Language, Culture and Cognition: An Introduction
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Module - 08
Part - 1
Lecture - 18
Language and executive control

Welcome to the Module 8th Part 1. In the last module we have looked at the attentional mechanism and its relationship with language through various language processing, and so on. Now, we will move on to the domain of executive control, executive function, executive control, cognitive control there are many ways to look at it. So, we will look at this particular mental mechanism and its relationship with language, as in language processing.

Before we move on to the language aspect of the mechanism, let us look at the function itself. What is executive function? Executive function is also called cognitive control. So, what is it, what is executive control? What is executive function? This is what we will look at in the beginning.

And then what are its components? What is it comprised of, what are its, you know, smaller parts, what are its sub subdivisions subparts and so on. Is it a single undifferentiated cognitive process or is it made up of separate parts that make it a whole process? And then we will move on to the brain regions responsible for the for carrying out this function in the in humans.

And then we will look at the role of language and then we will move on to the more complex aspects of language and executive function relationship.

So, first and foremost, the importance of executive functions. To till now, we have looked at many other mental functions, most recently we have looked at the attentional mechanism. Executive function and attentional mechanism are interconnected. They are part of one superimposed bigger category which is called by various names.

Sometimes it is called executive function; sometimes it is called cognitive control. So, it is considered a part of a very very important part of intelligent behavior, to the extent it is so important that sometimes it is considered the core of intelligent behavior in humans.

What is intelligence? If we ask this simple question what is intelligence and can we break it down to smaller parts as to what are the behavioral outputs, what are the negotiations that the human mind engages with the surroundings and environment and so on.

If we look at it deeply, we will see that executive function lies at the core of many of our intelligent behavior. So, that is why it is sometimes considered the core. It is also important to look at executive function in terms of when there is a compromised EF in certain patients.

So, executive function is not only looked at and understood and studied in normal people. But also in case of patients, because in many various kinds of psychiatric problems, disorders as well as neurological disorders, executive function gets compromised, meaning that is that it gets affected.

Just like we have seen that brain damage affects language functions, brain damage creates language disorders, similarly executive function also gets affected in certain cases of neurological disorder or psychiatric problem and so on and so forth. That is why this is also understood, this is also looked at from the from clinical literature perspective as well.

Another interesting fact about executive function is that it varies. It is not something that we are born with and it stays the same all throughout our lifespan, it changes. A child's small child's executive function mechanism and the controlling factors and so on and so forth are not the same as that of an adult.

So, as a child grows the executive function mechanism also grows and reaching it peak its peak somewhere around young adulthood and then it goes on like that. So, this is yet another way of looking at executive function. It also affects executive function affects performance in challenging task conditions. Why is it important? Because executive, function is at the core of human behavior, human intelligent behavior.

And that is what decides how we behave what is the output of our behavior or any other kind of verbal output and so on, in a challenging task condition. Given various kinds of

task demands, how a human being really negotiates those challenges is at the core of it. So, this is understanding executive function also may takes us to the domain of how humans really negotiate a challenging path.

For example, in real life one very challenging job is the job of a pilot, aircraft pilot or a normal passenger pilot or in a or a fighter aircraft and so on and so forth. So, the job inside the cockpit is extremely challenging, there can be many tasks simultaneously demanding the attention of the pilot. So, how does one handle those things?

So, these are also studied. So, as you can see there are many dimensions of the same thing same thing called executive function and that is why it has been studied by various domains various you know experts from various domains like cognitive psychologists, neuroscientists, linguists, education researchers and so on. So, what is this whole thing about?

Let us see what the trajectory has been. So, the notion of executive function has been around for a very long time. We have seen when we discussed Luria, that it has been around since the time of Luria and even before. So, psychologists have known the concept of executive function for a very long time. In fact, it goes back to the late 19th century, to Bianchi and then of course, to Luria.

So, this has been this notion of executive function of a higher mental function, a kind of a control system, that modulates our behavioral output has been around for some time within the domain of psychology. And when cognitive psychology came into being, then initial stages of initial research in cognitive psychology also use this term very heavily as I have mentioned a few important papers here.

However, like all things this the domain also has been changing a very rapidly in the very rapidly through last many decades. So, in the in the later years primarily due to the advances made in the communications and control systems and computer science, AI and so on, a new term started replacing the term executive function which is cognitive control. So, cognitive control has come to replace executive function in many domains though not entirely. There are still some places where we still use executive function, but largely cognitive control has come to replace the term executive function. So, it basically owes its origin to cybernetics and later cybernetics and then of course, AI and so on.

One important seminal book by Miller and his group, George Miller and his group was the first to bring to explicit notice of the academic world, the where they brought out cognitive control, human mental mechanisms, hierarchical structures, all these things together.

So, cybernetics on the one hand was on its on peak, the control system education; education academia was rather interested in control systems and the research was going on in full swing. So, at that time Miller's book actually got actually connected control theory, goal directed human behavior and human cognition, hierarchical structure of the cognitive mechanisms and so on, through this book.

Subsequently, there were other researchers, most importantly Posner and his group that brought out very very important three seminal papers. Almost all of these around they revolve around the same topic and basically these papers along with this book quickly and firmly established the construct called the 'cognitive control'. So, these three papers most important papers are listed here I have added them in the references.

So, what are these papers talking about? These articles focused on differences between automatic and controlled processes, because that is what they were looking at that time. So, control processes as well as control systems and human cognition and so on.

So, the difference between automatic process and controlled processes, what are the differences, how are they different, what are the finer nuances and so on is the entire gamut of things that these papers talked about.

So, they propose that control processes are, there were three main proposals. One was, controlled processes are slower as opposed to the automatic processes, controlled processes can suffer from interference of the automatic processes and thirdly, it is dependent on a limited capacity mechanism. These were the first important proposals given by those given by Posner, Snyder and Shriffin.

So, this is what basically brings us brings to the forefront the difference between automatic process versus controlled process. Automatic processes are those processes that are well learned, that has been established over a period of time. We know, for example, the

moment we see a written word we read it, it is not a controlled process, it is it does not require our selective attention, it just happens. This is why it is called an automatic process.

Automatic reading is an automatic process for most of us because it has been established well established, well learned process. So, these are the differences.

So, one of the important ways in which Posner started to show this difference is the famous color-word stroop task. In fact, stroop task is so relevant even today.

So, what they did was they were they showed that through that color-word stroop task they showed that adults are universally faster to read out the word than to name its color. Notice here that we have the word 'blue' written in three different colors, blue is written in red, blue is written in blue and red is written in green.

Now, all of you as you are looking at this slide, will have no difficulty whatsoever to read the word. So, blue, blue and red, it does not matter in which ink which color ink it is written. However, because reading is automatic process, reading the word is automatic process.

However, if we ask you to name the color in which the word is written, then there is a problem because that is a controlled process. It needs to be controlled, it needs to be regulated. So, there it becomes a problem because, it is written blue here, but the ink is red. So, there is a conflict in this particular case. However, here, there is no conflict blue is written in blue and again there is a conflict here red is written in green.

So, the primary finding that Posner and his group showed is that reading a word is automatic process and it is extremely quick, it does not take time. And it is also not affected by the color of the ink in which it is written. So, whether it is written in a blue is written in green or red it does not really matter.

However, on the other hand the process of naming the color is not an automatic process it is a controlled process and hence it gets affected by the word. So, if you have to name the color blue and it is written in blue it is slightly faster, but when it is written in when you have to mention the color, but it is written in the other color is written.

So, it is for example, here it is green you have to say green, but the word says red there is a conflict and in these cases the naming is impaired. So, naming a color is impaired if done with another task as well.

So, there is so controlled processes are open to interferences. In one case it is interference by the word itself, in another cases it is interfered by if there is an another task that is given to the participant which does not happen, if it is an automatic process.

So, these are some of the initial studies, initial landmark studies that showed the difference between automatic versus a controlled process. Of course because these are initial ideas so many of these notions have been challenged later and there are lots of debates and controversies.

For example, one big controversy is around the limited capacity mechanism, the notion of limited capacity mechanism as well as the automatic versus controlled process because the automatic versus control process may not be a fixed sort of a dichotomy.

Some processes which are controlled now, which need to be controlled now, may become an automatic process over a period of time if you where if you learn it well. If it becomes a continuous process, if it is regularly you know if you get habituated to it; it might become an automatic process and so on, similarly, the notion of flexibility.

However, that is that is how all theoretical constructs are, there are of course, debates and update on every theoretical construct, but the basic idea of cognitive control of difference between automatic and controlled processes remains.

So, we will we are back to the executive functions.

So, these are the primary components of executive function. One is flexible thinking or it is also called cognitive flexibility, as in you know being adaptable to the changed scenario, we will see it in a short while. And then the second most important aspect of executive function is working memory and then comes inhibitory control and of course, attention. Attention because we have already looked at before in detail, we will not go into it here, we will look at the other aspects.

So, then what then is it Is executive function? it is a high level cognitive process. There are two levels of cognitive process of course, it is not airtight or and also there is a lot of dialogue between the processes, but there is a hierarchy, in the in the mental mechanisms. Some are considered high level mental mechanisms, some are considered low level mental mechanism.

So, the low level mechanisms are correspond to the automatic processes. So, this is executive function on the other hand, is a high level cognitive process and this higher level process modulates the lower level processes. For example, reading the word 'blue'. So, the reading aspect, as soon as you see the word blue you read, it is an automatic process and that is why it is also called a lower level process, this is almost automatic.

Now, this process of reading can be guided by various other modalities, other variables let us call them. So, this can be guided by the goal: are you supposed to read the word or are you suppose to do something else? So, there are many other things like current goal, environments and so on. Now, this guiding part of the lower mechanism, lower processes is the higher part of the process.

So, depending on our current goal, we modulate our lower level perceptual analysis and our vocal output. Sometimes it is a vocal output, sometimes not, but this is how it works. So, the local lower level processes are guided by the higher level processes, which is basically taking into account the goal, current goal as well as the environment within which the entire process is set.

So, what do we mean by the current goal? Sometimes we may ignore the word may in fact, in experimental setup, we tell the participants to ignore the word and just look at the color and tell us the name of the color. So, that is what exactly is the task here. Sometimes the task is to read it aloud and so on.

So, even though the stimulus remains the same, participant remain the same, environment is same, but the goal might change, goal is at that point the current goal. Thus, even though the perceptual cue is same the task can be different and hence the response can be different. This control is the core of what we call executive function.

So, controlling your output, controlling your response, keeping in mind the current goal and the environment is what is the crux of the matter. So, it basically helps us in devising

new ways of behavior and thus it allows for flexibility, right? So, it is not that just the moment you see the word you have to read it, there are also other possibilities. There are many ways of looking at the same word blue.

So, thus this also is very very strongly related to the flexibility aspect. As a result of which this then leads to optimizing one's reaction to unfamiliar circumstances. In life there are two kinds of circumstances; one is familiar, the other is unfamiliar. Familiar circumstances automatically gives rise to the automatic responses, we already have a stimulus response connection set.

So, in this particular scenario the moment you see the word you automatically read and so on and so forth. However, there are also situations when circumstances demand a different reaction; different reaction not only because the circumstances have changed, but maybe the circumstances are still same, but the current goal has changed.

This is not only true about experimental setup, but also about life in general. So, that is why executive function is extremely useful for non routine behavior and responses. And all of these lead us to adapting a novel approach adapting to novel or changing situations and tailoring our responses, keeping in mind both the situation and our goal.

Now, executive function has many sub-parts of it, it is comprised of many stages. Logan for example, has listed these four stages, four parts of executive function of the human cognitive system. The first is the choice of strategy as to what has to be done, given this scenario, given this kind of a goal what kind of strategy is to be used.

And then instantiation of the chosen strategy, to initiate that particular strategy to be utilized and then of course, comes the execution and maintenance of the both are important execution as well as maintenance of the strategy to achieve that goal. So, you choose your strategy, then start utilizing it, execute the strategy, execute your particular job that you have to do.

And as long as this is required you have to maintain that strategy and then inhibition of the strategy in face of a changed goal or scenario. This is you can see this is in many ways similar to our attentional engagement and disengagement loop that we talked about.

So, we orient our attention, we engage our attention and then disengage and then the cycle goes on. That is why it is important to understand executive function, also keeping in mind the attentional network. So, these are the four functions of human executive functions of human cognitive system as proposed by Logan.

Of course we can go on and on, this is a very very broad area of research and it has really smaller parts and many smaller parts and finer nuances, but we need to sum it up because our primary goal is to look at it from a linguistic perspective. So, how do we sum up? General this is a general process executive function is a general process that regulate and guide cognitive processes in sensory, memory and motor systems, alongside an internal goal.

So, this is a this is a process that helps regulate our cognitive processes. In what domain? In sensory, in memory and in motor system. So, motor system will also include language, in the sense of linguistic output verbal output. So, this is composed of at least two components: conflict monitoring and conflict resolution.

If you if you really simplify the whole thing it ultimately boils down to conflict monitoring. So, first you have to identify there is a conflict, there is an interference you monitor and then there is a resolution aspect of the of the same conflict and then it also includes inhibition. So, not only you have to take action on one particular aspect, you have to also stop your action from on another aspect of the same scenario. Hence you need inhibition.

So, let us get into a slight detail about conflict monitoring. Conflict monitoring refers to the processes that monitor the occurrence of conflicts in information processing. Now, this information processing can be of any domain, it can be the language related or it can be any other sensory motor kind of information processing.

The conflict monitoring process evaluate current levels of conflicts and trigger and then it will trigger compensatory adjustments of processing pathways. What has to be done, first you monitor the scenario, identify the problem, monitor the problem and then trigger the processing pathway, as to how to deal with it and then comes the resolution. So, conflict resolution, this is a process that aim at eliminating the sources of conflicts.

The conflict resolution process enhances task relevant information and suppresses task irrelevant information. This is one of the most important aspects of executive function,

because they are sometimes in the environment there might be too many stimuli present, some stimuli might be more salient, there they might be more visible, they might be more you know more salient more kind of important to on the surface. However, they are not part of your goal at that moment. Hence, you have to suppress that particular aspect of the scenario and focus your attention on the one that is directly related to the goal. So, this is what we mean by enhancing task relevant information and suppressing task irrelevant information in the environment.

And this of course, needs organizing of behavior, along the internal goals. Inhibition is of course, the processes that suppresses an active representation or action tendency. So, even if, for example, if you are let us say if you are going to the library and your goal is to go to the library, sit there and study for 4-5 hours, but on the way there is a pizza shop.

So, now, pizza shop is more salient because that is more inviting, let us say. So, you have to eat now you need to your goal is to go and study and not eat a full snacks and then go to sleep. So, the goal is to go to the library and study, hence you have to suppress your tendency to go walk into the pizza shop. So, this is what we mean by inhibition. Inhibition is a very very important component of executive function in order to achieve.

So, these are the some simple examples to show you what exactly it is all about. We have we have said a lot of thing, but how does it really work. So, in terms of working memory, what is it what we are we looking at in terms of working memory?

This is the ability to hold information in mind while thinking either about it or to do something about it or thinking some about something else. So, juggling many things at the same time while everything is keeping it keeping all the information intact. So, basically, theoretically speaking, it refers to holding multiple things in mind while thinking of most suitable response, keeping track of all the thoughts.

You need you need all this information to be worked on right now. So, they are all in the in your working memory and, but you must keep track of all of them, in order to work on them, in order to find the most suitable response for that given scenario. For example, in a real life scenario practically speaking, let us say in a conversation, you have to remember others opinions and ideas while formulating your own.

Let us say there is a discussion going on, this is commonly seen in group discussions. So, everybody has their own opinions. So, another participant in the discussion has raised a significant point and then you have to keep those points in mind while formulating your own idea.

So, this is not something you come prepared for, here is where your working memory, your functioning of the working memory, it plays a very important role and this is part of your executive function. Similarly, inhibitory control, inhibitory control in fact, a lot of research is now going on inhibitory control among adolescents and smaller children, both in typical as well as atypical children to see how much of self regulation is in place and how it can be enhanced and so on.

So, basically this refers to the suppression of an automatic response. Something sometimes some stimulus you know elicits a knee jerk reaction from us, we just listen and immediately react. So, suppressing that kind of a reaction given the scenario is what inhibitory control refers to. So, for example, not leaping to the first possible response to a situation and assess the situation for different possible solutions.

A particular scenario given a particular a group of people might demand different kind of solution in different with different goals in mind, so this is where inhibitory control plays out. For example, not bursting the balloons in somebody else's party, not blowing out the candle on somebody else's birthday cake and not blurting out 'how stupid' even when you know it is, the situation is stupid or the person is stupid, but you have to control yourself not to blurt it out, skipping the pizza in favor of the sprouts and so on.

So, skipping the pizza in favor of sprouts basically is in keeping with your long term goal. So, we are basically skipping the instant gratification in terms of our long term goal to get healthy, to become healthy and so on.

So, inhibitory control is again a very very important aspect of executive function and then of course, flexible thinking. Flexible thinking is nothing, but is a fancy name, for a possibility that you can look at the same problem from the different possible angles, every problem has multiple solutions. So, typically we are more commonly we are used to take the same route again and again, but flexible mind will take different possible angles to look at the same problem. That is all there is about flexible thinking.

So, ability to notice when our original approach to a problem does not work and it needs a it needs to be reworked, the same problem can be reworked to find a new solution. So, this is what basically refers to in a real life situation as well, looking at a problem from multiple perspectives and choosing the best possible, best suited response.

Now, what is best suited is of course, we you can go back. Best suited response means best suited for the current goal and the environment, this is very important. So, what is suitable for a particular scenario may not be. So, that kind of flexibility and adaptability is what executive function is all about.

So, in terms of visible, behavioral output, executive control refers to adaptability and flexibility in the face of conflict. There is a saying: 'adapt or perish' this is basically what it comes down to. People who often we see some people cannot adapt to changing scenario the world is changing at a very very rapid pace.

And if we cannot change ourselves, change the way we look at the world, change the way we value things or you know the value systems and so on and so forth, there are so many things to look at it. So, the more you adapt, the more flexible you are the more you will be able to adjust to the changes. So, this is what is ultimately about executive control.

So, adaptability and flexibility in the face of conflict. It is the ability of conflict resolution using flexible approach, using mental mechanisms of selective, sustained attention. We did talk about selective and sustained attention which is a very very important crucial aspect of executive function and of course, working memory, inhibition of undesirable response and so on.

So, you see executive function is not only crucial in case of challenging challenging task conditions, but also it is an important part of social cognition. What to say when and what not to say when, what not to do in what scenario are also an important part of our behavior in the world, in the in the in the in face of conflict.

So, this is these are all the important things in terms of behavioral output, this is what is visible to us. So, executive control mechanism, executive function, cognitive control whatever you call it, there are many facets to it. One facet, the most visible one, is the behavioral part of it, this is what we see.

At the at and it lies at the core of intelligence and therefore, often success. Often we see there is a deluge of motivational speakers these days. What all they talk about is how to become successful, how what not to do and what to do to be successful and so on.

Notice how often they underline the same things, many of them. And more often they are not you will see they all will ultimately take you to flexibility and adaptability. So, this is what is at the core of intelligence and of course, success.

So, now this till here we are talking about what is visible, what we see people doing and all people not doing and so on and so forth. But this is the face of a larger mechanism, a very fine mechanism, a very complex mechanism that plays out in the background. That background mechanism happens in the brain therefore, we now go to the neurophysiology of the cognitive control.

Neuroscience as we have seen in the beginning has made huge strides in the recent times, huge strides it has it has developed very well, it has established itself as a very advanced domain of and domain of academic academic enterprise and so on.

So, therefore, we now have a lot of different methods, very very objective and very subtle methods to look at how the brain really works, in terms of various kinds of functions, in terms of even at the level of single cell recording. So, we now have been able to map the brain and its functioning in terms of even executive functions.

So, as the brain is busy doing taking part in some kind of an executive function task, we can actually map. So, techniques like neuroimaging, neuropsychological, computational modeling, single cell recording and meta analytic techniques etcetera so on and so forth, have enhanced the understanding of cognitive function, executive function at the brain level, at the level of brain anatomy, as to what region is busy doing what. The components of the executive function and the discrete brain regions responsible for this process.

There is a lot of agreement on this that primarily, most of the executive functions are located in the frontal lobe of the brain, not all of course, but most of the functions are located in the frontal lobe of the brain, particularly in the prefrontal cortex, it is called PFC.

So, prefrontal cortex is very very important when it comes to executive function, because not only because it has rich interconnections with its sub regions, within its sub regions.

So, prefrontal cortex has a strong relationship with the sub regions, lot of connections and it also receives signal from all sensory and motor cortical system.

It is connected to all the sensory and motor systems. It also has strong connection with subcortical regions, like basal ganglia and so on. So, patterns of activity within prefrontal cortex represent the current behavioral context and the current goals and intentions. So, basically, what with what this means is that various kinds of tasks, when the participants are busy in carrying out then we see a lot of activation in various domains within the prefrontal cortex, as per depending on the current goal, the environment and the task and so on and so forth.

So, but the problem is PFC is a large area, it is not a small brain region, it is a large region and hence it has been now divided into various sub domains in terms of the functions. So, it is possible to look at the PFC in terms of various functions that is located in different parts of the same thing same PFC. So, it has it is a large system with different cytoarchitecture and connectivity.

Remember when we talked about brain and its parts and how they are organized, how the structure is, how organized in terms of connections to the other brain regions as well as in terms of the density of cell and so on and so forth. We did talk about cytoarchitectonic grouping of various areas, so that PFC also has it is a large region, which has very different cytoarchitecture as well as connectivity level.

So, roles of different PFC regions can thus differ. Thus the PFC can be divided into sub regions, depending on the cytoarchitectonic as well as functional properties.

So, depending on how the structure is, how the morphology of particular domain is as well as what kind of function, within executive function what kind of which part of executive function it is busy doing, what it does and how it carries out those that part of the work. So, one of them is the Ventrolateral PFC, in short VLPFC, this is involved in comparatively simple tasks, such as short term maintenance of information that cannot currently be perceived in working memory.

For example, memorizing a phone number you have just been told, before keying the number into a telephone. So, you have you have just heard the phone number and now you

are keying in the number in the phone. So, that part of the work that, keeping it in mind so called, is basically what ventrolateral PFC is does.

There is also a slightly controversial many of the proposals are actually controversial because there is always data referring to different aspects of the same problem and often contradictory results also. So, one controversial proposal is that different parts of the ventrolateral PFC are used to store different types of information.

So, the again further breaking down the VLPFC also into further smaller parts, each part has different kinds of storage. One of them can be sound of a word, another can be the meaning of a word and so on and so forth. This has this is a slightly controversial claim, but this is one of the claims that have been made about the working of VLPFC.

Similarly, there is dorsolateral PFC, which has which is considered to maintain information that is no longer available in the environment, but it can be for manipulating later, ok. So, this information is not anymore there in the environment, you are keeping the information in your mind and for later manipulation. For example, though it is probably not involved in remembering a telephone number. But in more difficult tasks such as dialing the number in reverse order.

So, basically rearranging the digits we have I tell you a number phone number dorsolateral PFC may not remember the number, but it may be active in helping me typing that number in a reverse order.

So, there are, in fact, this is just one of the many possibilities of dorsolateral PFC. Each small act that we do for example, hearing a phone number and keying it in actually goes through a lot of smaller, finer nuanced processes, sub processes and each of these processes are taking place in the in different distinct.

Sometimes distinct areas, sometimes it needs a collaboration between different areas and so on. So, this is why we see such small little details here. Similarly, there is yet another very important area which is Anterior Cingulate Cortex, ACC in short, this is also this also plays a very important part in executive function mechanism.

So, part of the medial PFC has a strong projection to and from DLPFC, this is part of the medial PFC and it has strong connections between dorsolateral PFC, this that this region

detects the need for control. So, control the doing the control, needing understanding that there is a need for control, the telling the other regions that the to carry out the control mechanism and so on and so forth can be some smaller aspects of the control mechanism.

So, this particular this particular part, ACC detects the need for control. For example, there is a competition between two ways of behaving in a certain scenario, both of which may be triggered by events in our environment, it will require a top down input to resolve the conflict, what should be done given that particular scenario.

So, it ACC comes into this picture, then it does not do the controlling per se, but it rather tells PFC when control is required, as per the claims of certain some researchers. However, there had it has been challenged as we have seen in many other cases.

And in yet another area is the rostral PFC or RPFC. So, this is this is one of the largest, but most mysterious, sub region of the PFC. Patients with damage restricted to this area often perform well on standard neuropsychological tests, they do not, they do not falter there. However, they have difficulty in real life multitasking. So, this is one a very interesting aspect of RPFC.

Neuroimaging results show that there are distinct functions associated with different parts of RPFC again you see. So, we have already seen that the PFC is now broken down to 3/4 major areas and each of those measure areas can again be broken down into smaller parts, this is a very rich area of research.

In fact, as we speak, many groups are busy finding out the finer very very fine detail of each of these sub parts, different parts of each of these smaller regions also. But, for our purpose, we just we need to have a broader idea about how, what are the main areas that are responsible for executive function and these are those.

So, also a very important, much cited paper in 2007 Cole and Schneider, points to a different to the different distinct regions of the brain that are part of a network. So, now, as we have seen the PFC has this many parts and then there are also certain parts in the other part of the brain that are all connected.

So, now there is the proposal by this by researchers that this they all form a network and they call it 'cognitive control network', Cole and Schneider call it cognitive control

network. There are different regions which are distinct part of the brain and they together form a network, which is responsible for the carrying out executive function mechanism. All kinds of cognitive control related functions are carried out by this, not all of them are active all the time, but this is the network.

So, these regions as they have listed are some of them have already we have seen ACC is there and then there is pre-supplementary motor area, this we have already seen. Again another area is inferior frontal junction, anterior insular cortex and this we have already seen and then posterior parietal cortex.

So, these are some of the areas of course, it is getting updated every very very frequently, but this is the kind of the network that the brain cognitive control network that is responsible for or that is directly connected to all the executive function mechanisms or cognitive control mechanisms in case of humans.

This is this is one of the latest depiction of the various regions that we have just now talked about. So, inferior frontal gyrus, you can see this is the back of the head and this is the front. So, this is rostral PFC, this is ventrolateral PFC and then we have all the regions are mentioned here very clearly. This is from a paper by this Cristofori et al 2019 paper, where they have given this clear cut distinction of the areas.

And then we have basal ganglia here, which is also something that is. So, mostly there is a lot of agreement among the neuroscientists that these are the areas where various aspects of executive control or cognitive control takes place. So, you can see working memory, inhibitory control, reasoning, maintenance of information that we have just seen and then manipulation of information in working memory. So, this is roughly the map of the brain in terms of those areas that are directly linked to executive control, cognitive control mechanism

However still a lot more needs to be learnt that is that is as I said there is research going on in all these aspects and we are constantly getting updated. Various regions and their workings have now been found that, but the 'how' part, but necessarily not how we do not really necessarily still understand, how this connection really works.

That is this is a very very nuanced area, this is a very complex area of research and then is of course. So, the reason why I am mentioning this is that this is not the final, work is still going on.

Now, we have seen what is executive control or cognitive control, how do we see this in terms of behavior. Then we saw how there are very different brain regions that are directly responsible for carrying out those control mechanisms.

And now, we will see the various behavioral tasks that are utilized in experimental setup to really check it in controlled environment. So, there are various kinds of tasks that are utilized to figure out how a particular participant, given on given various kinds of variables, how they perform in executive control tasks in various dimensions.

So, there are some of them are here, not all of them I have listed, but these are the most commonly utilized ones. So, Simon task, Flanker, Card sorting, Stroop task, working memory and so on.

Let us see them one by one. This is Simon task one of the most commonly utilized one. Simon task is basically, it is a behavioral task as I just mentioned.

So, this is this looks at the capacity of conflict resolution in a participant. Now, depending on what the research question, is we might connect, we might like to connect it to various kinds of population. For example, children versus adults, typical versus atypical children and so on and so forth; also language can be brought in as a variable and so on.

The task is like this, if the participants are told if they there is a red dot on the red circle it can be a square or anything, there is a red circle on if they see a red circle they have to press the right key, if they see a blue one they will have to press the left key. That is the only instruction given nothing else is told, right?

Now, so the right key is connected to the red, left key is connected to blue. Now, the manipulation here is there are three possible manipulation, one is called the congruent condition. Congruent condition is when remember this is the right key, red is connected to right key. So, in the congruent condition the red circle appears on the right side of the screen.

So, the red dot is on the right side of the screen, you have to press the right key. In the incongruent condition, the red circle appears on the left side of the screen and you have to still press the right key, because the position of the circle does not matter. The only cue for the participant is to press right for red, left for blue.

Similarly, the blue can blue's position can also be manipulated and this is called neutral because it has nothing to do with the horizontal, left/right kind of a coordination. Now, what is happening here is this on the face looks very simple. You see a red circle or a red dot or whatever, you press the right key. But the conflict is here, you have to press the right key, but the circle appears on the left side of the screen.

This is a conflict that often results in slower response latency, meaning the participant takes slightly longer to react. They might still get it correct, but they will take slightly longer time, also errors will be higher in this incongruent condition.

So, what is happening here is if you are, if you are able to this shows basically the reaction time that the participant shows, the time the time to react one and how accurate your responses are: these are the two output, that we look at and this shows how much how quickly and how ably the participant has been able to resolve the conflict.

This is a very very effective and very productive task, that is utilized for executive to check executive control mechanism in participants. Now, the depending on what our research question is, let us say we want to see if a bilingual person is better at conflict resolution as opposed to a monolingual person or a child typical child as opposed to atypical child you can that that all that will depend on the research question, but this is how the task looks. This is the conflict that is built into the system and we look at the conflict resolution by the participants.

Similarly, there is this is Eriksen Flanker task. Flanker task also revolves around conflict resolution and selective attention, sustained selective attention, it is a behavioral task. So, the target participant is required to respond to the target stimulus that is flanked by other stimuli. So, this tests as I said selective attention.

So, the task typically is to say which way this is one of the manifestations, but there can be many other ways of flanker task. A simple flanker task may have just simple arrows

like this. So, what happens in a flanker task is that the participant has to look at the central arrowhead or in this case the fish send the central this is the target.

And these are the ones that are flanking the target. So, this is the target and these are the flankers. These have no other role except disturbing the participant's attention. The participant has to keep his eyes constantly on the central target stimuli, whatever that is an arrow or a leaf or a fish basically it has a, it points towards one of the directions.

Now, you see in this particular this is called congruent condition, in this case it is easier to identify the central target because it is flanked by other stimuli that are all pointing to the same direction, hence it is called congruent. So, the central target as well as the flankers are all pointing to the same direction.

In the incongruent condition, there is a problem here. This one is pointing this way, but the central is pointing this way, again this is pointing that way. So, this is creating a conflict for the participant.

This is again the there is no distraction, these are all oriented differently this is vertically oriented, this is horizontally oriented; this can also have no flankers at all only the. So, these are various ways of presenting the stimulus, but the target stimulus remains the same.

The target stimulus is the central one. Sometimes it is flanked by similar type of stimuli, sometimes it is flanked by different. So, the idea is to check how much, under what circumstances the participant fails to detect the central arrowhead or the fish or whatever. So, basically this is a test of selective attention and response inhibition.

More often than not, what will happen is in many cases if this might distract, the flankers might distract the target stimuli. So, who gets distracted under what conditions, what task conditions, what kind of variables in terms of the participants and so on, will be the research question, but this is how the task looks.

Wisconsin card sorting task is again a very commonly utilized one, to check cognitive control and this also has a very crucial aspect which is updating, which is flexibility, adaptability. So, this is a game; this game revolves around choosing cards, sorting cards. Now, the cards are different, there are many ways of playing the card. There are many

possible sets for children the sets are small lesser in number, for adults they are larger in number.

So, the cards are different in terms of you can you can make it as complex as you want. In this particular case the example that we have they are different in terms of color, in terms of shapes and in terms of the number of objects that are present, right? So, here there are two and there is this is red and then there are these are triangles this is this is star and so on and so forth.

So, the cards here in this particular set are different in terms of three different variables, so color, shape and the number. Now, the game starts like this, the experimenter plays starts playing and then starts sorting the cards as per some rule and then the other participants will have to subjects, that are participants who are participating in the experiment will have to play along.

So, they notice the experimenter and then they play along. Without telling the participants, the experimenter changes the rule after a few let us say 6 or 7 times of playing, after that the experimenter changes the rule and then the participant is supposed to follow suit. Now, how quickly you can adapt to the changed rule of the game is what Wisconsin card sorting task basically looks at.

So, let us say you start the game with color, sorting on the basis of color and then after 10 games you just change it into shape and after 5 games, you change it into the number of objects present and so on and so forth. So, this can change randomly number of tiles may not be same and so on and so forth.

So, that success in this particular game of the participants depends entirely on how flexible you are, how quickly you adapt to the new rule that has been brought into the game and so on.

So, basically you updating of relevant information and adaptability as part of the changed goal is what Wisconsin card sorting tasks task looks at. This is used for both children as well as adults, in various task conditions. So, this is again a very important aspect of executive control.

This is the famous Stroop task this is what we talked about in the beginning, that Posner and his group were talking about. Stroop task looks like this, stroop task has many different variations, there are many different types now. Nowadays we have many different manifestations, but this is the classic stroop task.

Here you notice the word purple is written, but it is written in red color similarly yellow and red and so on. So, the automatic response here will be to read them as purple, yellow, red, but the task might require you to say red, blue and green. So, this is the, this is the classic stroop task, this is called the color word stroop task. There can be picture and words stroop task and many other types.

But, stroop task basically looks at how you can suppress the automatic response. Automatic response is to automatic processing is to read the word. But our task is not to read the word, our task is to name the color of the word.

So, this is what it looks at, suppressing the irrelevant cue and basically with respect to selective attention. This is one of the most well known psychological tests and processing speed is often one of the outputs of this test.

There are many others also, there are tasks based on working memory like N-back task and so on and so forth. We will see some of them when we discuss the discuss various experiments. And of course, in today, these are the classic types of tasks behavioral tasks and today of course, we have some many new types and which also we will see. For example, interlocutor the presence of another person in the picture, or in presence of a culturally sensitive cue and so on and so forth.

So, now what happens in an experimental setup is that as the participant takes part in various kinds of behavioral tasks, sometimes simultaneously there is also a brain mapping that goes hand in hand. So, you might have a stroop task and an EEG, or a stroop task and an FMRI going side by side and that is how we know that which brain area is responsible for which kind of conflict resolution and so on.

Sometimes the behavioral tasks are utilized on their own, as a standalone experimental setup as well. We will see some of them as we go ahead. Now, so this is the background of cognitive control or executive function as we as we have just seen.

Now, cognitive control with respect to language is what we are primarily interested in. Now, why language? One of the basic assumptions is that communication itself is a complicated process. This is a not simple thing, with though we take it for granted as I have mentioned in the introduction that we communication, speaking, being understood these are taken for granted, but often it does not work that way.

We do not notice, but it is a very very complicated process. So, communication itself is a complicated process that needs organizing our thoughts, organizing the lexical outputs, organizing the sentence structure and so on and so forth. An action in accordance with a goal for example, choosing the right word. So, what is the right word in a friends' group is not a right word in a formal setup for example, for the same topic, for the same participants and everything.

So, choosing a right word, making sense of anomalous or ambiguous sentences and so on and so forth are some of the very simple problems we face in communication. Sensory and motor systems typically provide clues about other people, realities of the world and so on. If you notice in a communicative scenario we automatically update ourselves continuously on the feedback that we get, non verbal feedback.

So, how you know that is the sensory motor in input that we are getting. So, as I speak in a class let us say when we when we talk in a class or in a group of people. You are constantly taking in the feedback of the other people and then you accordingly change your way of speaking or you change the way you are the kind of words you are using or you use simpler words, simple sentences or whatever.

It can it is entirely dependent on the participants and the your goal and the environment. So, this is so communication happens within this kind of a complex system, even though we do not really we are not always conscious of it, but this is what actually goes on. So, we do, we do update, we do some play adjustments in our speak speech, even in a simple scenario.

So, the conflicts thus can arise. So, an internal state caused by incompatibility of multiple representations or opposition of action tendencies, this is what conflict is all about. In the domain of language processing, conflicts usually appear between simultaneously activated lexical items or sentential representations within or across languages.

So, a lot of literature, lot of research in terms of connecting language with executive control, basically revolves around these domains. So, we have we activate multiple lexical candidates at the same time, as we speak or as we even just hear that we have already seen in some cases before.

So, the simultaneously activated lexical items that already creates a conflict scenario that has to be resolved and it does get resolved without any delay. So, as we speak, let us say as we speak, sometimes the word that I was supposed to, I had in my mind I decide not to use it at the last moment and choose a different word.

I do not have to really pause, it automatically comes because that act that similar sounding or similar meaning word is already activated. In a in a normal scenario, in a normal communicative scenario we need to choose between all these possible candidates. Sometimes even sentential representation, if you are a bilingual or a multilingual and so on and so forth.

So, you see a simple communicative scenario also can create a lot of conflict. In fact, it does create a lot of conflict only thing is that we do not see it, we resolve it automatically, the brain resolves it automatically. It is for dealing with such confusions; confusions as in competitions among linguistic candidates, their relationship with worldly realities and so on, as well as interference; interference in case of bilinguals more importantly, of course it also happens in monolinguals.

So, you might have different word candidates, what we call synonyms. Synonyms are actually not an exact replica of each other, they are slightly different in meaning, but they are similar in meaning. So, for a monolingual the conflict is choosing the right word among the synonyms for a different, for a particular purpose, for a particular goal, for a particular environment.

So, what is suitable for a legal document, is not suitable for a normal scenario, even if you are talking about the same property with the same people. So, legal documents reads very different. Similarly, if this problem gets more complicated if you are a bilingual. So, there are too many candidates, too many lexical candidates, too many possibilities to choose from and that creates interference.

So, your language one might interfere with your language two or vice versa depending on various parameters. So, these are the some of the some of the problems, some of the conflict that we are talking about in terms of language; language as in language processing.

So, that is why the conflict, conflict monitoring and conflict resolution is part of language processing as well. And inhibition basically refers to the inhibiting the interferences from the other candidates, whether it is a lexical candidate or a sentential candidate.

So, that is where we bring in executive control in terms of language processing. So, language processing when we talk about language processing and executive control, this is where we are going. Why do we need executive control mechanism? Because we need to monitor and resolve conflict. Where is conflict in language? There is conflict in language in these kind of domains.

Sometimes ambiguous sentences, some sentences are ambiguous without a context we do not really know what it means. So, the word bank without a context, 'I am going to the bank', it can be riverbank, it can be the financial or institution organization bank. So, then you need a context.

So, these are simple things, but then there are many other complex scenario as well with respect to language use, whether you are comprehending or producing language. So, these are the domains that we will look at in detail in the coming sections and with respect to various kinds of mechanisms.

Similarly, you can the speaker may use executive function also to select the right word from competing alternate. So, these are some of the references that we have in many of these domains.

So, one is to select the right word among computations, another is to switch from one language to another. This is another very important area of research now in bilingualism when we switch from one language to another what happens, what are the sub processes that are part of it and how executive control mechanism, cognitive control is a part of that; that is also yet another area. So, these are the some of the references.

The listener may use executive functions. So, here this is when you are producing sentence, here when you are listening right. Select among competing interpretations according to the

communication goal. So, to grasp what the speaker really says and ignore what we already the person already knows.

So, when you are listening to somebody speaking as also you need to resolve a lot of conflicts. Sometimes you might already know, you already have a an idea that is established in your mind, but the speaker might mean completely different things. So, that also leads to conflict resolution.

So, this is the introduction to this particular segment. In the next part, we will look into more detail look at look in more detail into each of these aspects of relationship between language processing and executive control mechanism.

Thank you.