Sue Nelson
Hello, I'm Sue Nelson and welcome to the Create the Future podcast brought to you by the Queen Elizabeth Prize for Engineering.
[Music]
There are many reasons why people become engineers, teachers, parents, role models. For Professor Hugh Herr, an engineer and biophysicist at MIT Media Lab in the United States it was personal tragedy. In 1982, at the age of 17, Hugh was mountaineering with a friend when a fierce snowstorm interrupted their climb. After a harrowing few days, they were eventually rescued, but frostbite and later gangrene resulted in both of Hugh's legs being amputated. It happened just a couple of years after the end of a hugely popular TV series called 'The Bionic Man', about a badly injured astronaut whose body was famously rebuilt better than it was before. The idea of this type of enhanced body repair technology at the time of Hugh's accident, though, was mere science fiction. But today, TIME magazine has deemed Hugh the 'Leader of the Bionic Age', as his work on prosthetics has transformed lives, including his own. But we began our conversation at a point shortly after that accident as a teenager, and a description from him of what his first pair of prosthetic legs were like.

Hugh Herr
They were absolutely terrible. They were made of foam and wood and carbon composite, absolutely no computer on board, no sensors, no muscle tendon like actuators simply passive devices that were non adaptive.

Sue Nelson
And were they comfortable?

Hugh Herr
No, they were excruciatingly painful actually. And I said to my clinicians at the time "are you joking - is this the only thing that's available?" And sadly, it was the only thing that was available.

Sue Nelson
And was this what made you then apply your mind to, well, "I'm going to have to live with this device, with these devices. I can do better?"

Hugh Herr
Yeah, absolutely. When I realised how pathetic and unsophisticated current technology was in the 1980s, in the realm of prosthetics, I really began thinking and inventing in the realm of prosthesis to improve the state of the art.

Sue Nelson
So what were your first improvements? What did you find, you know, that you could sort of immediately do that would make a difference?

Hugh Herr
I'm very goal oriented. So, my first goal was to return to mountain climbing. So, my first design objective was to design my own legs for the vertical world of rock and ice climbing. So, I developed feet where I could stand on small rock edges, feet that would wedge into small rock fissures feet that were spiked, that would penetrate an ice wall, enabling me to ascend a shear vertical expanse.

Sue Nelson

Is this because you were told that yes, you'll be able to walk again with these legs, but there's no way you could use his legs to climb rocks?

Hugh Herr
Yeah I was told that by my physical therapy physician at the time. He said I would not be able to ride a bicycle, I would use require hand controls to drive a car and I would most certainly not be able to return to mountain climbing. He was so wrong.

Sue Nelson
And other than the connections that you could then adapt, particularly the feat to get into particular crevices, what for you was the bit that could actually make them more comfortable, because I'm trying to think that's a lot of pressure, isn't it in terms of the human body on a very small part of the leg?

Hugh Herr
I would contend that if you ask 1000 people with limb loss, what's the one problem they have with their prosthesis or the most dominant problem? Probably all 1000 would say that their limbs hurt them, and that to please fix the poor fit. So my team at MIT, we are continuously working on that problem. And we've made tremendous progress and in fact I'm standing right now on interfaces that my team has developed and they're very comfortable.

Sue Nelson
And so what have you done then to improve that comfort because obviously, somebody's body mass and the pressure, that's not going to change. So, what have you designed that makes it more comfortable?

Hugh Herr
So, for thousands of years, even going back to ancient Egypt, the technique for fitting devices to the human body was artisanal based very, very simplistic, wherein a mould was taken of the part of the body for which you want to interface. And then based on that mould a device interface was developed by carving and cutting and sculpting. That's a process that's artisanal, does not enable, you know, advanced technology, and so on. So what we're doing now, is we're using imaging, so we use CT or MRI, and various other imaging modalities to measure in detail the geometries of the tissue of the residuum, so we create an actual mathematical model of the body for which we want to interface to, in the case of amputation, it's the amputated residuum, we then once the that body part is in the computer, if you will, we then use what's called finite element analysis, a physics based approach to designing a interface around that biomechanical model. And because this is all done in the computer, we can rapidly try different designs of interfaces, and not try three designs like in the world's world of atoms, but try hundreds of designs, because we can do that with very fast computers in terms of virtual prototyping. And then when we find out the malady, then we 3D print the interface. So that's a whole pipeline, where you end up with a fit that's deeply personal to the individual that's very, very precise to their anatomy.

Sue Nelson
And as well as that, I think, for me anyway, is when you watch people wearing your devices, your prosthesis, is how natural, it looks in terms of how people walk.

Hugh Herr
Right. Yeah, my group at MIT, we were the first to develop a bionic limb, a bionic leg that restores natural gait, meaning that if you put a person in a black box, and you can only measure their walking speed and how much

metabolic energy they're using, you would not be able to tell whether they have biological legs or synthetic lights, which was quite an interesting point in human history.

Sue Nelson
That's an understatement. And I've seen people virtually in tears, relief in terms of the difference it's made to their lives. So, you've got this connection. How did you get this connection because you need the electrical connection from the brain to the device.?

Hugh Herr
Right? There's different interfaces between the bionic limb and the body. One is mechanical, which we've talked about already. And a second is electrical or neural. So as you state, can we connect the bionic limb, the synthetic computation on the bionic limb to the human nervous system? And can we do so by bi-directionally, where a person can think and influence the output of the of the synthetic motors on the bionic limb? And can they go the other way were sensors on the bionic limb, when you touch them, those signals actually go into the nervous system, giving the person with amputation, a natural sensation of the position of the limb space, as well as cutaneous touch, pursuing that interface with the nerves and muscles.

Sue Nelson
And how long does that take? Is that something that's individual to each person? And do they have to sort of practice it and learn it in terms of focusing “right, I am now going to move my right foot”?

Hugh Herr
No not at all, if you design the neural interface well, it's completely natural and intuitive. So that the whole design objective is that it is without learning, it is completely immediate and intuitive.

Sue Nelson
You've spent your career working and all your sort of your education goes through all the necessary aspects, whether it's physics, or the mechanical engineering, or the biophysics as well, and devices, has sort of led you to this point. Obviously, that terrible accident was a sort of defining moment of your life, because it's set you on this career path, it's a very single vision you have. To begin with, was it just sort of I want to, you know, like you said, “I want to go I want to climb again”. When did it become “I want to help everybody else now”?

Hugh Herr
Yeah, very, very interesting question. So, you're absolutely correct that had the accident not occurred, I would have never been where I'm sitting today. I had no interest in technology, I had no interest in science, I had no interest in school for that matter, prior to my accident. I think the experience of the accident, building myself limbs to return to climbing and actually succeeding to a remarkable level where I could climb at a more advanced level after the accident with synthetic limbs than I could ever achieve before the accident with normal biological limbs. That experience was so inspirational, because I realised the power of technology to heal, to rehabilitate, in my own case, to actually extend human physicality beyond innate capabilities. It was that inspiration that drove me towards a whole a whole career a whole focus in and bionic technology, and to provide that gift of movement, that gift of a body that is no longer limited to all of humanity.

Sue Nelson
You know, I know you've had the comparisons before with the bionic man. But when you were saying that, I did get the ‘build you back better than before’. It does sound like that. It must have been quite a high in all sense of the words when you were climbing and realising “Wow, I'm doing something I couldn't have done before”.

Hugh Herr
It was extraordinary. One of the greatest experiences of my life.

Sue Nelson
And what sort of responses have you had, personally, from people who have been able to do this for the first time who might have thought that was it, they would not be able to walk naturally, again?

Hugh Herr
Yeah, in terms of walking and movement, you know, either the person begins giggling out of joy, or they begin crying out of joy. One sees both responses. In terms of the neural connection, the connection to the brain, it's very interesting that when a person can think and move the bionic limb, they can actually feel the bionic limb moving as a natural limb, they actually view the limb in a different way, it's no longer a tool, to them, it becomes part of them, part of their body. And they say things like “I now feel complete”, they say “it's my leg”, even though it's made of titanium, silicone, and carbon composite. So what we've learned and what we are learning in the field is that a body part need not be made of flesh and bone for it to be part of self, and completely natural.

Sue Nelson
Does this take advantage of the brain's ability with some people that have had a loss of a limb, they call it that phantom limb syndrome, where they feel as though it's there when it's not there is that sort of using that ability of the human mind to imagine, in a way?

Hugh Herr
Yeah, it's based on actual sensory information. So, proprioception, a lot of proprioception comes from biological sensors in muscles and tendons. Muscles and tendons are filled with sensors that measure the length of the muscle, the force borne on the muscle, and by extension, they're sensing the position of your joint and how much force is on your joint or torque. So what we do is when we amputate the limb, we create these agonist antagonist muscle pairs so that when a person moves the phantom joint, those physical muscles in the real world are moving and sending sensory information to the brain, telling the brain that the joint is moving. And then when we attach the bionic joint, and the person looks down and sees with their eyes, the bionic joint moving, and they feel it in their brain, you close the loop and it's a complete sensory experience and is providing the person a neurological embodiment, or an ownership.

Sue Nelson
That's amazing. That's absolutely amazing. Do you test your own prototypes out yourself?

Hugh Herr
I usually do but recent design expeditions, if you will, have gone into the realm of regenerative medicine and surgery and I personally have yet to receive these regenerative and surgical techniques applied to my own body. I will in the future. So, for the first time, I am not cutting edge. The subjects of my studies are cutting edge.

Sue Nelson
And how do they the connections, how did these sort of connections to the nervous system, how is that done? Is it purely by external sensors attached to the skin?

Hugh Herr
Yes, so far we're doing non-invasive skin sensors, but in the future, we want to implant small magnetic beads into these muscles. And then using magnetic field sensors on the skin, we can compute the mathematics and

figure out where the beads are in three-dimensional space. And by doing so we can track the length and speed of the moving muscle. So as the person thinks, as these move muscles are moving dynamically, and they are perceiving their phantom joints moving, we're actually sensing that movement with very high accuracy. And then that's commanded to the motors in the bionic limb. So, the joint moves in exactly an appropriate way as if the limb were intact.

Sue Nelson
Is any particular injury easier to deal with than another? For instance, is it easier having an entire say, prosthetic leg as opposed to maybe just from the ankle down, or maybe just several fingers?

Hugh Herr
Yeah, absolutely, you're exactly correct. The more distal, is the language we would use, the lower down the amputation, the easier it is to emulate with a prosthesis. And in distinction, the higher up or proximal the amputation, the more challenging it is for the technology.

Sue Nelson
And where do you see that technology going further in terms of you know, do you think there's now nothing that this technology can't do. I know that you've been working with exoskeletons as well. Do you see the future then for even an able-bodied person to be constantly or enhanced if they want to?

Hugh Herr
Yeah, absolutely. So, regarding amputation before we put a period on that discussion, I do think in two to three decades, we will have bionic limbs that completely emulate biological function, even for very proximal high amputations. And we'll have many examples of augmentation where the bionic limb actually affords the person an enhancement that's not achievable with mere flesh and bone. But yeah, for persons with “normal limbs”, exoskeletons are robots that you wear, they wrap around the limb and exert forces on the limb to augment jumping height and walking and running and so on. And my lab is developing such technology I also have a new start-up company called Dephy which is very much pushing the boundaries of what's possible with exoskeletons. So, I believe in a decade, it'll be common to walk down the street in a major city and see people wearing bionics, augmentative robotic platforms that are reducing their muscle skeletal stress, lowering their energy rates, enabling them to move faster, more agile than is possible with their biological bodies.

Sue Nelson
And this could be particularly helpful for ageing, because that's one of the things that goes, isn't it in terms of people's knees go their hips go?

Hugh Herr
Yeah, so we're one thing we're working on is a bionic shoe that enhances the extension of the ankle, called plantar flexion of the ankle. So, it turns out, arguably, the most important muscle in the human leg for walking is the calf muscle, because it injects enormous amounts of energy and power into the walking gait. And what happens is, as people age, the calf muscle degrades and is not as strong and not as powerful as that muscle was when the person was 18. And the result of that is a very high muscle skeletal stress when the leg hits the ground with every walking step. Without that robust calf muscle, there tends to be a lot of stress emanating up the leg, the knee and hip and lower back and that drives joint disease. So osteoarthritis of the knees is a dominant reason why the elderly cannot get around comfortably, in a bipedal way. And so, if we have bionic exoskeletons, we can essentially put 18-year-old calf muscles on everyone independent of their age, and dramatically mitigate joint disease in the elderly.

Sue Nelson
That would transform society, wouldn't it because so many people are on medication for pain for that sort of thing.

Hugh Herr
And imagine that it was readily available. Imagine that you're 75 and you go to your local store, either online or a brick-and-mortar store, and you buy these bionic shoes, and you walk out as you've walked when you were 18, imagine that. That's the work we want to create.

Sue Nelson
Is it easy to commercialise the work that you're doing at the MIT lab?

Hugh Herr
It's never easy to commercialise. Every product I commercialise I have a new set of grey hair. It typically takes me about a decade to commercialise a product. So, it's very hard, but of course, it's very, very worthwhile indeed.

Sue Nelson
Now, it's funny, you know, I normally ask guests, you know, what their advice would be to those who want to be an engineer and often people that you know, that say, it's about studying science, studying medicine, and we've just heard you say that you weren't interested in science or engineering at all when you were younger, so maybe I'll rephrase that question.

Hugh Herr
I could have been had I been exposed to it.

Sue Nelson
Yes, yeah, well you've obviously got a talent, more than a talent for it. But how about I rephrase the question and say, what is it about the engineering side of your research, that you find inspiring and could also inspire others?

Hugh Herr
I mean, engineering, science, art, it's all creativity. You know, wherever ideas come deep within ourselves is a mystery. And when we come up with ideas, when things pop in our mind, it's almost a spiritual experience, at least for me, it is. So, I absolutely love creativity and in any domain of life. Engineering is fantastic, because one can solve problems that so many people are faced with. And one can solve problems, you know, fairly quickly. If I can engineer a technology and actually productize it and get it out in a decade and produce a world where people are limping less. Well, how fantastic is that?

Sue Nelson
Absolutely. And it's funny you just used the word spiritual then because I was really interested to see that you are from a Mennonite family. For people who don't know, Mennonites are a sort of religious group, particularly in Pennsylvania, which is where you were brought up, a lot of people get confused with the Amish, but that they're sort of peaceful. And I have in fact stayed with a Mennonite family in Pennsylvania. Did that background affect your way of thinking as, as well? Or was it more the influence of family?

Hugh Herr

I mean, the idea of believing in something even though you cannot see it, is central to creativity. Highly creative people, they believe in something often, in a world where no one else believes it can exist, but they believe it can exist. And they believe it so passionately that they work so hard, and they crystallise their imagination into a physical form in that creative process. So again, you know, believing without seeing is central to creation. So, in that sense, it does tie back to my early childhood and the spirituality of my family.

Sue Nelson
And do you still climb?

Hugh Herr
I do still climb. I rarely have the time, but I do enjoy getting out most definitely.

Sue Nelson
And may I ask how many pairs of prosthetic legs do you have and their different functions?

Hugh Herr
Well, I'm surrounded by probably about 40 different interfaces in my office. But I have limbs for scuba diving, for running, for walking, for biking. You know, whenever an activity requires a distinct design, I'll certainly come up with that design and have my closet get fuller and fuller.

Sue Nelson
That's great. Thank you so much, Professor Hugh Herr for joining me on the Create the Future podcast. I feel as though you've given me a glimpse of a better future.

Hugh Herr
Thank you. I enjoyed being here today.