A Conversation with Daniel Wolpert

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Daniel Wolpert is a Professor of Engineering at the University of Cambridge and appointed to the Royal Society Noreen Murray Research Professorship in Neurobiology.

Jan Witkowski: What's someone in a department of engineering doing at a biological symposium?

Dr. Wolpert: I would struggle to pass first year engineering! I'm a medical doctor by training, but I got involved in using computational ideas to understand the brain. Over the years I've used control theory, signal processing, and machine learning approaches to understand the brain. When the engineering department wanted someone to do bioengineering they thought they'd hire a biologist with interest in engineering, rather than an engineer with an interest in biology. That's been very productive.

Jan Witkowski: What problems interest you?

Dr. Wolpert: I work on how the brain controls movement. Movements are fundamental to our existence. The only way we can affect the world around us is through the contractions of muscles; there's no other way to improve our survival. It's important to remember that things like sensory, memory, and cognitive processes are important to drive or suppress future movements. The beauty of working on movement is that you have to work on the whole system. It's the final output.

Jan Witkowski: Does that imply then that you feel the primary purpose of the brain and all its systems is controlling movement and that evolutionary pressure on the brain is actually through the control of movements?

Dr. Wolpert: I would say there's no point laying down memories of childhood or perceiving the color of a rose if it doesn't affect how you're going to move later in life, because it has no evolutionary advantage. Although you can study processes like vision in isolation, it's really important to remember that the reason to have these processes is to drive actions.

Another beautiful thing about studying movements is that it's a very hard problem, and we can really appreciate that if we look at how well we do building machines that can do what we can do. We can build machines to play chess and they can beat grand masters, but we can't yet

build a robot which can manipulate a chess piece with the dexterity of a 5-year-old child. It's a very challenging mathematical and computational problem, and if we could reverse engineer the brain, not only could we understand it from an intellectual point of view and help people with movement disorders but we could also build better robots.

Jan Witkowski: When I think of robots or robotic arms I think of those big ones welding on a car assembly line. They seem to do okay.

Dr. Wolpert: They do okay. If you want a robot to do a very simple task you can get it to do that one task by hand-tuning a solution. Once you've done that, you can't get it to do another task. What humans are particularly good at is flexibility and manipulation tasks, whereas these big robots are really designed to do one specific thing. What we really hope to do is understand the learning algorithms, which we think are really fundamental to allow machines to learn anything they want to learn.

Jan Witkowski: How do you set about trying to learn those algorithms experimentally?

Dr. Wolpert: Our approach is with humans. We're really interested in the algorithms, and then hope that the neural underpinning of our algorithms will be of interest to other labs who do animal research. We work with undergrads, robotic interfaces, and virtual reality. By controlling what people see and feel, and by giving them new skills they have to learn, we can tease apart the algorithms they use in their brain when they're learning skills.

Jan Witkowski: Can you give an example of what one of those tests looks like?

Dr. Wolpert: We put people into an unusual situation, where they hold a robotic interface which produces a force on the hand as they move, something they've never experienced before. We particularly want to give someone a new skill to learn. I'll mention one of the experiments we've just done. We were fascinated why people follow

through in sport. Why is it that when you throw a ball or hit a ball in tennis or in golf, people tell you the follow-through is important when the action's all over by then? The key to understanding the follow-through is understanding how we activate different motor memories.

When we learn different skills—such as how to ride a bicycle or drive a car—we access different motor memories for these skills. What we've just found out is that the motor memory you activate now depends not only on what you've done in the past, but what you're going to do in the future. If you have a consistent follow-through after an action, you store that in one motor memory. Whereas, if you have different follow-throughs, you store them in different motor memories, and therefore don't consolidate them. What we've shown is that part of the reason you want to follow through is to store everything into one motor memory.

What we've shown is that the half-second before the movement determines which motor memories are accessed. Things happening more than half a second before the movement don't determine which motor memories you can access. Half a second before to half a second after the movement is the critical period. Basically the near future and the near past determine how you activate motor memories, which is an interesting time period. Why that half second is important we don't yet know, and that's an interesting question for us to answer.

Jan Witkowski: How broadly applicable do you think this is across species? Does *C. elegans* make use of this mechanism?

Dr. Wolpert: I don't know if *C. elegans* can learn quite as many things as humans can. I don't know whether they can store many motor skills, but they certainly can switch between skills.

What's really driven me is trying to understand how motor signals work, particularly from a point of view of what we call noise. When I talk about noise I don't mean sound, I mean the variability we have in our senses and in our muscles. One thing that characterizes humans compared with robots is how incredibly variable we are. If I put my hand under a table and try to localize it with my other hand I can be off by centimeters. If I try to play darts I have huge variability, yet we're very skilled. One of the things we've been working on is, how does the brain get around the problems of that variability.

We have so many ways we can do a task. If I asked you to point to your nose, you could do it in many different ways but most people will do such tasks in very similar way. We think the reason people do that is because it's somehow the optimal way to move so as to reduce the bad consequences of this variability. It turns out that this variability makes us move in a particular way. That's rather nice as it means we can generate models to predict

how people should move, and that if you move in different ways you're going to be less accurate. I've been driven very much by those noise models, which say what we have to learn about to perceive the world as statistics. As you go around the world you learn about statistics of the outside world, and that's really important to be able to estimate and predict the future.

Jan Witkowski: If you take a thousand people and they're all right handed and they've all got the right number of fingers and you ask them to touch their nose, how variable is the path by which they do it?

Dr. Wolpert: It's not very variable. We all walk roughly the same way, we all reach the same way. You don't have to. Out of the infinite number of ways you could reach to pick something up, there are many ways we don't choose. It's interesting to ask why we choose particular solutions. The way we walk is very stereotypical. People like John Cleese from Monty Python made their early career by violating biological motions, which somehow is funny to us. The fact that we all think so tells us something about the way the brain is organizing these movements.

Jan Witkowski: Presumably a baby learns these things. Is it learned by imitation or is it internally?

Dr. Wolpert: No, I think imitation helps, but I think it's internally learned. I think we start off with a right approximation, but the noise is very big. Variability is much greater in babies. For example, the way they start moving their eyes is very different to the way adults do, and only by the age of 3 or 4 do they start having eye movements similar to the way adults move their eyes. We move our eyes almost all the way to a target but they, because they have so much variability, make small steps, because if they tried to get there in one go they'd have so much variability they'd be hunting around the target all the time. We think these are probably learned throughout experience.

The real question, though, is why I'm not as good as Tiger Woods at golf. It could be that he's found the optimal solutions and I'm just not good and have to keep practicing. What I believe is that we have different levels of variability. I've just got higher level of variability, and therefore whatever I do I can never be as accurate as him. Some people are just born lucky in terms of that variability.

Jan Witkowski: Can you test that?

Dr. Wolpert: It's a little hard to test because it's hard to separate experimentally, the person who is optimal versus those who have noise. We're thinking of ways to do that. It would be wonderful to be able to sort children, to say, "You do piano, while you should be on a big drum." That's a little harder, that's a dream for the future.

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