Biomechanics
Prof. Varadhan SKM
Department of Applied Mechanics
Indian Institute of Technology – Madras

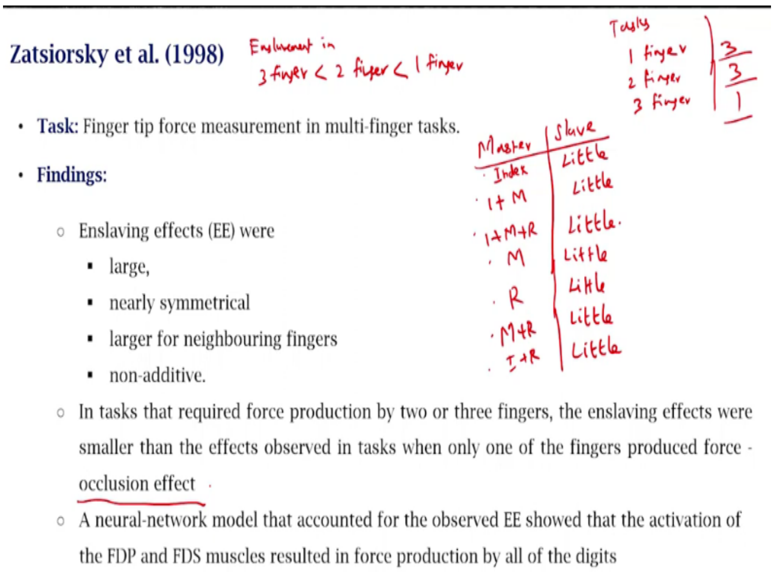
Lecture - 70
Enslaving Effects in Finger Force Production - 1

(Refer Slide Time: 00:17)

(FL) Welcome to this video on biomechanics. In the previous video, we introduced the notion of finger enslavement and we said that there are three hypothesized reasons for finger enslavement namely tendinous force transmission or intertendinous force transmission or multidigit motor units or diverging central commands. These are the three reasons that we hypothesized for this.

In this, video we will begin our discussion on a research article by Zatsiorsky, Zong-Ming Li and Latash on enslaving effects and multi-finger force production. It is a landmark paper discussing and contributing in a big way for our understanding of finger force enslavement. In this video I will just try to introduce or at least set up the methods, then in future videos we will discuss the results and possibly the implications.

(Refer Slide Time: 01:33)



Before we begin our discussion of the 2000 paper, there is a prequel or prerequisite. There was a paper in 1998 by Zatsiorsky and colleagues in which they measured and studied finger enslavement. The task was in a multi-finger force production, fingertip force production task they measured the fingertip forces and tried to correlate or relate come up with a relationship between these fingertip forces.

And specifically they were asking questions about how well correlated our finger forces are or finger forces enslaved or one finger enslaved with respect to another finger what is the magnitude of this enslavement and other such questions. They wanted to make some general observation support the finger enslavement. What they found from that study was that enslavement effects shortly called EE.

Going forward in the rest of the discussion I will call this EE, EE means enslavement effects or enslaving effects, what they found was that EE was large, in general enslavement effect is not trivial or something that is small. And enslavement effect is nearly symmetrical that the enslavement produced by one, finger x on finger y and the instrument produced by y and x nearly the same, not exactly the same, nearly symmetrical.

Another finding was that enslavement effect is higher if a slave finger is a neighbour of a master finger. So that enslavement effect is larger for fingers that are neighbours of each other that is if index finger is the master finger, then the enslavement effect on the middle finger is greater than the enslavement effect on the little finger because little finger is far away from index finger, but middle finger is right next to index finger.

Because of this reason enslaving effect is large for middle finger when compared with little finger if the instructed finger is the index finger. The other was that enslaving effects are not additive, you cannot merely add enslaving effects to find a net enslaving effect depending on the fingers that is something that you cannot avoid. One more interesting observation that they had was if you had more than two fingers involved explicitly involved.

If you had two or three explicitly involved fingers, then the enslavement effect on the uninvolved fingers was smaller than the enslavement effect when only one of those explicitly involved fingers was working. What I am saying let us try to unpack it. That is let us say I am interested in measuring the enslavement effect on the little finger when index finger is working. I will just write master slave, this does not necessarily imply a hierarchy, it is a terminology.

It does not necessarily mean that there is slave, it is some names that we are giving. They are actually collaborators in the large scheme of things, it is not like one is a master, the other is a slave and the one person here listens to the other, there is no implication of hierarchy. This is a terminology that I am using. Let us say index finger is the master and I am measuring little finger. Index and middle is the master and I am measuring little finger.

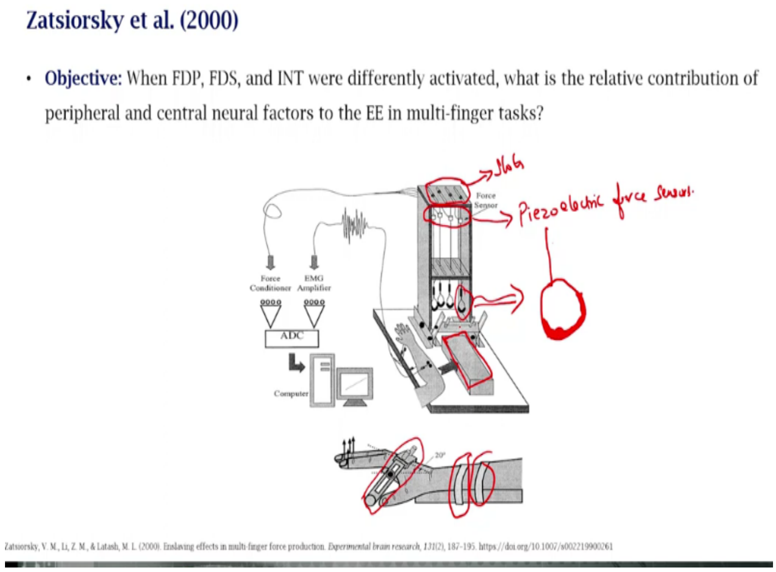
Index plus middle plus ring and I am measuring little finger. In all these cases, I am measuring the effect of force produced by these set of master fingers on the little finger. I can also for completeness study middle finger and little finger, ring finger and little finger. For completeness I can also study middle plus ring and little finger and index plus ring and little finger. I can also study these. Let us assume this is what I am doing.

The question is if I had a way to compare the amount of enslavement where the explicitly involved fingers was just one, either I or M or R or just two I M, M R or I R or 3, so there are three categories in which I can have you know one finger what are the type of tasks? The types of tasks are 1 finger tasks are 3, 2 finger tasks are 3, 3 finger task is 1, is that correct? One, two, three that is correct.

My question is can I compare the amount of enslavement in these three tasks with these three tasks and this one task? How would enslavement in the little finger vary? It turns out that enslavement in 3 finger tasks is less than the enslavement in the 2 finger tasks and which is less than the 1 finger task. When many fingers are explicitly involved in the task, the enslavement effect reduces. As the number of explicitly involved fingers increases, the enslavement effect reduces.

This is called as occlusion effect. There is an occlusion. They also modeled this using a neural network model that showed that activation of the flexor digitorum profundus and the flexor digitorum superficialis muscles resulted in force production by many of these digits or all of these digits. This is what they found in the 1998 paper.

(Refer Slide Time: 09:23)



Now in this paper which is the Zatsiorsky 2000 paper, by the way this is the 1998 paper that we are discussing, this is the background for the current work. This is our original paper of interest this is the 2000 paper in experimental brain research available freely on the internet, please do read the original paper for greater understanding and please do write to me in case you are not able to understand or you want some clarification, I am very happy to respond to you in the course forum.

When flexor digitorum profundus, flexor digitorum superficialis and the intrinsic muscles are differentially activated, the question is how would you do that, we will come to that in a bit. Suppose I can differentially activate these muscles what would be the relative contribution of peripheral and central factors to enslavement effect in multi-finger force production tasks that is the question. The question is how can you differentially activate the muscles?

Because it turns out that distal phalanges, the proximal phalanges and the middle phalanges are innervated by different muscles. Because of this reason if I use different segments either the proximal phalanx or the distal phalanx or the middle phalanx to produce the force then I would be activating only the muscles that are innervating that phalanx, that are supplying, that are supporting that phalanx, is it not?

Using this Zatsiorsky and colleagues they designed a normal experimental approach a tool to study this. Remember this kind of experimentation requires a relatively deep understanding of the anatomy and physiology. You need to know that these muscles supply differentially to the fingers, you cannot just measure the fingertip forces. You need to go a little deeper which is why this field is a multidisciplinary field.

An interdisciplinary field in which you combine your understanding of anatomy and physiology to arrive at these kinds of structure function relationships, especially in these kinds where you try to understand the neural contribution by measuring mechanics. This kind of studies require a relatively deep understanding of the anatomy and physiology. You need to know which muscles are innervating where, without that you could not have designed this experiment.

So something to keep in mind which is why I urge all of you to go a little deeper in anatomy and physiology and that is what I have attempted in my classes previously that I have given a relatively deep understanding of the structure function relationships throughout so that you will be in a position to take this forward and build upon that is what these authors have done. They actually built this experimental setup in which force sensors, these are piezoelectric force sensors.

Four of these they are present here see, it simply says force sensors here, I am saying piezoelectric force sensors, the type of force sensors. What these do is they are capable of measuring compressive or tensile forces on them, one directional force transducers are there, also commonly called as 1D load cells these are. These are load cells that measure either compressive force or tensile force, in this case they are interested in measuring the tensile force.

What they did was they suspended these four sensors from slots, you know there are these four slots, are you able to see these four slots? And from the other end of the force sensor they connected a rope or a thread, I think this is made of steel and metal, we will have to check that the details, I think these were steel ropes that went on to form loop kind of thing, this loop I will draw this, with some padding where you can keep the fingers, spongy padding, soft padding where you can keep your fingers.

I guess now if I place my fingers let us say the fingertips, the distal phalanges inside these loops and press hard on these loops such that I am going to pull down this rope the force that I am using to pull these ropes down will be measured by the force transducers. I can put multiple, I can place all the four fingers in these four loops. There are loops available for all these four fingers and force transducers available to measure the forces of all these four fingers.

An arrangement was also made such that the wrist position was secured, wrist position did not contribute much to the force because if the wrist is moving then all the four fingers will move or if the wrist is producing a force then all of them will produce, so it will complicate matters further. So, the wrist contribution was minimized or absolutely arrested using this kind of a setup and the participant's forearm was also tied to this wooden block using Velcro strips.

So people could not produce force either with the forearm or wrist. So, this was essentially a distal upper limb task that is the finger task to make sure. One more thing is that I can place the loop, let us say this is the loop, my left hand finger is the loop, I can place the index finger for example either with the distal phalanx touching the loop or with the middle phalanx touching the loop or with the proximal phalanx touching the loop.

So there are instructions depending on which phalanx is producing the force at which interphalangeal joint is producing the force. I can also keep it at the joint, the distal interphalangeal joint or the proximal interferential joint or the distal phalanx. So I can place this loop or I can place my finger in this loop such that either the distal phalanx or the interphalangeal joints, one of the two interphalangeal joints, is supported by the loop.

So that is a crucial aspect of this experimental design. So I can place it such that either only the distal phalanx or DIP joint or the PIP joint is involved.

(Refer Slide Time: 17:53)

Methods

For differential activation of FDP, FDS and INT muscles,

Three experimental conditions based on placement of loops to fingers:

- At the middle of the distal phalanx of each finger (ExpDP)
- At the DIP joint (ExpDIP)
- At the PIP joint (ExpPIP)

The question is for differential activation of FDP, FDS and INT muscles like thenar, hypothenar, lumbricals, interossei those remember long time ago we discussed, what are they intrinsic muscles of the fingers, we discussed this. These are thenar, hypothenar, lumbricals and interossei. Depending on where you place the loop different muscles will be activated. I can place the finger.

Such that the middle of the distal phalanx of each finger is going to contribute the force or at the DIP joint or at the distal interphalangeal joint or at the PIP joint, the proximal interphalangeal joint depending on that different muscles will contribute, and they can study differential muscle contributions to enslavement this is the idea or how the muscles differently contribute to this process, this is the idea.

(Refer Slide Time: 19:02)

Methods

Tasks:

Press down maximally on the loops with combinations of the four fingers:

the index (I), middle (M), ring (R), and little (L) fingers.

a. One-finger tasks: I, M, R, L; $^4C_1 = 4$

b. Two-finger tasks: IM, IR, IL, MR, ML, RL; $^4C_2 = 6$

c. Three-finger tasks: IMR, IML, IRL, MRL; and $^4C_3 = {}^4C_1 = 4$

d. Four-finger task: IMRL. (15 combinations * 3 conditions = 45 experiments) $^4C_4 = 1$

DP, DIP, PIP $4+6+4+1 = 15$ combinations

Ten right-handed male university students participated [age: 28.9±3.9 years]

They had 10 right-handed university participants in this study. The task is press as hard as possible on these loops with the given combination. Because if it is as hard as possible task you have to leave break between trials, perhaps they did that. Use one of these combinations. There are many different combinations that are possible. Let us just discuss this. I can use either just the individual fingers index, middle, ring and little individually so that is 4 choose 1, 4 different combinations.

Then I can use 2-finger combinations, how many different 2 finger combinations are possible in a 4-finger task? If there are 4 fingers available, how many different two fingers combination are possible that is 4, choose 2 equals 6. For clarity that is index middle, index ring index little, middle ring, middle little and ring little, is it not? These are the 6 possibilities. Then I can have 3-finger task that is actually 4 choose 3 but that is 4 choose 1.

Is it not, 4 choose 3 is 4 choose 1 which is 4. What are the four possibilities of 3-finger task? Index middle ring, index middle little, index ring little and middle ring little, these are the four possibilities of 3-finger task when we choose among the four that are available. Then if I use all the 4 fingers of the 4 that are available, I have 4 choose 4 which is exactly 1. So how many different experiments will I have to do?

How many different conditions do I have? That is 4 + 6 + 4 + 1 = 15 different conditions. There are 15 different conditions that are there and in each of these combinations, 15 different conditions or combinations and in each of this combination I have to produce the force either with just the distal phalanx or the distal interferential joint or the proximal interferential joint. So there are three different locations.

So they are calling this as combinations, this is condition, so I will also follow the same. This is 15 combinations. What are the conditions? These are DP, DIP, and PIP; 3 conditions 15 different combinations. So there are essentially 45 different experimental possibilities that are there. We will have to continue discussing this, but I just thought that I will set up the experiment for you. So what we discussed in this video was the experimental setup.

Whereby they use a loop to measure the tension produced by the fingers or the force produced by the fingers and they used 3 different conditions thereby the middle of distal phalanx or the center of the distal phalanx or the PIP joint or DIP joint are used to produce force and they used 15 different combinations of fingers as I just now discussed to measure in these cases. So these are the combinations for which the instruction is given. Forces are measured in all the fingers in all cases.

Forces are always measured in all the fingers in all the conditions, but these are the instructed or the mastered fingers. These are the various possibilities. So, we will continue this discussion of how they analyze this data and maybe even some of the results in the next video. With this we come to the end of this video. Thank you very much for your attention.