Huberman Lab #20 - How to Learn Skills Faster

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Introduction

Welcome to the Huberman Lab podcast where we discuss science and science-based tools for everyday life. I'm Andrew Huberman and I'm a professor of neurobiology and ophthalmology at Stanford School of Medicine. This podcast is separate from my teaching and research roles at Stanford. It is, however, part of my desire and effort to bring zero cost to consumer information about science and science-related tools to the general public. In keeping with that theme, I'd like to thank the sponsors of today's podcast.

Our first sponsor is Belcampo Meat Company. Belcampo Meat Company is a regenerative farm in Northern California that raises organic, grass-fed, and grass-finished certified humane meats. I eat meat about once a day. I'm neither pure carnivore nor am I vegetarian. Obviously, I eat meat. The way I eat is I tend to fast until about noon. And then, I have my first meal - which generally consists of a piece of beef. You know, it's either ground beef or a steak. I like rib eyes, I like flat irons - these kinds of things - and a small salad - sometimes a large salad. And then throughout the day, I generally am low-carb until the evening when I eat pasta, and rice, and things of that sort. Eating that way is what optimizes my levels of alertness and optimizes my sleep. I've talked about this on previous podcast episodes. Now, because I eat meat essentially every day, the source of that meat is extremely important to me. I want it to be healthy for me and I want the animals that it comes from to be healthy and to have lived a good life. Conventionally raised animals are confined to feed lots and they eat a diet of inflammatory grains - which is terrible for them. And it's terrible for us when we eat those meats. Belcampo's animals graze on open pastures and seasonal grasses, which results in meat that is higher in nutrients and healthy fats. They actually have very high levels of omega-3s, which I've also talked about on this podcast are important for mental and physical health for a variety of reasons. The way Belcampo raises its animals is also good for the environment. They practice regenerative agriculture, which means it's climate positive and carbon negative - which translates to good for us and good for the planet. You can order Belcampo's sustainably raised meats to be delivered straight to your door using my code "huberman" by going to belcampo.com/huberman and you'll get 20% off your first-time order. That's belcampo.com/huberman for 20% off.

Today's podcast is also brought to us by InsideTracker. InsideTracker is a personalized nutrition platform that analyzes data from your blood and DNA to help you better understand your body and reach your health goals. I've long been a believer in getting blood work done for the simple reason that many, if not most, of the factors that impact our immediate and long-term health can only be assessed from a blood test. And now with the advent of modern DNA tests, we can get additional information about our current health status and our health trajectory. One of the major problems with blood tests and DNA tests available from most sources is that you get the numbers back and you can easily see whether or not those numbers are within the standard range or outside the range, but it's very hard to know what to do with that information. Also, what the various factors are that are being measured is often very cryptic. With InsideTracker, they clarify everything. They make it very clear and simple as to what each of those factors relates to. So, they give you some understanding of what those are. And they give you ideas and suggestions about things that you

can do with your lifestyle - changes to your diet, changes to your supplementation, changes to your sleep schedule or exercise patterns - that can serve to optimize the levels of those various factors and your DNA. In addition, they have something called the InnerAge test - which compares your chronological age, which you already know, with your biological age - which gives you a sense of your lifespan or predicted lifespan. So, that's crucially important. And you can imagine why many people, including me, would want that information. If you'd like to try InsideTracker, you can visit insidetracker.com/huberman and you'll get 25% off any of InsideTracker's plans. Use the code "huberman" at checkout. That's insidetracker.com/huberman to get 25% off any of InsideTracker's plans and use the code "huberman" at checkout.

Today's episode is also brought to us by Athletic Greens. Athletic Greens is an all-in-one vitamin mineral probiotic drink. I've been using Athletic Greens for well over a decade now. I started using Athletic Greens and I still use Athletic Greens because I find it rather dizzying to know which vitamins and minerals to take. And with Athletic Greens, I cover all my bases of vitamins and minerals. In addition, it has probiotics. And we now know from an enormous number of quality peer-reviewed studies that the gut microbiome is critically important for our immune system function, for the gut-brain axis, and for our mental functions. And probiotics are one way to support the gut-brain axis and the gut health generally. With Athletic Greens, I basically just add water, put in a little bit of lemon juice - because that's the way I like it - mix it up. It tastes delicious. I'll do that once or twice a day. It's compatible with fasting - at least for me. It doesn't take me out of a fasting mode, which I do early in the day. So most often, I'll have my Athletic Greens early in the day. And then sometimes, I'll also have another one late in the evening or sometimes even before bed. I'm able to sleep after drinking it without a problem. If you'd like to try Athletic Greens, you can go to athleticgreens.com/huberman. And if you do that, you can claim a special offer. They'll give you five free travel packs, which are these little packs that make it very easy to mix up Athletic Greens while you're on the road, or in the car, or on a plane. It makes all of that very simple. And in addition, they will give you a year's supply of vitamin D3K2. There are also a lot of data supporting the fact that vitamin D3 is critical for a variety of health metrics. We all know that we can get vitamin D3 from the sun. But many people, including me, were not getting enough sunlight or D3 - even if I was getting a lot of sunlight, I know that because I had my blood levels measured of D3. So, I use vitamin D3 every day in addition to the other things I take - including Athletic Greens. If you go to athleticgreens.com/huberman, you'll get the Athletic Greens, the five free travel packs, and a year's supply of the vitamin D3 and K2. That's athleticgreens.com/huberman to claim the special offer.

This month on the Huberman Lab podcast, we're talking all about physical performance. So, that means athletic performance, recreational exercise, weightlifting, running, swimming, yoga, skills, and skill learning. Today, we're going to talk about and focus on skill learning. We are going to focus on how to learn skills more quickly - in particular, motor skills. This will also translate to things like musical skills and playing instruments. But we're mainly going to focus on physical movements of the body that extend beyond the hands, like just playing the piano - or the fingers, like playing the guitar. But everything we're going to talk about will also serve the formation, and the consolidation, and the performance of other types of skills. So, if you're interested in how to perform better -

whether or not it's dance or yoga - or even something that's just very repetitive, like running or swimming - this podcast episode is for you. We're going to go deep into the science of skill learning and we are going to talk about very specific protocols that the science points to and has verified allow you to learn more quickly, to embed that learning so that you remember it, and to be able to build up skills more quickly than you would otherwise.

We are also going to touch on a few things that I get asked about a lot. But fortunately, recently I've had the time to go deep into the literature - extract the data for you. And that's mental visualization. How does visualizing a particular skill or practice serve the learning and/or the consolidation of that practice? Turns out there are some absolutely striking protocols that one can use - "striking" meaning they allow you to learn faster and they allow you to remember how to do things more quickly and better than if you were not doing this mental rehearsal. But the pattern of mental rehearsal and when you do that mental rehearsal, turns out to be vitally important. So, I'm excited for today's episode. We're going to share a lot of information with you and they're are going to be a lot of very simple takeaways. So, let's get started.

Clarification - Cold / Heat / Caffeine
Before we get into the topic of skill learning and tools for accelerating skill learning, I want to briefly revisit the topic of temperature - which was covered in the last episode - and just highlight a few things and clear up some misunderstandings. So last episode, talked about these incredible data from my colleague Craig Heller's lab at Stanford - he's in the Department of Biology - showing that cooling the palms in particular ways and at particular times can allow athletes or just recreational exercisers to do more pull-ups, dips, bench presses per unit time - to run further - to cycle further - and to feel better doing it. There really our incredible data that are anchored in the biology of the vascular system - the blood supply - and how it's involved in cooling us. Many of you - dozens of you, in fact - said, "Wait a second. You gave us a protocol in this episode, which says that we should cool our palms periodically throughout exercise in order to be able to do more work. But on the episode before that on growth hormone and thyroid hormone. You said that heating up the body is good for release of growth hormone."

And I just want to clarify that both things are true. These are two separate protocols. You should always warm up before you exercise. That warm-up will not increase your body temperature or the muscle temperature to the point where it's going to diminish your work capacity - that it's going to harm your performance. The cooling of the palms, which is really just a route to cool your core in an efficient way - the most efficient way, in fact - is about improving performance. Heating up the body with exercise and focusing on heat increases - or using sauna for heat increases - is geared toward growth hormone release, which is a separate matter. So, you can do both of these protocols, but you would want to do them at separate times. So, just to make this very concrete before I move on to today's topic - if you're interested in doing more work - being able to do more sets and reps per unit time and feel better doing it, or to run further, or to cycle further - then cooling the palms periodically, as I described in the previous episode, is going to be the way to go. If you're interested in getting growth hormone release, well then hot sauna - and I offered some other

tools, if you don't have a sauna in the episode on growth hormone and thyroid hormone - is going to be the way to go. So, those are separate protocols. You can include them in your - in your fitness regime and your training regime, but you do want to do them at separate times.

And as a last point about this, I also mentioned that caffeine can either help or hinder performance depending on whether or not your caffeine-adapted because of the ways that caffeine impacts body temperature and all sorts of things like vasodilation and constriction. It's very simple. If you enjoy caffeine before your workouts and you're accustomed to caffeine - meaning you drink it three, or five times, or more a week - 100 to 300 milligrams is a typical daily dose of caffeine. Some of you are ingesting more, some less. If you do that regularly, well then it's going to be just fine to ingest caffeine before you train. It's not going to impact your body temperature and your vasodilation or constriction in ways that will hinder you. However, if you're not a regular caffeine user and you're thinking, "Oh, I'm going to drink a cup of coffee and get this huge performance-enhancing effect." Well, that's not going to happen. Chances are it's going to lead to increases in body temperature and changes in the way that blood flow is happening in your body - and in particular, on these palmar surfaces and in your face - that is going to likely diminish performance. So, if you enjoy caffeine and you're accustomed to it - so-called caffeine adapted - enjoy it before you're training. If you regularly - excuse me, if you do not regularly use caffeine - then you probably do not want to view caffeine as a performance-enhancing tool.

Side Stitch / Side Cramp
And while we're on the topic of tools and because this is a month on athletic performance, and exercise, and physical skill learning, I want to offer an additional tool that I've certainly found useful - which is how to relieve the so-called side stitch or side cramp when running or swimming. This actually relates to respiration and to the nervous system. And it is not a cramp. If you've ever been out running and you felt like you had a - a pain on your side. That pain could be any number of things, but that - what feels like cramping of your side is actually due to what's called collateralization of the phrenic nerve - which is a lot harder to say than a "side cramp" or a "side stitch". But here's the situation. You have a set of nerves, which is called the phrenic nerve - P-H-R-E-N-I-C - the phrenic nerve - which extends down from your brainstem, essentially - this region - to your diaphragm to control your breathing. It has a collateral - meaning it has a branch, just like the branch on a tree - that innervates your liver. And if you are not breathing deeply enough, what can happen is you can get what's called sometimes a referenced pain.

Reference pain is probably going to be familiar to any of you who have ever read about how to recognize heart attack. You know, people have heart attacks will sometimes have pain on one side of their body - the left arm. Sometimes people that have pain in a part of their back will suddenly also get pain in their shoulder or part of their face. This has to do with the fact that many of our nerves branch and are - meaning they're collateralized to different organs and areas of the body. And the way those nerves are woven together, it's often the case that if we disrupt the pattern of firing of electrical activity in one of those nerve branches that the other ones are affected to. The side stitch, the pain in your side, is often because of the contractions of the diaphragm because of

the way you're breathing while you're exercising - running, or swimming, or biking. And as a consequence, you feel pain in your side. But that's not a cramp.

The way to relieve it is very simple. You do the physiological sigh that I've talked about in previous episodes of the podcast and elsewhere - which is a double inhale through the nose - very deep. And then, a long exhale. And you might want to repeat that two or three times. Typically, that will relieve the side stitch because of the way that it changes the firing patterns of the phrenic nerve. So, the side stitch is annoying. It's painful. Sometimes when you think we're dehydrated - and you might be dehydrated - but oftentimes, it's just that we're breathing in a way that causes some referenced pain of the liver. We call it a side stitch or a side cramp. And you can relieve it very easily through the double inhale, long exhale [breathing sounds]. That pattern done two or three times. Often you can continue to engage in the exercise while you do the double inhale, exhale and it will just relieve itself that way. So, give it a try. If you experience the side stitch - some people I know are also doing the double inhale, long exhale during long continuous bouts of exercise. I actually do this when I run. We have decent data - although, these are still unpublished data that that can engage at - kind of - regular cadence of heart rate variability. So, there are a number of reasons why this physiological sight can be useful, but it certainly can be useful for relieving the side stitch or so-called "side cramp".

Physical Skills: Open-Loop vs Closed-Loop
Let's talk about the acquisition of new skills. These could be skills such as a golf swing, or a tennis swing, or you're shooting free throws, or you're learning to dance, or you're learning an instrument. I'm mainly going to focus on athletic performance. There are basically two types of skills: open-loop and closed-loop. Open-loop skills are skills where you perform some sort of motor action, and then you wait, and you get immediate feedback as to whether or not it was done correctly or not. A good example will be throwing darts at a dart board. So if you throw the dart, you get feedback about whether or not you hit the bullseye, you're off the dart board, or you're some other location on the dart board. That's open-loop. Closed-loop would be something that's more continuous. So, let's say you're a runner, and you're starting to do some speed work and some sprints, and you're running and you can kind of feel whether or not you're running correctly. Or maybe you even have a coach and they're correcting your stride or you're trying to do some sort of skill like the - like a hopscotch skill - which - you know - maybe you're doing the ladder work where you're stepping between designated spaces on the ground. That's closed-loop because as you go, you can adjust your behavior and you can adjust the distance of your steps, or you can adjust your speed, or you can adjust your posture. And you are able to essentially do more practice per unit time. But you're getting feedback on a moment-to-moment basis, okay,? So, you have open-loop and closed-loop.

And just to make this very, very clear - open-loop would be practicing your tennis serve. So, let's say that you set a target on the other side of the net. You throw the ball up and you - you hit the ball. It goes over. That's open-loop. You'll know whether or not you were in the court, you were on the location you wanted to hit, or close to it or not. That's open-loop. Closed-loop would be if you were in a regular cadence. So, maybe you're learning a swim stroke or maybe you're trying to learn a

particular rhythm on the drums. So, maybe you're trying to learn a particular beat - I'm not very musical, so I'm not going to embarrass myself by giving an example of this - although, later I - I will - where you're trying to get a particular rhythm down. And if you're not getting it, you can adjust in real time, and try and catch up, or slow down, or speed up, etc. Okay, so hopefully you'll understand open-loop and closed-loop. You should always know before you try and learn a skill, whether or not it's open-loop or closed-loop. And I'll return to why that's important shortly. But if you want to learn something, ask: Is it open-loop or closed-loop?

Three Key Components to Any Skill
There are essentially three components of any skill that involves motor movement. And those are sensory perception, actually perceiving what you are doing and what's happening around you. So what you see, what you hear - sometimes you're paying attention to what you're doing, specifically - like the trajectory of your arm or how you're moving your feet if you're learning to dance. Sometimes you're more focused on something that's happening outside of you - like you're listening for something in music - or you're paying attention to the way your partner is moving, etc. So, there's sensory input. Then, there are the actual movements, okay? So, there are the movements of your limbs and body. And then, there's something called proprioception. And proprioception is often discussed as kind of a sixth sense of knowing where your limbs are in relation to your body. So, proprioception is vitally important. If I reach down and pick up this pen and pick it up, I'm not thinking about where the pen and my hand is relative to my body. But proprioceptively, I'm aware of it at kind of a sixth sense, deeper subconscious level. I can also make myself aware of where - where my limbs are. And typically when we learn, we are placing more focus on proprioception than we do ordinarily. So, if I get up from this chair and I happen to walk out of the room, I don't think about where my feet are landing relative to one another. But if my leg had fallen asleep because I had been - you know - leaning on one of the nerves of my leg or something like that and my leg feels all tingly or numb, I - you - I and you - if this were to happen to you, would immediately notice a shift in gait. It would feel strange. I'd have to pay attention to how I'm stepping. And the reason is I'm not getting any proprioceptive feedback. Now, skill learning has a lot of other dimensions too. So, just to remind you, you need to know open-loop or closed-loop and you need to know whether or not - excuse me - you need to know that there's sensory perception - what you're paying attention to, movements themselves, and proprioception.

Central Pattern Generators (CPGs)
And there's one other important thing that you need to know - which is that movement of any kind is generated from one, two, or three sources within your nervous system - within your brain and body. These are central pattern generators, which are sometimes called CSPGs - excuse me, CPGSs. CSPGs are something entirely different in biology. CPGSs - this just goes to show that I have a module. CSPGs are chondroitin sulfate proteoglycans. They have nothing to do with this topic. CPGs are central pattern generators - or CPGs, they're sometimes called. These CPGs are in your spinal cord - mine and yours - different ones - and they generate repetitive movements. So if you're walking, if you're running, if you're cycling, if you're breathing - which presumably you are - and you're doing that in a regular rhythmic cadence - central pattern generators are controlling that

movement. After you learn how to walk, run, swim, cycle - do anything really - much of the work is handed off to these central pattern generators.

And there were experiments that were done in the '60s, '70s, and '80s that actually looked at decerebrate animals and even decerebrate humans. These are humans and animals that lack a cerebral cortex. They lack much of the brain. And yet, they can engage in what's called a fictive movement. So, it sounds like a kind of barbaric experiment. I'm glad I wasn't the one to have to do them, but this is the stuff of neuroscience textbooks - that cats - that - or dogs or mice - that have their neocortex removed - put them on a treadmill, they'll walk just fine. And they will adjust their speed of walking just fine even though they basically lack all their thinking-decision-making brain. And it turns out humans that have, unfortunately, massive strokes to their cortex and lack any neocortex but preserve the central pattern generators will also walk just fine even though they lack any of the other stuff in the brain. So, these CPGs or CPGSs are amazing. And they control a lot of our already learned behavior.

When you're really good at something, CPGs are controlling a lot of that behavior. And that's true also for a golf swing even if it's not really repetitive. Somebody who's really good at golf is going to - I guess you call it a tee. You put the ball on the tee. I showed my knowledge of golf. I've only done mini golf, frankly. But someday maybe I'll learn how to golf. But you set the golf ball down and swing. Set the golf ball down - swing. Central pattern generators are going to handle a lot of that. If I were to go to the golf course - Stanford has a beautiful golf course. If I were to go out there - put a ball on the tee - my central pattern generators would not be involved in that at all. The moment I get - you know - bringing the club back to swing, it's going to engage other things.

Upper Motor Neurons
And the other things it's going to engage because I don't know that behavior - now or then - is upper motor neurons. We have motor neurons in our cortex - in our neocortex - that control deliberate action. And those are the ones that you're engaging when you are learning. Those are the ones that you have to pay attention in order to engage. And that's what's happening. For instance, if I decide I'm going to reach down and pick up my pen - which I rarely think about - but now I'm thinking about it and I'm going to do this in a very deliberate way. I'm going to grab with these two fingers and lift. My upper motor neurons are now involved, okay? So, upper motor neurons are very important because a little bit later in the episode when we talk about how to use visualization in order to accelerate skill learning, it's going to leverage these upper motor neurons in very particular ways, okay? So, we have CPGs for rhythmic movement - upper motor neurons for deliberate, unlearned movements or movements that we are in the process of learning.

Lower Motor Neurons
And then, we have what are called lower motor neurons. Lower motor neurons are the ones in our spinal cord that send little wires out to our muscles, which actually cause the firing of those muscle fibers, okay? So, the way to think about this is you've got upper motor neurons, which talk to CPGs

and to lower motor neurons. So, it's really simple. And now you know most to everything there is to know about the neural pathways controlling movement - at least for sake of this discussion.

What to Focus on While Learning

So, anytime we learn something, we have to decide what to place our sensory perception on - meaning: What are we going to focus on? That's critical. If you're listening to this and you're the type of person who likes taking notes, this should be the second question you ask. Remember, the first question is: Is it open-loop or closed-loop? The second question should be: What should I focus my attention on? Auditory attention? Visual attention? Or proprioception? Should I focus on where my limbs are relative to my body. Or should I focus on the outcome? Okay, this is a critical distinction. You can decide to learn how to do a golf swing, or learn how to shoot free throws, or learn how to dance tango and decide that you are going to focus on the movements of your partner or the positions of your feet. You - maybe you're going to look at them. Maybe you're going to sense them. You're going to actually feel where they are. Or maybe you're going to sense the position and posture of your body - which is more proprioceptive, okay?

So, you have to allocate your attention. And I'm going to tell you how to allocate your attention best in order to learn faster. So, these are the sorts of decisions that you have to make. Fortunately for you, you don't have to think about whether or not you're going to use your upper motor neurons and your lower motor neurons or not - because if you don't know how to do something, you're going automatically going to engage your upper motor neurons. And if you do, you are already - then, you're not going to use your upper motor neurons. You're mainly going to rely on central pattern generators. You are always using your lower motor neurons to move muscle. So, we can really simplify things now. I've given you a lot of information, but we can simplify it. Basically: Open-loop or closed-loop? That's one question. And what am I going to focus on? And then, your neurology will take care of the rest.

Reality of Skill Learning / 10,000 Hours Myth

So now, I want to talk about realistic expectations. Somewhere in Hollywood, presumably, it got embedded in somebody's mind that instant skill acquisition was possible. That you could take a particular pill, or you could touch a particular object, or you could have a wand wave over you and you would suddenly have a skill. And so, that is the result of Hollywood et al. It doesn't exist - at least, not in reality. And I love movies, but it simply doesn't exist. Then, the self-help literature created another rule called the 10,000 hours rule. And frankly, that doesn't really match the literature - at least, the scientific literature - either. I like it because it implies that learning takes time, which is more accurate than the Hollywood et al. instant skill acquisition rule - which isn't really a rule, it's a myth. But the 10,000 hours rule overlooks something crucial, which is that it's not about hours. It's about repetitions. Now, of course, there's a relationship between time and repetitions.

Repetitions & the Super Mario Effect

But there are some beautiful experiments that point to the fact that by simple adjustment of what you are focused on as you attempt to learn a new skill, you can adjust the number of repetitions that you do, you adjust your motivation for learning, and you can vastly accelerate learning. Some of you may recognize this by its internet name – which is not a scientific term – which is the "Super Mario effect". There's actually a quite good video on YouTube describing the Super Mario effect. I think it – it was a YouTuber who has – I – I think, a background in science. And he did an interesting experiment. And I'll talk about his experiment first. And then, I will talk about the neurobiology that supports the result that he got.

The Super Mario effect relates to the game "Super Mario Brothers", but you'll see why at the end. But basically what they did was they had 50,000 subjects – which is an enormous number of subjects – learn a program – essentially taking words from a computer program – or the commands for a computer program – that were kind of clustered in a column on the right. So, these are the sorts of things that computer programmers will be familiar with, but other people won't. And those commands are essentially – they essentially translate to things like – you know – go forward. And then, if it's a right hand turn in the maze, then go right. And continue until you hit a choice point, etc. So, it's a bunch of instructions, but the job of the subjects in these experiments were to organize those instructions in a particular way that would allow a little cursor to move through the maze successfully, okay? So, basically the goal was – or at least what the subjects were told is that anyone can learn to computer program. And if somebody can just organize the instructions in the right way, then they can program this little cursor to move through a maze. Very simple. And yet, if you don't have any background in computer programming, or even if you do, it takes some skill. You have to know what commands to give and what particular order. And they made that very easy. You could just assemble them in a list over onto the right. So, people started doing this.

Now, there were two groups and some – one half of the subjects – if they got it wrong – meaning they entered a command, and the cursor would move, and it was the wrong command for this little cursor to move through the maze – they saw a signal jump up on their screen that said, "That did not work. Please try again." That's it. If they got – if they put in the wrong command or it was in the wrong sequence, it would say, "That did not work. Please try again." And then, the people would – the subjects would reorganize the instructions and then the little cursor would continue. And if they got it wrong again, it would say, "That did not work. Please try again.", okay? The other half of the subjects – if they got something wrong – were told, "You just lost five points. Please continue." So, that's the only difference in the feedback that they got.

Now, I have to confess. I would have predicted – based on my knowledge of dopamine circuitry, and reward contingency, and epinephrine, and stress, and motivated learning, and this other thing that we've been told in many, many books on behavioral economics and in the self-help literature – which is that people will work much harder to prevent losing something than they will to gain something. That you hear all the time. And it turns out that that's not at all what happened. If they looked at the success rate of the subjects, what they found was that the subjects that were told, "That did not

work. Please try again.", had a 68% success rate. 68% of them went on to successfully program this cursor moving through the maze. Whereas the ones that were told, "You lost five points", had a 52% success rate - which is a significant difference. But the source of the success or the lack of success is really interesting. The subjects that were told, "That did not work. Please try again." Tried many, many more times per unit time. In other words, they made more attempts at programming this thing to allow this cursor to move through the maze. Whereas the people that were told, "You lost five points.", gave up earlier or gave up entirely.

Okay, so let's just step back from this because, to me, this was very surprising. It violates a lot of things that I had heard in the - kind of - popular culture or the self-help literature that people will work much harder to avoid losing something than they will to gain something. And it didn't really fit with what I understood about reward contingencies and dopamine. But it did fit well with another set of experiments that I'm very familiar with from the neuroscience literature. And I'll give you the punchline first. And then, we're going to take what these data mean and we're going to talk about a learning protocol that you can use that will allow you to learn skills faster by willingly participating in more repetitions of the skill learning - meaning you will want to do more repetitions even if you're getting it wrong some or most of the time.

Learning to Win, Every Time
So, the experiment that I want to tell you about is called the tube test. And this is generally done in mice - although, it's sometimes been done in rats - and it has a lot of parallels to some things that you've probably seen and experienced even in human life - in regular life - maybe even in your life. So, here's the experiment. You take two rats. You put them in a tube - or two mice. You put them in a tube. And mice and rats, they don't like to share the same tube. So, what they'll do is they'll start pushing each other back and forth - back and forth. Sooner or later, one of the rats or mice pushes the other one out. The one that got pushed out is the loser. The one that gets the tube is the winner, okay? Now, you take the winner. You give it a new competitor. And what you find is that the mouse or rat that won previously has a much higher than chance probability of winning the second time. In other words, winning before leads to winning again. And the reverse is also true. If you take the loser and you put that loser in with another mouse - fresh mouse - new mouse - the loser typically will lose at much greater probability than chance. And this is not related to differences in strength, or size, or testosterone, or any other things that might leap to mind as explanations for this because those were all controlled for.

Now, that result had been known about for decades. But three years ago, there was a paper published in the journal Science - phenomenal journal - it's one of the three apex journals - that examined the brain area that's involved in this. Turns out it's a particular area of the frontal cortex, for those of you that want to know. And they did a simple experiment where they - the experimenters increased or decreased the activity of this brain area in the prefrontal cortex - a little subregion of the prefrontal cortex. And what they found is if they stimulated this brain area, a mouse or rat - regardless of whether or not it had been a winner or loser before - became a winner every single time. And they showed that if they blocked the activity of this brain area - regardless of

whether or not the mouse or rat had been a winner or a loser - it became a loser every single time. And this translated to other scenarios - other competitive scenarios - where they'd put a bunch of mice or rats in a - kind of - cool chamber. They'd have a little heat lamp in the corner and mice like heat. And there was only enough space for one mouse to get the - be under the heat. And the one that had won in the tube test or that had the brain area stimulated always got the nice warm spot, okay?

So, what is this magic brain area? What is it doing? Well, the reason I'm bringing this up today - and the reason I'm bringing it up on the heels of the Super Mario effect - is that stimulation of this brain area had a very simple and very important effect - which was it led to more forward steps, more repetitions, more effort. But not in terms of sheer might and will - not digging deeper - just more repetitions per unit time. And the losers had fewer repetitions per unit time. So, the Super Mario effect, this online experiment, and the tube test - which has been done by various labs and repeated again and again - point to a simple, but very important rule - which is neither the 10,000 hours rule nor the magic wand Hollywood version of learning. But rather, the neurobiological explanation for learning a skill is you want to perform as many repetitions per unit time as you possibly can - at least, when you're first trying to learn a skill. I want to repeat that. You want to perform as many repetitions as you possibly can - at least, when you're first trying to learn a skill. Now, that might sound like a, "Duh." It's just more reps, but it's not so obvious. There's no reason why more repetitions should necessarily lead to faster learning because you could also say, "Well, more repetitions - you can make more errors. And those errors would lead to poor performance, like misstepping a number of times." And in these cases, there's - there's very little feedback, right? It's not like every time the - the rat pushes forward or moves back that it is sensing, "Oh, I'm winning. I'm losing. I'm losing. I'm losing.", on a micro level. It probably does that as it starts to push the other one out. The rat or mouse probably thinks, "Oh, I'm winning." And as it's backing up, it probably thinks, "I'm losing." As you play the game - the Super Mario game - you are told, "Nope, that didn't work. Nope, that didn't work.Please try again." But the important thing is that the winners are always generating more repetitions per unit time. It's just a repeat of performance - repeat of performance - even if there are errors. And that points to something vitally important - which is reps are important, but making error reps is also important. In fact, it might be the most important factor.

Errors
So, let's talk about errors and why those solve the problem of what to focus on. Because as I said earlier, if you want to learn something, you need to know if it's open-loop or closed-loop and you need to know what to focus on - where to place your perception. And that seems like a tough task, but errors will tell you exactly what to focus on. So, let's talk about errors and why you can leverage errors to accelerate skill learning Okay, so we've established that performing the maximum number of repetitions per training session is going to be advantageous. And that might seem obvious. But there's a shadowy side to that, which is, "Well, why would I want to just repeat the same thing over and over again if I'm getting it wrong 90% of the time?"

And the reason is that the errors actually cue your nervous system to two things. One to error correction. And the other is it opens the door or the window for neuroplasticity. Neuroplasticity is the brain and nervous system's ability to change in response to experience - essentially to custom modify itself in order to perform anything better. We did an entire month on neuroplasticity and I talked a little bit about errors and why they're important. Now, we're going to make this very concrete and operationalize it - make it very actionable.

There was a paper that was published in 2021 from Norman et al. This is a very important paper. It was published in the journal Neuron, which is a Cell Press journal - excellent journal. The title of the paper gives it - gives it away, essentially - which is, "Post-error recruitment of frontal sensory cortical projections promotes attention..." Now, what that says is that when you make an error, it causes an activation of the brain areas that anchor your attention. Remember, we need perception / attention - which - they're essentially the same thing. We need proprioception and we need the upper and lower motor neurons to communicate in the proper ways. And this vital question is: What to pay attention to? Errors tell your nervous system that something needs to change. So, if you are performing a task or a skill - like you're learning how to dance and you're stepping on the other person's toes, or you're fumbling, or you're not getting it right - those errors are opening the possibility for plasticity. If you walk away at that point, you've made the exact wrong choice, okay? Unless the errors are somehow hazardous to your health or somebody else's well-being, you want to continue to engage at a high-repetition rate. That's really where the learning is possible.

Without errors, the brain is not in a position to change itself. Errors actually cue the frontal cortex networks - what we call top-down processing - and the neuromodulators - things like dopamine, and acetylcholine, and epinephrine - that will allow for plasticity. So, while the Super Mario experiment - the maze experiment - was only focused on generating errors - telling people, "That wasn't right. Please try again." - or, "That wasn't right. You lost five points." - the key distinction is that the errors themselves cued people to the fact that they needed to change something. So, if you're trying to learn a new skill and you're screwing up and you're making mistakes - the more mistakes you make, the more plastic your brain becomes. Such that when you get it right, that correct pattern will be rewarded and consolidated.

And you can trust that it will because the performance of something correctly is associated with the release of this neuromodulator dopamine. Dopamine is involved in craving and motivation. It's involved in a lot of things, but it's also involved in learning. We will do an entire episode on dopamine and learning. But because some of you are probably wondering, this does not mean that just increasing your dopamine levels before learning will allow you to learn faster. In fact, increasing your dopamine levels before learning using pharmacology will actually reduce what's called the signal-to-noise. It will make these increases in dopamine that pop up in your brain - that suddenly make you realize, "Ah, I got that one right!" It will make those smaller relative to the background levels of dopamine, okay? You want a big spike in dopamine when you perform a motor pattern correctly. And you want to make lots of errors - many, many repetitions of errors - in order to get to that correct performance.

Now, if you're like most people, you're going to do this in a way that's somewhat random - meaning - let's say it's a tennis serve. I can't play tennis. I've - I think I've probably played tennis twice. So, if I throw the ball up in the air and hit it, I'm going to get it wrong and probably hit the net. Then, hit the net. Then, I'll probably go too long. Then I'll probably go over the fence. At some point, I'd like to think, I'll get it correct. The dopamine signal for that is going to be quite big. And I'll think, "Okay, what did I do there?" I actually don't know. I wasn't paying attention. What I was paying attention to is whether or not the ball went to the correct location on the opposite side of the net. Remember, it's an open-loop move. So, I don't actually know what I did correctly. But your nervous system will take care of that provided I, in this case, complete more and more repetitions.

Why Increasing Baseline Levels of Dopamine Prior to Learning Is Bad
Now, if I were to just elevate my basal level of dopamine by taking - I don't know - 1,500 milligrams of L-tyrosine or something - that would be bad because the increase in dopamine would actually be much lower, right? The - we would say the delta is smaller - the signal-to-noise is smaller if my overall levels of dopamine are very, very high. So, I'm actually going to learn less well. So, for skill learning - motor skill learning - increasing your dopamine levels prior is not a good idea. It might help with motivation to get to the learning. But it's not going to improve the plasticity process itself and it's likely to hinder it, okay? So, that's very important.

Framing Effect
So, these errors cue the brain that something was wrong and they open up the possibility for plasticity. It's what's sometimes called the framing effect. It frames what's important. And so, I think this is a - a shift. We've heard about - you know - growth mindset - which is the incredible discovery, and theory, and practice of my colleague, Carol Dweck at Stanford. This is distinct from that, right? This isn't about a motivation to learn. This is about how you actually learn. So, the key is designate a particular block of time that you are going to perform repetitions. So, maybe that's 30 minutes - maybe that's an hour. Work for time. And then, try and perform the maximum number of repetitions that you can do safely, for you and others, per unit time. That's going to be the best way to approach learning for most sessions. I will talk about other things that one can do. But making errors is key. And this isn't a motivational speech. I'm not saying, "Oh, go make errors. Errors are good for you. You have to fail in order to win." No, you have to fail in order to open up the possibility of plasticity. But you have to fail many times within the same session. And those failures will cue your attention to the appropriate sensory events.

Warning to Coaches
Now, sometimes we're working with a coach. And so, this is a shout out to all the coaches. Thank you for doing what you do. However, there needs to be - at least, what the scientific literature say - there needs to be a period of each training session whereby the athlete or the person of any kind can simply pay attention to their errors without their attention being cued to something else. A really well-trained coach will say, "Oh, you know, your elbow is swinging too high.", or "You're - you're not gripping the racket in the appropriate way.", etc. They can see things that the practitioner can't see. And of course, that's vitally important. But the practitioner also needs to use this error

recognition signal. They need to basically focus on something. And the errors are going to tell them what to focus on.

So put simply, there needs to be a period of time in which it's just repetition, after repetition, after repetition. I think many people, including coaches, are afraid that "bad habits" will get ingrained. And while indeed that's possible, it's very important that these errors occur in order to cue the attentional systems and to open the door for plasticity. So, if I'm told, "Look…" – you know – I'm standing a little wide. I need to tighten up my stance a little bit. Great. But then, I need to generate many repetitions from that tightened stance, okay? So, if I'm constantly being cued from the outside about what I'm doing incorrectly, that's not going to be as efficient, okay? So, for some people, these learning sessions might be 10 minutes. For some people, it might be an hour. Whatever you can allocate – because your lifestyles will vary and your – whether or not you're a professional athlete, etc. – will vary. You want to get the maximum number of repetitions in and you want to make errors. That's allowing for plasticity.

So, science points to the fact that there's a particular sequencing of learning sessions that will allow you to learn faster and to retain the skill learning. And it involves doing exactly as I just described – which is getting as many repetitions as you can in the learning session, paying attention to the errors that you make, and then the rewards that will be generated – again, these are neurochemical rewards – from the successful performance of a movement or the approximate successful performance. So, maybe you get the golf swing better, but not perfect. But that's still going to be rewarded with this neurochemical mechanism. And then after the session, you need to do something very specific – which is nothing. That's right.

There are beautiful data describing neurons in our hippocampus – this area of our brain involved in the consolidation of new memories. Those data point to the fact that in sleep, there's a replay of the sequence of neurons that were involved in certain behaviors the previous day and sometimes the previous day before that. However, there are also data that show that after a skill learning session, any kind of motor movement – provided you're not bringing in a lot more additional new sensory stimuli – there's a replay of the motor sequence that you performed correctly and there's an elimination of the motor sequences that you performed incorrectly. And they are run backward in time, okay?

What to Do Immediately After Your Physical Skill Learning Practice
So, to be very clear about this – if I were to learn a new skill, or navigate a new city, or – let's just stay with the – the motor skill. Let's say the – the free throw, or a golf swing, or a tennis serve, dance move – novice – so, I'm still going to make a lot of errors – don't get it perfectly. But maybe I get a little bit better or I perform it correctly 3 times out of a 1,000. And it sounds like something I might do. And there, I'm probably being generous to myself. After I finish the training session, if I do nothing – I'm not focused on some additional learning. I'm not bringing a lot of sensory information in. If I just sit there and close my eyes for 5 to 10 minutes – even 1 minute – the brain starts to replay

the motor sequence of the - corresponding to the correct pattern of movement, but it plays that sequence backward.

Now, why it plays it backward, we don't know. If I were to wait until sleep - or regardless - when I sleep later that night, the sequence will be replayed forwards in the proper sequence. Immediately afterward, it's played backward for reasons that are still unclear. But the replay of that sequence backwards appears to be important for the consolidation of the skill learning. Now, this is important because many people are finishing their jujitsu class, or they're finishing their yoga class, or they're finishing their dance class, or they're finishing some skill learning. And then, they're immediately devoting their attention to something else.

You hear a lot about visualization and we are going to talk about visualization. But in the - kind of - obsession with the idea that we can learn things just sitting there with our eyes closed - without having to perform a movement - we've overlooked something perhaps even more important - or at least, equally important - which is after skill learning - after putting effort into something - sitting quietly with the eyes closed for 1, to 5, to 10 minutes, allows the brain to replay the sequence in a way that appears important for the more rapid consolidation of the motor sequence - of the pattern - and to accelerated learning.

If you'd like to learn more about this - this is not work that I was involved in. I want to be very clear. There's an excellent paper that covers this and much more for those of you who really want to dive deep on this. And we will dive deeper in a moment. This is a review that was published in the journal Neuron - excellent journal. Many of the papers that I'm referring to were covered in this - in this review - which is titled, "Neuroplasticity subserving motor skill learning" - by Dayan - D-A-Y-A-N - I hope I'm not butchering the pronunciation - and Cohen - by Leonardo Cohen, but not the - not the Leonard Cohen most of us are familiar with - the musician, Leonard Cohen. Dayan and Cohen - "Neuroplasticity subserving motor skill learning". And this was published in 2011. But there have been a number of updates and the literature that I've described in other portions of today's episode come from the more recent literature - such as the more recent 2021 paper, okay?

So, you have this basic learning session and then a period of time afterwards in which the brain can rehearse what it just did. We hear so much about mental rehearsal. And we always think about mental rehearsal as the thing you do before you - you train or instead of training. But this is rehearsal that's done afterward, where the brain is just automatically scripting through the sequence. And for some reason - it's still not clear as to why this would be the case - it runs backward. Then in sleep, it runs forwards. And certainly, absolutely, sleep and quality sleep - of the appropriate duration, etc. - is going to be important for learning of all kinds, including skill learning. We did an entire four episodes on sleep and how to get better at sleeping. Those are the episodes back in January - episodes essentially 1, 2, 3, and 4 - and maybe even episode 5. I don't recall. But you can go there to find out all about how to get better at sleeping.

Leveraging Uncertainty
Now, there are other training sessions involved, right? I'm not going to learn the perfect golf swing, or the tennis serve, or how to dance in one session. And I doubt you will either. So, the question is when to come back and what to do when you come back to the training session. Now, first of all, this principle of errors cueing attention and opening the opportunity for plasticity, that's never going to change. That's going to be true for somebody who is hyper-skilled - who's a - even a - you know - has mastery or even virtuosity in a given skill, right? Remember, when you're unskilled at something, uncertainty is very high. As you become more skilled, certainty goes up, right? Then eventually, you achieve levels of mastery where certainty is very, very high about your ability to perform - yours - certainty - and that of other people. And then, there's this fourth category of virtuosity where somebody, maybe you, invites uncertainty back into the practice because only with that uncertainty, can you express your full range of abilities - which you aren't even aware of until uncertainty comes into the picture, right?

I happen to have the great privilege of being friends with Laird Hamilton, the big wave surfer - who is phenomenal. I don't surf. I certainly don't surf with Laird. But he and - you know - another guy that he surfs with, Luca Padua, they're - these guys are virtuosos at surfing. They don't just want the wave that they can master. They want uncertainty. They're at the point in their practice where when uncertainty shows up, like a wave that's either so big or is moving in a particular way that it brings an element of uncertainty for them about what they're going to do, they - they recognize that as the opportunity to perform better than they would otherwise, okay? So, they're actually trying to eliminate uncertainty.

At the beginning of learning any skill and as we approach from uncertain to skilled to mastery, we want to reduce uncertainty. And that's really what the nervous system is doing. It's trying to eliminate errors and hone in on the correct trajectories. If you perform a lot of repetitions and then you use a period immediately after. We don't really have a name for this. Maybe someone will come up with it and put in the comment section if you're on YouTube - if you're watching this on YouTube - a name for this post-learning - kind of - idle time for the brain. The brain isn't idle at all. It's actually scripting all these things in reverse that allow for deeper learning and more quick - more quick learning.

What to Pay Attention to While Striving to Improve
But if we fill that time with other things, if we are focused on our phones or we're focused on learning something else, we're focusing on our performance - that's not going to serve us well - it's - at least, it's not going to serve the skill learning well. So please, if you're interested in more rapid skill learning, try introducing these sessions. They can be quite powerful. And then on subsequent sessions - presumably after a night sleep - or maybe you're doing two sessions a day - although, two sessions a day is going to be a lot for most people unless you're a professional or - you know - a high-level athlete. The subsequent sessions are where you get to express the gains of the previous session, right? Where you get to perform well - presumably more often, even if it's just subtle.

Sometimes there'll be a decrease in performance, but most often you're going to perform better on subsequent and subsequent training sessions.

And there, is the opportunity to devote attention in very specific ways, right? Not just let the errors inform you where to place your attention, but rather to direct your perception to particular elements of the movement in order to accelerate learning further, okay? So, to be very clear - because I know many of you are interested in - in concrete protocols. It's not just that you would only let errors cue your attention on the first session. You might do that for one session or five sessions. It's going to depend. But once you're familiar with something and you're performing it well every once in a while - you're accomplishing it better every once in a while - then you can start to cue your attention in very deliberate ways. And the question, therefore, becomes: What to cue your attention to? And the good news is it doesn't matter.

There is a beautiful set of experiments that have been done looking at sequences of keys being played on a piano. This is work that was published just a couple years ago. There are actually several papers now that are focused on this. One of them was published in 2018. This is from Claudia Lappe and colleagues - L-A-P-P-E. She's done some really nice work, which talks about the influence of pitch feedback on learning of motor timing and sequencing. And this was done with piano, but it carries over to athletic performance as well. So, I'm going to describe this study to you. But before I describe it, what is so interesting about this study - that I want you to know about - is that it turns out it doesn't matter so much what you pay attention to during the learning sequence provided it's something related to the motor behavior that you're performing, right? That seems incredible, right? I'm not good at a tennis serve. So, if I've done - you know - let's say a 1,000 repetitions of the tennis serve. Maybe I got it right 3 to 10 times. Now, I'm being even more generous with myself. And I do this post-training session where I let my brain idle. And I get some good sleep and I come back. And now, I start generating errors again, presumably - or hopefully, fewer errors. But I decide I'm going to cue my attention to something very specific - like maybe how tightly I'm holding the racket, or maybe it's my stance, or maybe it's whether or not I rotate my right shoulder in as I - as I hit the ball across. And I'm making this up. Again, I don't play tennis. Turns out that as long as it's the same thing throughout the session, learning is accelerated. And I'll explain why this is - makes sense in a moment. But just to be really clear, you can - and one should - use your powers of attention to direct your attention to particular aspects of a motor movement once you're familiar with the general theme of the movement. But what you pay attention to exactly is not important. What's important is that you pay attention to one specific thing.

So, what Claudia Lappe and colleagues showed was that if people are trying to learn a sequence of keys on the piano, there are multiple forms of feedback. There are error signals. If, for instance, they hear a piece of music and then they're told to press the keys in a particular sequence. And the noise that comes out - the sound that comes out of the piano does not sound like the song they just heard, right? So, instead of - and here, forgive me because I can neither - I'm neither musical nor can I sing. But instead of, "dah, dah, dah, dah, dah". They hear that, "dah, dah, dah, dah, dah". And then instead when they play - or if it were me, it would sound something like, "dah, dah, dah, dah,

dah". It wouldn't sound right, okay? It wouldn't sound right because I likely got the sequence wrong, or I was pressing too hard on the keys or too lightly on the keys, etc.

What they showed was - if they just instruct people about the correct sequence to press on the keys, it actually doesn't matter what sound comes back provided it's the correct sound or it's the same sound, alright? So, here's the experiment. They had people press on these keys. And the key - it was a typical piano and it generated the particular sequence of sounds that would be generated by pressing the keys on the piano. Or they modified the keyboard, in this case - or piano - such that when people pressed on the keys, a random tone - different tones - were played each time they pressed on the keys. So, it sounded crazy. It sounded like noise. But the motor sequence was the same. Or they had a single tone that was played every time they pressed the key. And the job or the task of the subject was just to press the sequence - press the keys in the proper sequence. So, instead of, "dah, dah, dah, dah, dah, dah", it was just, "dah, dah, dah, dah, dah, dah, dah". Instead of, "dah, dah, dah, dah, dah, dah", it's, "dah, dah, dah, dah, dah, dah, dah". It's even hard for me to say it at a constant - at an even tone. But you get the idea. So, a singular tone. Just think a doorbell being wrong with each press of the key. It would be really annoying, okay?

But it turns out that the rate of motor learning was the same whether or not they were getting feedback that was accurate to the keys of the piano or whether or not it was a constant tone. Performance was terrible and the rates of learning were terrible if they were getting random tones back. So, what this means is that learning to play the piano - at least at these early stages, is really just about generating the motor commands. It's not about paying attention to the sound that's coming out of the piano. And this makes sense because when we are beginners, we are trying to focus our attention on the things that we can control. And if you think about this - if you conceptualize this - pressing the keys on the piano and paying attention to the sounds that are coming out are two things. So, what this means is that as you get deeper and deeper into a practice, focusing purely on the motor execution can be beneficial.

Now, this is going to be harder to do with open-loop-type things where you're getting feedback. I guess a good example of open-loop would be the attempt at a backflip, right? If you get it wrong, you will immediately know. If you get it right, you'll immediately know. Please don't go out and try to do a backflip on - on the solid ground or even on a trampoline if you don't know what you're doing because very likely you'll get it wrong and you'll get injured. But if it's something that is closed-loop where you can repeat again, and again, and again, and again - that is advantageous because you can perform many, many repetitions. And you can start to focus or learn to focus your attention just on the pattern of movement. In other words, you can learn to play the piano just as fast or maybe even faster by just focusing on the sequence that you are moving your digit - your fingers - and not the feedback.

Now, I'm sure there are music teachers out there and piano teachers that are screaming, "No! You're going to ruin the practice that all of us have embedded in our minds and in our students." And I agree. At some point, you need to start including feedback about whether or not things sound

correct. But one of the beauties of skill learning is that you can choose to parameterize it - meaning you can choose to just focus on the motor sequence or just focus on the sounds that are coming back. And then, integrate those. And so, we hear a lot about chunking - about breaking things down into their component parts. But one of the biggest challenges for skill learning is knowing where to place your attention.

Recap
So, to dial out again - we're building a protocol across this episode. Early sessions - maybe it's the first one. Maybe it's the first ten. Maybe it's the first hundred. It depends on how many repetitions you're packing in. But during those initial sessions, the key is to make many errors to let the reward process govern the plasticity. Let the errors open the plasticity. And then after the learning sessions, to let the brain go idle - at least, for a short period of time. And of course, to maximize sleep. As you start incorporating more sessions, you start to gain some skill level. Learning to harness and focus your attention on particular features of the movement, independent of the rewards and the feedback, alright? So, the reward is no longer in the tone coming from the piano or whether or not you struck the target correctly, but simply the motor movement - focusing your - for instance, in a dart throw - on the action of your arm. That is embedding the plasticity in the motor pattern most deeply. That's what's been shown by the scientific literature. I'm sure there are coaches and teachers out there that will entirely disagree with me. And that's great. Please - you know - let me know what you prefer. Let me know where you think this is wrong. And it rarely happens, but let me know where you think this might be right as well.

So, we're breaking the learning process down into its component parts. As we get more and more skilled - meaning as we make fewer and fewer errors per a given session per unit time - that's when attention can start to migrate from one feature, such as the motor sequence - to another feature, which is perhaps one's stance - and another sequence - component of the sequence, which would be the result that one's getting on a trial-to-trial basis, alright? So, changing it up each time. So, maybe I served the tennis ball and I'm focusing on where the ball lands. And then, I'm focusing on the speed. Then, I'm focusing on my grip. Then, I'm focusing on my stance - from trial to trial. But until we've mastered the core motor movements, which is done session to session, that - at least, according to the literature that I have access to here - seems to be suboptimal. So, hopefully this is starting to make sense - which is that these connections between upper motor neurons, lower motor neurons, and central pattern generators - you can't attack them all at once. You can't try and change them all at once. And so, what we're doing is we're breaking things down into their component parts.

Super-Slow-Motion Learning Training
Some of you may be wondering about speed of movement. There are some data - meaning some decent papers out there - showing that ultra-slow movements - performing a movement essentially in slow motion, can be beneficial for enhancing the rate of skill learning. However - at least, from my read of the literature - it appears that ultra-slow movements should be performed after some degree of proficiency has already been gained in that particular movement. Now, that's not the way

I would have thought about it. I would have thought, "Well, you know - if you're learning how to do a proper kick or a punch in martial arts or something that ultra-slow movements at first are going to be the way that one can - you know - best learn how to perform a movement. And then, you just gradually increase the speed."

And it turns out that's not the case. And I probably should have known that. And you should probably know that because it turns out that when you do ultra-slow movements, two things aren't available to you. One is the proprioceptive feedback is not accurate because fast movements of limbs are very different than slow movements of limbs. So, you don't get the opportunity to build in the proprioceptive feedback. But the other reason why it doesn't work is that it's too accurate. You don't generate errors. And so, the data that I was able to find showed that very slow movements can be beneficial if one is already proficient in a practice. But very slow movements at the beginning don't allow you to learn more quickly because you never generate errors. And therefore, the brain doesn't - it's not open for change. The window for plasticity is never swung open, so to speak.

So, it brings us back to this theme that errors allow for plasticity. Correct performance of movements or semi-correct performance of movements cues the synapses in the brain areas and spinal circuits that need to change. And then, those changes occur in the period immediately after skill learning and in sleep. So, super-slow movements can be beneficial once you already have some proficiency. So, this might be standing in your living room and just in ultra-slow motion performing your tennis serve - learning to - or thinking about how you're adjusting your elbow, and your arm, and the trajectory exactly how you were taught by your tennis coach. But trying to learn it that way from the outset does not appear to be the best way to learn a skill.

When should you start to introduce slow learning? Well, obviously talk to your coaches about this. But if you're doing this recreationally or you don't have a coach - I realize many of you don't. I don't have a coach for anything that I do. I'm going to just - navigating it through the - by using the scientific literature. It appears that once you're hitting success rates of about 25 or 30%, that's where the super-slow movements can start to be beneficial. But if you're still performing things at a rate of - you know - 5 or 10% correct and the rest are errors, then the super-slow movements are probably not going to benefit you that much.

Also, super-slow movements are not really applicable to a lot of things. For instance, you could imagine throwing a dart super-slow motion. But if you actually try and throw an actual dart, the dart is just going to fall to the floor, obviously. So, there are a number of things like - you know - baseball bat swing, which you can practice in super-slow motion. But if you try and do that with an actual baseball, or softball, or something like that, that's not going to give you any kind of feedback about how effective it was. So, super-slow movements or a decelerated movement has its - has its place, but once you're already performing things reasonably well - like maybe 25 to 30% success rate. You know, and I've tried this. I actually - I struggle with basketball for whatever reason and my free throw is terrible. So, I practice free throws in super-slow motion and I nail them every time. The - the problem is there's no ball.

Tool – Metronomes
Some of you already have a fair degree of proficiency of skill in a given practice, or sport, or instrument. And if you're in this sort of advanced-intermediate or advanced levels of proficiency for something, there is a practice that you can find interesting data for in the literature – which involves metronoming. So, this – you'll realize – relates to generating repetitions and it relates to the tone experiment, where it doesn't really matter what your attention is queued to as long as you are performing many, many reps of the motor sequence. You can use a metronome. And obviously musicians do this, but athletes can do this too. You can use a metronome to set the cadence of your repetitions. Now, for swimmers, there's actually a device I was able to find online – I – I forget what the brand name was and I – that's not what this is about – but that actually goes in the swim cap that can cue you to when you need to perform another stroke. And for runners, there's – there are other metronome-type devices that through headphones or through a tone in the room – if you're running indoors or on a treadmill – will cue you to when you – basically, you need to lift your heels. And if you do that, what athletes find is they can perform more repetitions. They can generate more output. You can increase speed. A number of really interesting things are being done with auditory metronoming. And then, I'm involved in a little bit of work now that hopefully I'll be able to report back to you about using stroboscopic metronoming – so, actually changing the speed of the visual environment. These are fun experiments – basically, changing one's perception of how fast they're moving through space by playing with the visual system – something for a future discussion.

But you can start to use auditory metronoming for generating more movements per unit time and generating more errors. And therefore, more successes and more neuroplasticity. There are a number of different apps out there. I found several free apps where you can set in a metronome pace. So, it might be, "tick, tick, tick, tick, tick, tick". That's a little fast for most things. But you can imagine if this were darts or this were golf swings that it might be, "tick, tick, tick, tick" – or something more like, "tick, tick". And every time the metronome goes, you swing. Every time the metronome goes, you throw a dart.

There are actually some wild experiments out there. You know, there's a world championship of cup stacking? There's a – a young lady who I saw could take all these cups spread out on a table and basically just stack them into the perfect pyramid in the least amount of times. All the kids go wild. This is something I never thought to pursue and – and frankly never will pursue unless my life depends on it for some reason. But it's really impressive. And if you look at the sequence – because these have been recorded. You can look this up on YouTube. What you'll find is that these expert cup stackers – it's just all about error elimination. But there too, metronoming and auditory cues can actually cue them to pick up the cups faster than they would ordinarily and to learn to do that. You can do this for anything. I think cup stacking is probably not a skill most of you are interested in doing. But for any skill – if you figure out at what rate you are performing repetitions per unit time and you want to increase that slightly, you set a metronome which is slightly faster than your current rate and you just start generating more repetitions.

Now, what's interesting about this and is cool is it relates back to the experiment from Lappe and colleagues - which is your attention is now harnessed to the tone - to the metronome - not necessarily to what you're doing in terms of the motor movement. And so really, you need a bit of proficiency. Again, this is for people who are intermediate, or advanced-intermediate, or advanced. But what you're essentially doing is you're creating an outside pressure - a contingency - so that you generate, again, more errors. So, it's all about the errors that you get. Now, these aren't errors where all the cups tumble, or you have to stop, or you can't keep up. You have to set the pace just a little bit beyond what you currently can do. And when you do - when you do that, you're essentially forcing the nervous system to make errors and correct the errors inside of the session.

I find this really interesting because what it means is, again, you've got sensory perception, what you're paying attention to - proprioception, where your limbs are - and the motor neurons in your upper/lower motor neurons and central pattern generators. And you can't pay attention to it. "Well, they're my upper motor neurons. They're my lower motor neurons." Forget that. You're not going to do that. You can't pay attention to your proprioception too much. That would be the super-slow motion - would be the proprioception. But you have to harness your attention to something. And if you harness your attention to this outside contingency - this metronome that's firing off and saying, "Now, go. Now, go. Now, go." - not only can you increase the number of repetitions, errors, and successes, but for some reason - and we don't know why - the regular cadence of the tone of the metronome and the fact that you are anchoring your movements to some external force, to some external pressure or cue, seems to accelerate the plasticity, and the changes, and the acquisition of skills beyond what it would be if you just did the same number of repetitions without that outside pressure. We don't know exactly what the mechanism is. Presumably, it's neurochemical. Like, there's something about keeping up with a timer or with a pace that, presumably - and I'm speculating here - causes the release of particular chemicals. But I think it's really cool. Metronomes, they're totally inexpensive - at least, the ones that you use outside of water are very inexpensive. You can find these free apps. You can use a musical metronome. So, metronomes are a powerful tool as well.

In particular for speed work - so, for sprinting, or swimming, or running where the goal is to generate more strokes, or more efficient strokes, or more steps, etc. - the rate of the metronome, obviously, is going to be very important. Sometimes you're trying to lengthen your stride. Sometimes you're - you're trying to take fewer strokes but glide further in the pool, for instance. But the value of occasionally just increasing the number of repetitions - the number of strokes, or steps, etc. per unit time - is also that you're training the central pattern generators to operate at that higher speed.You know, one of the sports that's kind of interesting to me is speed walking. It's not one I engage in or ever plan to engage in. But if you've ever tried to really speed walk, it's - it's actually difficult to walk very, very fast without breaking into a run. All animals have these - kind of - crossover points where they go - where you go - you know - I think with horses, it's like they - what is it? They - they trot. Then, they gallop. I don't know. What's the next thing? I don't know anything about - about horses except that they're beautiful and I like them very much. But they - they break into a different kind of stride. And that's because you shift over to different central pattern

generators. So, when you're walking - or a horse is moving very slowly, and then it breaks into a jog, and then into a full sprint or a gallop for the horse. You're actually engaging different central pattern generators. And those central pattern generators always have a range of speeds that they're happiest to function at. So, with the metronoming for - for speed purposes, what you do is you can - you can basically bring the activity of those central pattern generators into their upper - upper range and maybe even extend their range.

And there's a fascinating biology of how central pattern generators work together. There's coupling of central pattern generators, etc. - in order to achieve maximal speeds and etc. It's a topic for - kind of - an advanced session. Costello loves this topic. He just barked. And he loves it so much he barked again. In any event, the metronome is a powerful tool, again, for more advanced practitioners or for advanced-intermediate practitioners. But it's interesting because it - it brings back the point that what we put our attention to while we're skill learning is important to the extent that it's on one thing - at least, for the moment or trial to trial. But that what we focus our attention on can be external, it can be internal, and ultimately, the skill learning is where all that is brought together.

Tool – Leveraging Your Cerebellum
So, let's talk about where skill learning occurs in the nervous system. And then, I'm going to give you a really - what I think is a really cool tool that can increase flexibility and range of motion based on this particular brain area. It's a tool that I used. And when I first heard about it, I did not believe would work. This is not a hack. This is actually anchored deeply in the biology of a particular brain region that we all have - which - whose meaning is "mini brain". And that mini brain that we all have is called your cerebellum. The cerebellum is called the mini brain because it's in the back of your brain and it looks like a little mini version of the rest of your brain. It's an absolutely incredible structure that's involved in movement. It also has a lot of non-movement associated functions. In brief, the cerebellum gets input from your senses - in particular, your eyes - and pays attention to where your eyes are in space - what you're looking at. It basically takes information about three aspects of your eyes and eye movements, which are occurring when your head goes like this - which is called pitch, okay?, So, this is pitch. For those of you listening, I'm just nodding up and down. Then, there's yaw - which is like shaking your head "no" from side to side. And then, there's roll - which - you know - is like - sometimes if you see a - a primate - like a marmoset or something - they will roll their head when they look at you. Actually, the reason they do that is it helps generate depth perception. It's a - kind of - form of motion parallax if you're curious why they do that. It's not to look cute. They do it because when they do that - even if you're stationary and they're stationary - they get better depth perception as to how far away from them you are.

So, you've got pitch, yaw, and roll. And as you move your head, and as you move your body, and you move through space, the image on your retina moves - pitch, yaw, and roll - in some combination. That information is relayed to your cerebellum. So, it's rich with visual information. There's also a map of your body surface, and your movements, and timing in the cerebellum. So, it's an incredible structure that brings together timing of movements, which limbs are moving, and has

proprioceptive information. It really is a mini brain. It's just the coolest little structure back there. And in humans, actually, not that little. It's just an incredible structure. Now, all this information is integrated there. But what most people don't tell us is that a lot of learning of motor sequences - of skill learning - that involve timing occurs in the cerebellum. Now, you can't really use that information except to know that after you learn something pretty well, it's handed off or - kind of - handled by your cerebellum.

But there is something that you can do with your cerebellum to increase range of motion and flexibility. Much of our flexibility, believe it or not, is not because our tendons are of particular length or elasticity - although, that plays some role. It's not because our muscles are short. I don't even know what that would even mean. Some people have - have longer muscle bellies or shorter muscle bellies, but your muscles always essentially span the entire length of the - of the bone or limb - or close to it - along with your tendons. But has to do with the neural innervation of muscle and the fact that when muscles are elongated, there's a point at which they won't stretch out any longer. And the nerves fire and they shut down. You actually have inhibitory pathways that - that prevent you from contracting the muscles or - or from extending them from stretching them out anymore.

Protocol For Increasing Limb Range of Motion
So, you can do this right now. If you're driving, don't do it. Because unless you have a self driving car, you'll need to take your hands off the steering wheel. But because of the way that vision and your muscles are represented in your cerebellum, it turns out that your range of visual motion and your range of vision - literally how wide a field of view you take - impacts how far you can extend your limbs, okay? So, we'll talk about this in a second - about exactly how to do this and explore this. But as you move through space - as you walk forward, or you walk backward, or you tilt your head, or you learn a skill, or you just operate in the normal ways throughout your day - driving, biking, etc. - your eyes are generating spontaneous movements to offset vision - visual slip. In other words, you don't see the world as blurry even though you're moving because your eyes are generating little compensatory eye movements to offset your motion.

So, if I spin - we could do this experiment. There's a fun experiment we do with medical students where you spin them around in a chair with their eyes closed, and then you stop, and you have them open their eyes, and their eyes are going like this [eye noises] - nystagmus. And I don't suggest you do this experiment. When we were kids, we did a different experiment - which was to take a stick, and to look at the top of the stick, and to spin around on the lawn looking at the top of the stick. Then, put it down on the ground and try and jump over it. And you end up like jumping to the side. You miss the thing entirely. The reason those two quote-unquote "experiments" - which I hope you don't do or force somebody else to do - the reason they work is because normally your eye movements, and your balance, and your limb movements are coordinated. But when you spin around looking up at the stick, what you're doing is you're fixating your eyes on one location while you're moving. And then when you stop, those two mechanisms are completely uncoupled and it's like being - you know - thrown into outer space. I've never been to outer space, but probably

something like that - low gravity - zero gravity. If you spin around in your chair with your eyes closed, you're not giving the visual input that you're spinning, and then you open the eyes, and then the eyes only have the - the - what we call the vestibular signal. Your eyes jolting back and forth - back and forth. Again, these aren't experiments you need to do because I just told you the result.

However, if you want to extend your range of motion, you can do that by - these things always look goofy, but at this point I'm just kind of used to doing these things. If I want to extend my range of movement - first, I want to measure my range of - of motion. So, I'm trying to - if you're listening, what I'm doing is I'm stretching out my arms from - like a "T" off on either side and I'm trying to push them as far back as I can, which for me is - you know - feels like it's in line with my shoulders and I can't get much further. I'm not really super flexible, nor am I particularly inflexible - at least, physically. So, what I would then do is stop. I would move my eyes to the far periphery, alright? So, I'm moving my eyes all the way to the left while keeping my head and body stationary. I'm trying to look over my left shoulder as far as I can. Then, off to the right. It's a little awkward to do this. Then up. Then down. But I'm mostly going to just focus on left and then right.

Now, what that's doing is it's sending a signal to my cerebellum that my field of view is way over to there and way over to there. Remember, your visual attention has an aperture. It can be narrow or it can be broad. And I've talked about some of the benefits of taking a broad visual aperture in order to relax the nervous system. This is just moving my eyes, not my head - like I just did for a second - from side to side. Now, I can retest. And actually, you get about a 5 to 15 degree increase in your range of motion. Now, I'm doing this for you. You can say, "Well, you know - he gamed it because he knew the - the result that he was hoping for." But you can try this, okay? So - and you can do this for legs too, alright? You can do this for any limb, essentially. And that's - it's purely cerebellar. And it's because the proprioceptive, visual, and limb movement feedback converge in - in their - in the ways that we control our muscle spindles and the way we control the muscle fibers and the tendons. And essentially, you can get bigger range of motion. So, I actually will warm up before exercise or for - before skill learning by both doing movements from my body, but also moving my eyes from side to side in order to generate larger range of motion if range of motion is something that I'm interested in. So, that's a fun one that you can play with a little bit. And it's purely cerebellar.

Some other time we'll get back into cerebellar function. There's all sorts of just incredible stuff that you can do with cerebellum. I talked in an earlier episode on neuroplasticity about how you can disrupt your vestibular world. In other words, by getting into modes of acceleration - moving through space where you're tilted in certain ways - it can open up the windows for plasticity and yet other ways. So, you can check that out. It's one of the earlier episodes on neuroplasticity. Everything's time stamped. But meanwhile, if you want to expand your range of motion before doing skill learning or afterward, this is a fun one. It's also kind of neat because I have this - kind of - aversion to stretching work. It never seems like something I want to do. And so, I always put it off. So, if I start with the visual practice of expanding my field of view to off to one side or the other side - or up or down - then what I find is I'm naturally more flexible. I'm not naturally more flexible. What's happened is I've expanded my range of motion.

Tool - Visualization / Mental Rehearsal

Let's talk about visualization and mental rehearsal. I've been asked about this a lot and I think it relates back to that - kind of - Matrix / Hollywood idea that we can just be embedded with a skill. Although in this case, in fairness, visualization involves some work. And I've talked about this on an earlier episode that some people find it very hard to mentally visualize things. And some people find it very easy. There was great work that was done in the 1960s, by Roger Shepard at Stanford and by others, looking at people's ability to rotate three-dimensional objects in their mind. And some people are really good at this and some people are less good at this. And one can get better at it by repeating it. But the question we're going to deal with today is: Does it help? Does it let you learn things faster? And indeed, the answer appears to be: Yes, it can. However, despite what you've heard, it is not as good. It is not a total replacement for physical performance itself, okay? So, I'm going to be really concrete about this. I hear all the time that, "Just imagining contracting a muscle can lead to the same gains as actually contracting that muscle. Just imagining a skill can lead to the same increases in performance as actually executing that skill." And that's simply not the case. However, it can supplement or support physical training and skill learning in ways that are quite powerful.

One of the more interesting studies on this was from Ranganathan et al. Forgive me for the pronunciation. This was a slightly older paper - 2004. But nonetheless, was one that I thought had particularly impressive results and included all the appropriate controls, etc. And what they did is they looked at 30 subjects. They divided them into different groups. They had one group perform essentially finger flexion. So, it's actually just sort of the - imagine, if you're just listening to this, the - you know - "come here" finger movement. They also had elbow flexion. So, sort of bicep-curl-type movement. And they either had subjects do an actual physical movement against resistance or to imagine moving their finger or their wrist towards the shoulder - meaning at the - bending at the elbow towards actual resistance. Just to make a long story short, what they found was that there were increases in this finger adduction strength - abduction, excuse me - strength of about 35%. And the elbow flexion strength by about 13.5%, which are pretty impressive considering that it was just done mentally. So, they had people imagine moving against a weight - a very heavy weight - or had - imagined people moving their wrist towards their shoulder against a very heavy weight. But again, they weren't doing it. They were just imagining it. Other experiments looked at the brain and what was happening in the brain during this time. So we'll talk about that in a moment. But essentially, what they found were improvements in strength of anywhere from 13.5 to 35%. However, the actual physical training group - the groups that actually moved their wrist or move their finger against an actual physical weight - had improvements of about 53%. So, this repeats over and over throughout the literature.

Mental rehearsal can cause increases in strength. It can create increases in skill acquisition and learning, but they are never as great - if done alone - as compared to the actual physical execution of those movements or the physical movement of those weights, which shouldn't come as so surprising. However, if we step back and we say, "Well, what is the source of this improvement?" You might not care what the source is because I could tell you it's one brain area or another brain

area. What - what difference would it make? But if - again - if you can understand mechanism a little bit, you're in a position to create newer and even better protocols. What mental rehearsal appears to do is engage the activity of those upper motor neurons that we talked about way back at the beginning of the episode. Remember, you have upper motor neurons that control deliberate action, you've got lower motor neurons that actually connect to the muscles and move those muscles, and you have central pattern generators. Mental rehearsal - closing one's eyes, typically - and thinking about a particular sequence of movement and visualizing it in one's quote-unquote "mind's eye" creates activation of the upper motor neurons that's very similar, if not the same, as the actual movement. And that makes sense because the upper motor neurons are all about the command for movement. They are not the ones that actually execute the movement, okay? Remember, upper motor neurons are the ones that generate the command for movement, not the actual movement. The ones that generate the actual movement are the lower motor neurons and the central pattern generators.

So, visualization is a powerful tool. How can you use visualization? Well, in this study, they had people perform this 5 days a week. I believe that it was 15. Yes, it was 15 minutes per day, 5 days a week, for 12 weeks. So, that's a lot of mental rehearsal. You know, it's not a ton of time each day - 15 minutes per day. But sitting down, closing your eyes, and imagining going through a particular skill, practice, or moving a weight. Maybe it's playing keys on a piano, if that's your thing or - or strings on a guitar. For 15 minutes a day, 5 days per week, for 12 weeks is considerable. I think most people, given the fact that the actual practice - the physical practice - is going to lead to larger improvements - greater improvements - then would the mental training would opt for the actual physical training. But of course, if you're on a plane, and you don't have access to your guitar, and you're certainly not going to be sprinting up and down the aisle. Or you are very serious about your craft and you want to accelerate performance of your craft, or strength increases, or something of that sort. Then augmenting or adding in the visualization training very likely will compound the effects of the actual physical training. There are not a lot of studies looking at how visualization on top of pure physical training can increase the rates of learning, and consolidation of learning, etc. It's actually a hard study to do because it's hard to control for because what would you do in its place? You would probably add actual physical training. And then, that's always going to lead to greater effects.

So, the point is - if you want to use visualization training, great. But forget the idea that visualization training is as good as the actual behavior. You hear this all the time. People say, "Do you know that if you imagine an experience to your brain and to your body, it's exactly the same as the actual experience?" Absolutely not. It's just not the way the nervous system works. I'm sorry. I don't mean to burst anybody's bubble, but your - your bubble is made of myths. And the fact of the matter is that the brain - when it executes movement, is generating proprioceptive feedback. And that proprioceptive feedback is critically involved in generating our sense of the experience and in things like learning. So, I don't say this because I don't like the idea that visualization couldn't work. In fact, visualization does work. But it doesn't work as well. It doesn't create the same milieu - the

same chemical milieu - the same environment - as actual - physically engaging in the behavior, the skill, the resistance training, etc.

And I'd be willing to wager that the same is true for experiences of all kinds. You know, PTSD is this incredibly unfortunate circumstance in which there's a replay often of the traumatic event that feels very real. But that's not to say that the replay itself is the same as the actual event. And of course, PTSD needs to be dealt with with the utmost level of seriousness. It should be treated. In fact, my lab works on these sorts of things. But my point about visualization and imagining something not being the same as the actual experience is grounded in this idea of proprioception and the fact that feedback to the cerebellum - the cerebellum talking to others the brain are critically involved in communicating to the rest of our nervous system that - not just that we believe something is happening, but something is actually happening. And in the case of muscle loads, muscle is actually feeling tension. The actual feeling of tension in the muscle - the contracting of the muscle under that tension - is part of the important adaptation process. In a future episode, we'll talk about hypertrophy and how that works at the level of upper motor neurons, lower motor neurons, and muscle itself. But for now, just know that visualization can work. It doesn't work as well as real physical training and practice. But these effects of - you know - 35% or 13.5% increases are pretty considerable. They're just not as great as the 53% increases that come from actual physical training.

Cadence Training & Learning Carryover
For those of you that are interested in some of the skill learning that more relates to musical training - but also how cadence, and metronome, and tones, etc. - can support physical learning. If you're interested in that - for you aficionados - there is a wonderful review also published in the journal Neuron - again, excellent journal - by Herholz and Zatorre. That's H-E-R-H-O-L-Z and Zatorre - Z-A-T-O-R-R-E - that really describes in detail how musical training can impact all sorts of different things. And how cadence training - whether or not with tones or auditory feedback and things of that sort carries over to not just instrumental music training, but also physical skill learning of various kinds. So, if you want to do the deep dive, that would be the place. You can find it easily online. It's available as a complete article free of charge, etc.

Tool - α-GPC
Many of you are probably asking, "What can I take in order to accelerate skill learning?" Well, the conditions are going to vary, but motivation is key. You have to show up to the training session motivated enough to focus your attention and to perform a lot of repetitions in the training sequence. That's just a prerequisite, alright? There's no pill that's going to allow you to do fewer repetitions and extract more learning out of fewer repetitions. It's actually more a question of: What are the conditions that you can create for yourself such that you can generate more repetitions per unit time? I think that's the right way to think about it. What - what are - are the conditions that you can create for yourself in your mind and in your body that are going to allow you to focus? And I've talked about focus and plasticity and motivation in previous episodes. Please see those episodes if you have questions about that. I detail a lot of tools and the underlying science.

So, for some people, it might be drinking a cup or two of coffee and getting hydrated before the training session. For some of you, it might be avoiding coffee because it makes you too jittery and your attention jumps all over the place. It's going to vary tremendously. There's no real - there is no magic pill that's going to allow you to get more out of less. That's just not going to happen. It's simply not going to happen. You're not going to get more learning out of fewer repetitions or less time.

However, there are a few compounds that I think worth - are worth mentioning because of their ability to improve the actual physical performance - the actual execution of certain types of movements. And some of these have also been shown to improve cognitive function, especially in older populations. So, I'd be remiss if I didn't at least mention them. I'm only going to mention one today, in fact. The one that's particularly interesting in for which there really are a lot of data is α-GPC. And I'm going to attempt to pronounce what α-GPC actually is. It's alpha-glycerylphosphorylcholine, alright? α-GPC - alpha-glycerylphosphorylcholine. See? If I keep doing it over and over - repetitions - alpha-glycerylphosphorylcholine. There! I made an error.

Okay, so the point is that α-GPC, which is - at least, in the United States - is sold over the counter. Typically, is taken in dosages of about 300 to 600 milligrams. That's a single dose. Or - have been shown to do a number of things that for some of you might be beneficial. One is to enhance power output. So, if you're engaging in something like shot put throwing, or resistance training, or sprinting, or something where you have to generate a job - something where you have to generate a lot of power. Maybe you're doing rock climbing, but you're working on a particular aspect of your rock climbing that involves generating a lot of force - a lot of power. Well then, in theory, α-GPC could be beneficial to you. For the cognitive effects, the dosages are much higher. Up to 1,200 milligrams daily divided into 3 doses of 400 milligrams is what the studies that I was able to find show or used. The effects on cognitive decline are described as "notable". Notable, meaning several studies showed a significant but modest effect on - in offsetting cognitive decline - in particular, in older populations and some populations even with some reported neurodegeneration.

Power output was notable. How notable? What does that mean "notable"? A study noted a 14% increase in power output. That's pretty substantial. You know, 14% - if you think about it. But it wasn't like a doubling or something of that sort. Believe it or not, the symptoms of Alzheimer's have been shown - at least, among the nutraceuticals - of which α-GPC is - to significantly improve cognition in people with Alzheimer's. Now, this episode is into about cognitive decline and longevity. We will talk about that. But this is a - a so-called another effect of α-GPC. Fat oxidation is increased by α-GPC. Growth hormone release is promoted by α-GPC - although, to a small degree. So, as you can see, things like α-GPC - in particular, when they are combined with low levels of caffeine - can have these effects of improving power output, can improve growth hormone release, can improve fat oxidation. All these things in theory can support skill learning, but what they're really doing is they're adjusting the foundation upon which you're going to execute these many, many repetitions, okay? The same thing would be said for caffeine itself. If that's something that

motivates you and gets you out of a chair to actually do the physical training, then that's something that can perhaps improve or enhance the rate of skill learning and how well you retain those skills.

Recap
Now, on a previous episode, I talked about - and this was the episode on epinephrine - on adrenaline. I talked about how for mental, for cognitive learning, it makes sense to spike epinephrine - to bump epinephrine levels up - adrenaline levels up - after cognitive learning. For physical learning, it appears to be the opposite - that if you are - if caffeine is in your practice or if you decide to try α-GPC, that you would want to do that before the training. Take it before the training. Use it. Its effect should extend into the training - presumably, throughout. And then afterward - if you're thinking about following some of the protocols that we discussed today, that you would use some sort of idle time where the brain can replay these motor sequences in reverse. And then, of course, you want to do things to optimize your sleep.

Now, a lot of the questions I get are about how different protocols and things that I describe start to collide with one another. So, let's say, for instance, you go to bed at 10:30 and you're going to do your skill training at 9:30. Well, taking a lot of caffeine then is not going to be a good idea because it's going to compromise your sleep. So, I'm not here to design the perfect schedule for you because everyone's situations vary. So, the things to optimize are repetitions, failures, more repetitions, more failures - at the offset of training, having some idle time - that could be straight into sleep or it could be simply letting the brain just go idle for 5 to 10 minutes - meaning not focusing on anything, not scrolling social media, not emailing, not - ideally, not even talking to somebody - just lying down or sitting quietly with your eyes closed - letting those motor sequences replay.
Then, we talked about how one can come back for additional training sessions - use things like metronoming, where you're queuing your attention to some external cue - some stimulus - in this case, an auditory stimulus most likely - and trying to generate more repetitions per unit time. So again, it's repetitions and errors. That's key. And then, we also talked about some things that you can do involving cerebellar neurophysiology to extend range of motion if that's what's limiting for you or to use visualization to augment the practice. Or let's say your particular skill involves nice weather and it's raining or snowing outside and you can't get outside - a thunderstorm. Then, that's where visualization training might be a good replacement under those conditions. Or in most cases, is going to be the kind of thing that you're going to want to do in addition to the actual physical skill or strength training session - done, at least in the study that we described, for 15 minutes a day, 5 days a week, over a period of 10 to 12 weeks or so. So, hopefully that makes it clear.

Today, we've covered a lot of mechanism. We talked so much about the different motor pathways - central pattern generators. So, you now are armed with a lot of information about how you generate movement. And I'd like to think that you're also armed with a lot of information about how to design protocols that are optimized for you - or if you're a coach, for your trainees - in order to optimize their learning of skills of various kinds. Today, we focused almost entirely on motor skills - things like musical skills or physical skills. These have some overlap. They're partially overlapping with

neuroplasticity for learning things like languages, or math, or engineering, or neuroscience for that matter.

Ultradian & Non-Ultradian Training Sessions

Before we depart, I just want to make sure that I return to a concept which is the ultradian cycle. Ultradian cycles are these 90-minute cycles that we go through throughout sleep and wakefulness that are optimal for learning and attention in the waking state. They - they are the stages of - in which - of sleep in which we have either predominantly slow-wave sleep or REM sleep. Some of you who have been following this podcast for a while might be asking, "Well, should a physical practice be 90 minutes?" That's going to depend. Because with physical practices, oftentimes - for instance, with strength training - that might be too long. You're not going to be able to generate enough force output for it to be worthwhile. For golfing, I don't know. I've never played golf - although, my friends that play golf, they disappear onto the golf course for many hours. So - I know there's a lot of walking and - and driving and - you know - other stuff. I even hear that somebody carries your stuff around for you - sometimes, not always. But it's going to differ. You know - at a 4-hour golf game, you're probably not swinging the golf club for 4 hours. So, it's going to depend. I would say that the ultradian cycle is not necessarily a good constraint for skill learning in most cases.

Density Training

And I should say that for those of you that are short on time or have limited amounts of time, 10 minutes of maximum repetitions - maximum focus skill learning work is going to be very beneficial. Whereas 2 hours of kind of haphazard - not really focused work - or where you're not generating very many repetitions because you're doing it for a few repetitions, then you're texting on your phone or paying attention to something else - that's not going to be beneficial. It's really about the density of training inside of a session. So, I think you should let the - you know - work toward maximal or near-maximal density of repetitions and failures - provided they're failures you can perform safely - in order to accelerate skill learning. And don't let some arbitrary - or in this case, the ultradian constraint - prevent you from engaging in that practice. In other words, get the work in - get as much work done as you can per unit time. And based on the science, based on things that I've seen, based on things that I'm now involved in with various communities, you will see the skill improve vastly at various stages. Sometimes it's a little bit stutter start. It's not always a linear improvement, but you will see incredible improvement in skill.

Conclusion

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In previous episodes and in this episode, I mentioned some supplements. Supplements certainly have their place for various things. They aren't necessary. But many people, including myself, derive benefit from supplements for things like improving sleep, and immune system function, and learning, and so forth. If you're interested in seeing the supplements that I take, you can go to thorne.com/u/huberman and you can see the supplements that I take. If you want to try any of those supplements, you can get 20% off simply by accessing the Thorne webpage through that portal - as well as 20% off any of the other supplements that Thorne makes. The reason we've partnered with Thorne is because Thorne has the very highest levels of stringency in terms of the quality of the supplements and the accuracy about the amounts of each supplement that are in the bottle. One of the major problems in the supplement industry is that when supplements get tested, often it's the case that the amount of a given ingredient is far lower or far greater than what's reported on the bottle. That's not the case for Thorne. Thorne has very high levels of stringency. They've partnered with the Mayo Clinic and all the major sports teams. And that's why we've partnered with them as well. So, if you want to check those out, again, it's Thorne - T-H-O-R-N-E.com/u/huberman - to get 20% off any of the supplements that Thorne makes.

And last but not least, I want to thank you for your time and attention. I very much appreciate your interest in neuroscience, and in physiology, and in tools that are informed by neuroscience and physiology. Today, we talked all about skill learning. I hope that you'll consider the information. You might even decide to try some of these tools. If you do, please let us know your results with them. Give us feedback in the comments. And as always, thank you for your interest in science.