

The Future of Robotics in Neurorehabilitation

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What is the future of rehabilitation, exercise and movement training?



A Typical Rehabilitation Clinic Today

Disclosure

I am a co-inventor of T-WREX (which led to ARMEO), along with Robert Sanchez, Tariq Rahman, and others

I have received royalties from and consulted for Hocoma.

Plan for the talk

- In this talk, I will imagine what rehabilitation might be like if I have a stroke when I am older.
- I will focus on how robotic devices and information technology might be used in my rehabilitation.
- You can imagine similar scenarios for spinal cord injury, traumatic brain injury, and other conditions.
- I will provide references for some of the ideas at the bottom of the slide.

Day 1 – The Stroke

It's Sept 23, 2036. I turned 70 yesterday. I wake up around 2 A.M. with a headache and get up to use the bathroom. I fall as I get out of bed. I can't move my left arm or leg. My wife recognizes the symptoms of a stroke and rushes me to the hospital.

In the hospital I undergo brain imaging and a doctor confirms that I have an ischemic stroke. I receive clot-busting and neuroprotective drugs.

Day 1 – continued

In my hospital room, a rehabilitation therapist attaches small robotic stimulators to my fingers, tongue, face, and foot. The devices push on my skin in rapid rhythmic patterns for the next three hours. The doctor tells me that they will stimulate blood flow reorganization, opening alternate arterial pathways to perfuse my brain.

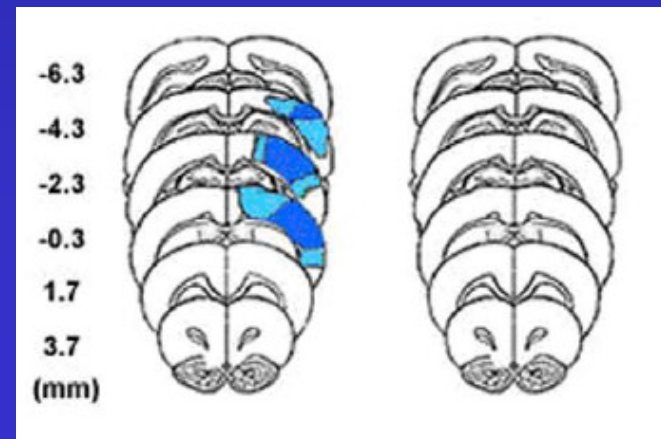
I can't walk and I can't move my hand or arm.

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PLoS one

Mild Sensory Stimulation Completely Protects the Adult Rodent Cortex from Ischemic Stroke

Christopher C. Lay^{1,2*}, Melissa F. Davis^{1,2*}, Cynthia H. Chen-Bee¹, Ron D. Frostig^{1,2,3*}



Day 2

The doctor explains that the neuroprotective treatments and sensory stimulation are helping, but that there is still damage to my brain. She explains that my brain has a lot of potential for re-wiring itself if I work hard, and she expects a full recovery.

She explains that she will be using a cocktail of stem cells, drugs, and an implanted brain recorder/stimulator to enhance my brain plasticity. Later today she will take cell samples from me, and induce the cells to become pluripotent stem cells. She will use a microrobotic device to deliver these cells to the site of my brain damage, as well as to implant a small electric stimulator in my brain.



Day 2 continued

My rehabilitation therapist emphasizes again that a full recovery will require a lot of hard work. She explains that she will design a movement training program for me that is based on my genetic profile, the pattern of damage to my brain, and the specific stem cell and drug treatments I am receiving. We'll start tomorrow.

Table 1 Summary of behavioral and histological differences between groups

| | | Staircase reaching task | Reaching in Whishaw apparatus | Placing response | Ladder walking | Grip strength | Sensory threshold | CST sprouting | CST regeneration |
|-------|-------------------------|-------------------------|-------------------------------|------------------|----------------|---------------|-------------------|---------------|------------------|
| Pen | No rehabilitation | — | — | — | — | — | — | — | — |
| | Specific rehabilitation | — | ↑ | — | — | — | — | — | — |
| | General rehabilitation | ↓ | — | — | ↑↑ | — | — | — | — |
| ChABC | No rehabilitation | — | ↑ | ↑↑ | — | — | — | ↑↑ | ↑↑ |
| | Specific rehabilitation | ↑↑ | ↑↑ | ↑ | — | — | — | ↑↑ | ↑↑ |
| | General rehabilitation | ↓ | ↓ | ↑ | ↑↑ | ↑↑ | — | ↑↑ | ↑↑ |

Improvements are indicated by an up arrow, larger improvements by two up arrows and decrements by down arrows. Overall, rats treated with ChABC showed greater behavioral improvement over the range of tasks. Rehabilitation treatments affected the behaviors that were practiced; thus, paw reaching rehabilitation improved only paw reaching and general rehabilitation improved locomotor tasks. There was competition between the rehabilitation effects, with paw reaching being extinguished by general rehabilitation.

Chondroitinase ABC treatment opens a window of opportunity for task-specific rehabilitation

Guillermo García-Alías, Stanley Barkhuysen, Miranda Buckle & James W Fawcett

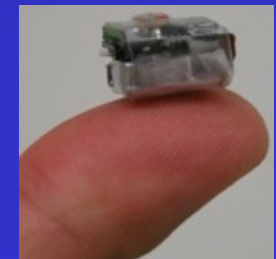
Day 2 continued

Later that day, after my minimally invasive robotic brain surgery, my rehabilitation therapist brings in a small electronic device and attaches it to my shin, and another one around my wrist. She explains that these devices will keep track of how often I am moving my hand and leg.

She downloads an app on my cell phone that shows me my chances for recovery, based on a database of thousands of patients who are similar to me and underwent similar treatment.

The app reminds me to try to move my limbs periodically with an alarm, and sets specific target numbers of repetitions for me.

I still can't walk or move my hand.



Day 3

I wake up and my bed transforms into a wheelchair. It has a robotic arm exoskeleton attached to it, which my therapist attaches to my arm and hand. The device responds to my intention to move, as measured by the electrodes implanted in my brain, so I can move my arm and hand a little better, but it's still difficult. My therapist explains that this is intentional – she wants me to have to struggle to move, to help my brain reorganize itself. She explains that the assistance is set on “high” for now, but that she will be decreasing it soon.



Day 3 continued

With help from the arm exoskeleton, and coaching from my therapist, I use my arm to roll my wheelchair to the exercise room. There are several rooms with large 3D displays there, and several patients in each room. “Are you ready for the holodeck, Captain Picard?” my therapist says with a smile on her face.

The therapist wheels me into the “holodeck”, and teaches me how to stand up. The chair helps me as I try to stand up, but it’s still difficult.

She attaches a soft harness to my pelvis, which is tethered to a robot on the ceiling. She also attaches a lightweight robotic exoskeleton to my impaired leg. She tells me these devices will allow me to safely practice standing, balancing, and walking as I exercise. She tells me that as I get better, they will actually perturb me so that my brain can learn better how to correct for the movement variability caused by my stroke.



Day 3 continued

She interviews me about my favorite sports and activities, and about what type of work I want to do when I get out of the hospital. I tell her I'm an avid golfer but a terrible dancer, and my wife would love it if that equation were a little more balanced. I'm also a teacher, and need to be able stand and write on a chalkboard.

She sets up a simulation for me in which I can play virtual golf. The robots help me bend over to place the ball, balance and swing, and I walk on a treadmill in a 3D virtual golf course after hitting each ball. She tells me I can learn how to drive a cart tomorrow, but for today I'm walking. She asks me to play a round with another patient in the room. She explains that the system will handicap us to approximately the same level, so it will be a good match.



Day 3 continued

I'm not as good a golfer as I used to be, even with help from the robots. But I play 9 holes and beat my partner by 2 strokes. He challenges me to a sailing race tomorrow in the "holodeck".

I'm tired, but the time flew by while I was playing golf.

Day 3 continued

Later, back in my room, my therapist tells me that she analyzed data from my golf session, and that I began moving my leg, showed some balance reactions, and improved my hand movement ability today. She shows my progress to me on my cell phone app, and notes that I moved just over the target amount for today.



She says after the sailing race in the morning, we're going to try to learn some dance steps in the afternoon. My wife will be my partner.



Days 4-21

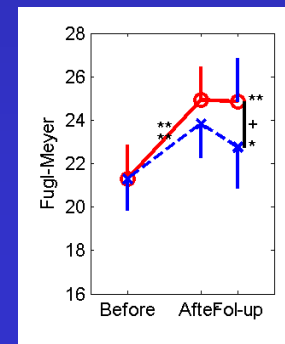
Each day I work hard at getting out of bed, walking, transferring to the toilet and using my arm. My therapist tells me my robots are helping me, but I'm skeptical – this is tough work, and sometimes it seems like the robots are challenging me even more!

But it's fun too – I've been practicing golf, sailing, and dance. I actually think I'm getting better at dance. And I've started practicing standing and writing on a chalkboard as well.

My therapist shows me data on my cell phone app that indicate I'm making good progress. I can move my hand a little more and I stand up each day without help from the wheelchair, and take some steps with my therapist helping me.

Comparison of error-amplification and haptic-guidance training techniques for learning of a timing-based motor task by healthy individuals

Marie-Hélène Milot · Laura Marchal-Crespo ·
Christopher S. Green · Steven C. Cramer ·
David J. Reinkensmeyer



Day 22

My therapist explains that it's time for me to go home. I'm medically stable, and my movement return is good enough that I should be able to keep practicing moving, with a little help from some devices she gives me.

One of these devices is a lightweight exoskeleton for my hand, and the other is a lightweight exoskeleton for my leg. She explains that these devices will be assisting me in walking safely and in using my hand, but only as much as I need to get around and to get jobs done. "They'll keep turning themselves down as you get better – so don't get used to them" she says.



Day 22 continued

She shows me also where I can access a “holo-deck” in my neighborhood. “It’s not as nice as the one in the hospital, but it still pretty fun” she says. “And you can work out with some of the friends you made in the hospital through the network.”

She shows me how we will keep in touch with a videoconferencing program on my cell phone. She says she’ll be watching my movement data. “Don’t even think about becoming a couch potato” she says.



Runs on a medical cart, home entertainment system, a laptop, or a PDA

Days 21-90

I spend my days working on re-training my movement, with help from my exoskeletons and my local “holodeck.”

I videoconference with my therapist a couple of times a week using my cell phone, and I visit her weekly.

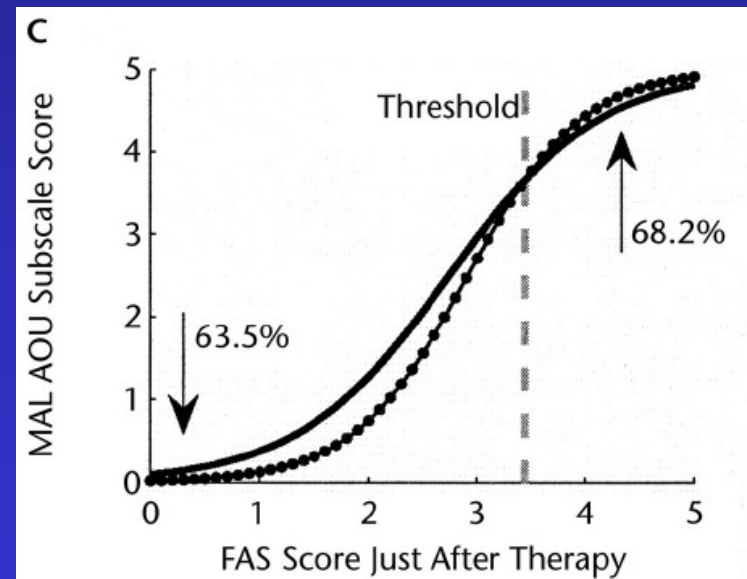
I keep track of whether I’m meeting my target practice amounts and types with my cell phone. I can also see that the amount of assistance from my exoskeletons is decreasing. I’m getting better.

Day 90

My therapist lets me know that its time to get rid of the exoskeletons completely, because I can move well enough to keep using my limbs without them. I am still a little weak and uncoordinated, but I will work hard, and I know I'll keep improving.

A Functional Threshold for Long-Term Use of Hand and Arm Function Can Be Determined: Predictions From a Computational Model and Supporting Data From the Extremity Constraint-Induced Therapy Evaluation (EXCITE) Trial

Nicolas Schweighofer, Cheol E. Han, Steven L. Wolf, Michael A. Arbib, Carolee J. Winstein



Summary: Some Key ideas

Robots will:

- be used for early sensory stimulation, brain surgery, and movement training.
- keep patients safe, allow engaging, meaningful practice in a social context.
- help the patient as little as possible, and in some cases increase the challenge for the patient.
- be matched to the patient's profile and the selected neuroregenerative treatments.
- measure what practice is done and its effect.
- avoid learned non-use at home by serving a smart assistive role.
- be powerful tools in the hands of creative clinicians who are skilled in their use.

Or, maybe not – why might we not get there?

Actuators?

Cost?

Intelligence?

Mechanistic optimization?

Large, longitudinal databases?

Slacking?