Linear Kinetics

Hello and welcome to the next part of Biomechanics for Human Movement Science that is the Kinetics in Bodies. So in the last part, you have covered Kinematics that is that deals with the motion of the body. Now we'll be going into the specifics of how that motion occurs and that is what we'll be covering under Kinetics. So what are the learning objectives, the learning outcomes that we're looking at in this particular class? So we'll be introducing the concept of force and torque. We'll be able to identify the effects of applied force and torque on bodies. What are the fundamental principles that we use in Kinetics? We'll be creating what are called free-body diagrams, which are used to understand and study individual movements of bodies and overall systems.

And finally, we will identify the various kinds of forces that you'll encounter in Biomechanical Analysis. So let's recall from Kinematics, which is fun on its own. What we said was Kinematics is motion without record to the cause of what is causing the motion. We didn't care about what were the forces that were acting, what was the torque that was acting, who was causing the motion, what was causing the motion.

All we cared about was the motion itself. So for example, if this is a ball and it is moving in space, all we care about is how it is moving in space. What is the trajectory of this ball? What is the speed with which it is moving? How fast did it attain a particular speed? How did it move when it went on, say, a projectile motion under gravity? And finally, we wrapped up by describing or quantifying these particular parameters for movement. So this ball is just a ball sitting in space, moving in space without any cause right now. What is Kinetics? So we've been studying one branch of classical mechanics.

Okay, start. So what is Kinetics? We've been studying one branch of classical mechanics, which deals with the motion of bodies. Previously, we were looking at kinematics of bodies. Kinematics deals purely with motion. It does not care what is the cause of the motion, what are the forces acting on the system, what are the accelerations.

No, sir. All it cares about is how is the body moving. Kinetics, on the other hand, is the branch of classical mechanics. Kinetics, on the other hand, is the branch of classical mechanics that deals with the relationship between motion and its cause. So let's take an example.

This guy here is pushing this cart. So he's applying some effort, applying some force, and that is going to cause this cart to move without, from our intuitive understanding at least, we can predict that you need a certain amount of force to be able to push the cart. So that relationship, how much force do I need to apply to move the cart at a certain speed, for example, or I want the cart to start moving at a particular instance? So how do I gradually increase that force? All of these come under Kinetics. So I use the term force, right? But we take it as a for-granted thing.

So let's try and really nail it down. What is force? It's a pretty ubiquitous term, like I said, commonly used in everyday language. However, in physics, force is particularly defined by the effect it has, a body has on other bodies. It's an external agent that influences the state of rest or motion. So to give an example, again, let's look at this ball.

It is right now at a state of rest, more or less. And it won't go anywhere unless I change something. Now, if I was to suddenly remove my hand from underneath, it falls. So this motion occurred because there was something acting on it. At this instance, it was the force of the earth, the gravitational force that pulls it back to the ground.

So you see this across all your sports, in fact. So here's a soccer ball. Same thing, just different size. It's sitting on the floor. It's not moving.

You apply a force, a kick, and it starts moving. The harder you kick, the faster it moves. So all of these relationships can actually be quantified under Kinetics. So again, let's try and understand a little bit more about what is this force. So force is definitely a vector quantity.

Because it's a vector quantity, it has a particular direction. You learned about vectors in Kinematics. So let's define this vector. If this represents the force, this here represents the magnitude. The size of the vector represents the magnitude of the force.

This arrow here represents the direction. So if I have this ball and I'm trying to apply a force on this body, and that is causing this motion, the force is acting in this direction. That is the line of action of this force. This here is the line of action of this force. The other principle is that because forces are vectors, you can have multiple forces that are acting on a body.

Now, if there are multiple forces, let's say you have a force F_1 that is acting in this direction, this particular direction here. You have another force, let's say F_2 that is acting in another direction. This can be a very realistic scenario where you can have, say this ball, I am trying to push this and there's another agent, another person who's trying to push it in another direction. And we'll see who wins. So there is some net force that is acting.

It won't move in the direction I want. It won't move in the direction the other person wants. It will move in some other direction. So that is decided by the net force that is acting on the body. For that, you can find the resultant of these two forces, which will essentially be this particular vector here.

So this is the vector sum of both these forces. This is a very useful concept, which will come in handy later on when we are looking at forces that are acting on one particular segment of the body. And if we are trying to identify what is the net force that is acting, especially in biomechanics, when you're trying to do inverse dynamics calculations, which is you have some measurement of the person's, of an athlete's or a person's behavior quantified in terms of the reaction forces. In those cases, you can have these multiple components of forces and you can look at the net reaction force that is acting on that body. And again, because force is a vector, I can split it into its Cartesian components.

So for that, I have to define a particular coordinate system, the x-axis and the y-axis, like you've seen in kinematics is just the same. I can have this particular force component F and then it has a component along the x-axis. So if this is, then you can have, let's take that again, have this component along the x-axis, which is F cosine, this angle theta, and you can have this component, which will be F sine of angle theta. So these are some pretty fundamental concepts that we need to understand and use across the board when we are performing our biomechanics calculations. At this point, we should also introduce this concept of momentum.

We've heard this a lot in both technical jargon, as well as colloquial conversations, as well as colloquial conversations, like that team, let's say the Indian team has a lot of momentum going into this World Cup. If a team has a lot of momentum, it typically means they are unstoppable. So momentum has something to do with motion. Right. And we have abstracted that in our languages, but as a physics term, it essentially represents mass in motion.

It is a way to quantify both the mass of a body, as well as how fast it is moving. So to that end, the definition for momentum, which is usually represented by p,

$$\vec{p} = m * \vec{v}$$

So velocity is what you learned in kinematics, how fast an object is moving with respect to a particular direction. It is an instantaneous quantity.

OK. Now, we know velocity is a vector. We identified the difference between speed and velocity in kinematics, and we know that velocity is a vector, which means that momentum is a vector as well. And from this relationship, we can see that the direction of velocity and the direction of momentum are the same. So momentum is directly proportional to the mass. It is also directly proportional to the magnitude of the velocity, which means that a light object moving really fast can have a lot of momentum, as well as a heavy object moving slow can also have a lot of momentum.

It is something you typically see in American football, for example. There are players who weigh more, and they have a lot more momentum sometimes, even when they're running at lower speed. You can sense that when they collide with people. With kinetics, we'll be able to quantify that interaction between these players. Or for a different kind of an example, again, if this ball is moving, so this ball's mass is fixed.

So to impart it, when I imparted a velocity to move along a particular trajectory, it has a particular momentum. The harder I throw it, the more velocity I give it, the more momentum it has. If I wanted the same momentum with a heavier ball, I would have to impart it at a lower velocity. So we said we'll talk about some of the principles that are used in kinetics, the fundamental principles. So we'll build on the definitions we have seen so far for force, for momentum.

And then we'll build them into some fundamental principles, the chief of which is the Newton's law of motion. Isaac Newton, his probably one of the greatest contribution is this and the law of gravity. So you must have heard Newton's laws of motion in your school at the very least and in popular culture as well. So what are these laws? So Newton's laws, so what are these laws? There are three laws.

Which quantify the interaction. These quantify the interaction between force and movement. So these are three fundamental laws which govern classical mechanics and movement of bodies. The way we will study them is predominantly targeted at linear motion. So the three laws, the first law is called the law of inertia. So to understand this, we'll go back to the ball.

So this is a ball currently sitting there not doing anything. I'm not doing anything to it. There's no external force, there's no wind here. It's just going to sit there forever as long as I can hold it I guess. Now if I put it on another surface and I apply a force to it, it will roll.

So that's what the first law governs. It says that a body will stay in its current state of rest or motion unless I've acted upon by a force. So when the ball was sitting there, it was just literally sitting there not doing anything. Along came a player, applied a force to it, did something to it, kicked it, or in my case moved it. The ball starts moving.

It goes from an initial position. Now the ball, will it keep on moving indefinitely? I think from practical experience you can say that no, the ball eventually comes to a stop. So rest, motion, then there is again some motion but it's slowing down so there's deceleration and finally, it reaches rest again. So here the force being applied was so here the force being applied was from this player onto the ball. But what about here? I don't see any forces acting here. Actually, there is, because it is in contact with ground, because it is in contact with ground, right?

There is always some friction force acting. It's the necessary evil. It is what keeps us in traction, in contact with ground, and allows us to move around because that force is constantly acting on it. You eventually have the ball stop at a particular location. So all of this happens across certain time instances. So fundamentally the body stays in its current state.

If the state is rest, it will stay in rest. If the state is motion, it will be in motion. If you have a soccer field and you have this ball being passed around between multiple players. So the direction of the movement of the ball will be decided by the player who kicks it. But if someone intervenes in between and kicks it in, but if someone intervenes in between and kicks it in, in another direction, say the opponent, then this ball will change its direction. So that external force, that external agent was necessary to change the state of the movement motion of the ball.

So we have used this term here inertia. So inertia is represented by mass of the body. In the international system of units, its unit is kilogram. So inertia essentially represents the property of how much mass a body has, how much mass a body inherently has. It is an intrinsic property of the system irrespective of what external forces are acting on it.

So let us talk about this concept of state of motion. So this is described by momentum. So because the body will stay in its current state, will stay at a particular level of momentum. This is how we can quantify the first law. This is how we can quantify Newton's first law. So if no net external force acts on a body, implies no change in the momentum.

All right. So we have quantified what happens if no external force acts on a particular body. Now let us look at what happens if an external force does act on a body, which is the second law or the law of acceleration. So the second law says an external force will cause the body to accelerate in direct proportion to the magnitude of the force and in the same direction as the force. And let us break this down. So there has to be an external force will cause the body to accelerate.

So if this ball is in a particular state right now and I apply a force on it, if I apply a force on it, it will accelerate. So here, this particular player has applied a force on this ball, which is causing this ball to go from say an initial velocity of 0 to a final velocity at time t of say 2 meters per second. Now this ball accelerated to 2 meters per second, say in a period of 1 second. So this means the acceleration of the ball is 2 meters per second square. So whatever force I have applied here or whatever force this player has applied here, so now if the acceleration is 4 meters per Second Square, the force applied by the player would be 2 times the initial force that this player applied.

Now you would have observed this in your personal life as well. Something as simple as opening a door, if you gently push it, it gently opens. If you apply too much force to it, it suddenly swings open with a lot of momentum, so to say. So the second law basically tells you how a force applied will impact a particular body. So if I apply a force in a particular direction, the acceleration of this body will be in that same direction, in the direction of the net force that is acting on the body.

So the force applied by the player is twice, 2 times the force applied previously in this instance. Now this field of study is called dynamics, particularly because you are dealing with moving bodies and the acceleration that you impart to a body by applying a certain force to it. So this brings us to a proper definition for this law, which is

$$\vec{F} = m * \vec{a}$$

And right now this is incomplete because we said force is a vector. So the mass is an inherent property of the system, the inertia of the system, acceleration is a vector.

And from this, you can see that direction of acceleration is the same as the direction of the force applied. Now what if there were multiple forces acting on the body? So in that case this law can be generalized to

$$\sum \vec{F} = m * \vec{a}$$

So this acceleration will be in the direction of the net force that is acting on the body. The international system of units for this is Newton's, which means that to accelerate a 1 kg mass by 1 meter per second square, 1 Newton of force is required. So now we have looked at increasing the acceleration of a body by applying a force on it or changing the acceleration of a body by applying a force on it.

Now the question arises, the agent that is applying the force on a particular body, what happens to that agent? So I have been moving this ball around, the player has been kicking the soccer ball on the field for a while now, what actually happens to this player? So that is where the third law comes in, as the law of reaction. Now you must have heard this every action has an equal and opposite reaction, that is an oversimplification of this. So let's break down the actual definition. When one body applies a force on another body, so this is important, there are two bodies involved on another body, the second body applies an equal and opposite reaction, applies an equal and opposite reaction on the first body. So when this person was kicking this soccer ball, the soccer ball is fighting back, it is kicking back.

Of course, it did not have enough inertia to resist that movement. When this person is pushing this cart here, the cart is pushing back. In fact, you can experience this yourself if you right now go and push against a wall, you will not be able to move it. You can experience that force against your own hands. If I was doing this movement, I would not be moving at all.

That is the wall pushing back on me. Now, how do these, how does this particular law come into effect? It is one of the most fundamental things we do in biomechanics. And with this, I will introduce you to the concept of ground reaction forces. So, I have this person going about their day. Now, they are walking on different kinds of surfaces. So, when they are walking on floor, on say carpeted floor, they feel like they have more traction, they have a lot more control.

They were walking on ice, they feel like they are slipping all over the place. It is because they are now, it is because they are now relying on this component of reaction from the ground. So, this is one of the ground reaction force. Let us do that again.

So, this is one of the components of the reaction force. What else could be the reaction force here? Well, they are standing on the ground, right? They have some weight. Let us do that again. So, they are standing on the ground, they have some weight, which means they are exerting a force on the ground. Now, the ground would not have it, it decides to push back.

It applies what is the vertical ground reaction force. So, with this, you have these two components of forces that now can be used for understanding the dynamics of the system. Let us do that again. So, with this now, you have these two components of forces, which can be used to study the net reaction force acting on this person from the ground. So, right now, we are dealing, we are looking at a purely planar system, or we are looking at this person from the side. So, the forces are in two dimensions, but in reality, the forces are three-dimensional.

They will be spatial in nature. We will deal with those particulars of reaction forces in some other course. Let us scratch that. So, let us look at some of the types of forces that can be experienced by. So, now let us look at some of the types of forces that you will typically encounter in biomechanical analysis. So, first of all, as long as we are on any planet, there will be some gravitational force.

So, if you are standing on Earth, your weight is always acting towards the center of the Earth. Of course, we typically assume the, let us do that again. Of course, we typically assume the surface to be horizontal, which is why we would typically have a situation like the weight going down vertically. Now, because there is weight, there is a reaction force like we looked at previously coming from the ground. Now, if this person was standing still, not moving at all, from the first law of, from, let us do that again.

If this person was standing still and not moving at all, the ground reaction force would perfectly balance out the weight of this person, which means they would be equal and opposite. So, the net force that is acting on this person would be 0. So, the net force that would be acting on this person would be 0. So, from Newton's first law, we can say that this person will continue to stay in a state of rest. Now, if this person decides to move in a particular direction, they will utilize some horizontal reaction force, which will come from friction.

They will utilize, so if this person decides to move in a particular direction, they will utilize the reaction force from the ground, which will be from the friction force. And then you have inertial force. So, within the scope of this course, we will only discuss, we will discuss primarily these forces and the external forces. Inertial forces are what you experience when say an elevator slows down. You experience a sudden increase in your weight, or when the elevator starts moving down, you suddenly feel a sense of weightlessness.

So, that comes from this kind of a representation,

$$F - ma = 0$$

Here, this minus ma, this is the inertial force. So, with this, we conclude this particular aspect of kinetics in linear motion. Next, we will take a look at kinetics in rotation motion. Thank you.