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The interaction between arousal and cognitive control

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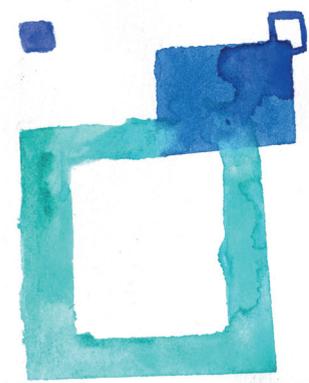
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Chapter 8

Summary



Summary

Imagine you are sitting in a library writing this summary. In front of you are a laptop, your phone, and some snacks you will save for later. To your left, a few students are whispering to each other. To your right, people walk by, occasionally stopping to browse the bookcase. Outside, the rain gently taps against the windows.

Remarkably, most people can concentrate most of the time on writing amid these myriad possible distractions. How do we manage to ignore millions of years of evolutionary tendencies (registering new movements in our environment) for a purpose that didn't even exist until a few hundred years ago (writing a dissertation) on a device invented only a few decades ago (the laptop)? This flexibility to both invent new goals and execute new behaviors is something that humans master like no other.

This capacity at issue here is **cognitive control**: the art of connecting a goal to behavior, even when it goes against more automatic or instinctive behaviors. In the example mentioned above, cognitive control is the art of focusing on writing the summary even when your automatic inclination would be to register movement in the environment or eat the snacks next to you.

While this is impressive, when you think of this definition, you probably think of cognitive control primarily as something that sometimes doesn't work. Especially in the context of studying or reading, you will find that you get into a flow in certain circumstances, while in other circumstances, you get distracted by the slightest thing. This difference is exactly what the dissertation is about. Why do we have such an impressive capacity to convert goals into behavior, but do we differ so much in whether we succeed? Why do I manage to write the summary undisturbed for an hour one time, but at another time, every little sound draws my attention away from that goal?

In this dissertation, we seek an explanation for this phenomenon in the workings of the brain, specifically in the mechanisms of the brain that regulate how active your nervous system is. We call this concept **arousal**, which is strongly associated with **stress**. This arousal mechanism is at a low ebb when sleeping and kicks on full blast when a tiger suddenly appears in your living room. Between these two extremes, there are still many gradations of arousal, and we think those subtle gradations affect how your cognitive control works.

The subtle and not-so-subtle gradations of arousal are largely regulated by groups of neurons in the brainstem, collectively called the **brainstem arousal system**. Here, a specific small group of neurons in your brainstem called the **locus coeruleus** is given an important role. The locus coeruleus produces and distributes an essential substance in the brain called **norepinephrine**. With the small size of the locus coeruleus, you might think its influence is limited, but nothing could be further from the truth: the offshoots of this small group of neurons reach almost all parts of the brain. With this, the locus coeruleus is in a key position to rapidly alter the state of the brain by pumping norepinephrine around, thereby also affecting the functioning of cognitive control.

An important finding made in the research on the functioning of the locus coeruleus and arousal is that the activity of the locus coeruleus correlates with the size of your **pupil**, given that light remains constant. Through **pupillometry**, researchers have found that there are indeed continuous fluctuations in the activation of the locus coeruleus, and these fluctuations

are related to arousal. If you've had a really strong coffee, see your crush walking by, or are startled by an unexpected horn next to you, the pupil will enlarge slightly.

So, we know that humans have the capacity to convert goals into behavior (cognitive control) and that the functioning of this capacity is variable. We also know that the locus coeruleus gives us the capacity to regulate the arousal state of the brain and that this also fluctuates continuously. In this study, we asked the question: is variation in the functioning of cognitive control related to fluctuations in arousal? We investigated this question in three different studies.

In each of the studies, we tried to answer this question not only by formulating and testing hypotheses in words but also by formulating and testing hypotheses in **computational models**. These computational models allowed us to create and test simulations of how we think arousal and cognitive control are related. You can think of this as the difference between describing what you think the weather will be tomorrow based on your observations today and feeding these observations into a weather simulation program so that a mathematical model predicts what the weather will be tomorrow.

In **Chapter 2**, we investigated whether fluctuations in arousal are related to performance in the famous Stroop task. In this task, we ask participants to name the color in which the word is written on the screen. The words denote colors. So you can get **RED** on the screen, but you can also get **RED**. In the second situation, you must suppress your impulse to read the word and answer “blue” instead of performing the task correctly. We found that pupil size before a task predicted how well participants could handle the tricky situations. Our computational models showed that cognitive control can best be defined in this task by distinguishing between **proactive cognitive control** (having a clear sense of purpose before the task begins) and **reactive cognitive control** (dealing adequately with conflicting information after receiving it).

In **Chapter 3**, we sought an explanation for a well-known phenomenon in cognitive control research: why does your cognitive control seem to work worse after a tone reminds you that the task is about to begin? We investigated this using the flanker task, in which you must determine the direction of the middle arrow. Sometimes, the surrounding arrows would point in the same direction (>>>>>) but sometimes in the opposite direction (>><<>>). In the second case, you would have to suppress the irrelevant information. We could explain the effect of the deterioration of cognitive control through an “urgency signal” that activates the brain after the tone. This signal is associated with a brief arousal boost, helping you respond faster but making it harder to process conflicting information properly. This also explains something you may have experienced yourself: when you experience a lot of stress, your actions will be faster, but as soon as you are faced with a difficult choice, you often become slower in making that choice.

In **Chapter 4**, we zoom out slightly and examine a trade-off you continually (unconsciously) make: how “not distractible” should you be in the moment? The connotation is that more cognitive control to perform a task is often good, but there are plenty of situations where that is not good. For example, if you are a doctor on the emergency phone, you need to shift gears quickly as soon as the phone rings, even though you had intended to write the thesis summary. This trade-off guards the balance between stability (focus on your current goal) and flexibility (quickly shifting gears to another goal). In this study, participants performed two tasks. Which task they had to perform, they were shortly before each one. Participants

returned on two different days: on one day, they had to change tasks back and forth very often, and on the other day, they had long sequences of the same task. We found that when participants had to switch tasks more often, they switched more to flexibility on the stability-flexibility scale, as we predicted. This correlated with changes in pupil size and brain waves, suggesting that the arousal system at least partly regulates the stability-flexibility trade-off. This study highlights an important lesson: if you create a context where you switch tasks often, you will be less able to focus on your current goal given that context.

In summary, these studies show how subtle fluctuations in arousal can partly explain variations in cognitive control. This research provides clues to understand better why cognitive control in people with an ADHD or ADD diagnosis sometimes functions less well and why cognitive control in people without a diagnosis sometimes seems not to work as well.

