Engineering Psychology

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Week-06

Lecture-15

Motor skill and control - 1

Namaskar. In the past few lectures, we have examined various cognitive and physical limits and capabilities of humans and how these factors assist human factors engineers in designing modifications for products and services, as well as improving interfaces. We have focused on topics such as attention, memory, and decision-making. Today's class will concentrate on another critical aspect that aids human factors engineers in studying human capabilities and limitations: motion and movement.

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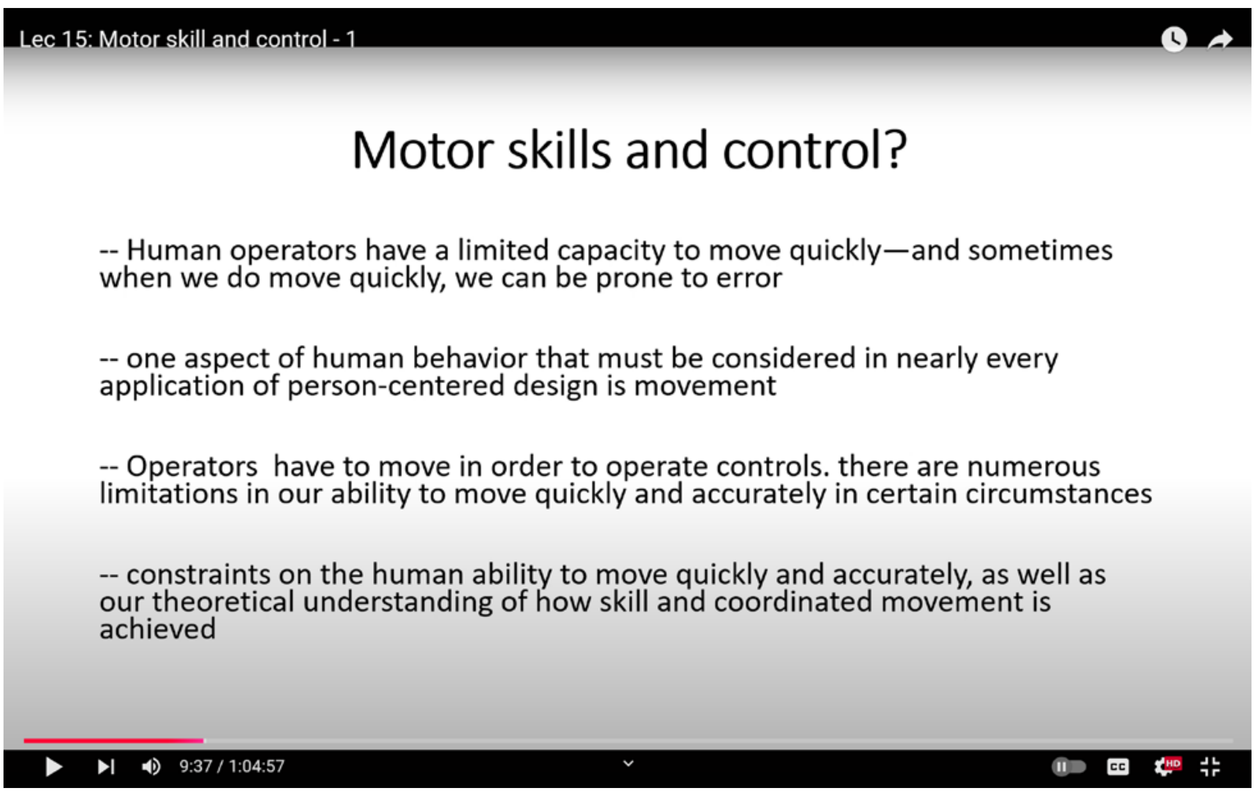

We will explore how movements and control design facilitate the assessment of necessary modifications in any design interface or product. To illustrate this, let us consider an example involving Manohar, a crane operator working in a shipyard. His job entails operating the crane to transport heavy loads from ships docked in the yard, moving these loads from a fixed position A to a fixed position B. In his role, he uses two or three control levers and several foot pedals that help maneuver the crane in various directions.

By manipulating the levers, Manohar can lower the crane to attach heavy loads, and with the movement of another lever, he can transport the crane, complete with the heavy load, from the ship to a designated area on the dockyard. While this may sound straightforward, a conversation with Manohar reveals the challenges he sometimes faces.

Let us add a twist to this scenario. One day, Manohar arrives for work on a routine day, sitting on a higher platform inside the crane. He operates a lever and a foot pedal to elevate the crane handle to a certain height while executing a rotational movement to position the crane near the deck of the ship. After activating another lever, the crane descends, and a heavy load is attached. Manohar lifts the heavy load cautiously, as his experience has taught him that hasty actions can result in excessive swinging of the load, potentially leading to mishaps. Therefore, he carefully pulls the lever back, raising the crane with the added weight.

He then presses the foot pedal, causing the crane to rotate toward the designated dumping area. Manohar swiftly aligns himself to lower the load onto the deck, emptying it before returning to the original position to pick up more cargo. However, as he lowers the lever to drop the load, he suddenly notices that some engineers are very close to the area where the load will be released. In a moment of panic, he freezes, unsure of how to react. His hand has already begun to move, and the lever is partially depressed, causing the crane to start descending.

Manohar realizes that stopping the crane or the lever at this point would lead to an unavoidable mishap. He spots the emergency button on the crane console, which, if pressed, would immediately shut off the crane motor, bringing it to a halt. The critical question arises: Can Manohar quickly press this button to stop the crane and protect the workers below? Can he identify the emergency button swiftly enough to avert disaster? If he fails to act, the crane will continue to lower the load, posing a serious risk of injury or even death to the personnel beneath.

The situation I have described is reflective of many work environments where individuals must make rapid decisions. In such scenarios, it is not only the cognitive capabilities and limitations of humans that play a role, but also a crucial factor related to how quickly and efficiently decisions can be made: the concept of reaction time and movement. Studying how swiftly humans can execute movements provides human factors engineers with essential data to design interfaces and modifications for equipment, ensuring that necessary emergency actions can be performed quickly.

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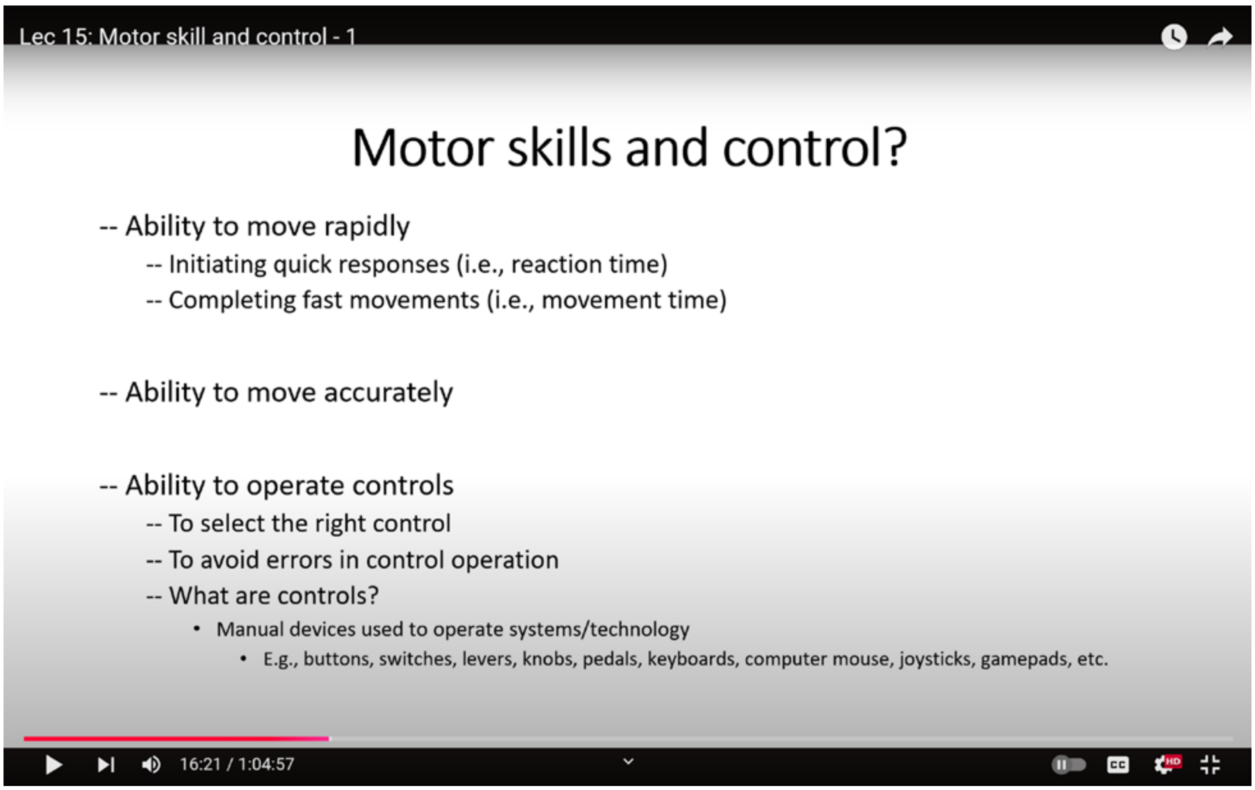

This chapter will address these two aspects. In the first part, we will define movement and explore the principles governing human movement. We will examine theories related to the speed and accuracy of movement, as well as how movement is measured. Additionally, we will investigate closed-loop and open-loop theories that describe human movement. Toward the end, we will discuss controls: their design, layout, and display. We will analyze the characteristics of controls that facilitate faster responses during emergencies and explore the fundamental theories guiding effective control design. Let us begin by understanding motor skills and skills related to movement.

Human operators have a limited capacity to move quickly, and when they do move rapidly, they can be prone to errors. This was illustrated in the earlier story about Manohar, who needed to act swiftly to press the emergency button to halt the crane and prevent an accident. If he presses the button too hastily, he risks not applying sufficient pressure to stop the crane effectively.

Emergency buttons are designed to be large and require extra effort to activate. This design choice is intentional; if these buttons could be inadvertently activated by normal activities or movements, it could pose a risk to the operator. In Manohar's case, the critical question is: How quickly can he respond? This can be evaluated based on his movement speed and capacity for action.

There is an inherent limitation on how swiftly one can respond and how accurately those movements can be executed, which we will explore in this lecture. For now, it is important to recognize how Manohar's limitations will affect his ability to respond. One critical aspect of human behavior that must be considered in nearly every application of person-centered design is movement.

The cognitive processes involved in perception play a significant role. A stimulus is perceived, which is then interpreted through perception. Subsequently, a decision is made using higher cognitive functions regarding what action to take. This action culminates in a motor response, which is essential. Regardless of how accurate your decision may be, the effectiveness of that decision ultimately hinges on how quickly and accurately you can execute the corresponding movement. Even if the right decisions are made, improper execution of actions can lead to errors.

Consider a scenario where you approach an ATM and insert your card. You may struggle to recall your PIN, but using mnemonic devices or memory retrieval techniques allows you to remember it. However, if you input the PIN incorrectly due to speed or haste, you might time out and fail to complete the transaction. Therefore, the execution of responses or motor movements is a crucial element in human factors engineering and designing effective interfaces and products.

Operators must move to interact with controls. There are numerous limitations to our ability to move quickly and accurately in certain situations. Operators, whether they are crane operators or pilots, interact with systems through controls. Human factors engineers understand that system design requires both an operator and a system, and the operator interacts with the system via specific controls. These controls serve as interfaces that merge human input with machine input, acting as the link connecting humans and machines. Consequently, the design of these controls is of paramount importance.

The speed at which humans execute actions will influence how quickly a control is pressed or how promptly a decision to press a control is made. If the decision is executed with the appropriate speed and accuracy, the desired result can be achieved. Conversely, inefficiency or inaccuracy in pressing a control can lead to problems. Constraints on human ability to move quickly and accurately, as well as a theoretical understanding of how skills and coordinated movements are achieved, are critical considerations.

Several constraints determine how movement should be mapped. These constraints could relate to perception or be tied to the motor response itself. They may also involve factors affecting how accurately a control can be perceived. Various factors, environmental, internal, and contextual, can impact how quickly individuals execute a response.

First, consider the ability to move rapidly, which hinges on the capacity to initiate quick responses. How quickly can you initiate a response? While you may perceive and comprehend a situation, translating that into an actual response involves additional challenges. The faster you decide to press a button, the more swiftly you can initiate a response.

Think about scenarios like quiz shows, where participants must quickly respond with answers. Often, contestants might forget or half-press the button, which prevents them from submitting their answer in time. Knowing the answer is only part of the competition; equally important is how quickly and accurately you can press the buzzer to convey your response. Therefore, the ability to move quickly is heavily dependent on reaction time.

Another crucial factor is called movement time, which pertains to completing rapid movements. It is not solely about how quickly you can initiate an action; it also involves how swiftly you can execute and complete fast actions.

How quickly can you move? Some individuals experience difficulties with limb movements, and this limitation affects their ability to execute responses effectively. The faster you can move your limbs, the more efficient your response execution will be. Observations of accidents reveal that certain individuals excel at avoiding them. Their ability to maneuver and perform specific actions stems from a flexible body, enabling them to avert potential accidents. Conversely, some skilled drivers may lack quick hand movements, leading to unfortunate accidents.

Thus, both the speed at which you can initiate a response and the speed of limb movement are critical to the accuracy and speed of that movement. Not only does the velocity of your movements contribute to motor skills, but the precision with which you can perform a motion also plays a significant role in developing those skills.

The ability to operate controls depends on several factors. In human factors engineering, we focus on individuals interacting with systems, and the primary means of interaction is through controls. Therefore, considerable attention has been devoted to understanding these controls. The ability to operate controls that allow humans to interact with systems hinges on various factors.

The first factor is the speed at which you can select a control. When operators engage with a system, they typically encounter multiple controls. One crucial aspect that influences the successful execution of a response is how quickly an operator can identify the correct control. Misidentifying a control can lead to errors. Thus, comprehending the appropriate control layout and size is essential.

Another factor that facilitates control operation is the ability to recognize and avoid errors. Once a control is engaged, how quickly can an operator discern that they have made a mistake and halt their action? The third consideration is defining what controls are. Controls are manual devices utilized to operate systems and technologies; examples include buttons, switches, levers, knobs, pedals, keyboards, computer mice, and joysticks.

We find that human movement, essential for executing a response, depends on two primary factors: reaction time and movement time. We will examine these two factors individually to grasp their meanings.

The first factor is reaction time. What is reaction time? It refers to the duration it takes for individuals to respond to specific stimuli and provide a reaction. The first psychology laboratories, established by William James, investigated reaction time. James aimed to understand how quickly individuals can perceive certain stimuli and respond to them.

He conducted experiments where balls were dropped from a certain height onto a plate, and the participant's task was to press a button as soon as they heard the ball hit the plate. James was interested in measuring how rapidly participants could respond, which encapsulates the essence of reaction time. Reaction time is the interval required to perceive a stimulus, interpret it, and produce a response.

When a surprise event occurs, how long does it take for you to notice and react? If you are familiar with browsing the internet, you may have encountered content designed to capture your attention. We previously discussed this concept in relation to attention. These stimuli possess a quality called saliency, which draws your focus away from your current task to something that may or may not be relevant.

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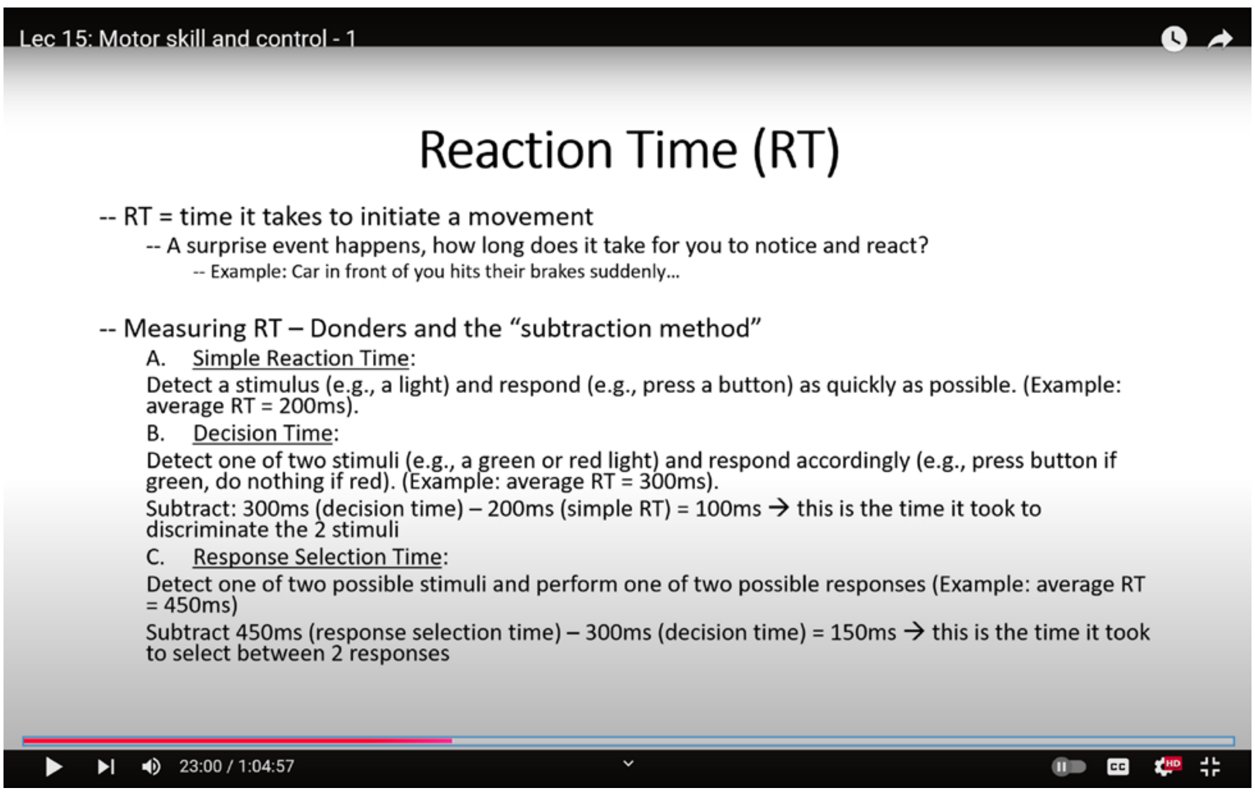

Reaction time is the speed at which you recognize that your attention has shifted to a more salient stimulus, something more engaging or relevant, and the action you take to close or dismiss this additional stimulus to return to your original task. For example, consider a situation where a car in front of you suddenly applies its brakes. How quickly do you realize you are in danger and move to evade the car’s path? When the car brakes, you will both hear and see it. If you are preoccupied with something else, your ears still have the capacity to detect the loud sound of the braking. With this loud noise alerting you, how rapidly do you react to escape danger? This scenario illustrates reaction time.

So, how should reaction time be measured? A reliable method for measuring reaction time was proposed by Donders in the late 1800s and early 1900s, known as the subtraction method. Consider any cognitive act.

Now, the cognitive act comprises three parts. First, a stimulus is perceived, leading to a reaction. This reaction is, in fact, a decision derived from the interpretation of the stimulus. Initially, the perceived stimulus is interpreted at a basic level, and then more complex meanings are extracted from it. These complex meanings are compared to information stored in long-term memory, which helps determine whether the encoded stimulus requires a response. Based on this evaluation, the appropriate response for the situation is decided.

However, merely deciding on a response is not the conclusion of the process; the response must also be executed. Take, for example, the scenario described earlier: you are walking down the road when you suddenly hear a loud braking sound from a car. This event can be divided into three parts. The first part involves hearing the sound of the car brakes. The second part is how the auditory signal is interpreted by the primary auditory cortex, the secondary auditory cortex, and other complex processing areas of the brain. Based on the sound of the brakes, these complex areas categorize the sound based on previous experiences. Among these experiences, the one that closely matches is the sound of a car's brake. Consequently, your higher cognitive processes generate two responses: first, the recognition that this sound may be the brake of a car, and second, the imperative to quickly move your hands, legs, or body out of harm's way.

As soon as this response is generated, signals are sent to the relevant muscles, prompting your hands and legs to move away from the road to prevent potential harm or an accident. Therefore, the act of hearing the braking sound and moving out of the car's path represents a complex process. The reaction time is defined as the duration it takes to move out of the car's path after hearing the brake. The three components I have described contribute to the overall reaction time.

Donders proposed that there are three types of reaction time, which can be determined by subtracting two primary reaction times from a third reaction time. The first component is perception time, which reflects how quickly you perceive the stimulus. The second component is the reaction time related to response selection, and the third component is decision time, which denotes the duration taken to determine which action to initiate.

Thus, reaction time is composed of these three elements. According to Donders, there are specific methods to measure these three reaction times. The first is referred to as simple reaction time. Donders defined simple reaction time as the interval required to detect a stimulus (for instance, a light) and respond to it (for example, by pressing a button) as quickly as possible. The average human simple reaction time has been measured at approximately 200 milliseconds.

Using Donders' method, it was found that when a sound or light is presented and individuals are instructed to push a button as soon as they perceive the sound or light, the time taken to press the button from the onset of the stimulus is around 200 milliseconds. Thus, simple reaction time pertains to responding to a singular stimulus occurrence.

The second type of reaction time discussed by Donders is decision time. This refers to the duration individuals take to detect two stimuli and then formulate a response. In this case, the task is to detect one of two stimuli (for example, a green or red light) and respond accordingly: press the button if the light is green and refrain from action if it is red.

Here, two stimuli are present, but only one response is required, necessitating that the operator decide which stimulus to respond to. This process is referred to as decision time, which has been found to average around 300 milliseconds in such scenarios. According to the subtraction method, to derive decision time, one must subtract the simple reaction time (200 milliseconds) from the decision time (300 milliseconds).

In simple reaction time, there is one stimulus and one response; however, in decision time, there are two stimuli, resulting in dual inputs for the operator to process. The operator must not only press a button but also make a decision regarding which stimulus to respond to. Therefore, to ascertain how much time the operator requires to make this decision, one subtracts simple reaction time from decision time.

In this case, 300 milliseconds (decision time) minus 200 milliseconds (simple reaction time) yields 100 milliseconds, indicating the time taken to discriminate between the two stimuli. Another type of response time is referred to as response selection time.

Assuming there are two stimuli and two responses, the subject must not only decide which stimulus to respond to but also determine which button corresponds to each stimulus. This is known as response selection time. To calculate response selection time, one must subtract the decision time and simple reaction time from the total response selection time.

For instance, if the operator is presented with two lights, red and green, the task is to press the square button for the green light and the circular button for the red light. Although this might seem straightforward, the subject must discriminate between the stimuli and comprehend which response to execute for each light. Thus, the subject must not only decide between the stimuli but also determine which response to carry out.

In this context, response selection time is essentially the difference remaining after accounting for decision time and simple reaction time. The average reaction time for this task is approximately 450 milliseconds. Therefore, if we subtract the 450 milliseconds of response selection time from 300 milliseconds of decision time, we find that the time taken to select between the two responses is 150 milliseconds, which represents the overall response time.

In the example I discussed earlier, where a bulb is lit and the subject has to press a button, the scenario of one bulb and one button is categorized as simple reaction time. However, if there are two bulbs and the subject is required to press a button for one bulb but not for the other, this situation is referred to as decision time. Now, consider a situation with two bulbs and two buttons, where the subject must not only distinguish which bulbs are illuminated but also respond with specific key presses for each bulb. This situation involves response selection time.

Response selection time is the residual duration derived from the addition of simple reaction time and decision time. For instance, if my reaction time in a scenario involving two responses and two stimuli totals 450 milliseconds, the response selection time would be calculated as 450 milliseconds (total reaction time) minus 300 milliseconds (decision time), resulting in a response selection time of 150 milliseconds. This demonstrates how reaction times can be measured.

Several factors can influence reaction time. The primary determinant of simple reaction time is the speed of neural transmission, which remains constant. Reaction time depends on how quickly neurons transmit information from the central nervous system to the effector muscles, enabling action. It is important to note that the nerve conduction velocity is fixed at approximately 25 meters per second, indicating that this factor is not a primary cause of variation in reaction time. So, what other factors influence reaction time?

Reaction time is affected by the intensity of the stimulus. Generally, the more intense the stimulus, the faster the reaction time. When dealing with stimuli near the threshold, reaction times are longer than those for stimuli above the threshold. A simple explanation for this phenomenon is that if a stimulus is not clearly visible, it becomes challenging to concentrate and extract it from the surrounding noise. For example, if a faint light is present among several brighter lights, it will take additional time to identify the faint light, thereby increasing reaction time as you must focus on distinguishing the weaker stimulus within a brighter context.

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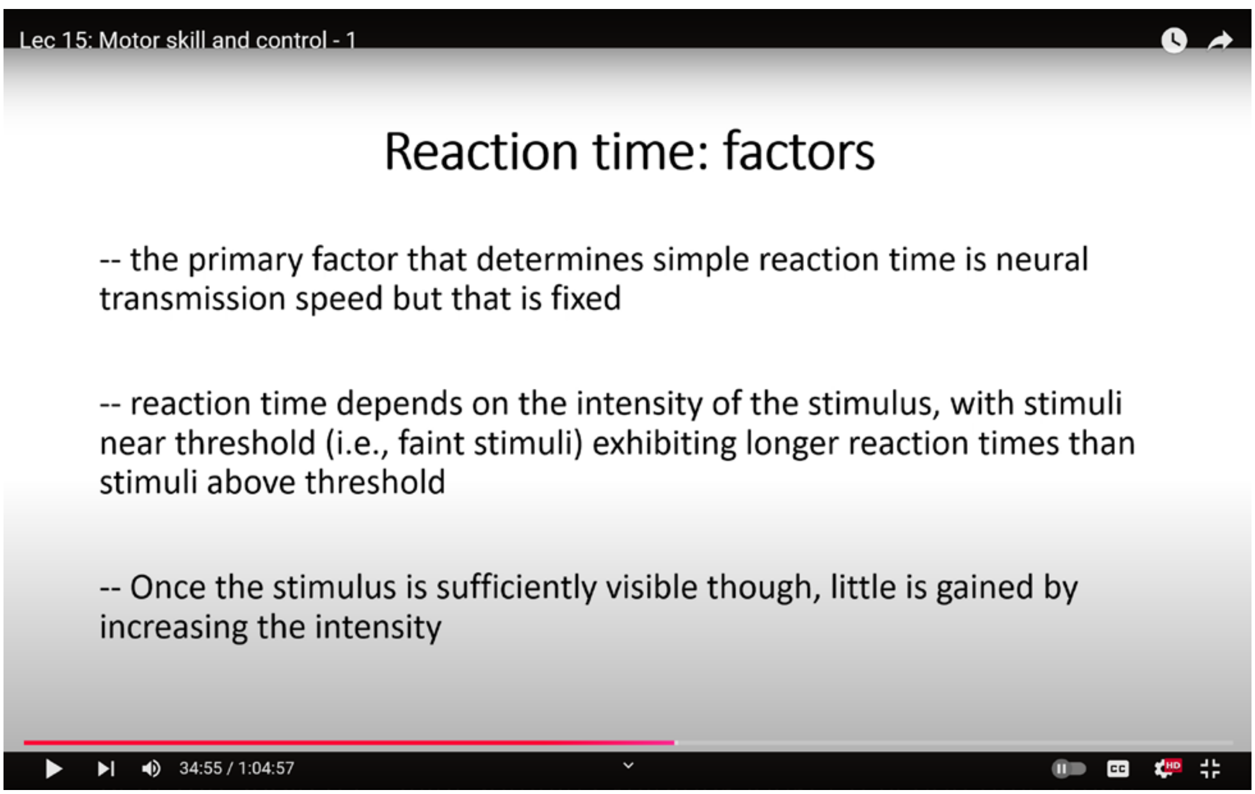

Once the stimulus is sufficiently visible, however, increasing its intensity yields diminishing returns in terms of reaction time. If the faint light approaches the threshold or the brightness of surrounding lights, further increases in intensity will not enhance reaction time.

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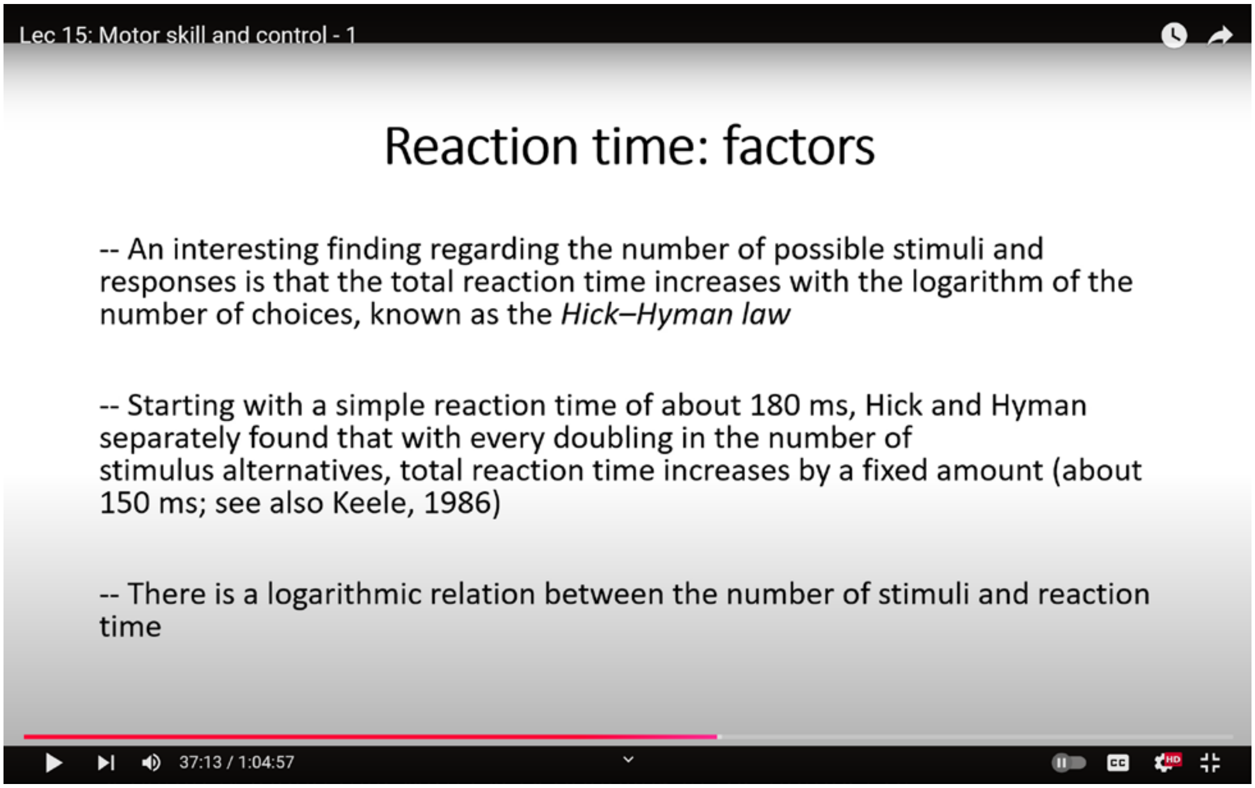

An interesting finding regarding the number of possible stimuli and responses is encapsulated in Hick-Hyman's law, which posits that total reaction time increases logarithmically with the number of choices. Hick-Hyman's law indicates that reaction time is directly proportional to the number of options available, and the relationship between them is expressed as a logarithmic function.

Starting with a simple reaction time of approximately 180 milliseconds, Hick and Hyman independently discovered that each time the number of stimulus alternatives is doubled, the total reaction time increases by a fixed amount of about 150 milliseconds. A study conducted by Kiel in 1986 provides additional insights into this topic. In simple terms, Hick and Hyman's findings suggest that increasing the number of alternatives or controls a subject must operate leads to higher reaction times. Specifically, for each additional stimulus, reaction time increases by approximately

150 milliseconds. Thus, if one stimulus is present, the reaction time would be around 180 milliseconds. However, if a second stimulus is introduced, the reaction time would increase to approximately 300 milliseconds, and with each subsequent stimulus, it would continue to rise by 150 milliseconds. This trend persists until reaching three, four, or five stimuli, at which point it becomes a matter of short-term memory.

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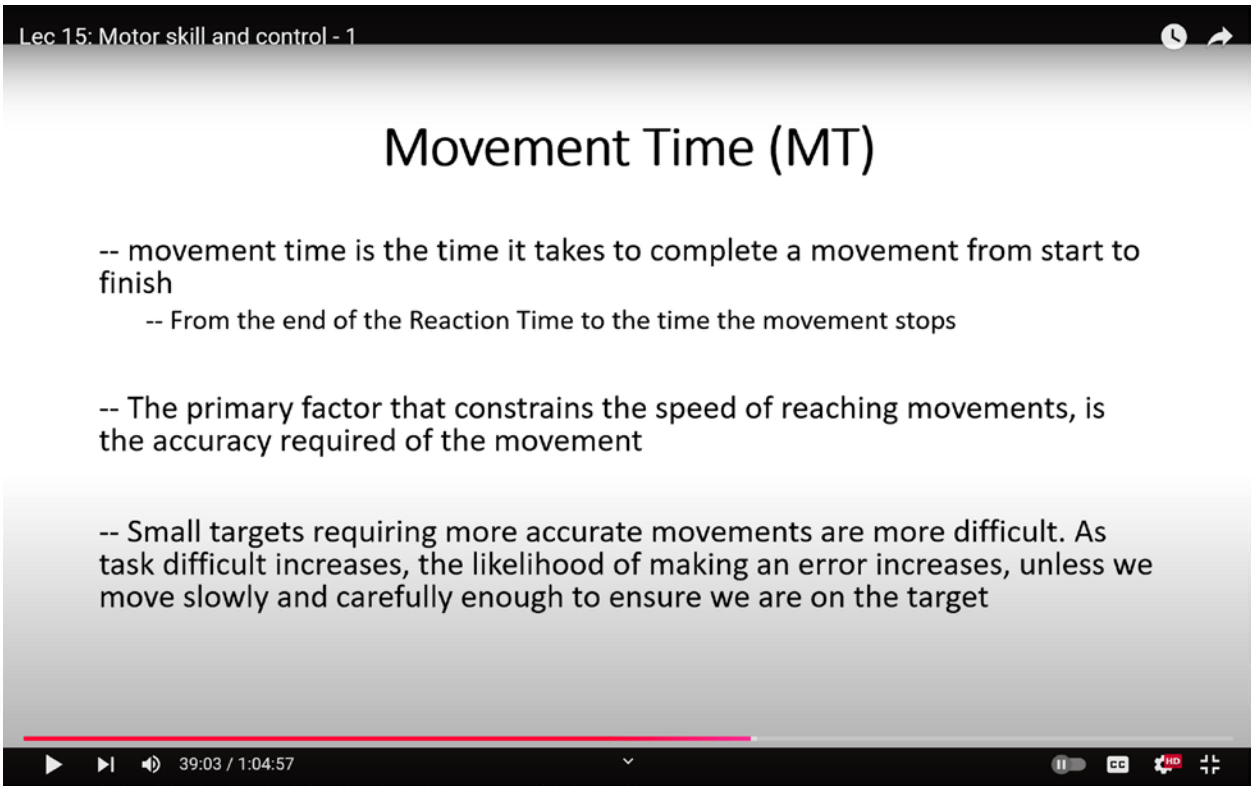

The relationship between the number of stimuli and reaction time is logarithmic; Hick and Hyman articulate that the increase in the number of stimuli correlates with reaction time in a logarithmic fashion. As illustrated, for each doubling of stimuli, the time increases by roughly 150 milliseconds, illustrating that as the number of stimulus alternatives grows, reaction times follow a similar trend until they stabilize at a certain point.

Having discussed reaction time, we should also consider another aspect of movement, known as movement time. Movement time refers to the duration required to execute a movement through a limb or any other body part. Specifically, movement time is the total time taken to complete a movement from start to finish, extending from the conclusion of the reaction time to the moment when the movement stops.

For instance, in the earlier example involving a hypothetical individual named Manohar operating a crane, movement time encompasses the duration it takes for Manohar to grasp the control and press the lever to align the machine's arms with either the ship's deck or the shipyard. The accuracy required for that movement is a primary factor that constrains the speed of the reaching movement.

One of the factors determining how quickly a person can act is the accuracy required for the action. The greater the accuracy needed, the more time it will take to complete the task. Consider the interface of a smartphone: the display contains several buttons, and if you want to press an icon accurately, you must proceed slowly.

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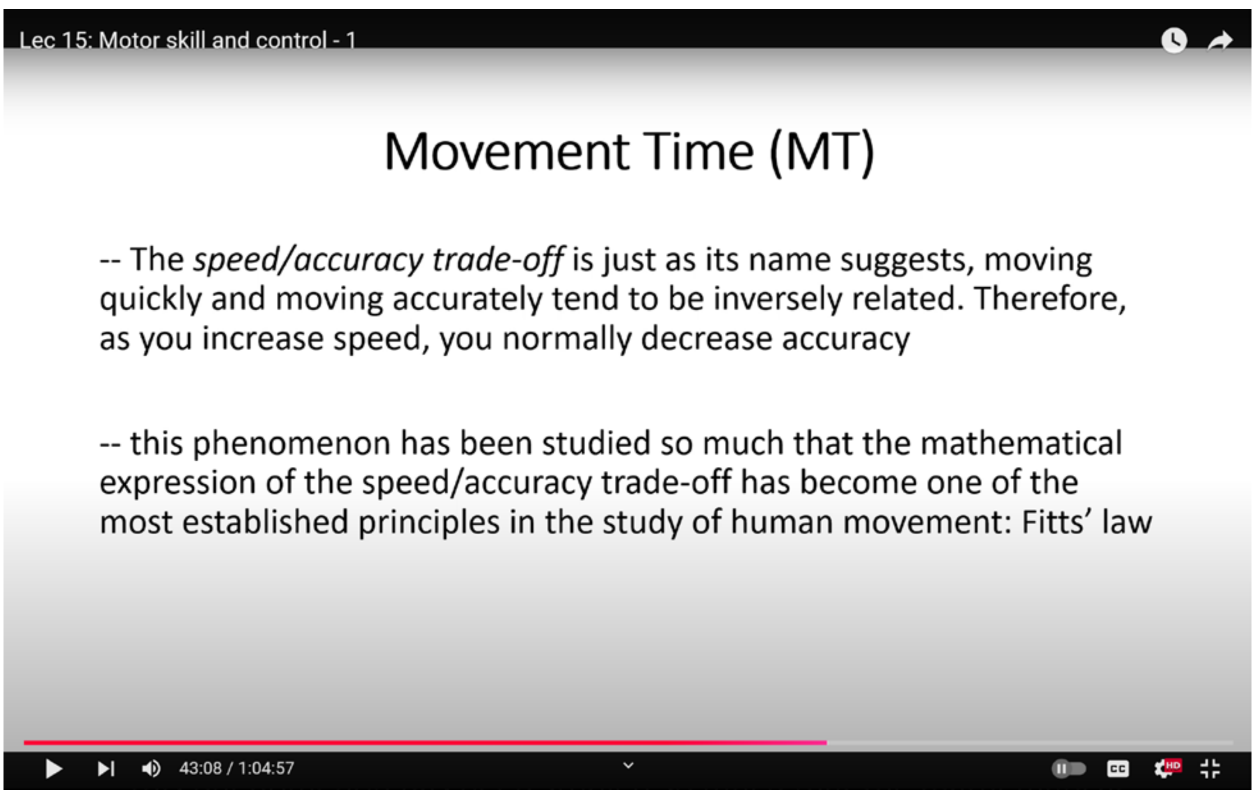

In a traditional display, there are various icons, such as the Google Pay option. If you press your finger quickly, there is a significant chance that you will accidentally activate another button instead of the Google Pay button, potentially causing it to be dislodged from its original position.

To accurately select the Google Pay button, you must press it slowly and with precision to ensure that the action is performed correctly. The principle is straightforward: fast actions tend to lack accuracy, while accurate actions are generally slower.

Smaller targets necessitate more precise movements, making them more challenging to hit. The smaller the target, the more time you must take because smaller targets demand greater attention. As the difficulty of a task increases, the likelihood of making an error also rises, unless you proceed slowly and carefully to ensure that you remain on target. For instance, when observing a goldsmith at work, you can see that goldsmiths handle tiny pieces of gold, and their movements must be deliberate and slow to carve out intricate designs.

Conversely, if you visit an iron smith, you will notice that his actions are much faster. This is because the tools he creates are larger, allowing for quicker movements since accuracy is less critical in his line of work. In contrast, for a goldsmith, accuracy is paramount due to the finer and smaller materials he manipulates, necessitating a higher level of precision. The rule again is clear: if you desire accuracy, you must be slow; if you rush, accuracy will suffer. This concept is known as the speed-accuracy trade-off, which posits that the ability to move quickly and accurately is often inversely related.

As speed increases, accuracy typically decreases. This relationship exists because the faster you attempt to perform a task, the less precise your actions become. Understanding this dynamic can assist in designing and executing movements effectively. Accuracy is related to focus; when you devote more attention to a task, your movements tend to be slower since the cognitive processes involved in maintaining focus cannot operate at high speeds. Thus, when you concentrate on a task, your actions must be deliberate and measured to achieve the desired outcome.

On the other hand, if you are performing a task more automatically with less attention, accuracy may decline. For example, consider driving. When you drive automatically, you pay less attention, which may result in basic accuracy but can lead to missing finer details or actions. You might navigate the road competently, but if a small object, like a bottle, appears, you may not notice it and could run over it. Conversely, if you are fully focused on driving, you will likely see the bottle and avoid it. Hence, accuracy and speed are inversely proportional: when one increases, the other decreases.

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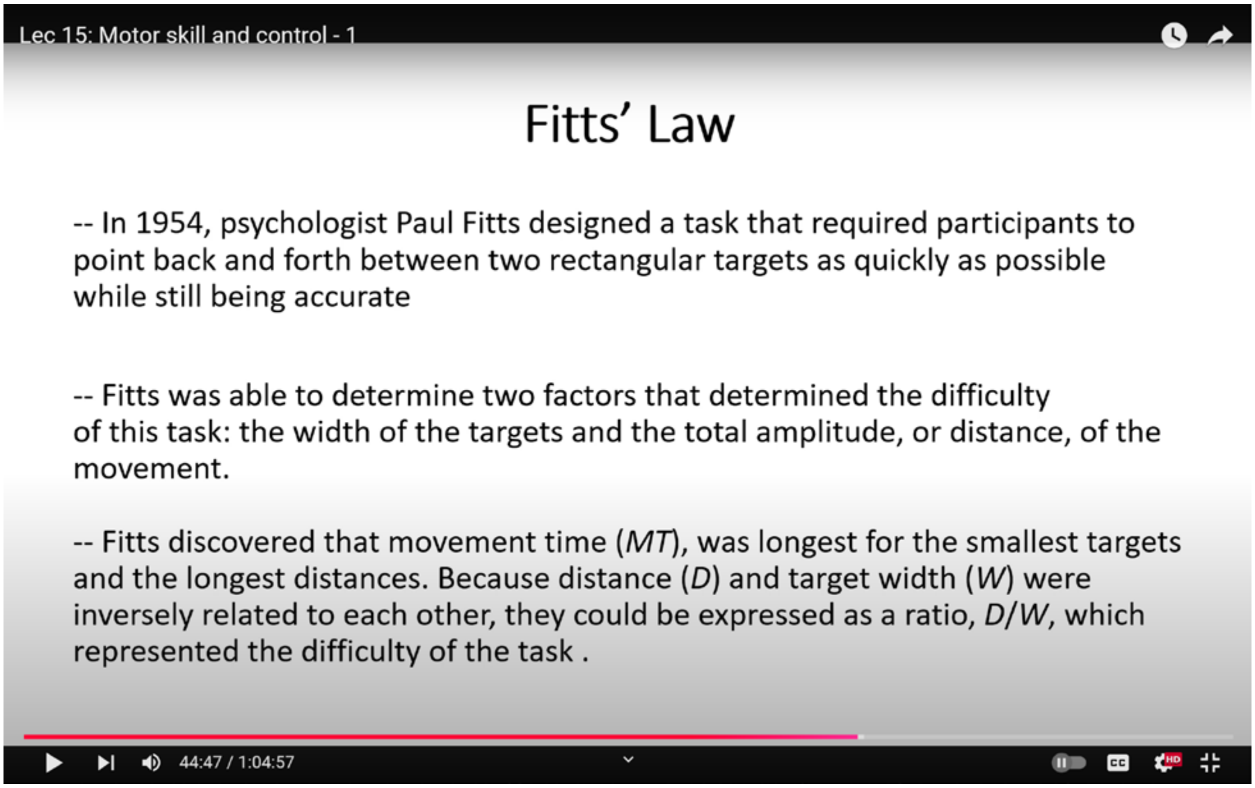

This phenomenon has been extensively studied, leading to the mathematical expression of speed-accuracy trade-offs, which is a well-established principle in the study of human movement known as Fitts's law. In 1954, psychologist Paul Fitts designed a task requiring participants to point back and forth between two rectangular targets as quickly and accurately as possible. The objective was to move rapidly while maintaining precision between these targets.

Fitts identified two factors that influence the difficulty of this task: the width of the target and the total amplitude, or distance, that the movement must cover. Specifically, the width of the target and the distance required to move between targets are essential for achieving speed and accuracy. Fitts discovered that movement time, the time it takes for individuals to transition from one target to another, was longest when both the targets were small and the distance between them was significant. When the distance between two targets is long and the targets are small, it results in increased movement time.

The relationship between distance (D) and target width (W) can be expressed as a ratio, $\frac{D}{W}$, representing the difficulty of the task. Therefore, the difficulty of a movement task is expressed in terms of this ratio, where D denotes the movement distance, and W represents the target width. The difficulty of performing a task is inversely related to the width of the target and directly proportional to the distance that needs to be traversed to complete the task.

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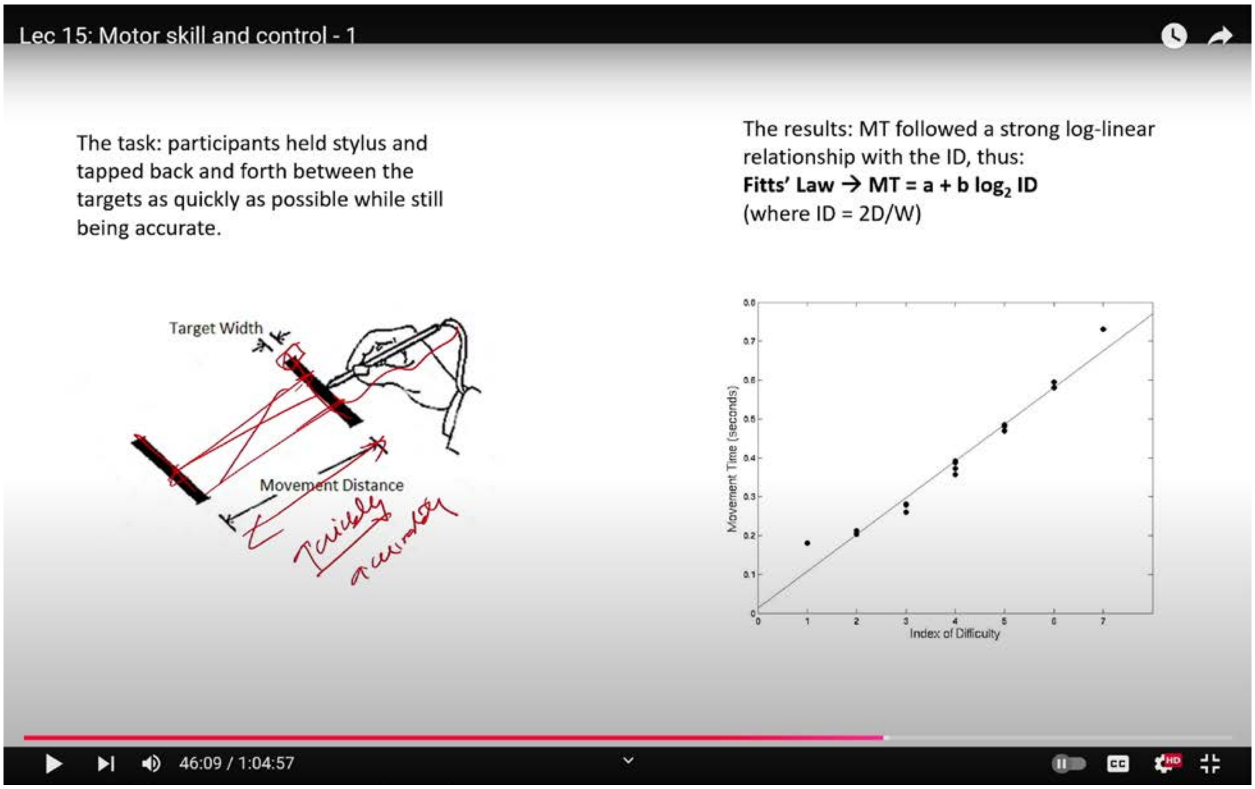

In the case of Manohar, his ability to act quickly, such as stopping the crane, depends on the size of the emergency button. A larger emergency button increases the likelihood of successfully pressing it. Additionally, the proximity of his hand to the emergency button is crucial. If his hand is still on the lever that lowers the crane's arm, and the distance between the lever and the emergency button is considerable, it will take more time for Manohar to press the button. However, if the stop lever is situated near the lever that lowers the load, he can perform the action much more quickly, allowing the crane to be stopped promptly.

Fitts's task required participants to hold a stylus and tap back and forth between targets as quickly and accurately as possible. According to Fitts's law, the movement time (MT) or the time required for individuals to move between two targets can be expressed in terms of A and B and follows a logarithmic function of base 2, denoted as ID, which signifies the item difficulty or the challenge associated with performing a movement. Thus, movement time adheres to a strong log-linear relationship with item difficulty.

Furthermore, it can be reasonably assumed that participants will aim for the center of the target. While target width is important, operators typically focus on the center of the target as their aim when concentrating on executing the motion effectively.

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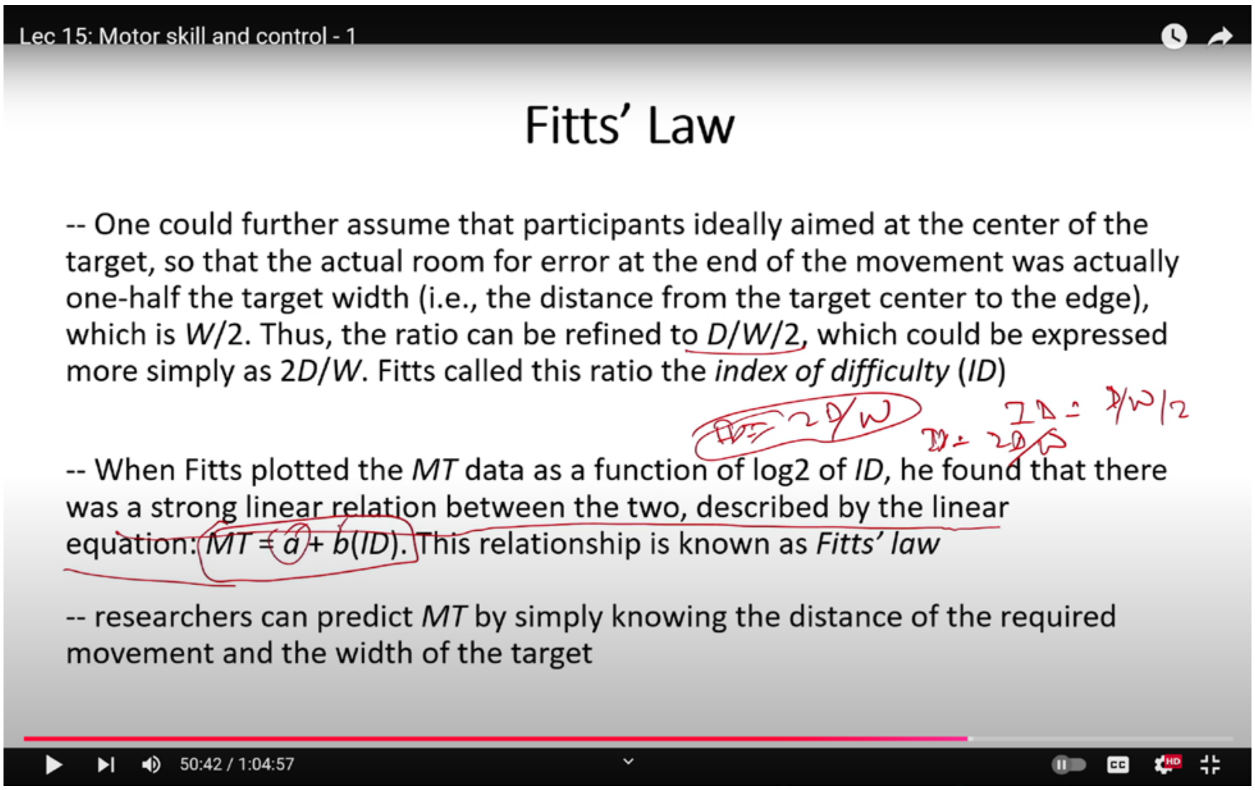

He will not move from side to side. In this target context, it is assumed that when individuals tap on the target, they will aim for the center rather than the edges. Consequently, the actual margin for error at the end of the movement is half of the target width. Since we focus on the center, the width effectively gets divided in half, resulting in a distance of $\frac{W}{2}$ between the center of the target and its edge.

We can refine the ratio of the Index of Difficulty (ID) in terms of the distance to the target and the width of the target. This can be expressed as $ID = \frac{2D}{W}$, where D represents the distance to the target and W denotes the width of the target. This relationship describes the difficulty of completing a movement task and is encapsulated in Fitts's Law.

When Fitts plotted the empirical data as a function of $\log_2(ID)$, he discovered a strong linear relationship between movement time (MT) and the index of difficulty, described by the equation $MT = A + B \cdot ID$. In this equation, A is a constant, while B is the coefficient that determines how the index of difficulty affects movement time. The slope of this line corresponds to B, and the position of the line above the origin reflects the constant A. Since the line does not start from zero, the distance at which it begins represents the value of B.

Researchers can predict movement time by knowing the required movement distance and the width of the target. Thus, movement time can be estimated simply by examining the distance and the size of the target.

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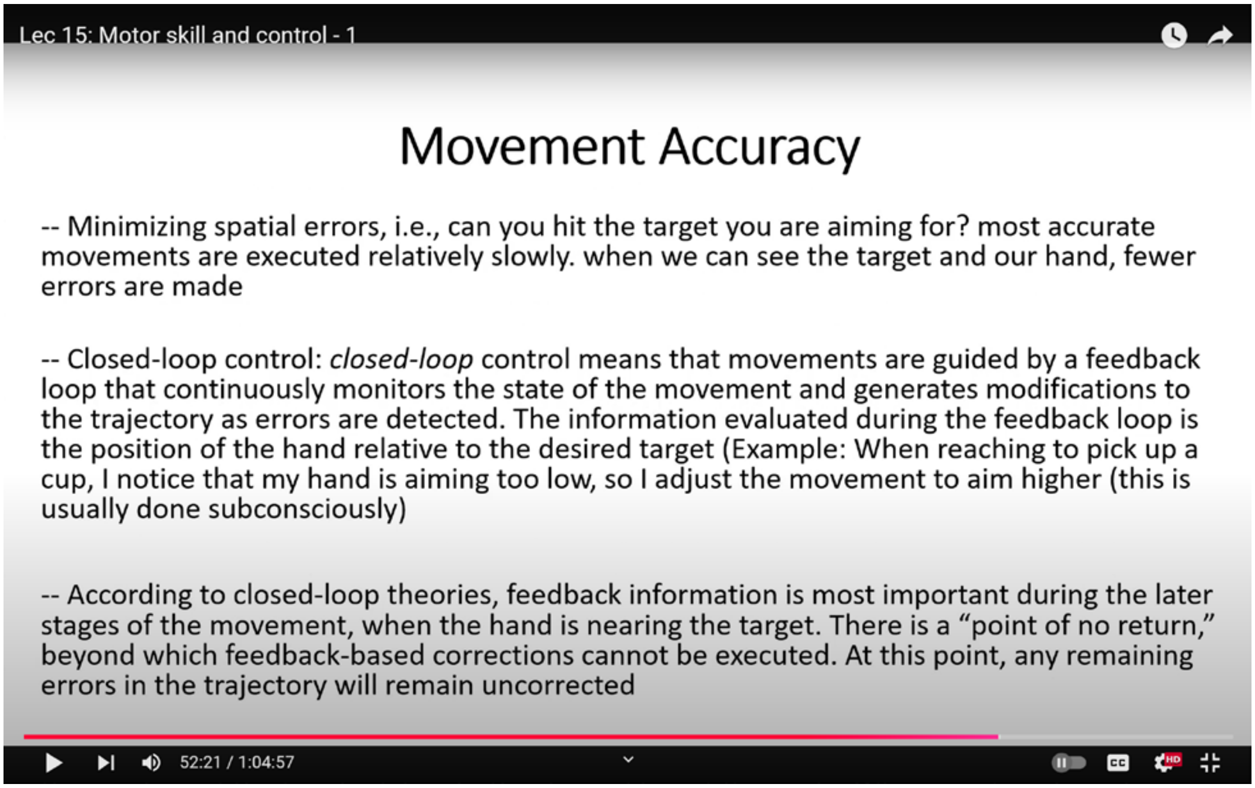

To enhance movement accuracy, it is crucial to minimize spatial errors, essentially, the ability to hit the intended target. Most accurate movements are performed relatively slowly when the target and one’s hand are visible, leading to fewer errors. One factor that improves movement accuracy is visual feedback, specifically if individuals can see their hands or the limb that is aimed at the target. This concept is fundamental to understanding closed-loop control systems.

A closed-loop control system involves individuals seeing their limbs perform actions. When they observe their limbs, feedback is sent to the cognitive system executing the movement, enabling the brain to make necessary adjustments to ensure the target is accurately hit or the correct button is pressed. In contrast, open-loop systems lack this feedback mechanism, meaning no information is sent back to the brain about the action being taken.

The accuracy of a movement can thus be framed through the lens of closed-loop and open-loop systems. In closed-loop systems, feedback is provided with each hand movement, allowing the cognitive system to make corrections, thereby minimizing errors. Open-loop systems, however, depend on the quality of the stimulus and context-related factors to determine the accuracy of a movement.

Closed-loop controls involve movements guided by a feedback loop that continuously monitors the state of the action and adjusts the trajectory as errors are detected. Your actions and trajectory are monitored through this feedback loop, allowing for control measures that reduce errors. During this process, the information assessed includes the hand's position relative to the desired target. For example, when reaching for a cup, if I notice that my hand is too low, I subconsciously adjust my movement to aim higher.

According to closed-loop theories, feedback is most critical in the later stages of movement when the hand is approaching the target. Corrections are not typically made quickly in the initial phases of motion but occur later when finer adjustments are necessary. There exists a point of no return beyond which feedback-based corrections can no longer be executed. At this juncture, any remaining errors in the trajectory will persist uncorrected.

That being said, corrections can still be made up to a certain point; however, once movement has passed this threshold, no amount of feedback will enable further adjustments. At this stage, the action must be completed. Nonetheless, prior to reaching this point of no return, feedback from the visual system or the proprioceptive system, which provides continuous information about the hand's position in relation to the target, can facilitate necessary corrections. However, as previously noted, there is a limit beyond which feedback will not aid in making corrections.

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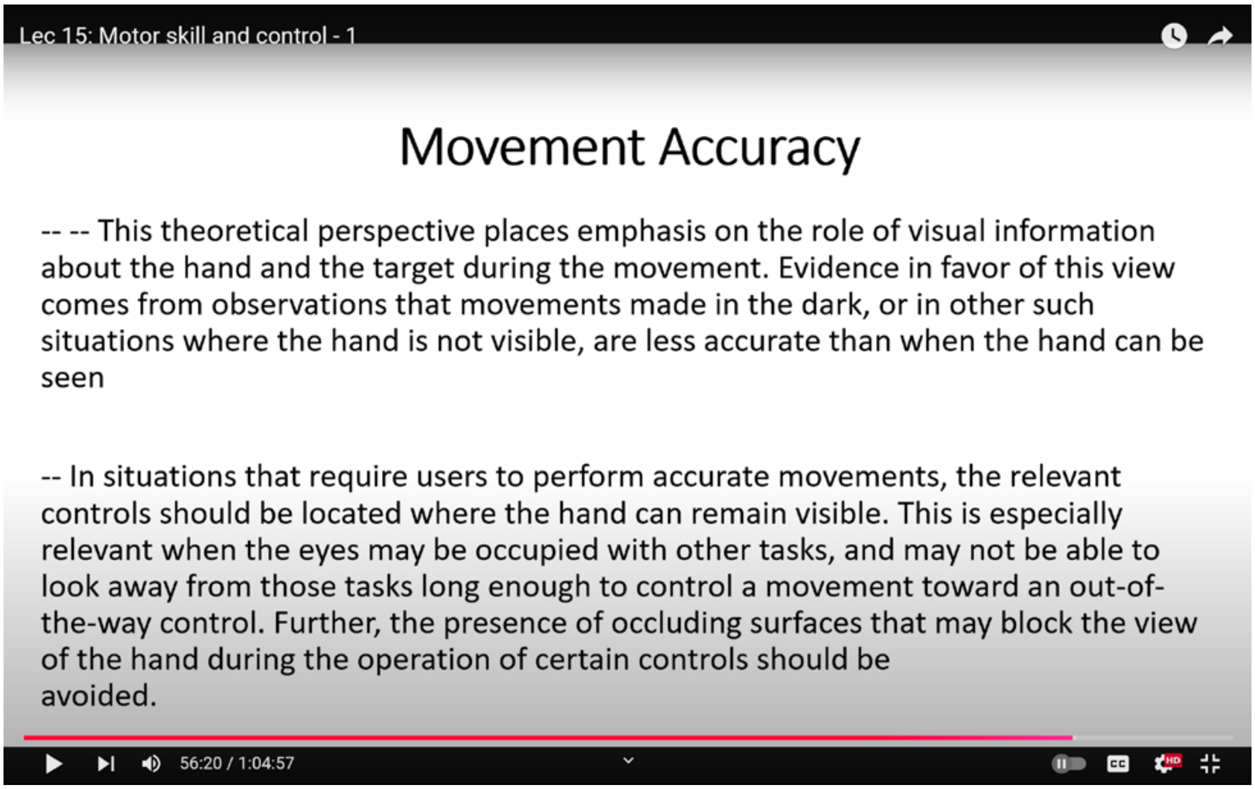

Now, the theoretical perspective emphasizes the importance of visual information regarding the hand and the target during movement. Evidence supporting this viewpoint comes from observations of movements made in the dark or in bright sunlight. Situations where the hand is not visible tend to be less accurate compared to when the hand can be seen. The question arises: what evidence suggests that visual feedback about the hand's position relative to the target facilitates finer movements? When the light is off and the hand is obscured, corrections cannot be made, leading to accuracy levels comparable to those of individuals relying solely on closed-loop systems. Consequently, individuals are significantly less accurate when they cannot see their hand executing the motion in relation to the target.

In scenarios requiring precise movements, it is essential for relevant controls to be positioned where the hands can remain visible. This is particularly pertinent when the eyes may be preoccupied with other tasks, preventing individuals from diverting their attention to control movements directed toward out-of-reach controls. Furthermore, the presence of occluding surfaces that may obstruct the view of the hand during the operation of certain controls should be avoided. Thus, avoiding occluding surfaces and maintaining visual focus on the target and the hand are crucial for facilitating accurate movements in closed-loop actions.

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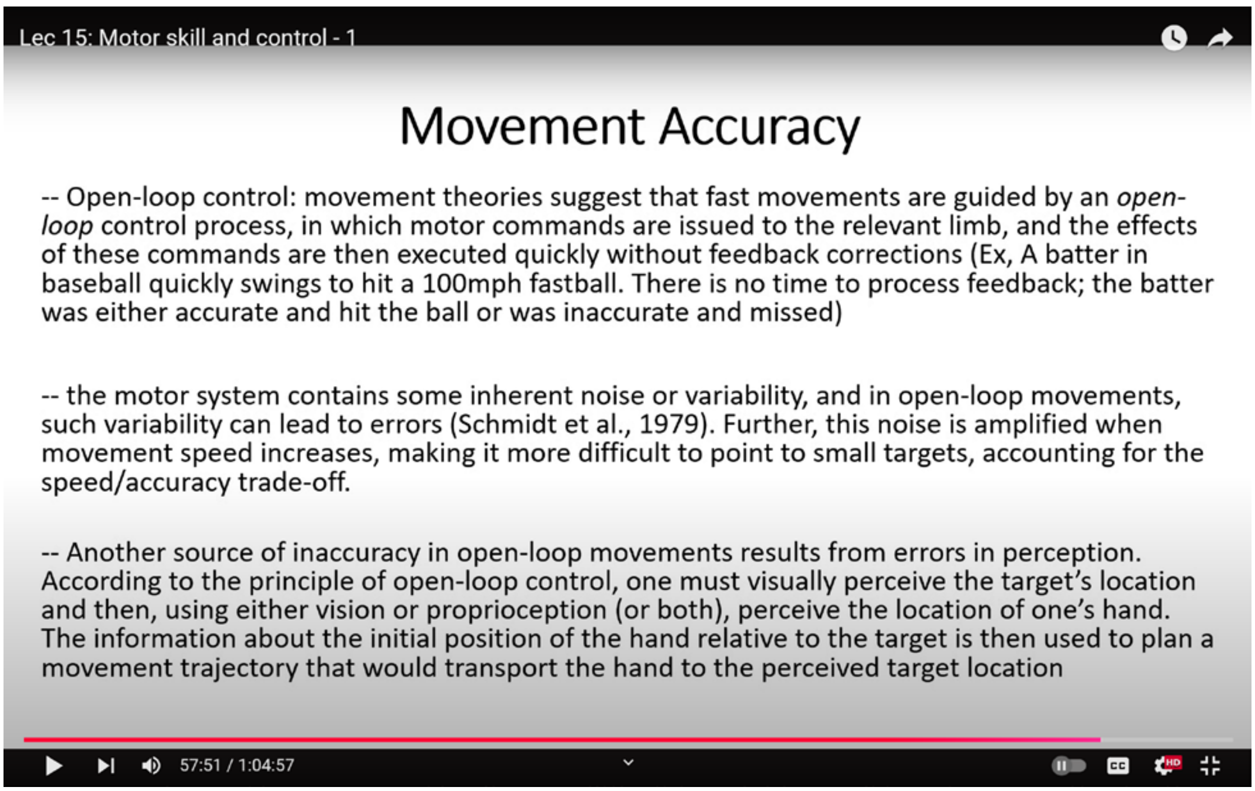

There is also another type of control mechanism that defines how movements are guided, known as open-loop control. Movement theory posits that rapid movements are governed by an open-loop control system, wherein motor commands are issued to the relevant limb. The limb receives information from the cognitive process responsible for executing this motion. Commands are relayed; for instance, when pressing a button, but the cognitive system does not receive feedback regarding the hand's actions as it would in closed-loop circuits. In contrast, in closed-loop control theories, the motion of the hand relative to the target is provided as feedback to the cognitive processors overseeing the hand’s movements. In an open-loop system, however, such feedback is absent.

The effects of these commands are executed swiftly without any feedback corrections. An example of this can be seen with a baseball batter who must quickly swing to hit a 100-mile-per-hour fastball. There is insufficient time to process feedback; the batter either successfully hits the ball or misses it. In this scenario, when hitting a rapidly approaching ball, the action taken at the moment of contact is the only opportunity to influence the ball's trajectory. Once the bat strikes the ball, the path it will take is determined by the force applied at the moment of contact, illustrating an open-loop system.

Moreover, the motor system is inherently noisy or variable, and such variability in open-loop movements can lead to errors. Errors in motion arise because the system responsible for these decisions contains noise. This noise becomes amplified as movement speed increases, making it more challenging to accurately aim at small targets. This phenomenon is described as the speed-accuracy trade-off. The speed-accuracy trade-off, as articulated by open-loop systems, stems from the inherent noise produced during motion. This noise contributes to a conflict between speed and accuracy; as speed increases, accuracy typically decreases. Additionally, the smaller the target, the more difficult it becomes to locate and effectively interact with it. External factors, such as target size and other context-related variables, combined with the internal noise of the system, collectively account for this trade-off.

Another source of inaccuracy in open-loop movements originates from perceptual errors. How one perceives a stimulus and the meaning derived from that stimulus also contribute to inaccuracies in open-loop systems. According to the principles of open-loop control, it is necessary to visually perceive the target location and then use either vision, proprioception, or both to ascertain the position of the hand. Therefore, open-loop systems indicate that errors in motion arise from perceptual inaccuracies. These perceptual errors may stem from visual perception, which involves observing the hand in relation to the target, or proprioceptive feedback, which pertains to the awareness of body balance. By comparing normal body balance to the balance observed during motion, one can determine whether inaccuracies have occurred.

The information about the initial position of the hand concerning the target is subsequently utilized to plan a movement trajectory that directs the hand to the perceived target location. In this context, both the body's position and the visual stimuli associated with the target, along with the hand's position, are integrated to inform how the action should be executed. If one can effectively process these two sources of information and formulate a coherent plan for the action, there will be fewer errors during the execution of movements, ultimately leading to successful task completion.

In the context of the scenario I have described, in a closed-loop system, the operator would receive constant feedback from his internal system regarding the position of his hand, the levers, and the button that needs to be pressed. This information would be integrated to enable him to make necessary corrections, allowing him to stop the lever that is lowering the load midway. With his other hand, he would firmly press the emergency button to halt the lever's movement. By doing so, the lift would come to a stop, thereby preventing an accident.

Conversely, in an open-loop control system, Manohar must rely on information from his proprioceptive system, which includes the vestibular system and other sensory systems, as well as visual input, to plan his movements. He needs to coordinate his actions so that one hand quickly presses the button while the other hand holds the lever in a position that ensures the emergency button is pressed firmly and promptly, thus stopping the crane. This coordinated action will prevent the load from being lowered and keep it suspended above the ground, ultimately averting a disaster and safeguarding people below, resulting in a positive outcome for all involved.

In today's lecture, we examined reaction times and movement times, exploring how motion informs the design of controls and systems to facilitate optimal interaction between human operators and technological systems. In the next lecture, we will delve into control design, focusing on how information about controls can guide us in determining the appropriate motions to be made and how these motions should be executed and incorporated into interfaces. This will ensure that operators have a positive experience while interacting with systems, ultimately enhancing efficiency. Thank you, and Namaskar from the MOOC studio. Amen.