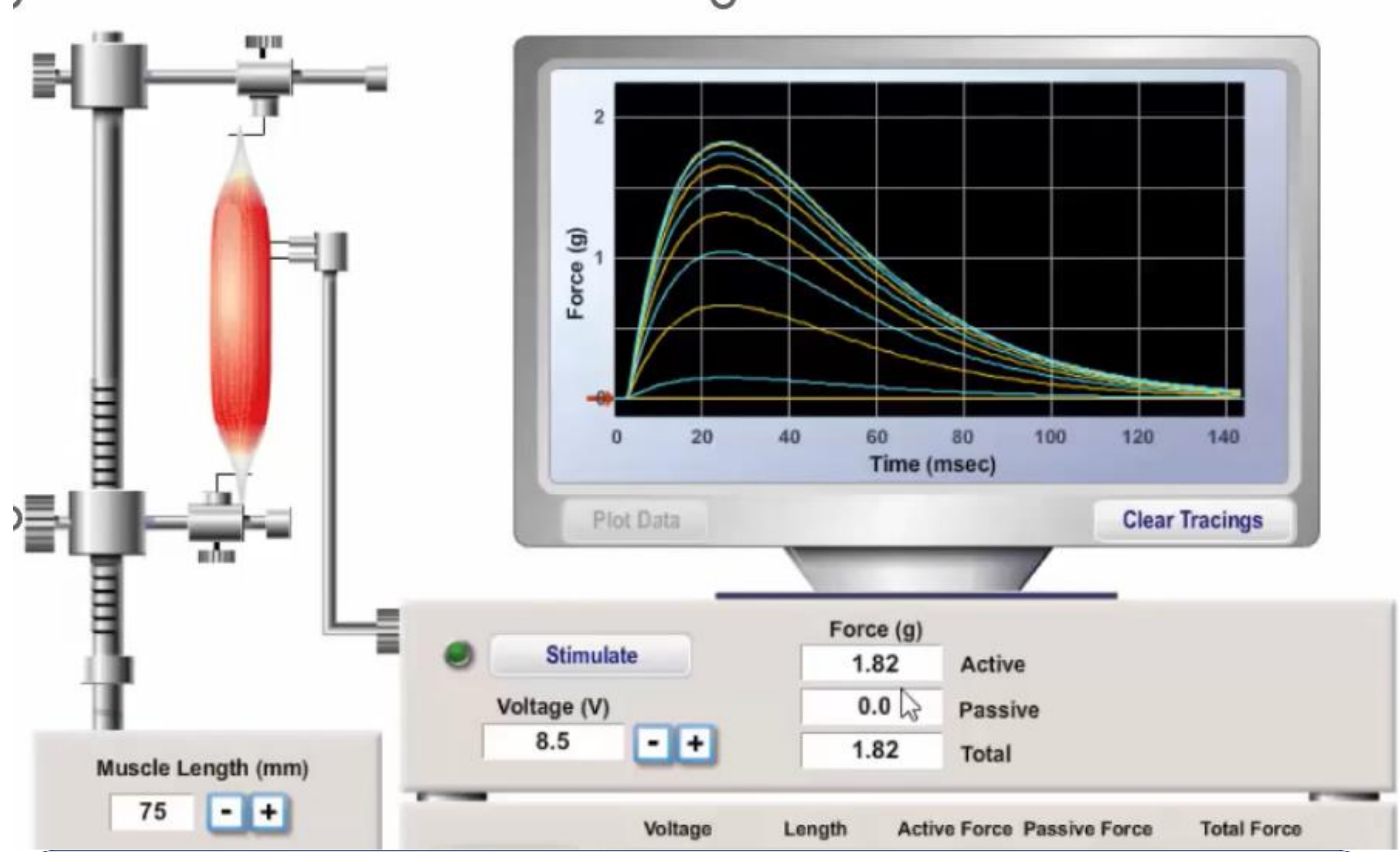
Simple Muscle Twitch

- 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.



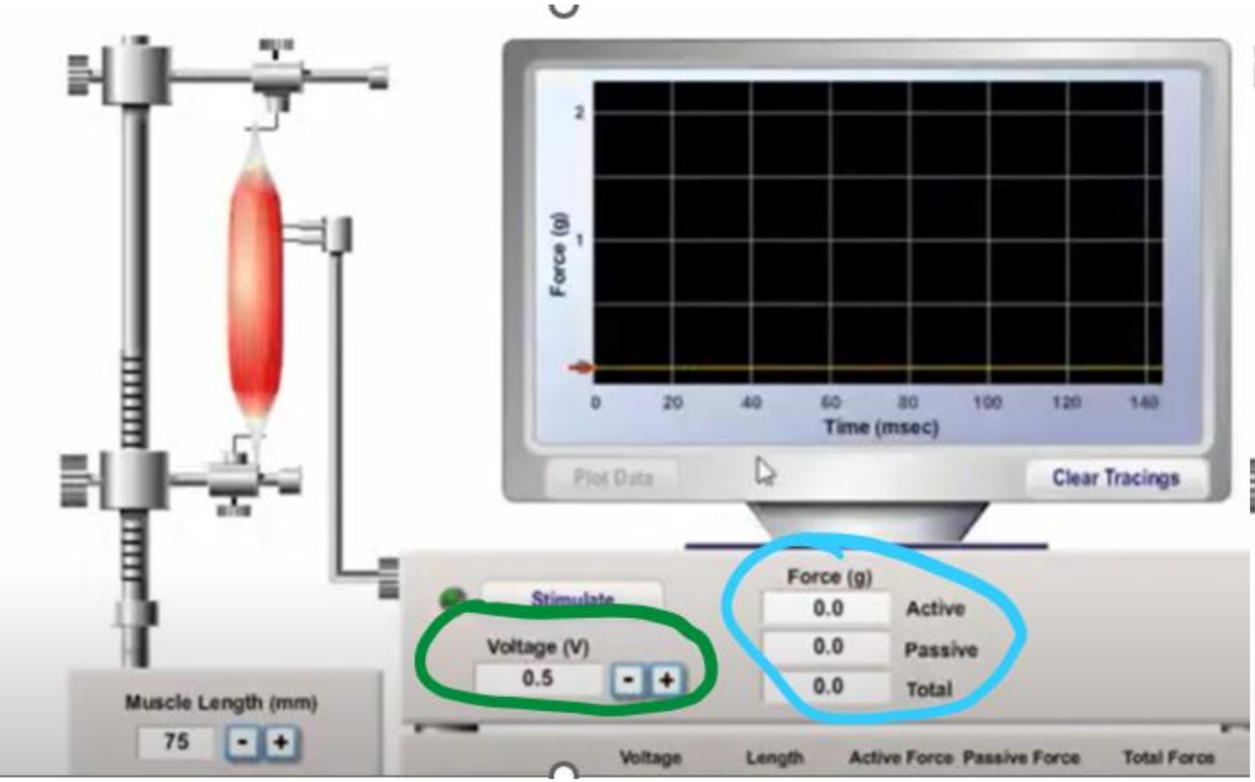
Give a stimulus above the threshold at low frequency

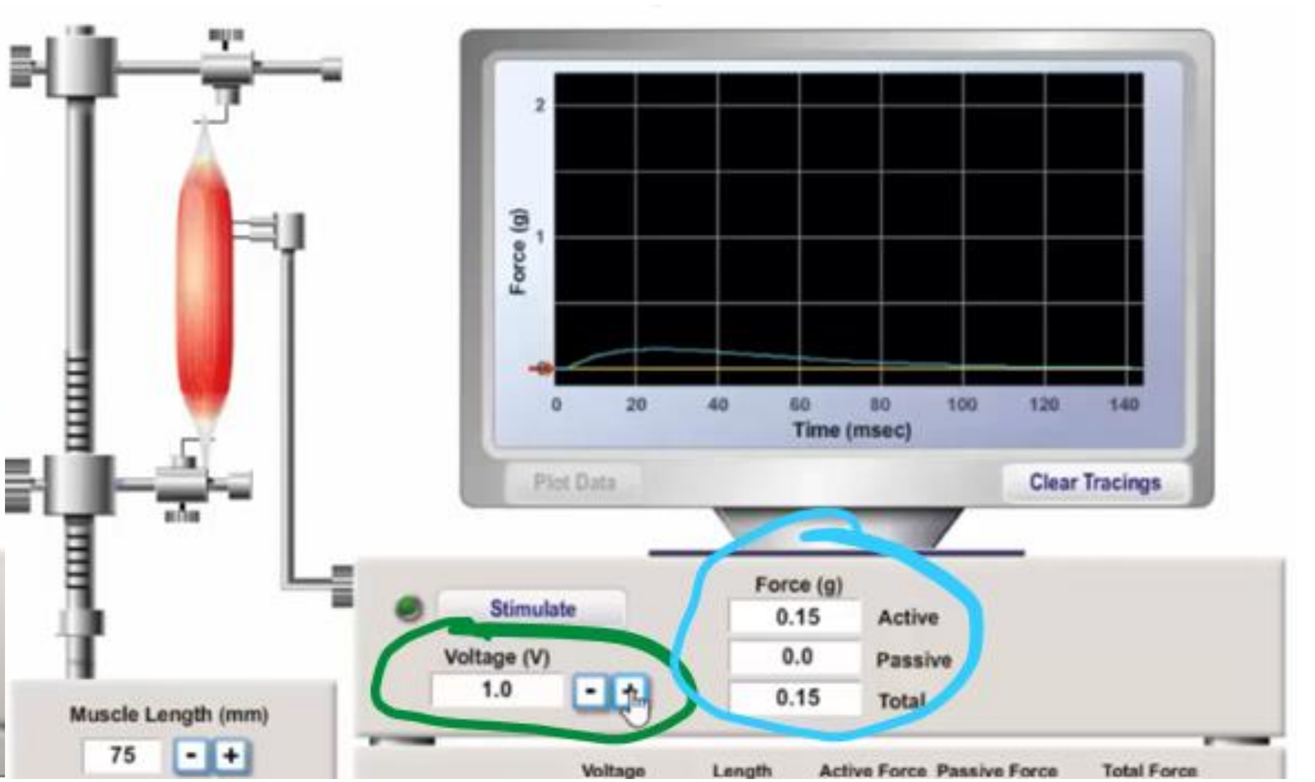


This is how the simulator looks, as you can see. The muscle is fixed to maintain no changes in its length and it's attached to a transducer (محوّل) which converts energy from one form to another. This transducer converts kinetic energy (resulting from the pulling of the muscle to the transducer when it's stimulated) to electrical energy which can be detected as a soft wave on this device. The aim of this experiment is to represent this contractile process as a graph (myograph) (or myogram). It illustrates the relationship between the force of contraction (gram) vs the time (milliseconds)

How do we induce the muscle to contract? We apply an electrical stimulus, similar to the stimuli in neuromuscular junctions in our body. You can try the simulation via this link: https://drive.google.com/file/d/1J67_U1QUi8vtmofhlb1iUNrVhDyl67zx/view?usp=sharing

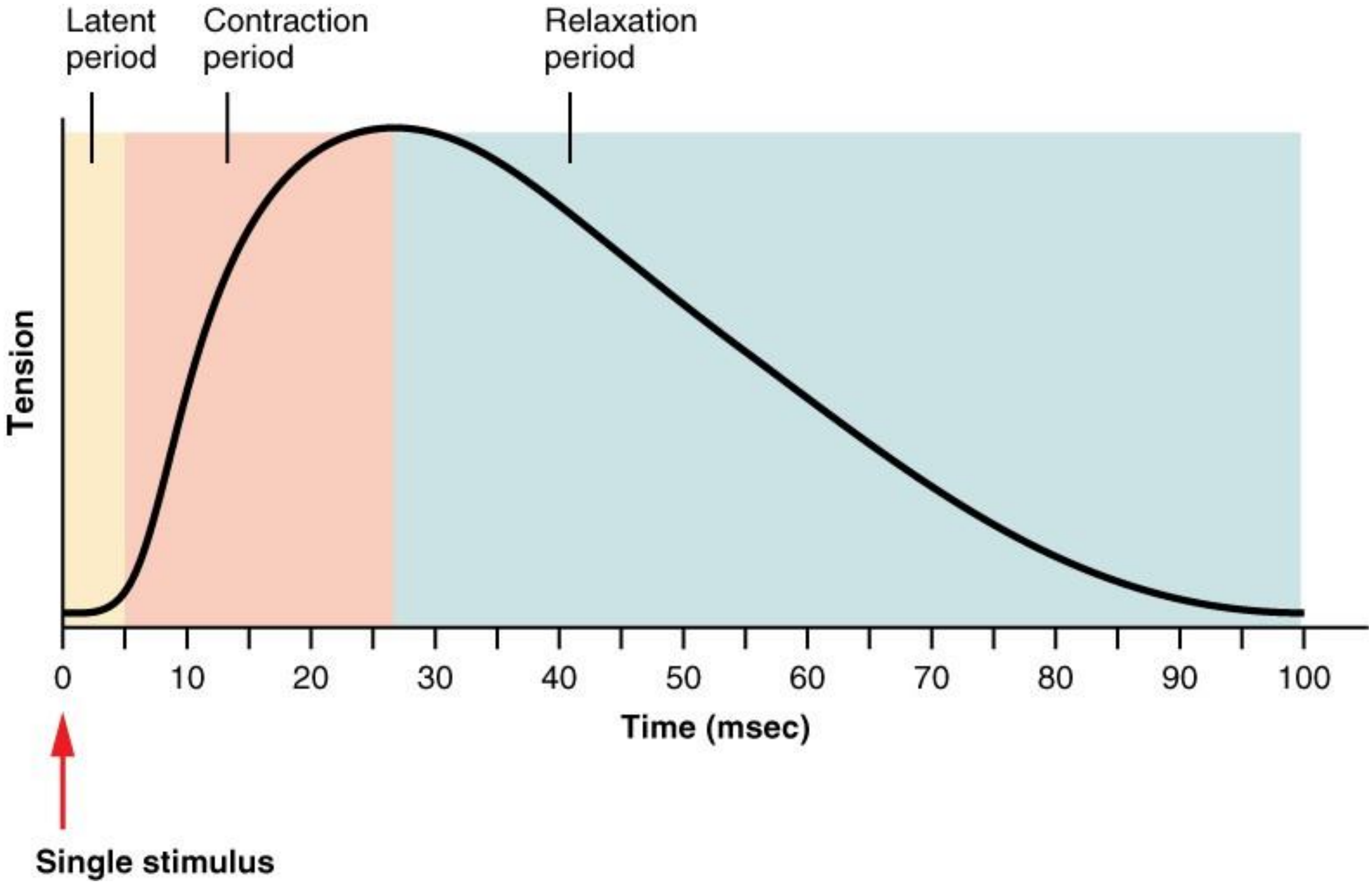
Throughout this lecture, keep track of the stimulus applied (labeled in **green** in the pictures below), the curve on the graph, and the readings below the graph (labeled in **blue**).





Notice here that when a stimulus of **0.5V** is applied, the graph shows a flat line and the reading shows **0.0g of force**. **This is a subthreshold stimulus.** Meaning that the stimulus was not enough to elicit a contraction.

When **1V** of stimulus is applied, we get a small peak on the graph and the reading gives a force of 0.15g. This is called a **simple muscle twitch** which is a brief muscle contraction. This is the result of applying a **threshold stimulus**.



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:

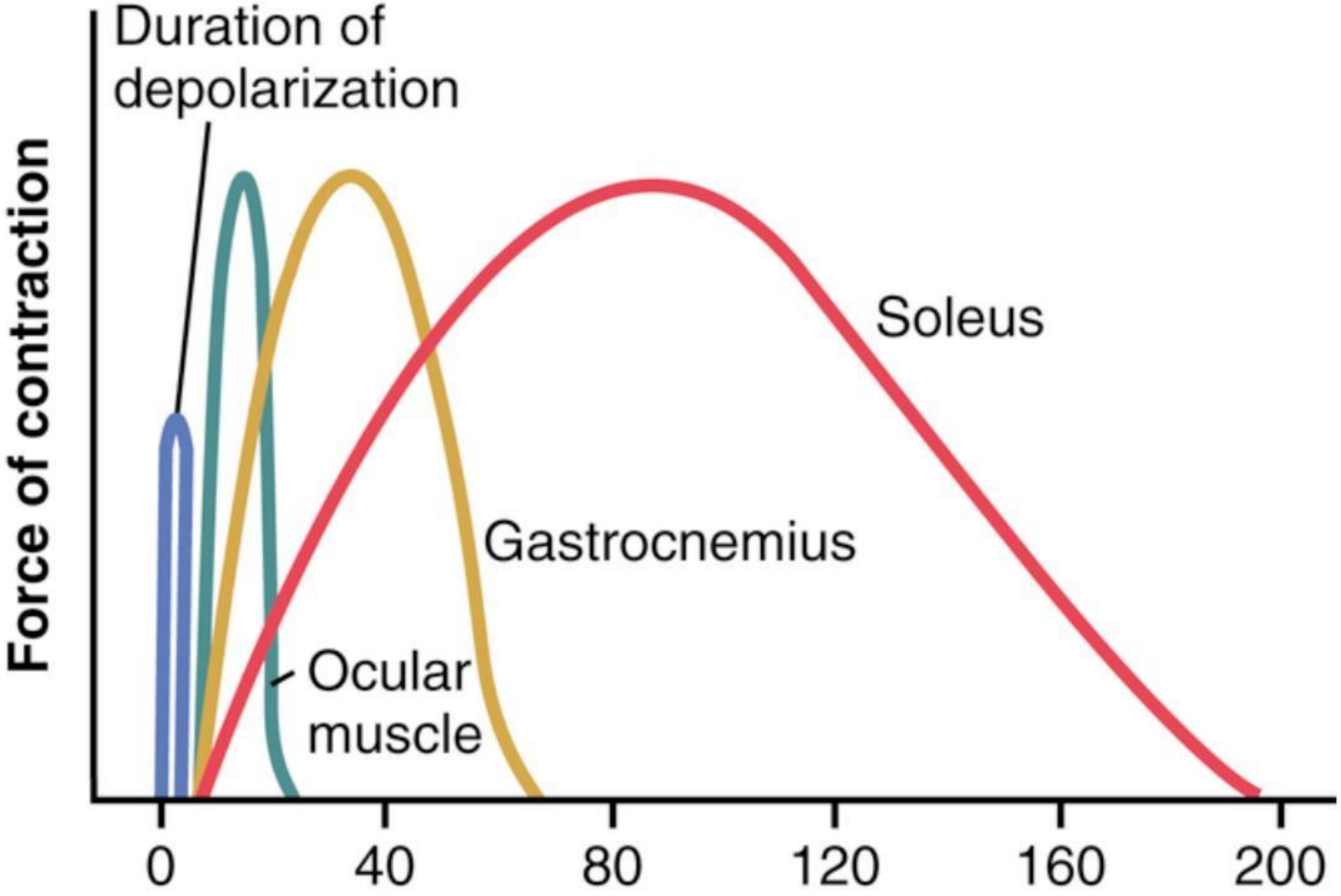
- When the tension starts to decrease till it returns to baseline.
- Calcium ions are actively transported back into the sarcoplasmic reticulum, myosin-binding sites are covered by tropomyosin, myosin heads detach from actin, and tension in the muscle fiber decreases.

The image seen in the previous slide is a clearer example of the simple muscle twitch. It consists of three periods:

1. Latent period: the time between applying the stimulus and the actual increase in tension, (Changes that occur on the molecular level which lead to the actual contraction and interaction between actin and myosin)
2. contraction period: calcium channels open and bind to troponin to allow for the cross-bridging to occur
3. relaxation period: this occurs when most of the calcium is pumped back into the sarcoplasmic reticulum (by Ca+2-ATPase pump), and the concentration of calcium drops within the cytosol.

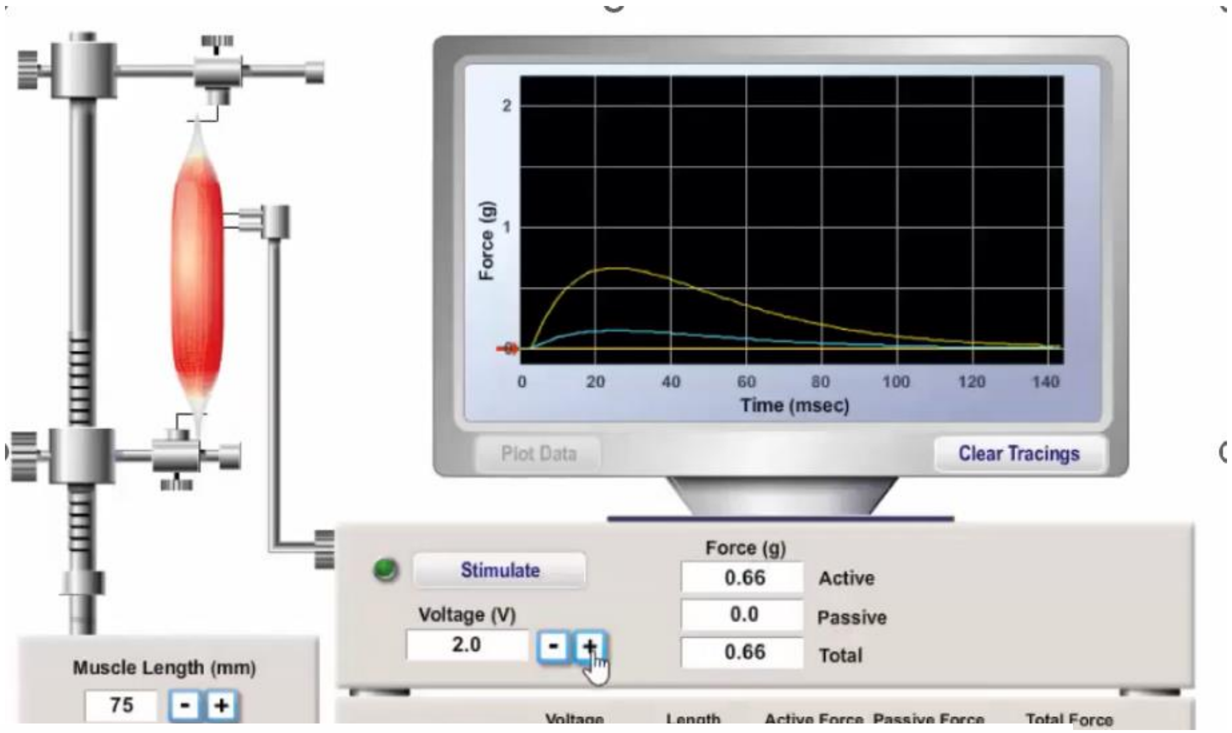
As we said, the simple muscle twitch is only a brief contraction, though the duration of this contraction varies between muscles due to their contents of fast and slow fibers.

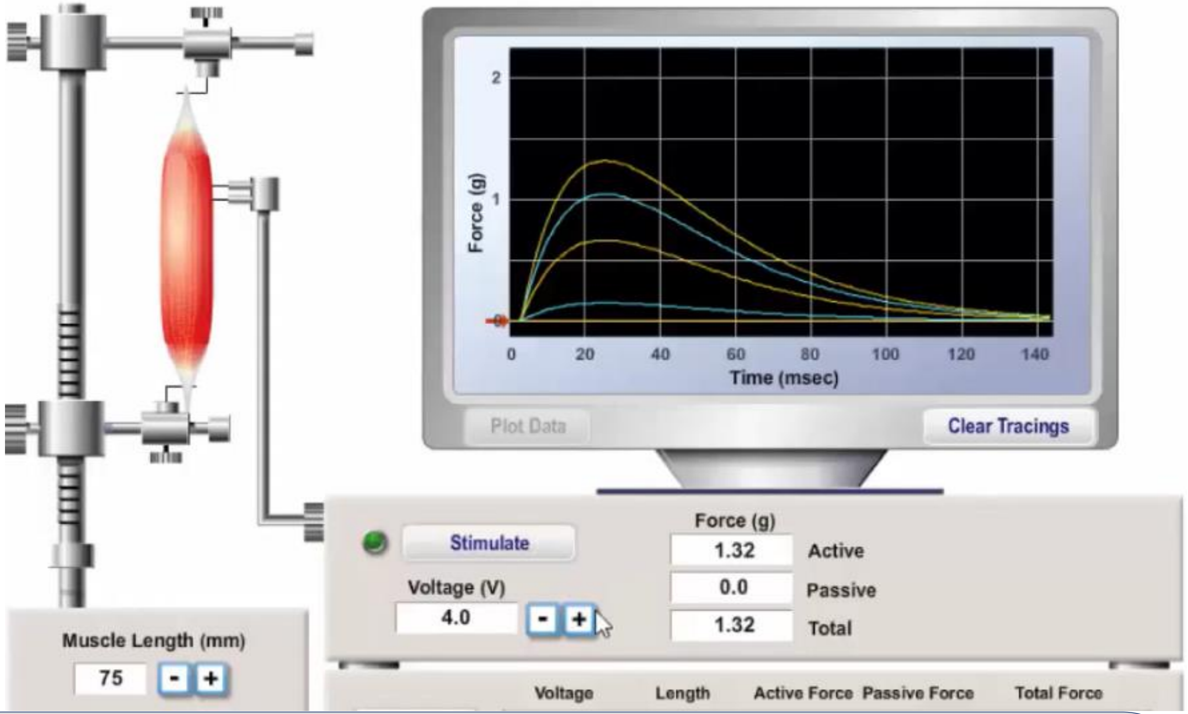
Remember that the main trigger of the interaction between actin and myosin and consequently the concentration is the **Calcium**.

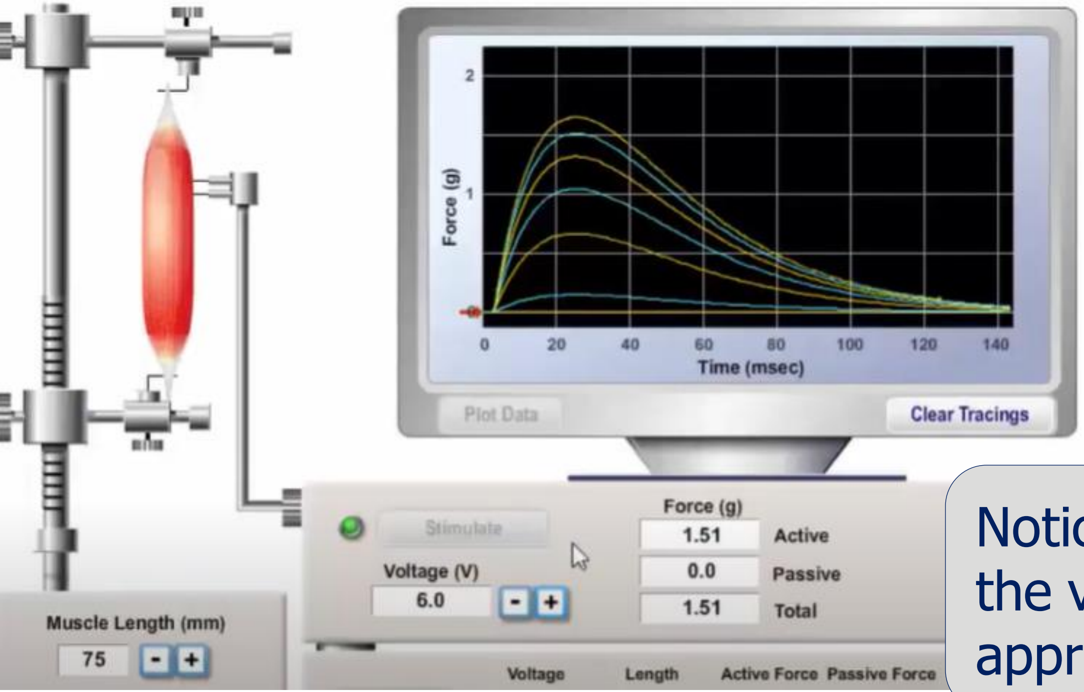


We have seen this image before in previous lectures showing the different speeds of contraction for different muscles in our body. Nevertheless, at the end, they all have the three components: latent period, contraction period, and relaxation period, (provided that a threshold stimulus is applied!)

If the muscle is composed of relatively high amounts of fast fibers, its simple muscle twitch will be shorter (~30 msecs) like ocular muscles. Compared to Gastrocnemius which is composed of higher amounts of slow muscle fibers and thus a longer duration.

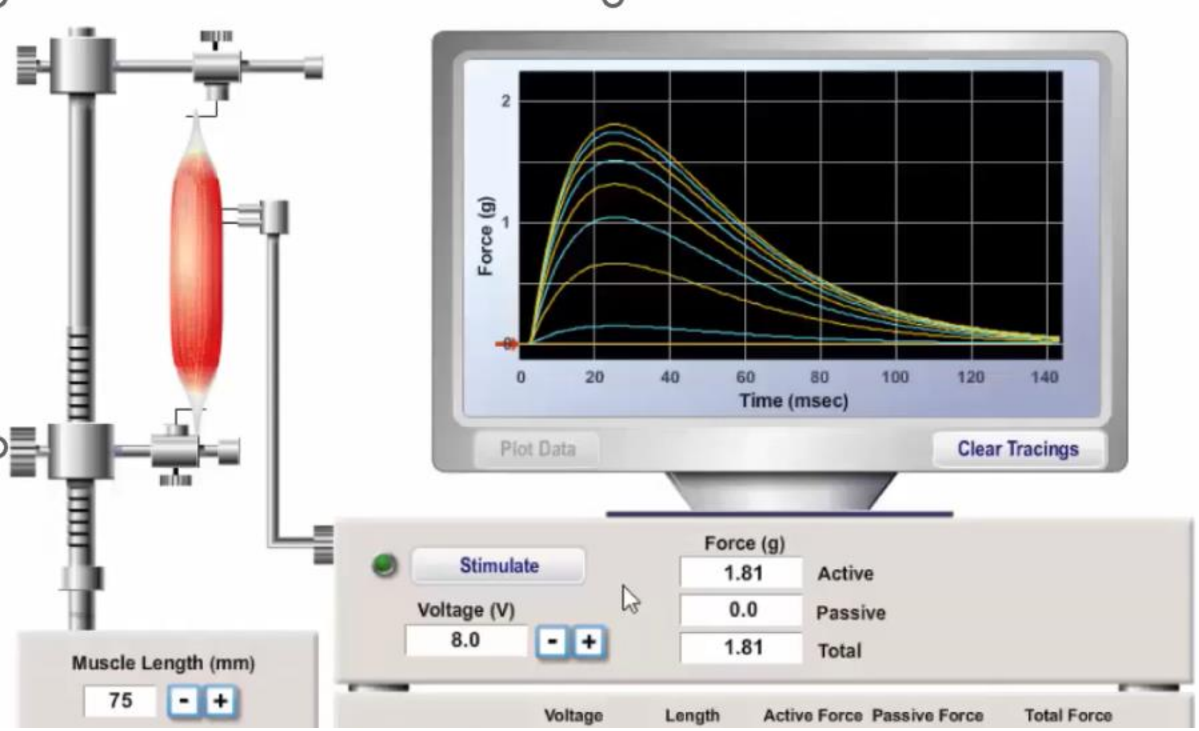


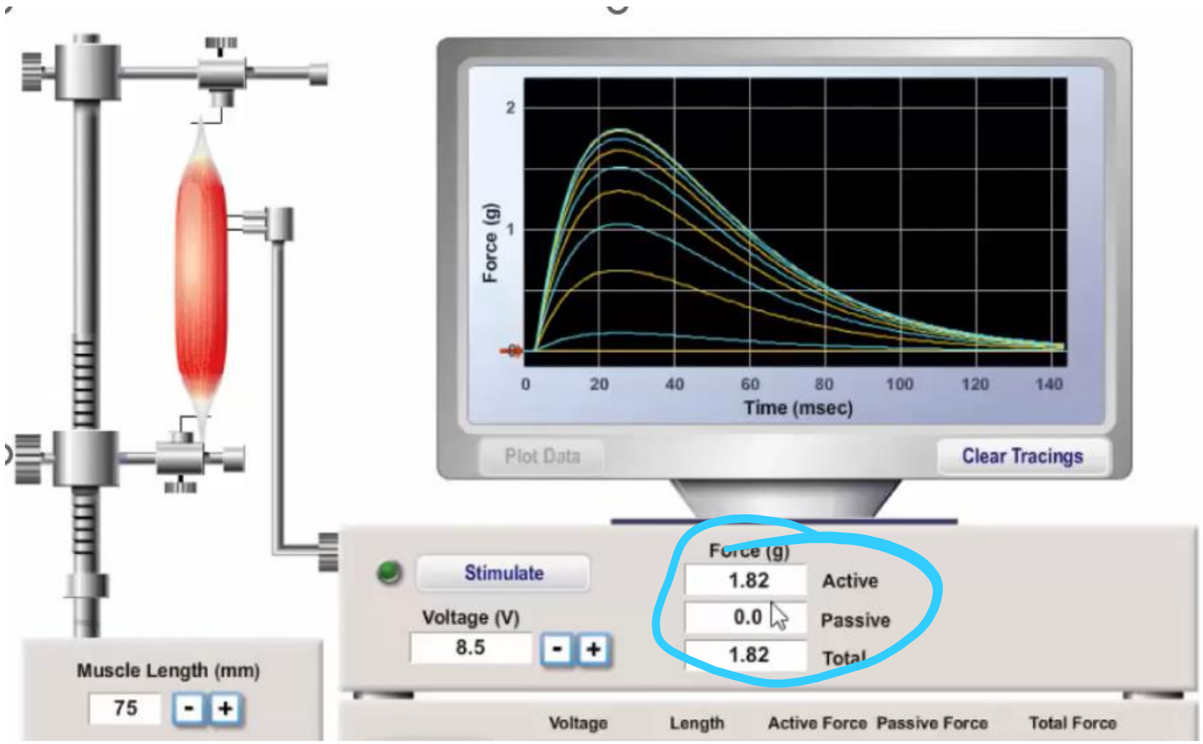


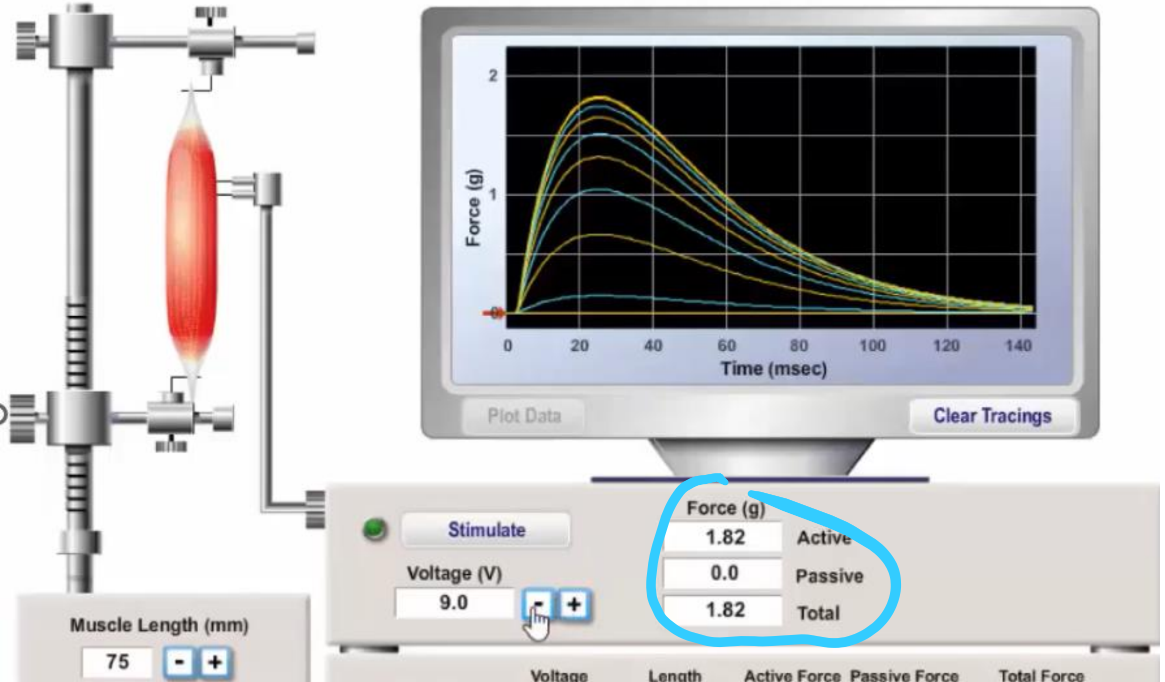


If we keep increasing the voltage of the stimulus, the force generated by the muscle increases. However, the increase in force of contraction is not proportional to the increase in stimulus, that as we approach the maximal stimulus, the increase in the force of contraction will diminish.

Notice that the difference between the forces generated when the voltage increases starts to become less, curves start to approximate as it gets closer to tetanization (maximal force)

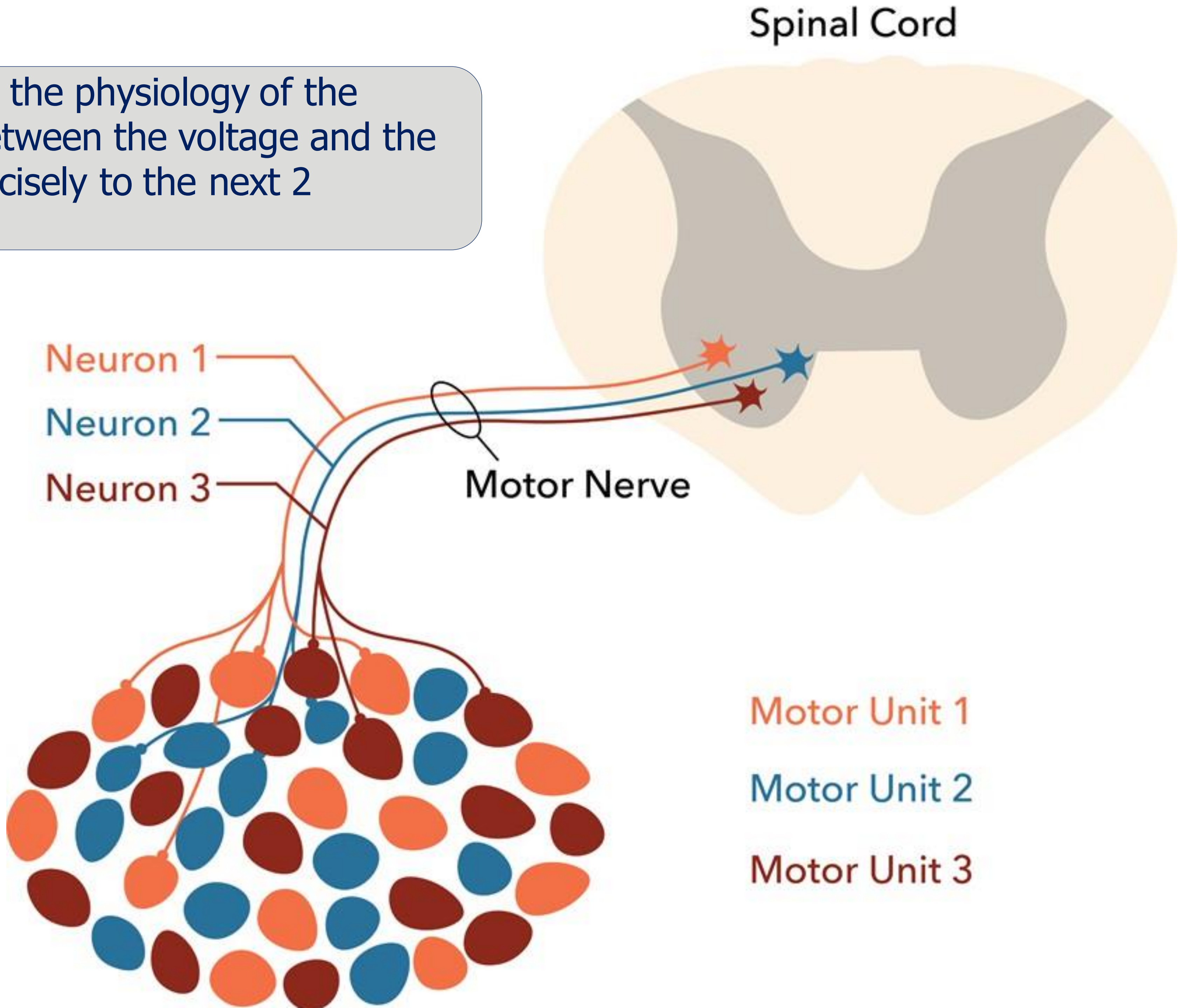






We can see here that there is no increase in the contraction force between a stimulus of 8.5V and 9V. This means that 8.5V is the maximal stimulus in this example and any additional stimulus (like 9V is called supramaximal stimulus) that will just exhaust the nervous system عالفاضي with no effect on the force.

To understand the physiology of the relationship between the voltage and the force, look precisely to the next 2 slides🤠



Let’s talk about the motor unit شوي. This image is a simple representation of a virtual muscle and its motor units (one motor neuron and the fibers it innervates). Notice that the muscle fibers within one motor unit are dispersed and not concentrated in one area so that the contraction would be uniform throughout the whole muscle. If a threshold stimulus is applied , only one motor unit is stimulated and contracted. As the voltage increases, the number of recruited motor units increases at the same time hence a greater tension within the muscle . In most cases in our bodies, all motor units aren’t recruited at the same time because that would result in a fatigue in the muscle very quickly due to consumption of nutrients, oxygen, ATP… So, to avoid this issue, motor units work by shifts that they are recruited in different periods, allowing for the contracted fiber to restore its nutrients and energy when its done contracting and to get ready for another contraction more efficiently . Also, we usually do not need them all to work at the same time.

At the maximum stimulus, all the motor units are active, that’s why increasing the stimulus will not increase the force of contraction. *The aim of the increase in voltage is to recruit more motor units, once all are recruited, no greater force can be added.

Summation

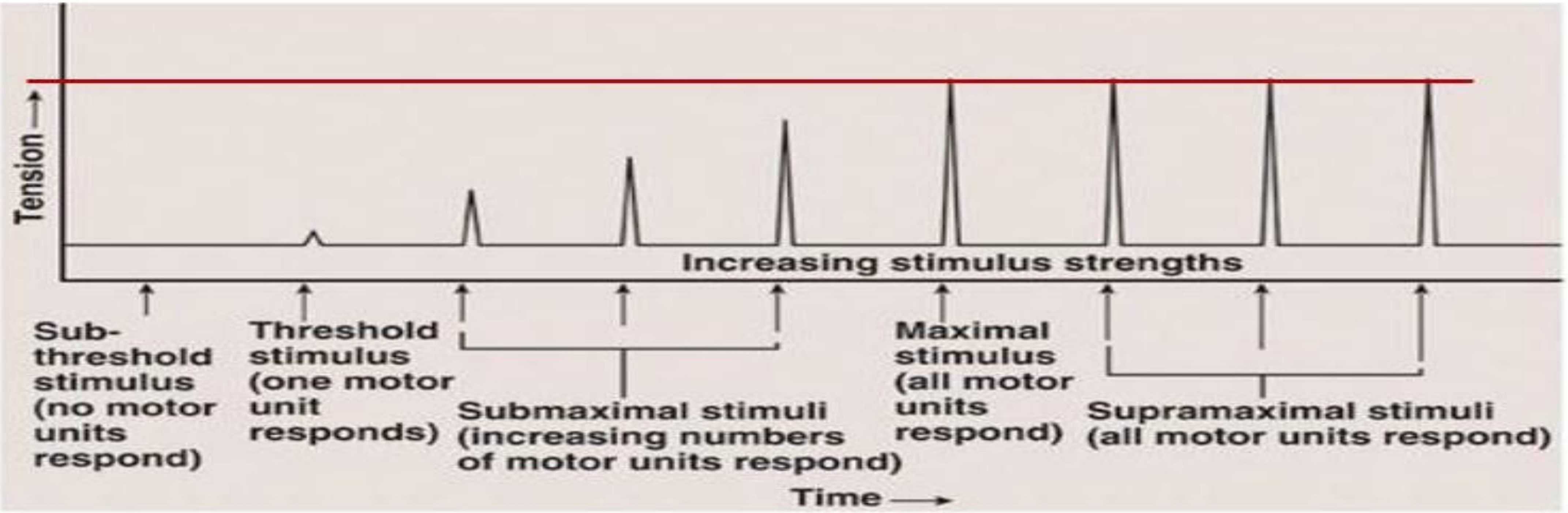
- Summation is used to increase the intensity of overall muscle contraction.
- Summation occurs in two ways:

1. Multiple fiber summation: by increasing the number of motor units contracting simultaneously. This is achieved by increasing the stimulus strength **(the voltage)--->** (won't lead to tetanization)
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

Smooth, sustained voluntary muscle contractions are achieved mainly by asynchronous unfused tetanus.

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

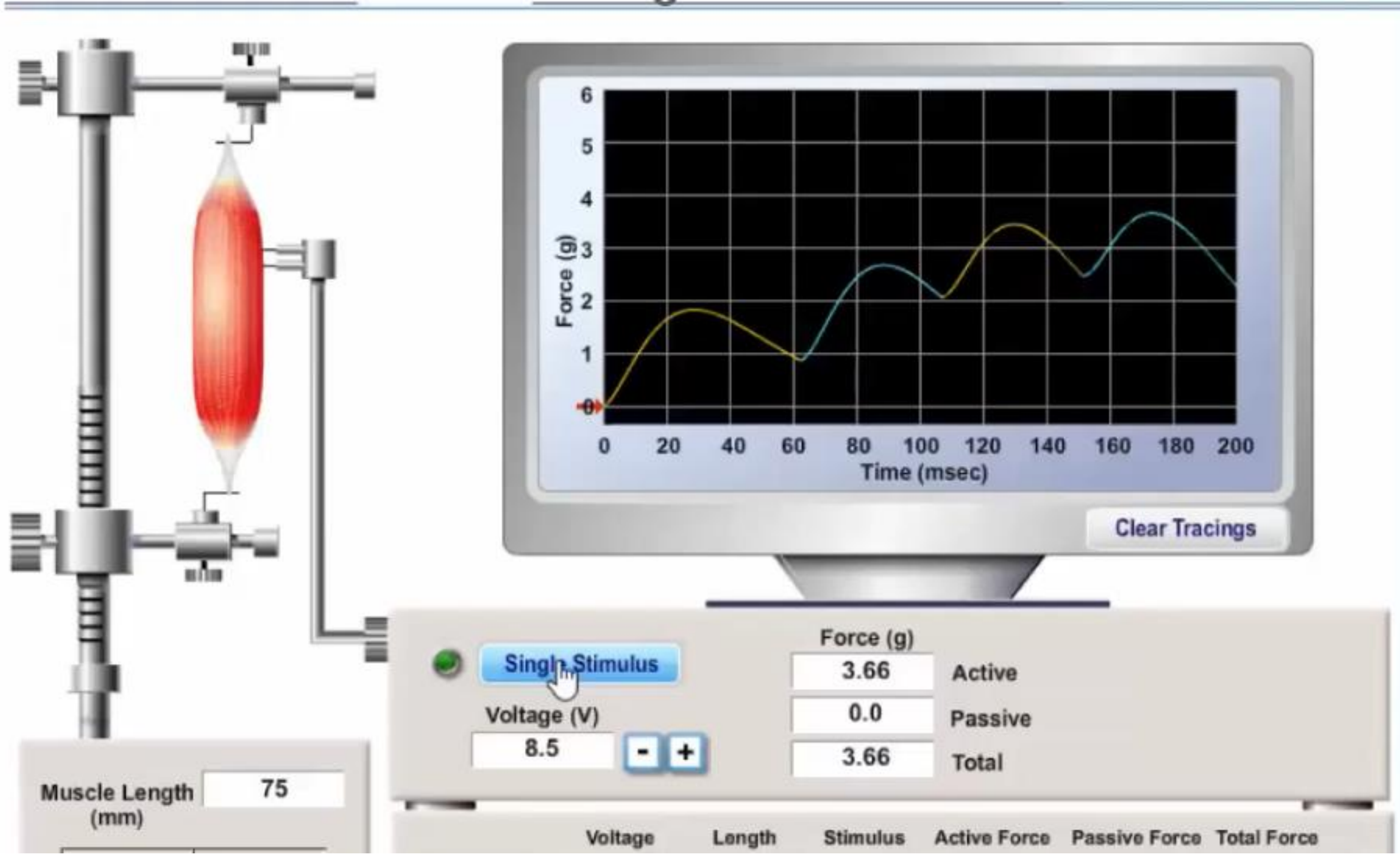


Frequency Summation

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

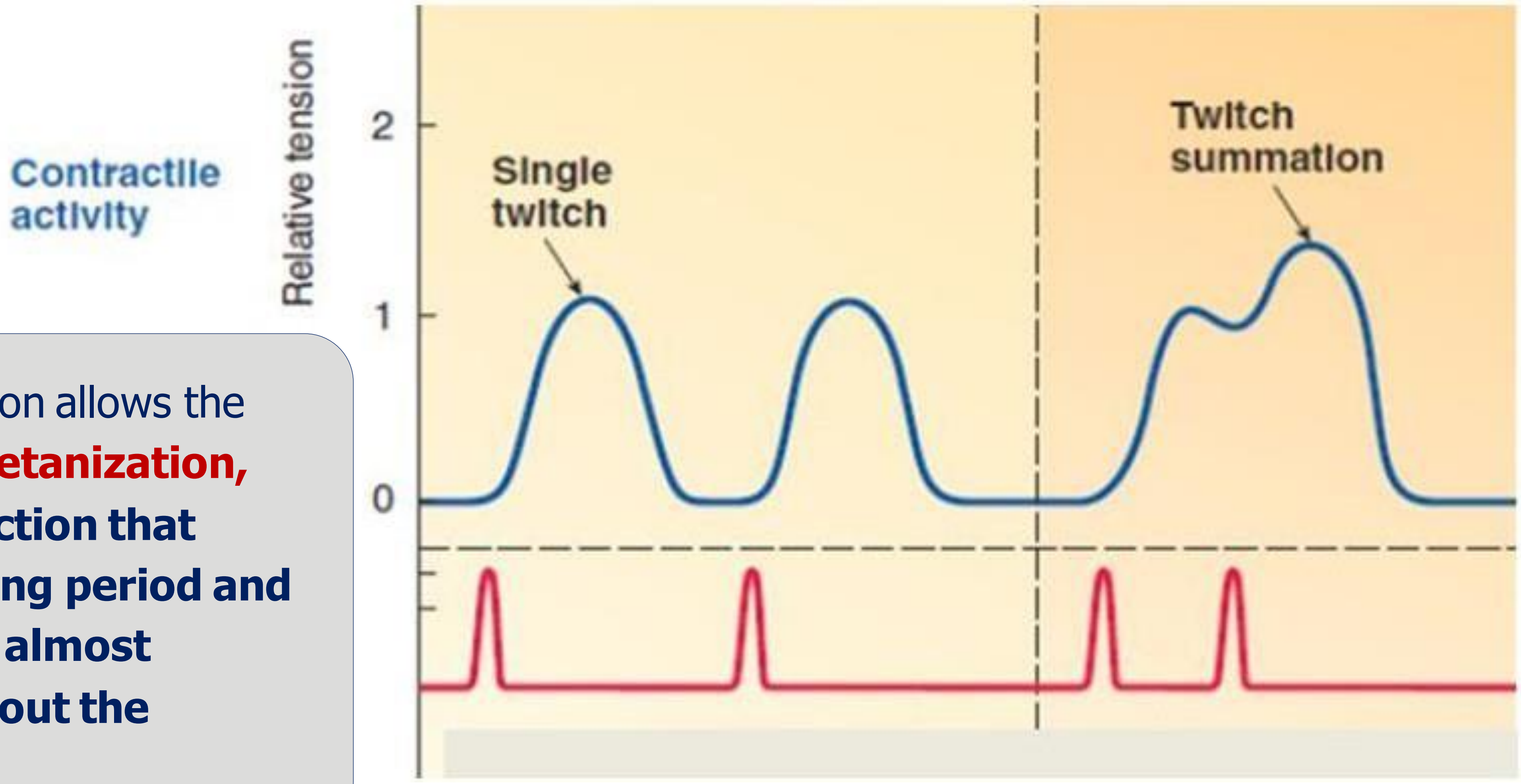
- The overall concentration of Calcium in the muscle sarcoplasm becomes higher with each successive stimulation (which allows for a better interaction between actin and myosin and more shortening of the sarcomere)

The concept of frequency summation is applied here in the second simulation ([click here to watch]()). A stimulus is given to the muscle before it fully relaxes, increasing total tension each time a stimulus is applied. We can see here that one maximum stimulus gave us a maximum force of 1.82g (in the previous simulation), but when we apply the concept of frequency summation, we can increase the force of contraction beyond what the muscle can achieve by one stimulus. Here we see that the 4th stimulus applied resulted in a force of almost 4g.

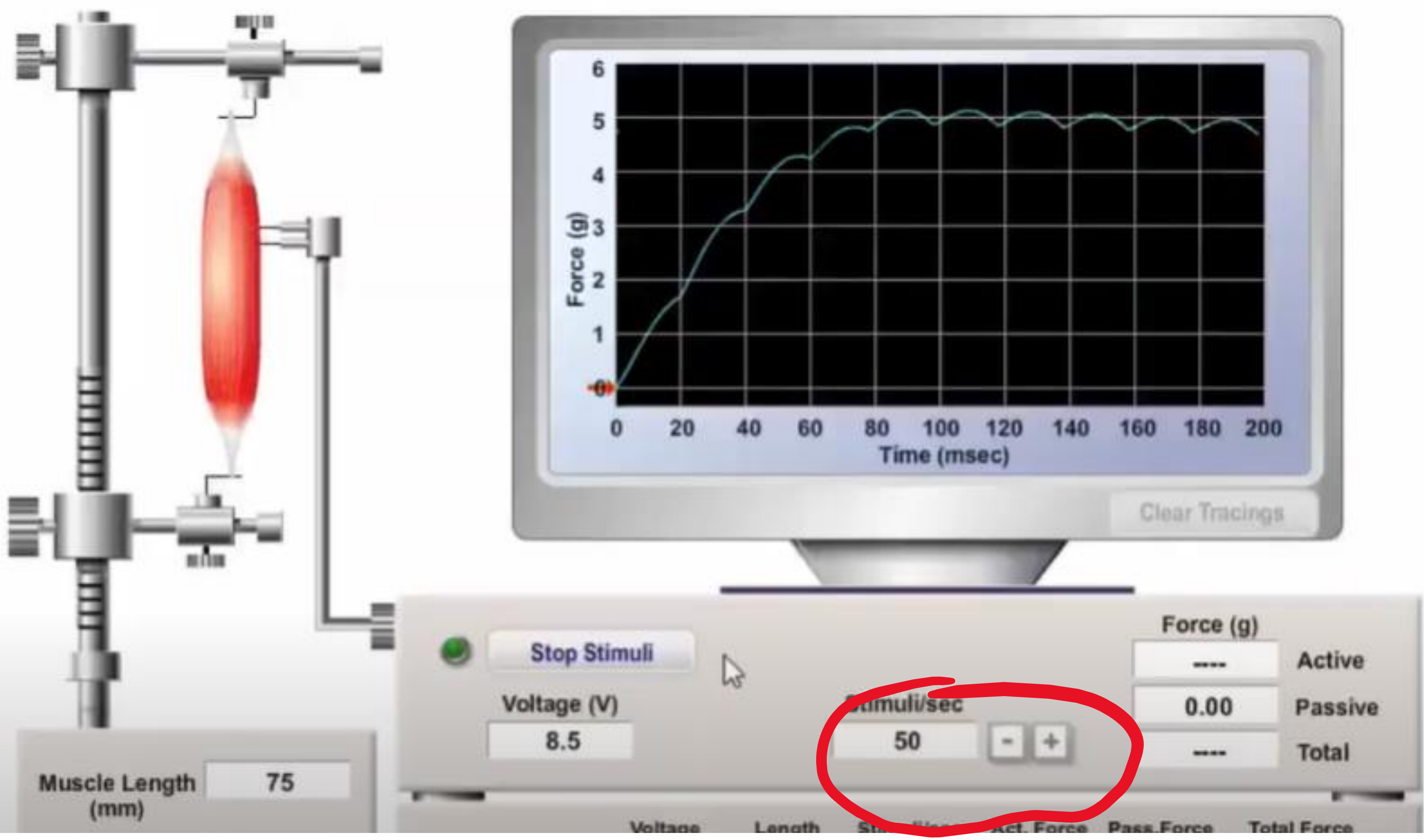


By applying multiple stimuli, we were also able to increase the duration of the contraction (200 milliseconds here, and only 130 milliseconds in the previous simulation)

Frequency (Wave) Summation



Frequency summation allows the muscle to achieve **tetanization, which is a contraction that continues for a long period and the tension stays almost constant throughout the contraction.**



In this simulation we can apply a certain number of stimuli per second (as labeled in **red**). At first, we see a gradual increase in tension (this is the summation stage) until we reach the constant tension stage (**tetanization**). You can notice here at the top of the graph the wave shape. This means that the muscle begins to relax, and the tension begins to decrease a bit before the next stimulus is applied and the force increases again. This is called **incomplete or unfused tetanization.**

We can still see the waves of each muscle twich although reached platue.

Incomplete tetanization

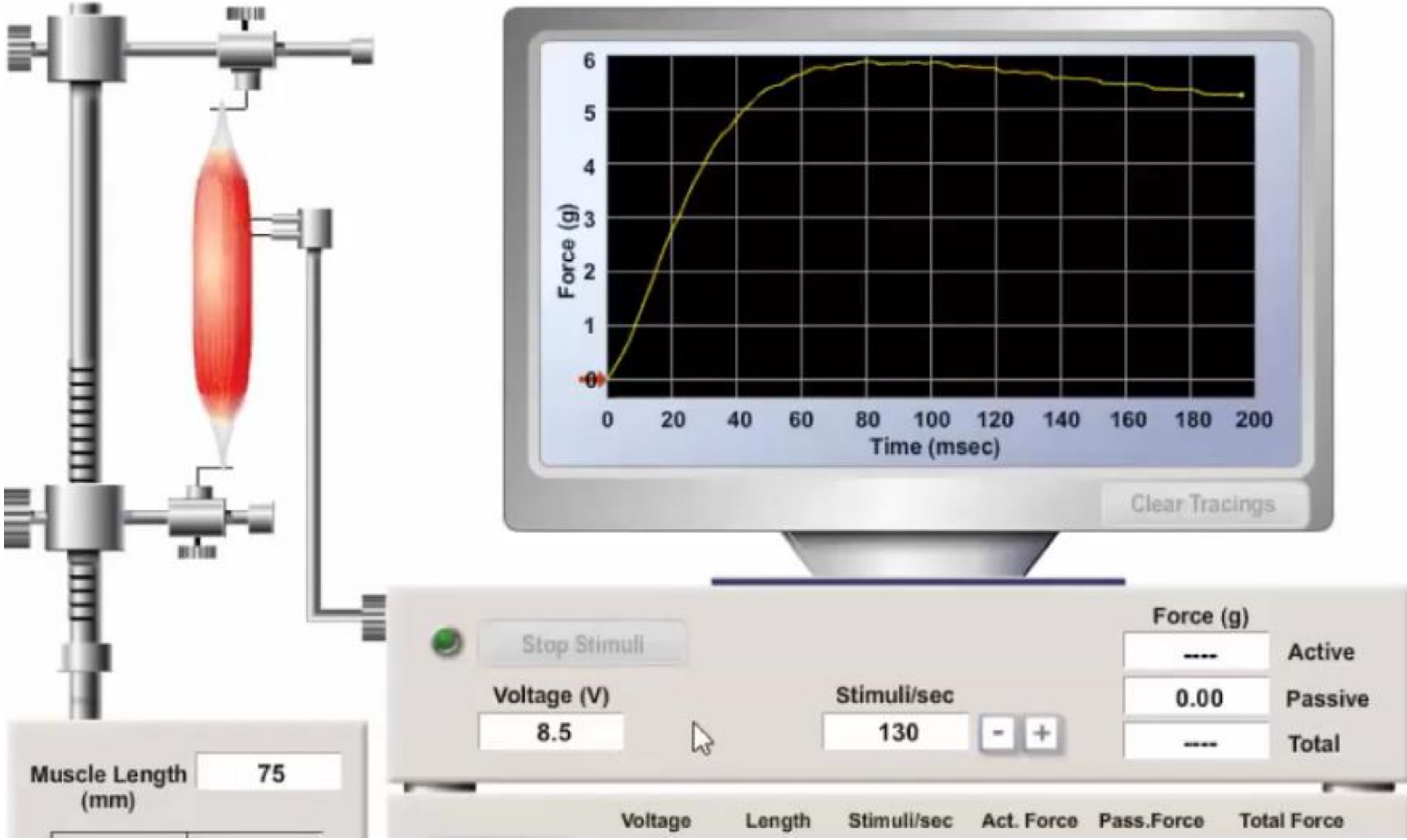
- Unfused (incomplete) tetanization is a sustained but wavering contraction.
- Occurs When a skeletal muscle fiber is stimulated at a high rate, so it can only partially relax between stimuli.

-**in normal muscle contraction**; we use **asynchronous recruitment** (stimulation) :
⚡don't make recruitment for all motor units.
⚡use unfused tetanus -->that will make sure that the contraction will continue as long as possible without reaching fatigue.

In this last simulation (click here to watch), we increase the stimuli to 130 per second. Here we notice :

1. A rapid increase in tension
2. An increase in the force of contraction (6g vs 5g in the incomplete tetanization)
3. The waves' appearance disappears.

This is **complete or fused tetanization.**



Since complete tetanization was achieved at 130 stimuli per second, even if we increase the frequency of stimulation (to 150 for example) we will have the same response. This is the maximum response that the muscle can give.

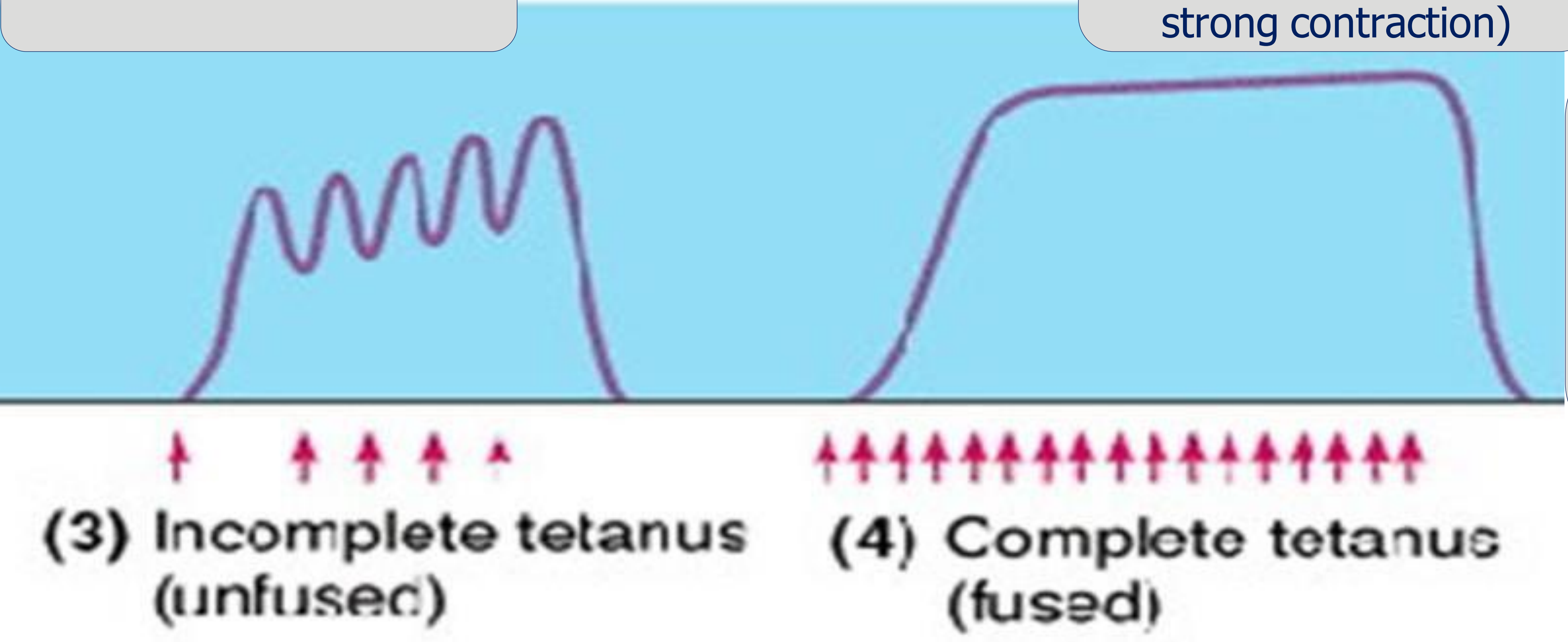
Complete tetanization

- 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

We still see some waves

-Almost flat line
-Can reach higher tension(very high and strong contraction)



💡Disadvantage:
-the contraction can't be maintained for a long period of time

-As we increase the frequency of stimulation ----> [Ca+2] will increase as well----> allowing for stronger contraction .

Fatigue

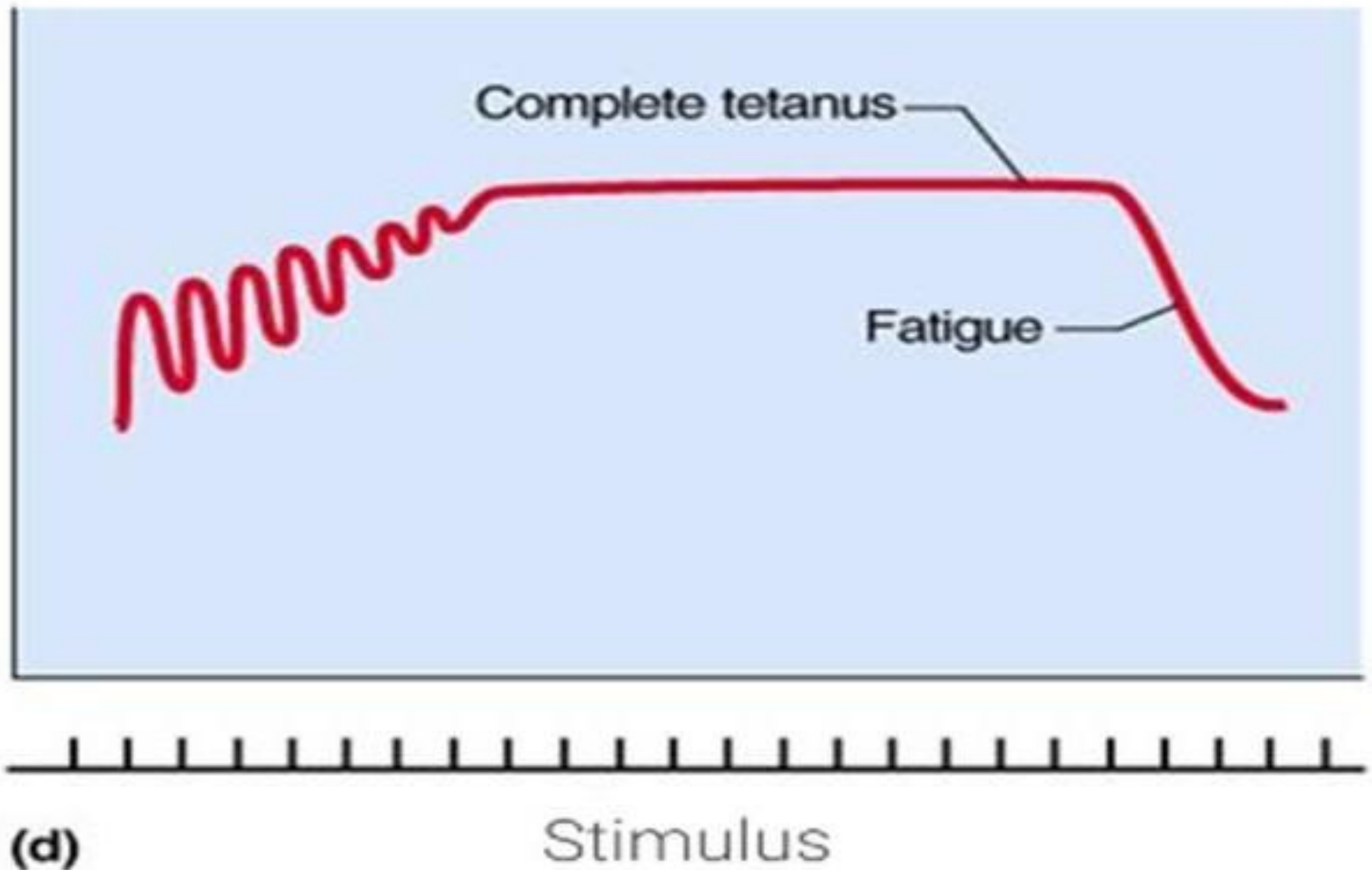
- Fatigue is a decline in the ability of the muscle to respond to stimulation, occurs after prolonged and strong contraction **even though I am stimulating it with the same stimulus.**
- On the graph it is depicted as a drop in tension despite continued stimulation

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. **(During the strong continuos contraction)** Interruption of blood flow which leads to loss of nutrient supply, especially loss of oxygen.

💡in everyday life within our muscles, we **rarely use complete tetanization** and that's simply because:
-->Complete tetanization is very exhaustive to the muscle (as the muscle reached the maximum tension and this tension dropped rapidly –in spite that the stimulus is constant and continuously applied- this called **Fatigue).**

Fatigue



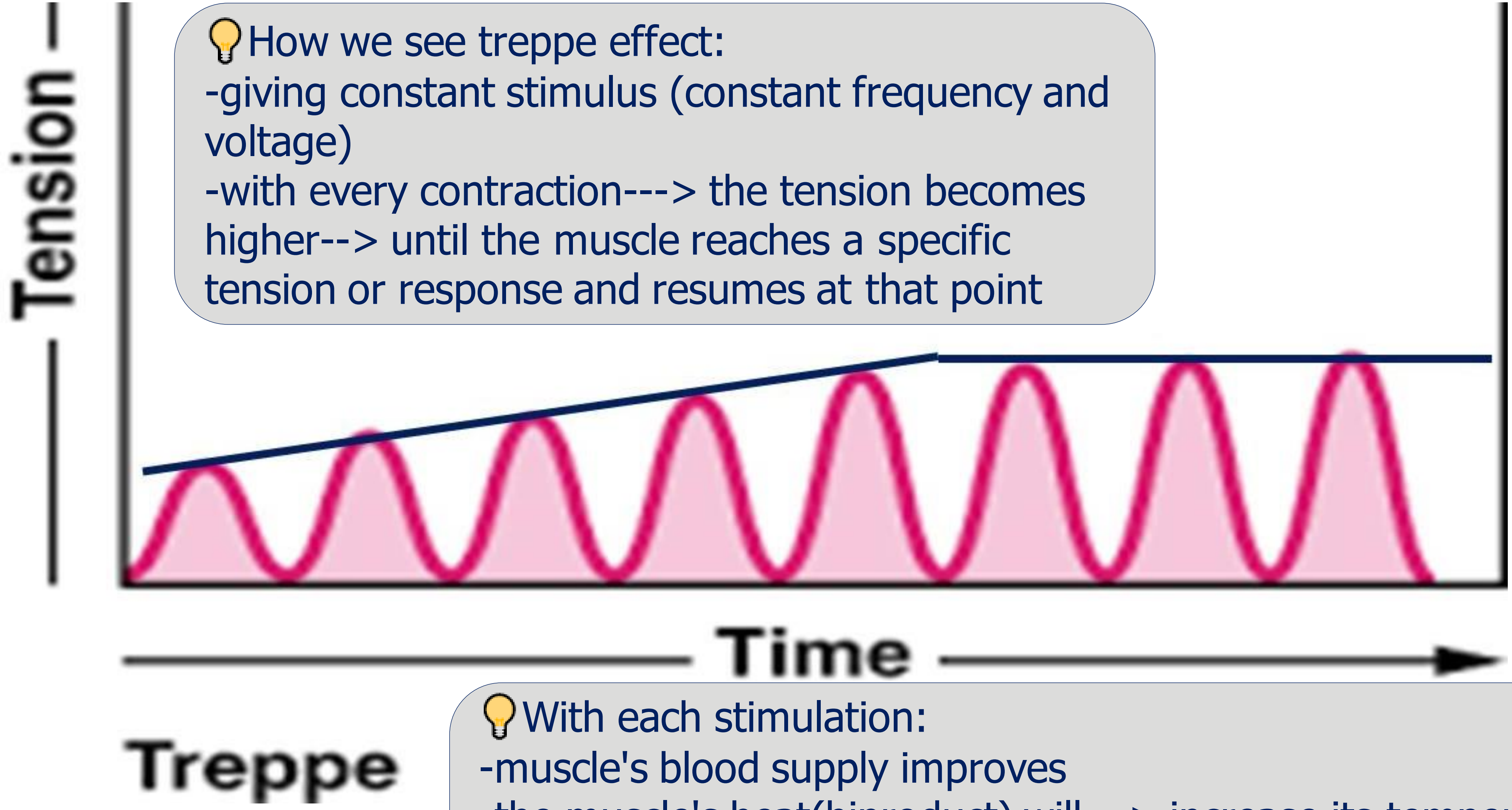
Treppe=stair
Treppe effect : gradual increase in tension (while the stimulus is constant-same voltage,same frequency-) but the response of the muscle improves 💪

Treppe effect

- 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** (stimulating the muscle frequently).
- It is believed to be caused by:

1. The rise in muscle temperature.(ex: athletes warming up before any match)
2. Increased concentration of calcium ions in the cytosol
3. The enhanced blood flow

Treppe Effect



💡How we see treppe effect:
-giving constant stimulus (constant frequency and voltage)
-with every contraction---> the tension becomes higher--> until the muscle reaches a specific tension or response and resumes at that point

💡With each stimulation:
-muscle's blood supply improves
-the muscle's heat(biproduct) will---> increase its temperature --->improvement of the the muscle's metabolic reactions —>improvement of the activity of its different enzymes—> **improvement in the function of the muscle** 💪

اللهم انصر أهل غـــزة نصرًا من عندك
يغنيهم عن نصر من سواك ، اللهم تقبّل
شهداءهم ، واشـــفِ جرحاهم ، واربط
على قلوبهم ، وأنزل السكينة عليهـم ،
اللهم أرِنا في اليهود المحتلين عـجـائب
قدرتك ، وفجاءة نقمتك ، وجميـــــع
سخطك ، اللهم اهزمهم وزلزلهم ، اللهم
ارفع الذلَّ والهوان عن أمـــةِ نبيِّك ﷺ