Biomechanics
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Lecture: 69
Introduction to Finger Enslavement

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(FL) Welcome to this video on biomechanics. We have been looking at biomechanics of soft tissues in the past week, specifically we looked at biomechanics of tendons. We also discussed how tendons interact with other tissues and tendons interact with other tendons that might be for example shear that might happen between tendons or we also looked at a case when one muscle gives rise to multiple tendons and if the muscle is contracting all these tendons might simultaneously contract.

So there are many complications like this where one muscle is contracting, all the tendons are contracting, different tendons are connected to different compartments of the same muscle or different tendons are connected to different motor units of the same muscle or one motor unit connecting to multi-digit or multi-tendons. So one motor unit gives rise to other or muscle fibers of one motor unit attach to different tendons.

So, remember one motor unit is the set of one motor neuron and the set of all muscle fibers are connected to that motor neuron, is it not, set of all muscle fibers. So, if that muscle fiber, if

there are say 100 muscle fibers connected to one motor neuron, let us say 40 of them connect to tendon 1 and 60 of them connect to tendon 2, whenever this motor unit is firing these 40 muscle fibers connected to tendon 1, so tendon 1 will also get pulled with some strength.

Tendon 2 will also get pulled with a different strength. Many of these complicated situations happen. One particular example of such intertendinous interactions or between tendon interaction happens in the case of human fingers because we have multi-tendent muscles that give rise to many tendons and connect to different fingers. Probably because of this reason forces produced by fingers are somewhat dependent on each other.

And movements produced by fingers are also dependent on each other. The question is forces and movements that are produced by the fingers if they are dependent on each other, is it purely due to mechanical factors or is it purely due to neural factors or if it is a combination of the two can be dissociate the amount of contribution each of this is making? This is a relatively complicated topic. So we will unpack it as we go along.

I am just introducing what the topic is, the broad topic this, so we will discuss. So from this week will take a step upwards and discuss some research papers. We go one notch higher and discuss some research papers. As a first paper we discuss the work by Vladimir Zatsiorsky, Zong-Ming Li and Mark Latash on enslavement in forces, force sense limit, published in year 2000. Another paper is from our own lab at IIT Madras.

Our neuromechanics lab at IIT Madras, co-authored by me with my past dual degree student Niranjan Chakrabhavi. We will discuss kinematic enslavement and the possible role of wrist posture in affecting kinematic enslavement in that paper.

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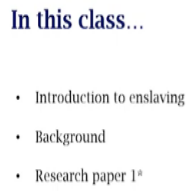

* Zatsiorsky VM, Li ZM, Latash ML. Enslaving effects in multi-finger force production. Experimental brain research. 2000 Mar;131:187-95.

So in this video, I will introduce the notion of enslavement and I will discuss the background on enslavement and in relatively good detail we will discuss the research paper on enslavement which is enslaving effects in multi-finger force production published in the journal experimental brain research in the year 2000 authored by my advisor Mark Latash and professor Vladimir Zatsiorsky, Dr Z as we respectfully and affectionately call him.

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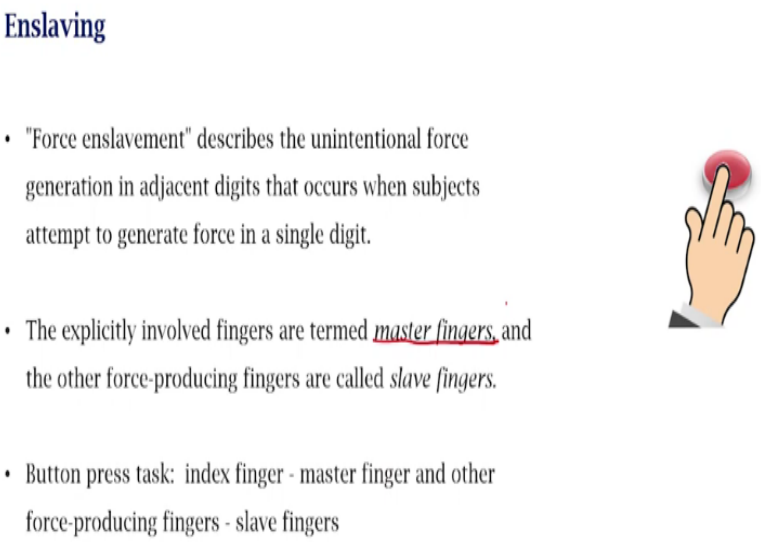

So what is enslavement? So when you move one finger the other fingers also move, we saw this in one of the previous classes. So keep your hand like this and do this exercise, move only the ring finger, this was the task that I gave the other day. Now I am moving only the ring finger, is it not? When I move the ring finger with no explicit instruction to the other fingers what happens is that the other fingers are also moving at least slightly.

Now this is some unwanted or unintended movements. The question is what is the source of this lack of finger individuation or finger enslavement? When this form of enslavement when it happens in the force domain when you are pressing on an object, when you are holding this object, for example when I am holding and pressing on the object or when I am pushing or pressing on an object and doing some pressing task force produced by one finger affects the forces produced by the other fingers.

Also force produced by one finger is affected by the other fingers forces. These are two different things. If the index finger is producing a force it is affecting the force produced by middle ring and little fingers. The force produced by the index finger in a multi-finger task if three or four fingers are producing a task and I am only measuring the force produced by the index finger, the force produced by the index finger alone is not just reflection of the intended force that is meant for index finger.

Let me unpack that. What I mean is in a multi-finger task, let us say I am performing index, middle, ring, little. With four fingers I am pressing on an object and I am measuring say all the four finger forces and I am taking for example only the data from the index finger, this is not purely the result of index finger intention or force intended for index finger, but rather some spillover from the other finger actions also is reflected in the index finger, but I have only one measurement.

I have only the index finger force, from this I want to know what was the intended index finger force, how much of the other force is coming from force produced by the other fingers, spill over from the other fingers, is there a way to measure? Is there a way to dissociate? These are the questions, so relatively complicated topic. It appears like a complicated topic, it is not. We will slowly and patiently move through this paper.

So, we can upgrade ourselves and move to the next level in our question, our journey to appreciate and understand research in the field of biomechanics because that is our goal. We started out at a low level, we are slowly moving up. So when I ask one finger to produce a force, the other fingers are also producing an unintended force that happens in adjacent digit, but also happens in far away digits.

Now if I give an instruction to produce a force with just the index finger or just one particular finger that is the instructed finger, let us say I am asking someone to produce a force with the ring finger, now that is the instructed finger or the master finger, by the way there can be more than one master fingers. I can say produce this force with index and middle, produce this force with index and ring, produce this force with index and little or middle and ring, middle and little or ring and little, however it is.

Likewise, three finger tasks, four finger tasks all of these are possible. So there can be more than one instructed finger or master fingers, those fingers that have not received instruction, the instruction is usually to not worry about what the uninstructed fingers are doing. Suppose the instruction is to produce a force with these two fingers, do not worry about what the other two fingers are doing, let them be, let them do whatever they want, do not worry about them.

They may produce a force or they may not produce, do not explicitly produce a force, at the same time do not explicitly stop them from producing whatever it is that they are producing. That is I am giving, I am explicitly interested in measuring what these two fingers are doing, this is instruction, these are the masters, but I am also measuring what these two fingers are doing but I am telling the participant, the human participant do not worry about what these two fingers are doing.

In particular do not stop them from doing what they are doing, do not also explicitly produce a force, do not also explicitly involve them. Now this is a relatively challenging task to perform. Actually, the task itself is easy, but this is a relatively challenging experiment to perform. If you tell someone to not do something, it is an extremely difficult instruction to follow for all of us, for all humans, something that all of you will relate to.

When you tell someone to not do something they will do exactly that. For example while you are taking this medicine you take this medicine and while you are taking this medicine do not think about the monkey. It is extraordinarily hard for you to not think about the monkey when you are taking that medicine that is the joke that floats around, it is extraordinarily hard to because the instruction usually; when this is something that my colleagues and senior professors told me.

When you instruct your students, tell them what to do, tell them submit the assignment by this date, in particular avoid telling them what not to do that is it is better to not tell the students please do not delay the assignments. If you tell them please do not delay the assignment submission, it is very likely that they will delay the assignment submission, tell them what to do please make sure that the assignment is submitted by say March 25th.

Some date, by that date please make sure that you submit, tell them what to do. That is in this particular case that is a very difficult instruction because you are telling them not to worry about what the other fingers are doing that is a very difficult instruction to interpret. What does it mean not to worry? Should I worry or should I not worry? Should I follow that instruction or not? Should I completely ignore those fingers or can I also involve those two other fingers?

So what does it mean to not worry about the other two fingers is not clear and different people are likely to interpret it in different ways. So do not worry paradigm, do not care experimental paradigm has this major disadvantage where it is not clear whether a particular participant followed instruction or not. You tell someone to do something or not do something how do you know they followed your instruction?

You actually do not know, you assume that they do, these are humans who understand the language that you speak and who want to help you who are sincere and they are following your instruction, but it is entirely possible that a well-intended and sincere human also does not follow instruction because they simply do not understand the instruction. Even if they understand the language, they do not know what it means, the deeper meaning.

There might be many reasons why this might simply not work. There is a way ahead, there is a way out of this, we will discuss that in the rest of the discussion. There is a way to avoid this, there is a way to account for this. This is the major challenge in these types of instructions and experimental paradigms. Let us discuss this in much greater detail in going forward. So let us say for example you have a button press task like the one that you have, press with the index finger.

The instruction is press the button with the index finger and do not worry about what the other fingers are doing. By the way in all this experiments, it is very important, it is absolutely

crucial to measure the forces produced by all the four fingers. You measure all the four finger forces but the instruction is only for the index finger, only for the master finger, not necessarily index, whatever is or are the master combinations you measure everything. Let us discuss this in some more detail.

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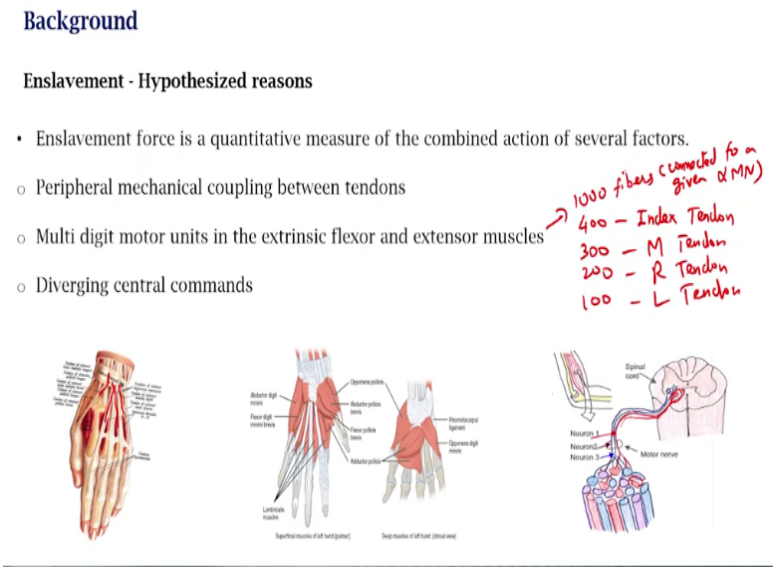

The question is what are the hypothesized reasons for enslavement? The question is what is the cause of enslavement? We discussed this in the previous week in some good detail, but let me try and refresh this. What are the hypothesized reasons? We said at least three different reasons for this, one is there can be mechanical coupling between tendons that can be shear force transmission between tendons.

And other such things that can be when one tendon is moving the other tendon is also moving purely because of mechanical reasons, mechanical coupling between tendons that is one possibility. The other possibility is the existence of multi-digit motor units in the extrinsic flexors and extensors of the hand. This is what is multidigit, multifinger, so one motor unit is the set of all muscle fibers that are connected to a particular motor neuron.

If these muscle fibers, let us say there are 1000 muscle fibers under discussion, say 400 of them connect to tendon 1 that goes to the index finger, 300 of them connect to the middle finger or ring finger, 200 of them connect to the little finger or middle finger and 100 of them connect to say the ring finger or the little finger whichever way it is say for example. Let us say 1000 fibers connected to a given alpha motor neuron, a given alpha this is the key.

One alpha motor neuron connects to say this 1000, it is an example number, one alpha motor neuron connects to this 1000 fibers. Now of this 1000 say 400 of them connect to index finger tendon, say 300 connect to middle finger tendon, 200 to the ring finger tendon and 100 to the little finger tendon. Well actually it does not have to be this way, I mean it appears as if there is a gradation 400, 300, 200, 100, it does not have to be this way.

Let us say some different numbers, the sum must be 1000 let us say for example like this, it does not have to be exactly 400, 300, 200 it is an example. Now remember that whenever an alpha motor neuron is firing all the muscle fibers connected to this alpha motor neuron will fire, this is the rule because the neuromuscular synapse or the neuromuscular junction is an obligatory synapse.

That is whenever the alpha motor neuron is firing, the muscle fibers will produce an action potential and contract, this is a known fact. So that means whenever this alpha motor neuron is firing this 1000 fibers all of them will get activated but they will have differential consequences on the four fingers, why? Well assuming actually these 1000 muscle fibers need not be of same force producing capacity that is a different discussion.

It might be that different muscle fibers have different force producing capacity and because of that the forces might change that is a different discussion. But let us assume that all these 1000 have very similar or same force producing capacity, they are uniform, they are all the same, they are all identical. They have similar force producing capacity for the sake of discussion we will assume this.

Now when this alpha motor neuron fibers all these 1000 muscle fibers will fire that means if 100 units of force, let us say 100 million Newton or whatever, let us say some 100 units of force is produced by the little finger, then 400 units of force will be produced by the index finger. If this was the only tendon, if this was the only force or if this was the only motor neuron under muscle fibers that are contracting at that time.

Let us assume that this is the only motor unit that is contracting at that time for the sake of discussion, so many assumptions we are making. If this was the only motor unit that is contracting at that time then the force will be distributed like this 1 is 2 is to 3 is to 4 between little, ring, middle and index in that order, is it not? That means it does not matter what the

instructed finger is, the instructed finger might be the ring finger, it does not matter or the instructed finger might be the index finger it does not matter.

Because this alpha motor neuron is activated, all the fibers will get activated because they have no choice, they cannot say only the index finger has to produce force why should I contract? That option is not there, they have an obligatory synapse, it is an obligatory synapse, so they will produce force. The real situation is actually a bit more complicated. There are many motor units and there is quite a bit of distribution.

The point is that there are this multidigit motor units in the extrinsic flexor and extensor muscles that may or may not originate from different compartments. There is also muscle compartment complication that we are not discussing as part of this discussion. They may originate from different compartments for example. There is quite a bit of complexity involved in this. The point is that this may be one of the sources of enslavement, going back our original discussion was what may be the cause of enslavement.

First, we said that peripheral mechanical coupling between the tendons, sharing, force transmission and other such things merely because one tendon is transmitting some force to another tendon may be due to shears or lateral forces or something is happening and because of that there is some force transmission that is happening tendon to tendon that is what that can also happen. Because these tendons move in close proximity with each other, this is one of the possibilities.

The other is that multidigit motor units, remember in the last week's video we discussed how in a given region of the brain there might be neurons that might send commands to different fingers but located close to each other. So two neurons that are neighbours to each other, that are next to each other, adjacent to each other may actually end up sending commands to fingers index and little, fingers that are far away from each other, this is a possibility.

We discussed that saying that there can be a mosaic arrangement of finger representation in the motor cortex. So remember that also one more thing to consider is that these neurons are usually cortical motor neurons are those neurons that have a monosynaptic connection with the alpha motor neurons that supply to the hand and fingers, something that is discussed in much greater detail in my other courses.

The point is that if a particular region of the brain corresponding to the fingers is activated, it is likely that if that region is activated, let us say a region of the brain is activated then many different neurons that supply to many different fingers will get activated because of this reason it is likely that the fingers will also produce force differently not because of mechanical reasons but because somebody is sitting up there, I mean I am oversimplifying that situation.

The neurons in the motor cortex are sending commands to diverse regions, a bunch of regions that may be far away from each other, diverging central commands is what is the other reason that we discussed. So the first cause is this where the tendons may shear for example with respect to each other. The other causes this is also the same, again showing the tendons this and this is the second cause where this motor unit is applying to different fibers that may connect to different tendons.

These are the three hypothesized causes of finger enslavement. But our question is not this, our question is can I understand or identify or dissociate which of these causes is a major cause or which of this is contributing to enslavement in a great way, can I do that? That is the question. So these are the possible reasons for finger enslavement. Our question is which is causing more or which is contributing in a greater manner, to a greater level for this phenomenon?

To study this, we will have to discuss these research papers, but for now we will end this video. So in this video we looked at the definition and what is finger enslavement and we discussed that in good detail and we also discussed the hypothesized reasons for enslavement. With this, we come to the end of this video. Thank you very much for your attention.