

How to Learn Skills Faster | Huberman Lab Podcast #20

This episode I discuss the science and practice of learning physical skills: what it involves at a biological level, and what to focus on during skill learning at each stage to maximize learning speed and depth. I also describe what to do immediately after a training session (note: this is different than the optimal protocol for cognitive skill training) and as you progress to more advanced levels of performance. I also cover the science of skill-based visualization which does have benefits, but only if done correctly and at the correct times. I discuss auto-replay of skill learning in the brain during sleep and the value of adding in post-training 'deliberately idle' sessions. I cover how to immediately improve limb-range-of-motion by leveraging cerebellum function, error generation, optimal repetition numbers for learning and more. As always, scientific mechanism, peer-reviewed studies and science-based protocols are discussed.

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Timestamps:

- 00:00:00 Introduction
- 00:06:28 Skill Acquisition: Mental & Physical
- 00:08:40 Clarification About Cold, Heat & Caffeine
- 00:12:45 Tool: How To Quickly Eliminate the Side-Stitch 'Cramp' & Boost HRV
- Entrainment
- 00:16:08 Physical Skills: Open-Loop Versus Closed-Loop
- 00:18:50 Three Key Components To Any Skill
- 00:21:00 Sources of Control for Movement: 1) CPGs Govern Rhythmic Learned Behavior
- 00:23:30 Upper Motor Neurons for Deliberate Movement & Learning
- 00:25:00 Lower Motor Neurons Control Action Execution
- 00:25:26 What To Focus On While Learning
- 00:27:10 The Reality of Skill Learning & the 10,000 Hours Myth
- 00:28:30 Repetitions & The Super Mario Effect: Error Signals vs. Error Signals + Punishment
- 00:34:00 Learning To Win, Every Time
- 00:39:26 Errors Solve the Problem of What Focus On While Trying to Learn Skills
- 00:43:00 Why Increasing Baseline Levels of Dopamine Prior To Learning Is Bad
- 00:44:40 The Framing Effect (& Protocol Defined)
- 00:46:10 A Note & Warning To Coaches
- 00:48:30 What To Do Immediately After Your Physical Skill Learning Practice
- 00:53:48 Leveraging Uncertainty
- 00:56:59 What to Pay Attention To While Striving To Improve
- 01:04:45 Protocol Synthesis Part One
- 01:07:10 Super-Slow-Motion Learning Training: Only Useful After Some Proficiency Is Attained
- 01:11:06 How To Move From Intermediate To Advanced Skill Execution faster: Metronomes
- 01:16:44 Increasing Speed Even If It Means More Errors: Training Central Pattern Generators
- 01:19:12 Integrated Learning: Leveraging Your Cerebellum ("Mini-Brain")
- 01:22:02 Protocol For Increasing Limb Range of Motion, Immediately
- 01:28:30 Visualization/ Mental Rehearsal: How To Do It Correctly
- 01:33:50 Results From 15 Minutes Per Day, 5 Days Per Week Visualization (vs. Actual

Training)

01:35:34 Imagining Something Is Very Different Than Actually Experiencing It

01:37:58 Cadence Training & Learning “Carryover”

01:39:00 Ingestible Compounds That Support Skill Learning: Motivation, Repetitions, Alpha-GPC

01:43:39 Summary & Sequencing Tools: Reps, Fails, Idle Time, Sleep, Metronome, Visualization

01:46:20 Density Training: Comparing Ultradian- & Non-Ultradian Training Sessions

01:49:24 Cost-Free Ways to Support Us, Sponsors & Alternate Channels, Closing Remarks

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- 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 a 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. It's either ground beef or a steak. I like ribeyes, 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 feedlots 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 threes 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 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 longterm 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 major problems with blood tests and DNA tests available for 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 inner age 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 'cause 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 supply of vitamin D3 K2. 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 'cause 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 supply of the vitamin D3 and K2,

00:06:28 Skill Acquisition: Mental & Physical

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. It 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 going to be a lot of very simple takeaways.

00:08:40 Clarification About Cold, Heat & Caffeine

So let's get started. 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 are 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 warmup 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 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 you're 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 this 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 palmer 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 your 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. And while we're on the topic of tools

00:12:45 Tool: How To Quickly Eliminate the Side-Stitch 'Cramp' & Boost HRV Entrainment

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 pain on your side, that pain could be any number of things, but 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 have ever read about how to recognize heart attack. 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 or 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, 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 too. The side stitch, the pain in your side as 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 side that I've talked about in previous episodes of the podcast and elsewhere which has 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 we 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. 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 a kind of regular cadence of heart rate variability. So there are a number of reasons why this physiological side

00:16:08 Physical Skills: Open-Loop Versus Closed-Loop

can be useful, but it certainly can be useful for relieving the side stitch or so-called side cramp. 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 dartboard. 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 even have a coach and they're correcting your stride or you're trying to do some sort of skill, like a hopscotch skill, which 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. So you have open loop and closed loop. And just to make this 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 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're in a regular can. So maybe you're learning a swim stroke, or maybe you're trying to learn a particular rhythm on the drum. 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 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, et cetera. 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.

00:18:50 Three Key Components To Any Skill

But if you want to learn something, ask is it open loop or closed loop. 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, et cetera. So there's sensory input. Then there are the actual movements. So they're 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 reached down and pick up this pen and pick it up, I'm not thinking about where the pen in 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 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 leaning on one of the nerves of my leg or something like that, and my leg feels all tingly or numb. 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, but those are the main

ones that we're going to focus on. 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

00:21:00 Sources of Control for Movement: 1) CPGs Govern Rhythmic Learned Behavior

what you're paying attention to, movements themselves and proprioception. 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, CPGs, CSPGs are something entirely different in biology. CPGs, 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 the 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 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 and 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 CPGs 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,

00:23:30 Upper Motor Neurons for Deliberate Movement & Learning

somebody who's really good at golf it's going to, I guess you call it a T. You put the ball on the T. I show with 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 and put a ball on the T, my central pattern generators would not be involved in that at all. The moment I bring the club back to swing, it's going to engage other things. And the other things that'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. 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. So we have CPGs for rhythmic movement,

00:25:00 Lower Motor Neurons Control Action Execution

upper motor neurons for deliberate unlearned movements or movements that we are in the process of learning. 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 caused the firing of those muscle fibers. So the way to think about this as you've got upper motor neurons which talk to CPGs and the lower motor neurons. So it's really simple. And now, you know most everything there is to know

00:25:26 What To Focus On While Learning

about the neural pathways controlling movement, at least for sake of this discussion. 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? 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 are 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 proprioception. 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 automatically going to engage your upper motor neurons. And if you do, 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

00:27:10 The Reality of Skill Learning & the 10,000 Hours Myth

and what am I going to focus on? And then your neurology will take care of the rest. 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 at all. 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 at all instant skill acquisition rule, which isn't really a rule, it's a myth. But the 10,000 hours rule overlook something crucial, which is that it's not about hours, it's

about repetitions.

00:28:30 Repetitions & The Super Mario Effect: Error Signals vs. Error Signals + Punishment

Now, of course there's a relationship between time and repetitions, 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 was a YouTuber who has 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 a 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 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, et cetera. 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 main successfully. 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 amaze, 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 in 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 put in the wrong command or is in the wrong sequence, it'll say that did not work please try again. And then the subjects would reorganize the instructions and then the little cursor would continue. And if they got it wrong again, it would say that does not work, please try again. 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 epinephrin 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'd 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

00:34:00 Learning To Win, Every Time

some or most of the 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. 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 results have 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 a particular area of the frontal cortex for those of you that want to know. And they did a simple experiment where the experimenters increased or decreased the activity of this brain area in the prefrontal cortex, little sub region 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 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 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. 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 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 very little feedback. It's not like every time the rat pushes forward or moves back that it is sensing, oh I'm winning, I'm losing, I'm winning, 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, "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. 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.

00:39:26 Errors Solve the Problem of What Focus On While Trying to Learn Skills

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 at all. 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 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. Unless the errors are somehow hazardous to your health or somebody else's wellbeing, 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 epinephrin 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,

00:43:00 Why Increasing Baseline Levels of Dopamine Prior To Learning Is Bad

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, "Oh, I got that one right." It will make those smaller relative to the background levels of dopamine. 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 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 it hit the net. Then I'll probably go too long then I'll probably go over the fence. At some point, I 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 and more repetitions. Now, if I were to just elevate my basal level of dopamine by taking, I don't know, 1500 milligrams L tyrosine or something, that would be bad because the increase in dopamine would actually be much lower. We would say the delta is smaller. The signal to noise is smaller if my overall levels of dopamine are very, very high.

00:44:40 The Framing Effect (& Protocol Defined)

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. And so that's very important. So these errors cue the brain that something was wrong and they open up the possibility for plasticity. It's what sometimes called the framing effect, it frames what's important. And so I think this is a shift that we've heard about, growth mindset which is the incredible discovery and theory and practice of my colleague, Carol Dweck at Stanford. This is distinct from that. This isn't about 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

00:46:10 A Note & Warning To Coaches

to the appropriate sensory events. 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, your elbows swinging too high, "or you're not gripping the racket "in the appropriate way," et cetera. They can see things that the practitioner can't see. And of course that's the 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, 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 tighten stance. So if I'm constantly being cued from the outside about what I'm incorrectly, that's not going to be as efficient. 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 in your whether or not you're a professional athlete, et cetera 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 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,

00:48:30 What To Do Immediately After Your Physical Skill Learning Practice

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 points 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. 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 motor skill, let's say 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 three times out of 1000. And it sounds like something I might do and there I'm probably being generous to myself. After I finished 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 five to 10 minutes, even one minute, the brain starts to replay the motor sequence corresponding to the correct pattern 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 of when I sleep later that night, the sequence will be replayed forwards in the proper sequence. Immediately afterward it's played a 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 one to five 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 that 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 review which is titled, Neuroplasticity Subservicing Motor Skill Learning by Dayan D-A-Y-A-N, I hope I'm not butchering the pronunciation and Cohen, by Leonard Cohen, but 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've 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. 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 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, that'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, et cetera 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 one, two, three, and four and maybe even episode five, I don't recall.

00:53:48 Leveraging Uncertainty

But you can go there to find out all about how to get better at sleeping. Now there are other training sessions involved. 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 set. Now, first of all, this principle of errors queuing 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 even has mastery or even virtuosity in a given skill. Remember, when you're unskilled at something, uncertainty is very high. As you become more skilled, certainty goes up. Then eventually you achieve levels of mastery where certainty is very very high about your ability to perform, yours certainty en 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. I happened to have the great privilege of being friends with Laird Hamilton, the big wave surfer who's phenomenal. I don't surf, I certainly don't surf with Laird, but he, and another guy that he starts with Luca Patua, these guys, they're 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 that they recognize that as the opportunity to perform better than they would otherwise. 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 it 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 is an idol at all, it's actually scripting all these things in reverse that allow for deeper learning and more quick learning. But if we fill that 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's 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

00:56:59 What to Pay Attention To While Striving To Improve

or a high-level athlete, the subsequent sessions are where you get to express the gains of the previous session, 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, 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. So to be very clear, 'cause I know many of you are interested 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, is 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 of 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 the 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. That seems incredible. I'm not good at a tennis serve. So if I've done let's say a thousand repetitions of the tennis serve. Maybe I got it right three 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 hit the ball across. And I'm making this up, again I don't play tennis. Turns out that it as long as it's the same thing throughout the session, learning is accelerated. And I'll explain why this

make 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. So instead of, and here, forgive me because I'm neither musical, nor can I sing. But instead of dah, dah dah, dah, they hear that, dah, dah dah, dah and then instead when they play. If it were me, it sounds something like, dah, dah dah [indistinct], it wouldn't sound right. 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, et cetera. 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. All right, so here's the experiment. They had people press on these keys and 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 a key and the job or the task of the subject was just oppressed the keys in the proper sequence. So instead of dunt, dunt, dunt, dunt, dunt, it it was just dunt, dunt, dunt, dunt, dunt. Instead of dah, dah, dah, dah, dah, dah, it's dah, dah, dah, dah, dah. It's even hard for me to say it in even a tone, but you get the idea. So a singular tone, just think a doorbell being rung with each press of the key will be really annoying. But it turns out that the rate to 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 back flip. 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 and do a back flip 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 digits, 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.

01:04:45 Protocol Synthesis Part One

But one of the biggest challenges for skill learning is knowing where to place your attention. 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 10, maybe it's the first 100. 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. 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 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's one getting on a trial to trial basis. 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 has 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.

01:07:10 Super-Slow-Motion Learning Training: Only Useful After Some Proficiency Is Attained

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. 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, 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 best learn how to perform a movement and then you just gradually increase the speed. 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 of 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 show 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 has 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 proficiencies. 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 have just navigating it 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 five 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's just going to fall to the floor, obviously. So there are a number of things like 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 place but once you're already performing things reasonably well like maybe 25 to 30% success rate. And I've tried this, I actually, I struggle with basketball for whatever reason and my free throw is terrible. So I practiced free throws in super slow motion

01:11:06 How To Move From Intermediate To Advanced Skill Execution faster: Metronomes

and I nailed them every time, the problem is there's no ball. 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 cued 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 forgot what the brand name was and 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 are other metronome type devices that through headphones or through a tone in the room if you're running indoors or on a treadmill we'll 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, or 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. Actually there's some wild experiments out there. You know there's a world championship of cup stacking. There's 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 and all the kids go wild. This is something I'd never thought to pursue 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 'cause 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 they're two metronomic 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 in 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 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, "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,

01:16:44 Increasing Speed Even If It Means More Errors: Training Central Pattern Generators

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, et cetera. The rate of the metronome obviously is going to be very important. Sometimes you're trying to lengthen your stride, sometimes you're trying to take fewer strokes but glide further in the pool for instance. But the value of occasionally just the number of repetitions, the number of strokes or steps, et cetera per unit time is also that you're training the central pattern generators to operate at that higher speed. One of the sports has kind of interesting to me is speed walking. It's not one I engage in or ever planned to engage in, but if you've ever tried to really speed walk, it's actually difficult to walk very very fast without breaking into a run. All animals have these kinds of crossover points where you go. I think with horses it's like it was that they trot, then they gallop on, or what's the next thing. Clearly, I don't know anything about horses except that they're beautiful and I liked them very much. But 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 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 speed purposes, what you do is you can basically bring the activity of those central pattern generators into their 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, et cetera in order to achieve maximum speeds and et cetera. It's a topic for a kind of an advanced session. Costa 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 brings back the point that what we put our attention to while we're still 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,

01:19:12 Integrated Learning: Leveraging Your Cerebellum ("Mini-Brain")

it can be internal and ultimately the skill learning is where all that is brought together. 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, 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 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. 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, particularly, 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. So this is pitch. For those of you that are 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 is that like sometimes if you see 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 on 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, it's 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 involves timing occurs in the cerebellum. Now, you can't really use that information except to know that after you learn something pretty well,

01:22:02 Protocol For Increasing Limb Range of Motion, Immediately

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 particular length or a elasticity, although that plays some role, it's not because our muscles are short. I don't know what that would even mean. Some people have longer muscle bellies or shorter muscle bellies, but your muscles always essentially span the entire length 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 that you actually have inhibitory pathways that prevent you from contracting the muscles or from extending them, from stretching them out any more. 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. 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. So we'll talk about this in a second 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, et cetera, your eyes are generating spontaneous movements to offset visual slip. In other words, you don't see the world as blurry even though you're moving because your eyes are generating low 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, is nystagmus. 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 ended up like jumping to the side, you miss the thing entirely. The reason those two "experiments" which I hope you don't do or for 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 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 what we call the vestibular, your eyes jolting back and forth, back and forth. Again, these aren't experiments you need to do 'cause 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 motion. If you're listening what I'm doing is I'm stretching out my arms like a T on either side and I'm trying to push them as far back as I can, which for me 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. 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 five to 15 degree increase in your range of motion. Now I'm doing this for you. You can say, "Well, he gamed it 'cause he knew "the result that he was hoping for." But you can try this. And you can do this for legs too. 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 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 actually we'll warm up

before exercise or before skill learning by both doing movements for 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 a cerebellar function. There's all sorts of just incredible stuff that you can do with cerebellum. I talked in an earlier episode on neuro-plasticity 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 timestamped. 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.

01:28:30 Visualization/ Mental Rehearsal: How To Do It Correctly

I'm not naturally more flexible. What's happened is I've expanded my range of motion. 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 Shepherd at Stanford and by others, looking at people's ability to rotate three-dimensional objects in their mind. And some people 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. 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 Rang Ganason at all, 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, et cetera. And what they did is they looked at 30 subjects. They divide them into different groups. They had one group perform essentially finger flexion. So it actually sort of the imagine if you're just listening to this, the come here a finger movement. They also had elbow flexion, so bicep curl type movement. And they either had subjects do a 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 was just done mentally. So they had people imagine moving against a weight, a very heavyweight or had imagined people moving their wrist towards their shoulder against a very heavyweight. 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 moved 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 difference would it make? But 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 "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. 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.

01:33:50 Results From 15 Minutes Per Day, 5 Days Per Week Visualization (vs. Actual Training)

So visualization is a powerful tool. How can you use visualization? Well, in this study, they had people perform this five days a week. I believe that it was 15. Yes, it was 15 minutes per day, five days a week for 12 weeks. So that's a lot of mental rehearsal. 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 strings on a guitar, for 15 minutes a day, five 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, et cetera. It's actually a hard study to do because 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.

01:35:34 Imagining Something Is Very Different Than Actually Experiencing It

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. This is not the way the

nervous system works. I'm sorry, I don't mean to burst anybody's bubble, but your bubble is made of myths. And the fact of the matter is that the brain, when it executes a 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, et cetera. And I'd be willing to wager that the same is true for experiences of all kinds. 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 other areas of 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, muscles 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 35% or 13.5% increases are pretty considerable.

01:37:58 Cadence Training & Learning "Carryover"

They're just not as great as the 53% increases that come from actual physical training. For those of you that are interested in some of this skill learning that more relates to musical training, but also how cadence and metronomes and tones, et cetera, can support physical learning. If you're interested in that, if are you a fussy and autos, 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.

01:39:00 Ingestible Compounds That Support Skill Learning: Motivation, Repetitions, Alpha-GPC

It's available as a complete article free of charge, et cetera. 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. 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 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've detailed a lot of tools in the underlying science. So for some people, it might be drinking a cup 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 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 I think 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 population. 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 and for which there really are a lot of data is alpha GPC and I'm going to attempt to pronounce what alpha GPC actually is. It's alpha glycerylphosphorylcholine. Alpha 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 alpha 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 Shotput throwing or resistance training or sprinting or 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, alpha GPC could be beneficial to you. For the cognitive effects, the dosages are much higher up to 1200 milligrams daily divided into three 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 neuro degeneration. Power output was notable. How notable, what does that mean, notable? A study noted a 14% increase in power output. That's pretty substantial, 14%. And 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 alpha GPC is to significantly improve cognition in people with Alzheimer's. Now this episode, isn't about cognitive decline and longevity, we will talk about that, but this is a so-called another effect of alpha GPC. Fat oxidation is increased by alpha GPC, growth hormone release is promoted by alpha GPC although to a small degree. So as you can see, things like alpha 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 are going to execute these many, many repetitions. 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

01:43:39 Summary & Sequencing Tools: Reps, Fails, Idle Time, Sleep, Metronome, Visualization

and how well you retain those skills. Now on a previous episode I talked about, and this was the episode on epinephrin on adrenaline. I talked about how for mental, for cognitive

learning, it makes sense to spike epinephrin, to bump epinephrin levels up adrenaline levels up after cognitive learning. For physical learning, it appears to be the opposite that if caffeine is in your practice or if you decide to try alpha 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 that optimize your sleep. A lot of the questions I get are about how different protocols and things that I described 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 'cause it's going to compromise your sleep. So I'm not here to design the perfect schedule for you because everyone's situation's vary. So the things to optimize are repetitions, failures, more repetitions, more failures at the offset of training. Having some idle time that can be straight into sleep or it could be simply letting the brain just go idle for five to 10 minutes, mean 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 or 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

01:46:20 Density Training: Comparing Ultradian- & Non-Ultradian Training Sessions

for 15 minutes a day, five 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 pathway, central pattern generator. So you now are armed with a lot of information about how you generate movement. And I 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 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. 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 are the stages of sleep in which we have either predominantly slowey 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 with all my friends that play golf, they disappear onto the golf course for many hours. So I know there's a lot of walking and driving and other stuff, I even hear that somebody carries your stuff around for you sometimes, not always. But it's going to differ. A four hour golf game, you're probably not swinging the golf club for four 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. 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 two hours of kind of haphazard not really focused work or where you're not generating very many repetitions 'cause you're doing few repetitions then you're texting on your phone or pay 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... Work toward maximal or near maximum 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,

01:49:24 Cost-Free Ways to Support Us, Sponsors & Alternate Channels, Closing Remarks

it's not always a linear improvement but you will see incredible improvement in skill. If you're enjoying this podcast and you're finding the information interesting and or of use to you, please subscribe on YouTube. That really helps us. As well, please subscribe and download the episodes on Apple and Spotify. On Apple, you also have the opportunity to leave us up to a five star review if you think we deserve that. And on YouTube, please hit the thumbs up button if you liked the episode and please give us feedback. Place your feedback in the comment section. That's a place to tell us how we're doing but also to ask us questions. We read all the comments. It takes us some time to work through them, but we read all of them and we use your comments and your feedback to sculpt the content and the direction of future episodes. As well, please check out our sponsors. The sponsors that we mentioned at the beginning of each podcast episode are really important in order to support our production team. And as well, we have a Patreon. It's patreon.com/andrewhuberman. There, you can support us at any level that you like. 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, that's the letter U slash 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 partnered with the Mayo Clinic and all the major sports teams and that's why we partnered with them as well. So if you want to check those out again, it's Thorne, T-H-O-R-N-E slash the letter 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.