Biomechanics
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Lecture - 68
Enslaving – Intertendinuos Force Transfer and Motor Units

Welcome to this video on biomechanics. We have been looking at a biomechanics of soft tissues. Specifically in the last few classes we have been looking at the mechanical properties of tendons we looked at stress strain relations we looked at the nature of tendon forces and we also developed some models of non-linear elasticity in the toe region of a tendon, the physiological region, the elasticity is not linear.

The modulus change with deformation is something that we saw and we developed some models of this. So, we continue our discussion on mechanics of soft tissues or tendons in particular.

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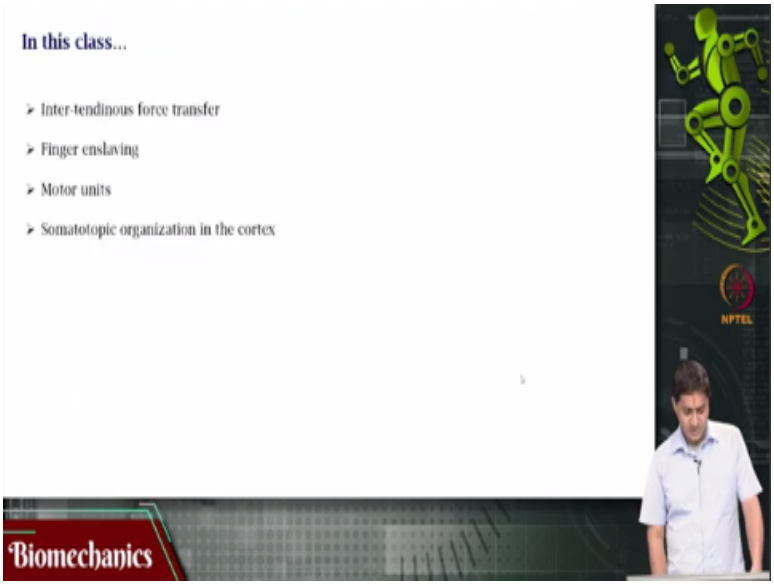

So, in this video we will be looking at inter-tendinous force transfer. How between tendons force can transfer? Shear for example and one critical example of tendon related force transfer or transfer of some mechanical effect due to tendon behaviour. So, called finger enslaving then we look at possible causes of finger enslaving. We will continue this discussion in the next week in much greater detail looking at some research articles on what possibly causes finger enslavement. In this video I will just introduce this and give some hints about this topic.

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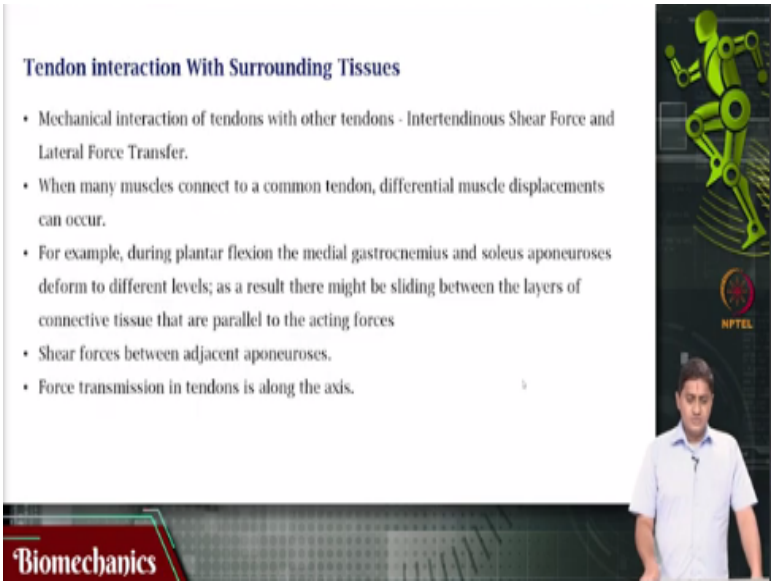

So, when tendons interact with other tendons what happens is that sometimes there is transfer of force between tendons. Mostly shear force are lateral force transfer that is if there are two tendons that are moving close to each other then they may shear with respect to each other. And when many muscles connect to a common tendon it is possible that the different muscle displacements may happen.

For example, during plantar flexion the medial gastrocnemius and soleus aponeurosis they deform to different levels. Because of this there might be some form of sliding between layers of connective tissue between the connective tissue that are parallel to the acting forces. This sliding cause shear forces between aponeurosis that are next to each other or adjacent consecutive next to each other aponeurosis that are next to each other.

But something that we need to keep in mind is force transmission in tendons is mostly assumed to be along the long axis of the tendon where the fibres are oriented along the axes. So, usually you would assume that most of the force is transmitted longitudinally I mean you would actually assume 100 percent efficiency in first transmission but that is not a very reasonable expectation. So, some forces also get transmitted laterally.

So, force transmission is assumed are expected to be along the long axis of the tendon, mostly this is also met. But here we discuss the special case of the situation when tendons shear between each other.

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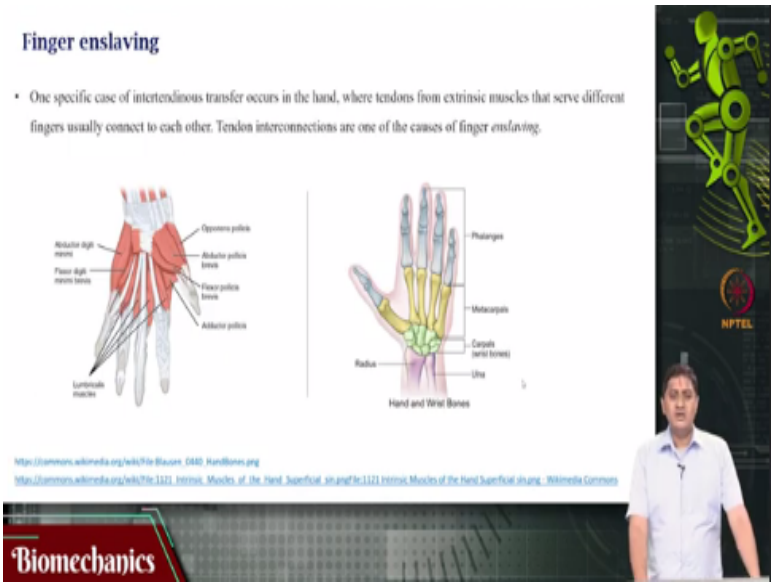

One particularly interesting case of inter-tendinous force transfer happens in the human hand even in animal hands. But it is the human hand that is of interest for us so happens in the hand. In this case, what happens is there are these multi-compartment muscles located in the forearm whose bellies are located in the forearm that send long tendons to the fingers. These muscles whose bellies are located in the forearm are called extrinsic muscles because they are external to the hand itself.

They are in the arm, they are in the forearm because of the citizen they are called as extrinsic muscles. This muscle gives rise to multiple tendons four different tendons that all these four tendons arise from the same muscle. Because of this reason there is some kind of interconnection between tendons. It is believed that one reason for finger enslavement is these inter-tendinous connections you know tender interconnections.

What is this enslavement? Suppose let us take your hand and you can do this exercise on yourself. You try to move only the ring finger, do not worry about what the other fingers are doing and try to do only the ring finger and observe what the other fingers are doing. I do that I

am moving only the ring finger what I observe is that the other fingers are also moving because I am not actively moving them or stopping them, the other fingers are also moving.

This situation in which when one instructor finger is moving the other non-instructed fingers are also moving is called as enslavement or enslaving. This is also called as lack of finger individuation. There is a compromise in the amount of individuation that a finger has. So, enslavement is a measure of finger interdependence, between finger that is interdependence. Enslaving or enslavement is a measure if we can quantitatively measure it this is essentially a measure of finger interdependence.

So, what you have for example in the hand are these tendons that have supplied. They are all originating actually not shown here that they are going to go through this and through this, they are all originating in the same muscle. So, in this region it is reasonable for you to expect some amount of shearing between tendons. So, when one tendon is moving the other tendon might also move because of purely because of shearing or a component of shear causing a one component of longitudinal force.

I mean you have to be very specific but this is not an entirely unexpected situation this can happen. So, when you want to move the distal phalanges for example this is the distal phalanges the segment this is the distal phalanges. Remember we discussed this in the previous weeks many weeks ago we discussed the anatomy of the hand. When we want to move the distal phalanges, a long muscle connects to these tendons from the long muscles connects to these segments.

And then either extends or fluxes them segments. And then you have you know middle phalange; you have the proximal phalange then you have the metacarpals you have the carpels and so on and so forth. We discussed all of this while we discussed the anatomy of the hand remember.

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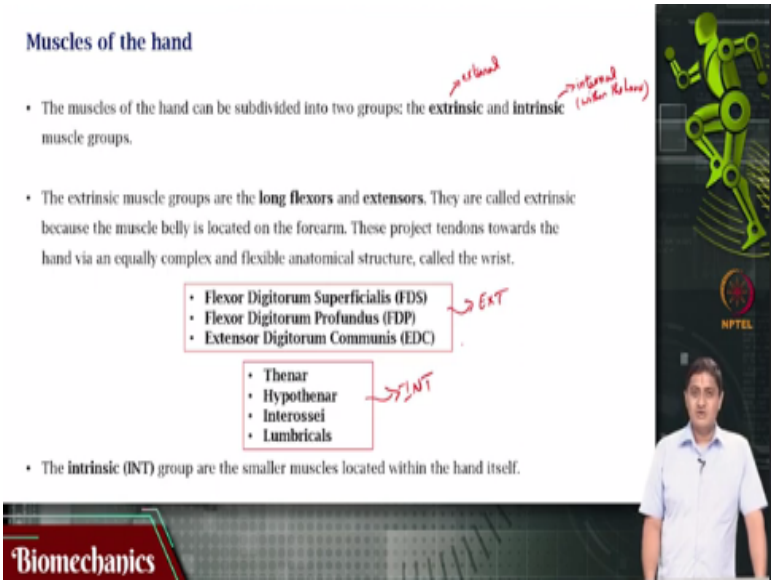

Also, the muscles of the hand can be divided into two groups. Those whose muscle bellies lie in the forearm and those whose muscle bellies lie within the hand itself. Those whose belly is lie within the forearm are called they are external to the hand and so they are called extrinsic. So, they are called extrinsic muscles and the intrinsic muscles are those that are internal to the hand are those that are found whose bellies are found within the hand.

These extrinsic muscles are those long flexors and extensors. They are called extrinsic, why are they extrinsic I just mentioned this because their belly is located in the forearm. So, but if their bellies are located in the forearm how are they transmitting force to the fingers? Through these multiple tendons that pass through geometrically complicated structure called as the wrist. Some examples of these you know extrinsic muscles are given flexor digitorum superficialis, flexor digitorum profundus, extensor digitorum communis.

These are the extrinsic group or the EXT group then those muscles whose bellies are found within the hand and whose tendons are also within the hand are the intrinsic muscles, thenar muscles, hypothenar muscles, interossei and lumbricals. These are small but their contribution cannot be necessarily underestimated. They are small muscles but they may have crucial role in providing this extra amount of dexterity and the finish to the functions of the human hand.

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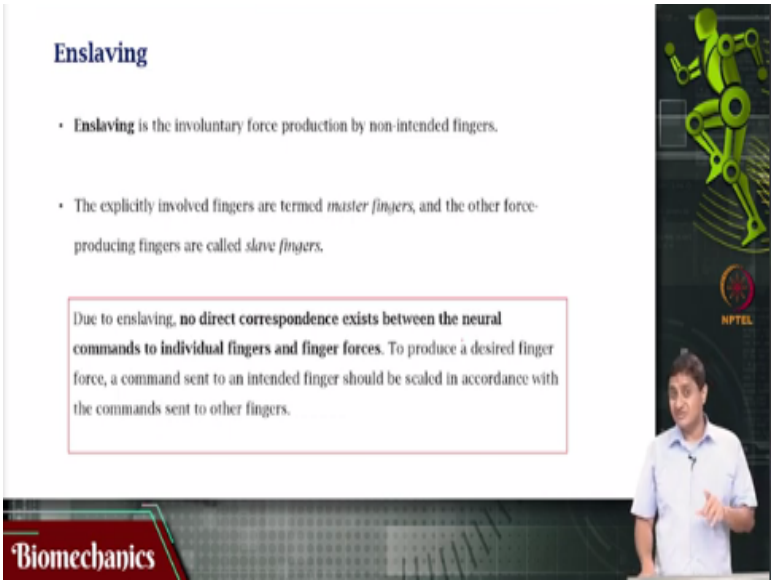

We just discussed what is enslaving. What is this? When you are it is either unintended or involuntary movement that is found in you know fingers that is called as lack of finger individuation or kinematic enslaving. Some form of kinematic enslaving are when you are pressing on an object and close or holding an object the force produced by one finger is also affected by the force produced by the other fingers or one force causes some an effect on other finger forces.

So, this is the involuntary or unintended force that is produced by the other non-instructed fingers. For discussion sake we call the explicitly involved fingers as master fingers and these other force producing fingers that are not instructed as slave fingers. For example, we performed this instruction where I am asking to move the ring finger the other fingers are moving without instruction and so they are all called in this particular case they are all called slave fingers.

That does not mean that the index finger is a slave. What it means is that for this task when in the instruction is to perform this task with ring finger, index finger, middle finger and little finger are slaves. When the instruction is to perform this task with the index finger, middle ring and little are slaves index finger is the master finger. So, this depends on the instruction that is given and what the person is following what the person is doing.

Because of this reason there is no one to one correct respondent between the command given to the individual fingers and the forces that are actually produced. So, if a particular force is actually produced in a finger that means that is a back worked force. If this is the force that is being produced that is not necessarily the force that is intended by the brain. So, there is no one to one correspondence between what is intended by the central nervous system brain or the central nervous system.

And what the finger is actually doing, there is no one to one correspondence. So, to produce a particular force an inverse model, from form of an inverse model of this enslavement must be present in the body. So, I need to know how my other fingers are moving when a particular finger is instructed to do a task so, that I can avoid these unintended forces. So, the command that is sent to an intended finger should be scaled in accordance with the commands that are sent to the other finger.

So, there must be some form of I need to have an idea of what is the amount of enslavement that is present in my hand.

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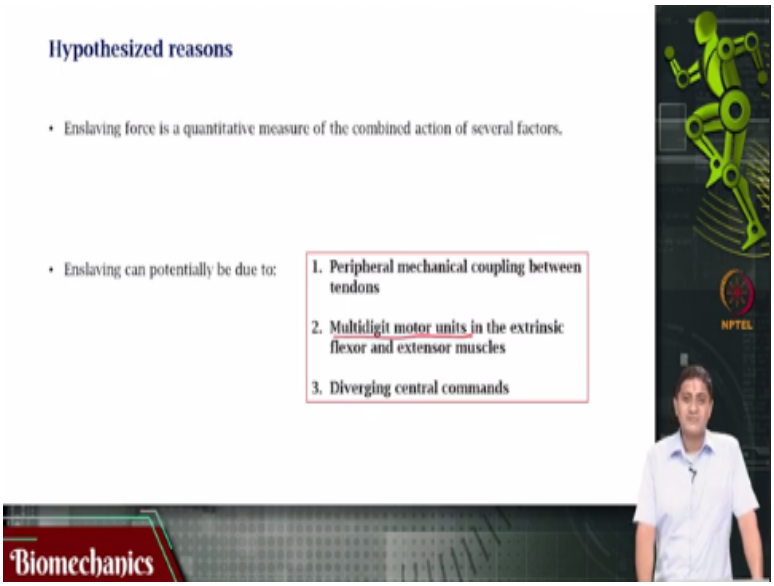

So, I can actually measure the enslavement using the fingertip forces. It is a quantitative measure there is a way to quantitatively measure this. This might be due to many factors or may be a combination of all these factors. What are these factors? Potentially it may be due to mechanical

coupling between tendons that we just discussed. There might be shearing, there may be some form of coupling between tendons.

So, peripheral mechanical coupling between tendons that is one possibility. The other is, it is possible that one motor unit in a muscle supplies, forced to many fingers or multi digit motor units in the extrinsic flexor and extensor muscles are one motor unit that is capable of supplying fibres and forces to many fingers simultaneously this is called multi digit motor units. The other possibility is likely central there might be neural factors.

There might be diverging or differential central commands. Maybe the neural architecture that controls are the neural structures that control individual fingers themselves are different and are themselves somehow dependent on each other that they cause some form of **(()) (16:25)**. We actually do not know which one this is. We will discuss part of this, in this video and part of this in the next week in much greater detail.

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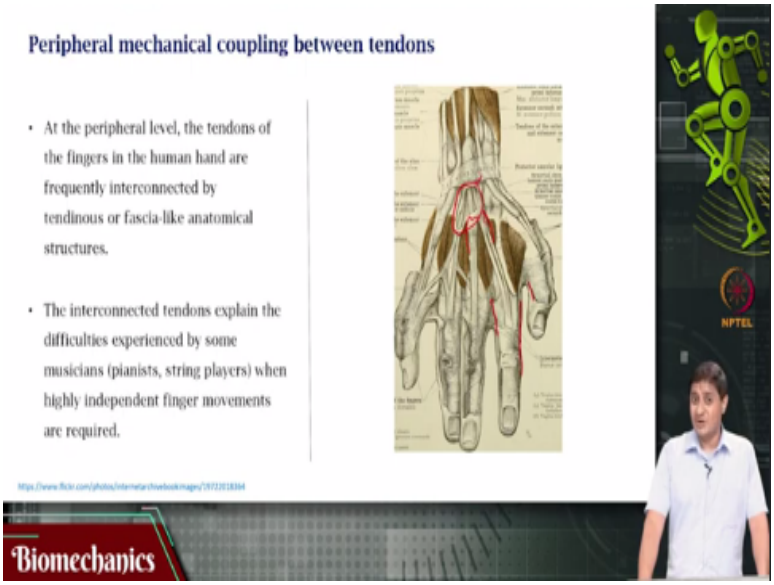

The first case that we discuss is peripheral mechanical coupling between tendons of the fingers. So, at the peripheral level the tendons of the fingers are somehow interconnected by fascia type of anatomical structure some tissues that interconnect the tendons. These interconnections or perhaps one of the reasons why it is hard to overcome the enslavement and produce the highly

independent finger movements that are required in some string musical instruments are maybe piano.

These are some of the instruments that require individuated finger movements where one finger is moving relatively independently of other fingers. So, this causes physical difficulty because there is a physical you know barrier that prevents independent movement of the fingers. But if that is indeed the case how are these expert musicians performing relatively independent movements, that is a different question that we need to separately discuss.

We will discuss that in just a little bit. Consider these fascias like tissues that are shown in this finger for example here there is always this interconnection that you see here for example. You know tendons are interconnected here they are there everywhere throughout the hand. There is fascia like you know interconnections that could cause some form of shear or some form of force transmission.

So, this is an aspect of morphology or structure or geometry itself, morphology itself is causing this limitation. But then coming back to the older question how then are the expert pianists performing these independent movements. Now with practice somehow, they are able to perform independent movements that mean that they are able to produce compensatory movements when the other fingers such that each finger movement appears to be independent maybe.

So, that means that this is something that you can unlearn. This is a controversial topic; it might appear controversial but it is not controversial. It is known that expert pianist and expert string musical instrument players have a different type of enslavement have much lower enslavement. So, that means that it seems like enslavement can be unlearned that means that this is probably neural but then you know let us not jump.

Let us not immediately from hyper sensing if this is something that I can unlearn that means that it is neural in origin and I will simply unlearn the neural learning. For that you also have to rule out the possibility then as you are unlearning there are no morphological changes in the hand.

Perhaps there are no morphological changes in the hand but that is something that we will have to confirm.

So, all we know is that expert piano answering musical instruments do have an low level of enslavement or do have a high degree of finger independent. So, their finger movements and finger actions are relatively more independent than the rest of the typical population something to keep in mind.

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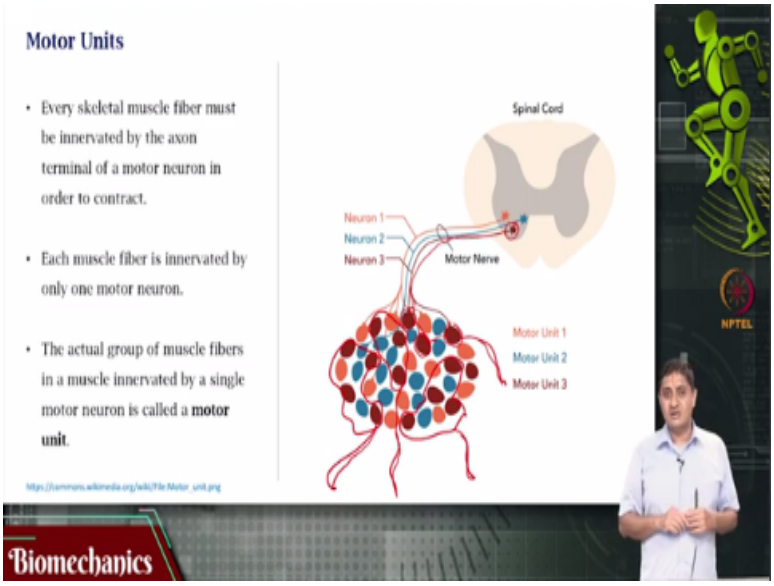

The other possibility that we discussed is the possibility that motor units multi-digit motor units. But let us discuss what is a motor unit first. Every skeletal muscle receives a command from a neuron or an alpha motor neuron to contract and to produce force. These fibres are the set of all fibres that are integrated by a given alpha motor neuron are called as motor units. If you take any single muscle fibre that is innervated by one and exactly one motor neuron.

But one motor neuron can innervate more than one muscle fibre a given fibre is integrated by exactly one motor neuron but any given motor neuron can and usually does innervate many fibres. So, the set of all fibres that are innervated by a single motor neuron is called as a motor unit. So, here you have this motor neuron and the set of all fibres that are innervated by this motor neuron are all coded in the brown colour here.

These are all there, this set is the motor unit. Now let us take these three muscle fibres connect to one tendon, these four muscle fibres connect to another tendon, these four connect to another tendon and these three connect to the fourth tendon. Now whenever this and the relationship between the motor, neuron and the fibres is such that whenever that motor neuron is firing the fibre must also fire.

So, whenever this brown motor neuron is active all these fibres will contract and the corresponding amount of force will be felt in each of these tendons. And remember these fibres are not necessarily of the same size they may be of the same size and they are also not of the same number. Some of them have four muscle fibres some of them have three so the forces will be different. So, this dependence on multi-digit motor units are multi tendinous motor unit.

So, one motor unit supplying to muscle fibres that are connecting to different tendons cause of the situation. Wherein if that motor neuron is activated all these tendons will become slightly and differentially activated. This may be a cause of enslavement. This is the second hypothesis reason.

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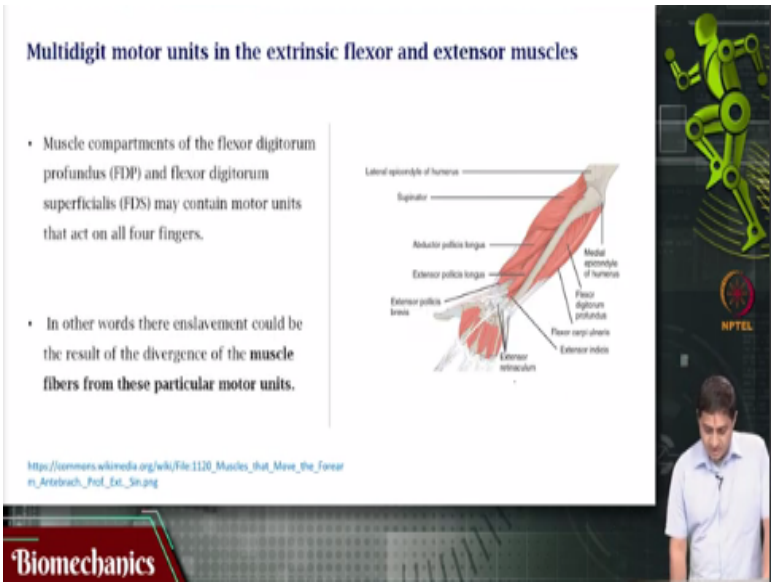

And for example, multi digit this is found and demonstrated there is some evidence to suggest that this happens at least in the extrinsic flexor and extensor muscles of the human hand. Because there are many different compartments of the same muscle, flexor digitorum profundus and

flexor digitorum superficialis that contain motor units and these act on all the four fingers. So, maybe there is some kind of divergence of commands or divergence of muscle fibres from these motor units.

So, if they are diverging to four different fingers although only one of them may be activated all of them because there is divergence of fibres to different tendons. This may cause a difference in either movements or forces the other hypothesis reason.

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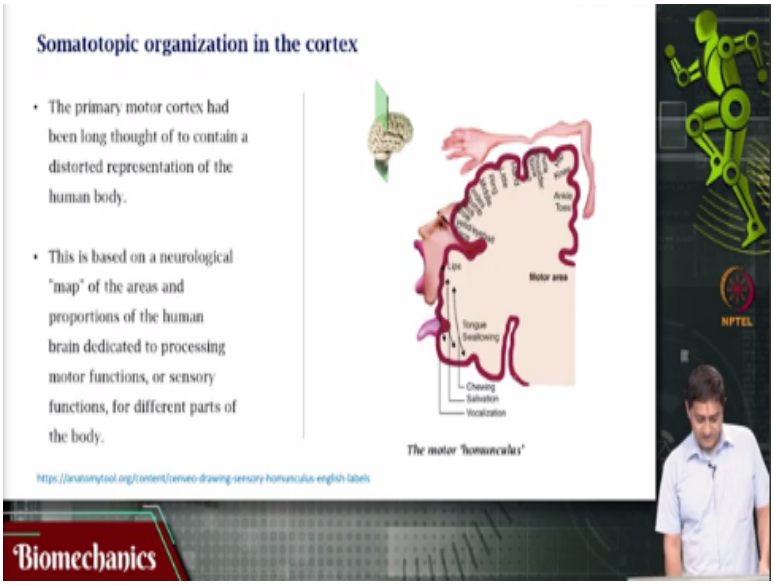

One more reason comes to us from the idea that in the primary motor cortex in the brain. So, primary motor cortex is this area in the brain that is just anterior to the central nervous. It is believed that the primary motor cortex is responsible for control of movements. In the 1930s an experiment was performed on epilepsy patients or patients who undergo surgery where different regions of the motor cortex was stimulated and which part of the body responded to that stimulation was recorded.

And what was found was that different regions were activated by activating different parts of the motor cortex that is something that is expected. But what was also found was that the face mouth and hand and finger regions hand and finger occupied at disproportionately large volume of the motor cortex volume. So, although the; hand and the face are having a relatively small volume in the whole body.

They occupy or they are represented in a relatively large area or their command the neurons that command these regions are spread over a relatively large area in the motor cortex. This gave rise to the idea that is a little man or a homunculus present within the motor cortex but not necessarily having a symmetric size. So, but disproportionately sized a little man is present inside or commanding man is present in the human brain.

So, in this model in this idea this is of course from the work of Wilder Penfield neurosurgeon from the 1930s suggested that there is a hand area, there is a little finger area, there is a ring finger area, that is a middle finger area, there is index finger area, there is a thumb area suggesting that there may be necessarily some form of boundaries between them. So, if suppose this is the ring finger area if you stimulate just outside that you will either activates the little finger or you will activate the middle finger.

If you stimulate just outside this ring finger area this suggests that there might be some form of a boundary if this is indeed the case that any cause of enslavement is not likely neural. But this is the 1930s view.

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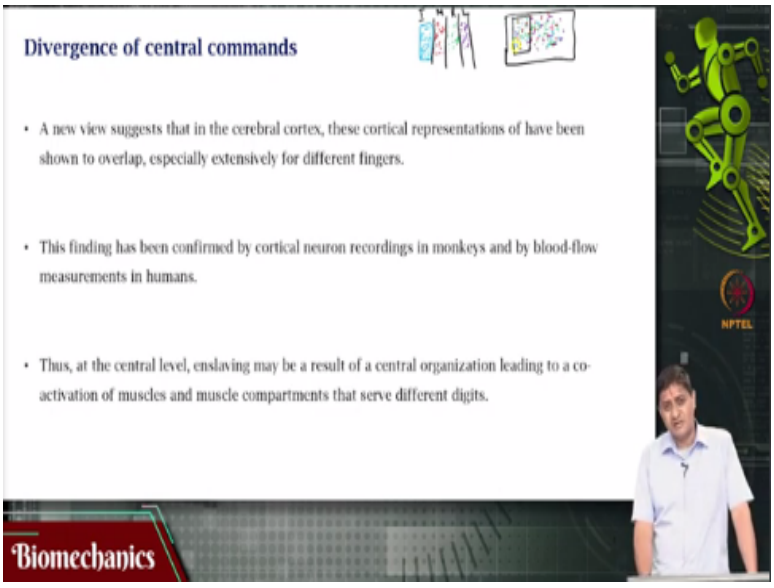

More recently what has been suggested is that in this cerebral cortex in the motor cortex these representations are not having stringent or strict boundaries. In particular between fingers there is

quite a bit of overlap between neurons that command different fingers. If I represent neurons that send command to different fingers in different colours and map this in the brain it is not like what you would expect from this homunculus model.

Let us say this is index finger and these are all the neurons, these are all the index finger neurons, this is the index finger region of the brain, these are all the index finger neurons that I am marking in light blue. Then I have the middle finger neurons that are plotted that are marked in red then I am going to have the ring finger neuron in bright green then I have the little finger neuron in purple. This appears to suggest existence of some form of boundaries between them.

There is a boundary here, the boundary here, there is a boundary here and there is a boundary here. This is what is suggested by the homunculus model. But what is actually present is and, and, and now what I have within this big black square is looking more like a mosaic of different colours. So, it does not look like if I take a small region within this hand area of the brain of the motor cortex if I take say a small area here will I find only the index finger neurons?

The answer is no because it is not just blue. Will I find only the middle finger neurons? The answer is no because it is not just red, not only green not only purple. Purple is found everywhere and, in this region, purple is found, green is found everywhere and, in this region, grain is found, red is found everywhere and, in this region, red is found, blue is found everywhere and, in this region, blue is found.

That means that it is possible that neurons that are neighbours to each other may actually command fingers that are distant from each other. Let me say that again. Neurons that are located close to each other in the motor cortex may command fingers that are located far away from each other. For example, it is possible for so this is index, this is middle, this is ring, this is little we said. So, little finger and index finger are far away from each other, is it not?

So, in the hand you see that the index finger and little finger are far away from each other. So, is it possible for the index finger neurons which are represented in blue and the little finger neurons which are represented in purple to be neighbours in a selected region. The answer is yes and let

me highlight one example of that. In yellow colour I am highlighting this example. For example, here I have circled in yellow, two neurons one in blue and one in purple.

So, fingers that are far away from each other can receive command from neurons that are very close to each other. So, if a small region of the motor cortex in the brain becomes active then it is possible for that activation to spill over to other neurons that are commanding fingers away from each other giving rise to a form of divergence of neural commands from the brain. Giving rise to a possibility that enslaving might be primarily a neural phenomenon.

This idea has been confirmed by a studies on monkeys and by blood flow measurements in humans. So, at the central level it may be thought of at you know that enslavement might be purely a result of cortical organization some form of organization leading to some form of co-activation between muscles that are sending commands to different fingers are receiving commands at the same time.

Because they these two neurons are located close to each other and that region of the brain is active for some reason. So, this might be purely because of divergence in the central cortical commands may be this is the other hypothesis that we came out with.

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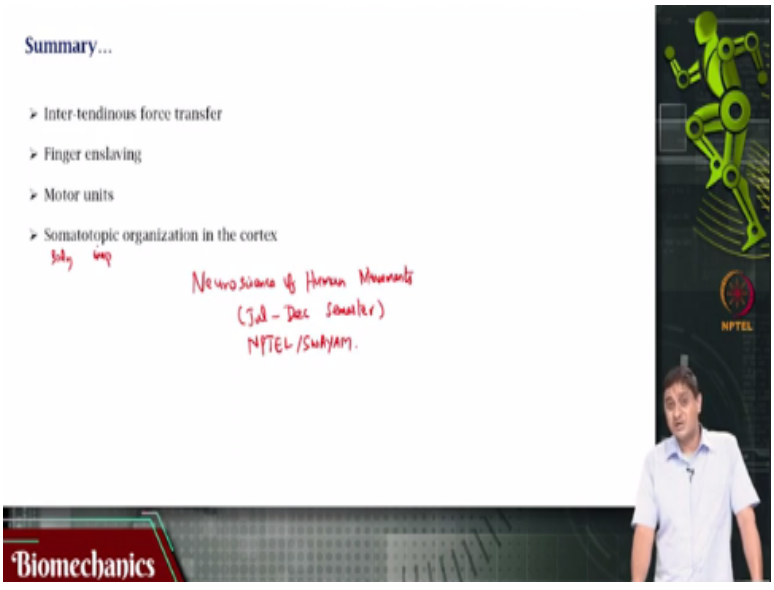

So, we still do not know and it is beyond our scope in this video and in this week to study about the possible causes of this enslavement. We dedicate practically one entire week to studying the possible causes of enslavement which is next week I will be discussing two research papers in great detail and discuss the possible causes of lack of finger individuation are enslavement. If you are interested in the neural topics that I just discussed if that inspires you.

And if you are interested in the neural control of movement, I recommend that you consider taking my other course that is offered in the July to November semester, the name of the course is Neuroscience of human movements. Usually, it is offered in the July to December semester in NPTEL SWAYAM. Those who are liking this those who are interested in this neural control of moment are in this how the brain controls movement I strongly recommend my other course on Neuroscience of human movements.

So, in this video we saw what is inter-tendinous transfer of force or lateral force transmission or shear force transmission. We looked at what is finger enslavement and what are the possible causes of finger instrument. We looked at what is a motor unit, what are motor units that supply to many digits multi-digit motor units and we also looked at the possible cause of enslavement in the form of somatotopic.

Somatotopic means somato means body topic means map or the body map representation or the body map organization or the presence of a mosaic organization of the body in particularly the hand as one of the other causes of enslavement. So, with this we come to the end of this video, thank you very much for your attention.