Recent Trends in Rehabilitation Robotics

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Agenda

- Some Rehabilitation Therapy Robot Trends
- Some Assistive Robotics Trends
- Discussion
Robotic Therapy Training Gains are Modest (e.g. Fugl-Meyer score)

Reference Slide: Reinkensmeyer et al.

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**Figure 3** Perspective on the magnitude of recovery of the upper extremity following stroke with robotic therapy. Plot summarizes data from four studies. The long solid curve (robot therapy) and dashed curve (no robot therapy) represent recovery reported in References 90 and 129. The two short curves represent data from References 76 (upper curve) and 73 (lower curve). All studies used the Fugl-Meyer upper extremity scale, which scores a series of movements 0, 1, or 2, then adds the individual movement scores to obtain the total score.
Summary Findings: Stroke Rehabilitation

**Health Condition (CNS damage)**

**Body Functions & Structure (Impairment)**
- Increase strength
- Increase motor control
- Reduce spasticity
- Improve interjoint movement
- Training-specific – shoulder and elbow

**Activity (Disability)**
- Train mainly reaching tasks not hands or grasping
- Inconsistent carryover to real activities of daily living (ADLs)
- Not address personal needs and life goals

**Participation (Handicap)**
- Not address long-term handicap
- No relevant address of life outside of clinic

**Facilitators vs Barriers**

**Personal Factors**
*Internal influences*
- Not address motivation and compliance or social factors

**Environmental Factors**
*External influences*
- Not address learned non-use that aggravate compensatory behaviors

*Important in home therapy*
Rehabilitation Robotics Therapy Trends

- Rehabilitation Therapy
  - Include exoskeleton machines
  - Build on motor learning theories and utilizes more complex tasks
  - Use of systems with additional technologies such as fMRI
  - Focus on home rehabilitation and low-cost systems
  - Incorporate new motivational paradigms and task-oriented paradigms
  - Use hands-off therapy in non-traditional environments
  - Go beyond stroke such as Autism and TBI
Trends: End-effectors to Exoskeleton Machines

ArmIn
Swiss Federal Institute of Technology (ETH) in Zurich, Switzerland.
6DOF
3D movement and practice of tasks in VR
Exoskeleton
HapticWalker

LokoMat

• Automated
• Reduce Cost
• Some Not Mimic
• Real Life
• Improve with better simulations

Gangtrainer GT I

StringMan

Lower Limb Rehabilitation Robots
Trends: Use Motor Learning Theories

- **Robot-assisted adaptive training: Custom force fields for teaching movement patterns.** Patton, JL and Mussa-Ivaldi FA.
  - Internal models: sensory motor mappings used by the NS to anticipate the force requirements of movement tasks
  - Feed-Forward Control: the use of preprogrammed movements used to predict the limbs response to disturbances
  - Aftereffect: Occurs when forces are unexpectedly removed, displacing the hand path in the direction opposite the force
  - Seven phases of testing (Unperturbed familiarization, Unperturbed baseline, Machine-learning, Unperturbed baseline, Learning, After-effects, Washout)

- **Hemiparetic stroke impairs anticipatory control of arm movement.** Takahashi, CD, Reinkensmeyer, DJ
  - Decreased ability to adapt to the perturbing forces with their hemiparetic arms
  - Smaller aftereffects when the perturbing force was unexpectedly removed
  - Hemiparetic stroke impairs the ability to implement internal models used for anticipatory control of arm movement
Using Motor Learning Knowledge to Improve Motor Re-learning: Motor adaptation to a force field

Seven phases of testing
- Unperturbed familiarization
- Unperturbed baseline
- Machine-learning
- Unperturbed baseline
- Learning
- After-effects

Thoroughman and Shadmehr 2000 Neurophys found that the evolution of trajectory error can be modeled with a difference equation:

\[ x_{i+1} = a_0 x_i + b_1 F_i + b_0 F_{i+1} + c_o \]

- \( x_i \) = average trajectory error on \( i^{th} \) reach
- \( F_i \) = average force on \( i^{th} \) reach

“Performance Dynamics”: “Scheidt Equation”

"the nervous system updates its currently selected internal model on the basis of sensory information from only one previous trial and an internal state variable, performing a sort of moving average”

Reference Slide: Reinkensmeyer Presentation
Error amplification techniques in stroke rehabilitation

- Patton et al. (Exp Br. Res 2006) showed how stroke-impaired reaching paths could be made straighter using error amplification.

- However, path curvature was not explicitly constrained in this task (subjects only had to attain target, and were not asked to reach as straight possible -- note in the above figure that directional error actually increased for another direction).

- Using error amplification to bring attention to “neglected” aspects of some tasks may be effective, particularly if there exist tasks in which those “neglected aspects” are insidious.
Gravity Retraining: Act 3D

The ACT3D system creates a virtual world designed to help stroke victims regain a measure of control over their limbs.

“muscle synergies is an abnormal coupling between shoulder abduction and elbow flexion, which significantly reduces a stroke survivor's reaching space when he/she lifts the weight of the impaired arm against gravity.”

Theory – Control gravity during reaching to retrain arm.
Trends: Combining Imaging Technologies

- Use of systems with imaging technologies such as fMRI and DTI
  - Began with advances in Constraint Induced Therapies and the use of PET techniques to determine hand area changes after CI Therapy (Miltner et al.)
  - Influence the use of bilateral therapy as well as other strategies
The path of voluntary movement in the normal brain

1. The idea of movement begins in the prefrontal cortex.

2. The information from the prefrontal cortex is sent to the lateral cerebellum also known as the cerebrocerebellum.

3. The information from the prefrontal cortex are received by the basal ganglia which serves as a regulatory mechanism for movement.

4. The thalamus serves as a relay center through which sensorimotor integration occurs.

5. The premotor cortex is involved in the preparation for movement.

6. The Motor cortex is the area of the brain that sends the signal to the spinal cord and motor neurons to carry out the actual movement.

The intermediate cerebellum and the somatosensory cortex (located in the parietal cortex) are responsible for the ongoing control of movement. The somatosensory cortex provides feedback during movement that allows for the continued guidance of the limbs during movement by receiving information from the basal ganglia.
1. Prefrontal Cortex

Lesions in the prefrontal cortex result in a reduced ability to organize daily movements and movement planning disorders. This translates to difficulties with initiation of movement.

2. Cerebellum

Damage to the cerebellum, depending on the location within the cerebellum, cause errors in timing and in the accuracy of movement. There is also an impaired multi-joint coordination which manifests in a curved hand path. Disorders that are related to cerebellar damage include hypotonia, dysdiadochokinesia, tremor, clumsy movements and delays in initiation. Specific to reach-to-grasp.

3. Basal Ganglia

Damage to the Basal ganglia is manifested in two ways. The first is impaired initiation of movement, and jerky random movements that are seen with Parkinson's disorder. This disorder is related to under activity in the direct pathway within the basal ganglia. The second is excessive motor activity and violent proximal arm movements that are related to Huntington's Disorder. This results from over activity within the direct pathway.

4. The Thalamus

Lesions within the thalamus can impair the passage of information from the basal ganglia and cerebellum to the motor areas.

5. The Pre-motor Cortex

Lesions in the pre-motor cortex result in an inability to use the contra-lateral limbs. The patient has difficulty performing based on external and internal cues and has difficulty initiating movement he wishes to make.

6. The Motor Cortex

Damage to the motor cortex affects movement itself. If for example the hand area is lesioned, the individual would not have control of the hand.
No single method is sufficient; each has its relative advantages and limitations.

- **fMRI** – functional magnetic resonance imaging; measures changes in blood oxygen flow in response to neuronal activity. [Whole Brain]

- **PET** – Positron Emission Tomography: PET measures the amount of metabolic activity at a site in the body; PET scanning is the ability to measure tissue metabolism, viability of ischemic tissue, neurochemistry, and receptor kinetics. [Whole Brain]

- **TMS** – Transcranial magnetic stimulation (TMS) provides insights into neurophysiology of the motor system, including conduction velocity, motor-evoked potentials, cortical inhibition, and cortical excitability [LOCAL BRAIN ASSESSMENT]

- **DTI** – Diffusion Tensor Imaging - Tractography
Trends: Include Bimanual Training and Assessment

- Upper extremity stroke rehabilitation protocols always focus on the strengthening, neuromotor re-education and functional training of the impaired arm.
- Day to day life involves many tasks which are bimanual in nature.
- The need to coordinate use of both the arms in real life makes it very important to train the impaired arm in bimanual environments not just in unilateral ones.
Bilateral Motor Learning Theory

- A reduction in the laterality of brain activity
  - the effect of stroke is to increase the extent to which both hemispheres are recruited rather than just the contralateral hemisphere
- Suggest a place for bilateral training and use
Bilateral Technologies

•Low-cost
•Simple Movements
•Typically Symmetric
•Tele-rehab

Bi-Manu Trac, Berlin
Example Intervention:
1 hour of robotic therapy 3X week
•20 to 25 min/day, 5 days/wk x 6 wks (Hesse et al. (2004,2005))
•Practice wrist flexion, extension, and pronation and supination
Bilateral Assessment and Compensatory Behaviors

- To evaluate if a bias (natural or due to learned non-use) for the dominant arm can be assessed objectively.
- To a new rehabilitation protocol that tries to change the impaired arm use.
Bilateral Arm Use and Contribution

- To evaluate if a bias (natural or due to learned non-use) for the dominant arm can be assessed objectively.

Johnson et al. 2007
Bilateral Arm Use and Contribution

Unilateral arm Contribution by target distance

Bilateral arm Contribution by target distance

Johnson et al. 2007
Trends: Home Service Delivery

- **InPerson Home Care or Outside of Clinic**
- **Teleconsultation**: standard “face-to-face” telemedicine model using interactive videoconferencing, typically with high bandwidth between sites.
- **Telehomecare**: often uses a tele-nurse coordinating service delivery
- **Telemonitoring**: unobtrusively monitors patient data remotely, with possible interactive teleassessment.
- **Telementherapy**: patient “plays” or “exercises” in the home environment, and therapist has the ability to change settings remotely based on patient’s performance.
- **Telecooperation**: by using the telerehabilitation link, multiple persons can cooperate together to accomplish a goal-directed task
Therapy-Based Rehabilitation for Stroke Patients Living at Home

Lynn Legg, MPH, Dip COT SROT; Peter Lancashire, BSc, PhD, MRCP

Background
Stroke unit care is now accepted as an effective service model for hospital care, but the effectiveness of outpatient services are less certain. This review focuses on therapy-based rehabilitation services (defined as input from occupational therapy, physiotherapy, or a multidisciplinary team) targeted at stroke patients living at home.

Objectives
To assess the effects of therapy-based rehabilitation services targeted toward stroke patient resident in the community within 1 year of stroke onset or discharge from hospital following stroke.

Methods

We considered all unconfounded, truly randomized controlled trials of stroke patients resident in the community receiving a therapy service intervention, which was compared with conventional care (ie, normal practice or no routine intervention). Two reviewers independently selected trials, extracted data, and assessed trial quality.

Results
A total of 27 trials were identified by November 2001 of which 10 did not meet the inclusion criteria. Three trials are not yet completed, and the remaining 14 contained outcome information on a total of 1617 patients. Losses to follow-up were small (138 patients; 8.3%).

Patients allocated therapy-based rehabilitation services were less likely to deteriorate in ability to perform activities of daily living (odds ratio 0.72; 95% CI 0.57 to 0.92; P=0.009) and increased their ability to perform personal activities of daily living (standardized mean difference 0.14; 95% CI 0.02 to 0.25; P=0.02). These findings were not substantially altered if analyses were restricted to trials that described a clearly concealed randomization process and unequivocally blinded final outcome assessment.

Reviewer’s Conclusions
Stroke patients living at home who received input from a therapy-based rehabilitation service were less likely to experience deterioration in their ability to perform activities of daily living. The absolute risk of deteriorating in ability to perform activities of daily living was 7 per 100 patients allocated therapy-based rehabilitation. However, interpreting and implementing these results raise a number of challenges. Further research is needed to define the most effective interventions, their economic benefit, and the most appropriate level of service delivery.
Trends: Home systems

- Use of systems at home as well
  - Low-cost technologies
  - Distributed technologies
  - Game-based technologies
  - Wearable technologies
Figure 1.
AutoCITE with all fo cabinet automatically at lap level. Work surfa subject’s lap. Touch-screen rectangular control butt to left side of chair fix moved to right side of chair for participant with left hemiparesis.

Figure 2.
Distributed Modular Simple and Complex Robotic Devices with UniTherapy Glue

- Low-Cost
- Portable
- Game Playing

TheraJoy
LM Johnson et al. 2004
Marquette Univ.

TheraDrive
Johnson et al. 2004, 2007
MCW/Marquette Univ.

Palanca
Bach-y-Rita et al. 2001
Univ. of Wis. Madison

Feng et al. 2004
Marquette Univ.
Low-cost, Home Rehabilitation Strategies system for Therapy and Monitoring

Johnson et al. 2007
Wearable Technologies for Home:

- Wearable
- Joint Based
- Portable
- Challenges with size, actuation, weight

Arizona State: Jiping He et al.
## Articles

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<th>Articles</th>
<th>HCI</th>
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<td>Transfer sensor data to data-logger</td>
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<td>Used to relay sensor data to a base station to be recorded</td>
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<td>- Amount of info needs to be reduced</td>
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<td>Classifier Software</td>
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<td>Used to determine motor activities</td>
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<td>Data used in closed loop system; Allows for adaptive system</td>
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Trends: Task-Oriented/Motivation

- Motivation, engagement, and task important for motor learning
- Increase task context and relevance, collaborative rehab, and use games.
INCLUDE THE HANDS

Reasons...

- Support fully functional tasks
- Increase engaging or motivating
- Include the hand

Rutger’s Handmaster

RUPERT

HWARD

SPIDAR-G
Unilateral Focus

Bilateral Whole Arm Movement

Reaching + Grasping + Manipulation

Reaching and Grasping

Manipulation

Reaching

Single Joint Movements

Strengthening

Popular Methods

Lock Manipulation Tasks

Cup

Robot

Bowl

Spoon

Robot
Trends: Social Assistive Robotics (Therapy and Personal Care)

- New applications with hands-off therapy in non-traditional environments

Ref: Mataric

- Daily Living Monitor
- Assist in under-supervised environment
- Encourage and Motivate

USC
Trends: Personal Robots

- **Objective:**
  - Implement intelligent machines capable of assisting human beings in practical circumstances
  - Targeted Consumer: Elderly, Physically or Mentally Disabled, Severely Sick, Severely Restrained

- **Definition:**
  - Robotic technologies that enable persons with chronic physical or cognitive impairments, including those associated with old age to conduct activities of daily living.
  - Classification: assistive robots & ubiquitous robotics,

- **Difficulties to overcome:**
  - Achieving adequate safety
  - Proper human-robot interaction
  - Useful performance
  - Affordable cost
Reasons for a humanoid service robot

- Robot needed to perform in environments where humans work and live
- Human environment is designed to meet special human characteristics and needs
- Robot placed in a human environment should have comparable sensory and motor skills in order to service the human
- Service robots interact and communicate with humans in many different forms, from touch to gestures to speech
Elderly and Disabled Care at Home and Clinic

- **Cognitive prosthesis.** A large fraction of the elderly population suffers from varying degrees of dementia.
- **Safeguarding.** Prevent home risks such as falls.
- **Systematic Data Collection.** Collect data for people living in private homes.
- **Remote tele-medicine.** Home visits by healthcare professionals
- **Social interaction.** Elderly people is forced to live alone

Nicholas Roy et al  CMU NurseBot; Towards Personal Service Robots for the Elderly
Other Home Robots

- **Care-O-Bot II**
  - Includes Manipulator
  - Avoids obstacles
  - [Play Movie]

- **PAMMs**
  - Includes Vital signs monitoring
    - ECG-based pulse monitor
    - Stride-to-stride variability in gait as fall predictor
  - Force/Torque input

http://www.care-o-bot.de/english/Care-O-bot_2.php
http://robots.mit.edu/
Task-specific robots

- Seven Commercial Feeders
  - 3 Robotic Feeders (Handy 1 and MySpoon)

- Three products recently developed
  - MySpoon
  - The Neater Eater
  - The Assisitive Dining Device

- MySpoon (5 DOF)
- The Neater Eater
- Assistive Dining Device (3 DOF)
Future Trends of Assistant Technologies

- Improved measuring and understanding of the user’s intent and effort level.
- Improved natural HCI
- Home robots and smart products with embedded intelligence serve as a platform
- Better haptics, physiological and human movements sensors
- Speech and natural language interpretation
- Direct connections between computer and neurons
DISCUSSION:

- What would it take to gain acceptance and promotion in the therapy community?
- What are the challenges of these systems?
- What are other future directions?
Acknowledgements

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  - AHA Grant #0635450Z

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- Rehabilitation Robotics Research & Design Lab
- Human Motion Analysis Lab