Operational Machines for Arm Rehabilitation (Or End-effector Arm Rehabilitation Robots)

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Presented at EURON WORKSHOP ON REHABILITATION ROBOTICS
Agenda

- Definitions and Background
- Elements of Operational Machines for Arm Rehabilitation
- Challenges/Opportunities

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Definition of an Operational Machine

“A robot is a reprogrammable, multifunctional machine designed to manipulate materials, parts, tools, or devices through variable programmed motions for the performance of a variety of tasks”
   – Robot Industries

“An Operational Machine for Arm Rehabilitation is a reprogrammable, multifunctional machine designed to manipulate the human arm through variable programmed motions in operational space for the performance of a variety of tasks.”
   – Modified Definition
Operational Machine for Arm Rehabilitation

Typically Fixed and Desktop Systems
Operational Space Analysis

Assumes Human Arm is connected to robot end-effector

\[ \tau = M(q)\ddot{q} + V(q, \dot{q}) + G(q) + \tau_{\text{friction}} + J^T (F_{\text{environment}} + F_{\text{human}}) \]
The Rehabilitation Process

- Functional Evaluation
  - Functional Recovery
  - Functional Substitution
  - Functional Surgery
- Motor Rehabilitation
- Evaluation of Residual Abilities
- Technical Aid
- Professional Evaluation
- Assistive Devices
- Re-entry into daily life

Operational Machines

INAIL-RTR Scheme
**Typical Application Areas**

- **Stroke**
  - 5.4 Million in US; 700,000 cases per year
  - A public health cost: 5.8 billion dollars and a lifetime yearly cost of about $140,048
  - Hemiparesis affects 75% of stroke survivors
  - Weakness on one side of the body
  - Unable to use arm and leg well
  - Long-term disability most likely to be a reality
  - Need to relearn daily tasks

- **Other Areas:**
  - Cerebral Palsy
  - Traumatic Brain Injury
  - Muscular Dystrophy

- **Treatment Goals After Neurological Injury or Trauma:**
  - Stabilize; Keep uncompromised functions; Reduce impairment; Restore function

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Typical Treatment Strategy

- Apply Rehabilitation Strategy
  - Ex: Repetition and Intensity;
  - Provide task-specific training (in context, directed toward a goal)
- Apply of controlled forces to assist or resist the impaired limb (arm and/or hand)
- Provide feedback on performance (Knowledge of results or performance)
- Provide adequate motivation and purpose for therapy
Traditional Examples in Robot-Assisted Stroke Therapy

MIME, Stanford
Example Intervention:
24 1 hour of robotic therapy over 3 Months (Lum et al 2002)
• 6-DOF (3-D Tasks)
• Applies forces during goal directed movements
• Reaching movements in active-assist and active-resist modes

MIT MANUS, Boston - InMotion
Example Intervention:
1 hour of robotic therapy 3X week for six weeks (Fasoli et al. 2003, 2004)
• Planar 2-DOF robot for the elbow and forearm
• Move, guide, or perturb upper limb movement
• Practice planar tasks

Gentle/s, Reading
Example Intervention:
1 hour of robotic therapy 3X week for six weeks (Loureiro et al. 2004)
• 6-DOF robot supports the elbow and forearm
• Move, guide, or perturb upper limb movement
• Practice virtual 3D tasks

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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
Some Design Choices for Operational Machines

Control Techniques?

Purpose/Motivation?

Customize/Personalize?

Feedback?

Learning?

Task-oriented nature?

Task Complexity?

Robot/ Mechatronic-Assist Device

Questions
How should training proceed?
How should improve ADL outcome?
How do we address motivation, personalized rehabilitation and more relevant task practice?

Increase engagement

Incorporate quantity and quality of limb use
Decrease errors
Promotes Learning

CNS Plasticity

Increase real-world use
Increase ADL Function
Decrease learn nonuse

Carryover to Real World
Unilateral Focus

Bilateral Whole Arm Movement

Reaching + Grasping + Manipulation

Reaching and Grasping

Manipulation

Reaching

Single Joint Movements

Strengthening

Popular Methods

Lock Manipulation Tasks

Cup

Bowl

Spoon

Robot
Operational Machine General Architecture

- Need *Hardware Structure* to implement rehabilitation strategy
- Need *Supervisory Structure* to safely regulate interaction with patient and regulate the intensity and repetition and movement goals
- Need *Motivational Construct* for regulating motivational elements
- Need *Task Construct* for trajectory planning
- Need *Control/Training Strategies* for controlling force and position during treatment
- Need *Assessment and Treatment Strategy* for implementing the rehabilitation strategy and for interpretation of results
Hardware Structures

- Typical Robot Configuration
  - Movement in plane (e.g., InMotion, MEMOS)
  - Movement in 3-D space (e.g., Gentle/s, ADLER, ACT-3D)

- Typical Sensors
  - Position sensors to monitor robot movement
  - Force sensors to monitor interaction between robot and human

- Safety Hardware
  - E-stop
  - Force limiters

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Hardware Structure: ADLER: Activities Daily Living Exercise Robot

HapticMaster Robot
- 6 Degrees of Freedom (3 active, 3 passive)
- Position sensing at all DOF
- 3-axis force sensing at end-effector
- Force overload detection via solenoids
- 100 N maximum force resistance and support at the end-effector

Current Functionality
- Administers functional unilateral robotic therapies to stroke (reaching and grasp)
FES Grasp Glove

- Custom made spandex base
- Commercially available wrist splint
- Open ended finger tips
- Sensor Channels
- Bend sensors
- Microprocessor
- Custom controller and analysis program
- Electrical Stimulation for grasp assistance
ADLER Safety System

Panic Situation

- Discomfort
- Tired

Excessive Force or Velocity

Footswitch or Remote control

Orthosis detachment and Robot stop

Solenoïd Holding Power

E-stop

Gentle/s inspired
Stroke Patients in ADLER

Adler View

Peg n hole

Reaching
Supervisory Structures: GUI

- **Therapist/Patient Interface**: Manages patient data
  - Records patient data (clinical and biomechanical)
  - Records and process data from tasks

- **Experimenter/Therapist Interface**: Manages task specifications for therapy activity
  - Define interaction modes
  - Create and execute tasks

- **Experimenter Interface**: Manages robot interactions
  - Defines all robot level commands and govern interactions
  - Safety supervisor to regulate interaction

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Example of Supervisory Control
Supervisory Structure

**HERALD Software**

- HapticAPI programming environment
- Crystal Space v0.98
- PC-based Environment
- The GUI shows a one-to-one mapping of the environment and the trajectory

**Programming Activities**

- On the fly using start, end, and multiple via points to define the task
- By uploading data from a file with real or pre-defined trajectories
- Various models of task trajectories are programmed
- Moves the subject in Training modes
ADLER Control Flow

- Task Display
- Foot Pedal
- Remote
- Safety Box

HAPTICMASTER

Graphical / Logic Thread
~ 100 Frames/Sec

Polling / Recording Thread

HERALD

Position updates sent every 60 milliseconds via TCP/IP
Haptic effect updates sent via TCP/IP 100 FPS
Position and force data requested at 500 Hz
Signal for emergency stop

TCP/IP 100 FPS

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Supervisor Control Strategy

Ref: Erol, Johnson, Sarkar
Motivational Construct

Common Motivating Strategies
- Provide feedback about error and performance
  - Give a sense of errors created as move
  - Give a graphic of results - error
- Provide feedback about biological Signals
  - EMG - assist
- Provide a motivating context
  - Embed therapy into point-to-point games

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## Motivation Construct: Why Important?

<table>
<thead>
<tr>
<th>GENERAL CASES</th>
<th>SCENARIOS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 The immediate rewards of engaging in compensatory behaviors are more apparent and achievable than for engaging restorative behaviors</td>
<td>Patient becomes confused and feels encouraged to engage in both compensatory activities and restorative behaviors. Patient becomes satisfied with the level of independence attained either through caregivers (proxy control) or through the compensatory strategies.</td>
</tr>
<tr>
<td>2 The effort (or cost) to engage in restorative behaviors is beyond their ability.</td>
<td>Patient stops using the impaired arm due to the frustration encountered during attempts to use the arm. The effort to engage in restorative behavior is prohibitive and therefore achieving bilateral arm use is perceived as an unrealistic goal. Patient perceives that the activities are too challenging and therefore impossible to achieve or too easy and therefore irrelevant. Patient loses range of motion, muscle strength, dexterity and other motor abilities due to factors such as abnormal muscle activation and force generation. Patient loses sensory feedback in the impaired limb. Patient has a frontal lobe lesion and diminished motivation.</td>
</tr>
<tr>
<td>3 The effort to engage in restorative behaviors is not seen as resulting in getting their perceived needs met.</td>
<td>Patient perceives that continuing in rehabilitation is unproductive because it will not help in regaining previous roles in life.</td>
</tr>
<tr>
<td>4 The reasons (or incentives) given to encourage them to engage in restorative behaviors are not sufficient.</td>
<td>Patient believes their discharge from the hospital signals the end of recovery and believes the standard predictions that there is minimal to no recovery after 6 months. Patient loses the ability to focus on treatment activities because of neurological deficits and must be reminded to do it.</td>
</tr>
</tbody>
</table>

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Motivation Construct: Learned Non-Use

Taub et al.

2 weeks
5 days/week with less-affected arm slinged or in a glove


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Justification: ADLER Task-Oriented/ADL Approach

- Engaging patients in functional activities increase task persistence (Trombly 1995)
- Improves patients’ ability to engage in the rehabilitation process and relate it to their lives (Trombly 1995, 2002)
- Increases motivation (Trombly 1995)
- CNS recovery maybe due to repetition AND specific practice variables such as the performance of specific, intensive, and complex movements used to solve motor problems and attain goals (Fisher and Sullivan 2001)
- Skilled motor activities requiring precise temporal coordination of muscles and joints must be practiced many times over (Nudo et al. 2007)

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ADLER: Motivating Construct

- Use real tasks that reflect ADLs
- Adaptable to many motivating and engaging task environments

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Motivating therapy: Game as therapy

- Increase motivation
  - Pacman, Solitaire

- Driving Games: Smartdriver, trackmania
Tasks Types and Trajectory Plans

- Point-to-point reaching movements (Simple, cone movement, etc.)
- Minimum Jerk Trajectory Planning (Best for PTP)

Trajectory plans to implement ADL and Functional Movements?

- Reach and Grasping movements
- Modified Minimum Jerk Trajectory Planning with Curvature Considerations (Reach to Real Objects)
- Exponential Models

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### Trajectory Planning

Johnson et al, Task-Oriented and Purposeful Robot-Assisted Therapy, Rehabilitation Robotics, Chapter 13

<table>
<thead>
<tr>
<th>Model</th>
<th>Defining equations and boundary conditions</th>
</tr>
</thead>
</table>
| A. 5th order minimum jerk | \[
\begin{align*}
x(t) &= x_e + (x_e - x_f)(0.5t^4 - 6t^2 - 10t^3) \\
y(t) &= y_e + (y_e - y_f)(0.5t^4 - 6t^2 - 10t^3) \\
z(t) &= z_e + (z_e - z_f)(0.5t^4 - 6t^2 - 10t^3)
\end{align*}
\] Zero velocity, acceleration at initial and final points |

| B. Modified 7th order minimum jerk | \[
\begin{align*}
p(\tau) &= a + b \tau + d \tau^2 + f \tau^3 + h \tau^4 \quad \text{where} \\
a &= \frac{1}{2} \sum p_i \tau^2; \ b = v_{\text{mid}}; \ d = -3v_{\text{mid}} + \frac{35}{16} \Delta p \\
f &= 3v_{\text{mid}} - \frac{21}{8} \Delta p; \ h = -v_{\text{mid}} + \frac{15}{16} \Delta p \\
\sum p &= p_f + p_i \Delta p - p_f - p_i
\end{align*}
\] Zero velocity, acceleration at initial and final points. Maximum velocity and zero acceleration at 50% reach. |

| C. 5th order minimum jerk | \[
\begin{align*}
x^-(\tau) &= \frac{t_f^5}{720} \left( \pi_1 (t_f^5 - 30t_f^3 - 30t_f^2 + 80t_f^4 - 30t_f^5) + \pi_2 (80t_f^5 - 30t_f^4) - 60t_f^2 \pi_1 + 30t_f^4 \pi_1 - 60t_f^3 \pi_1 + c_1 (15t_f^5 - 10t_f^4 - 6t_f^3) \right) + x_o \\
x^+(\tau) &= x^-(\tau) + \pi_f (t_f - \tau)^5 \quad \text{where} \\
c_i &= \frac{1}{t_f^5 (t_f - \tau_i)^5} \left( x_f - x_o \right) \left( 300t_f^4 - 1200t_f^2 + 1600t_f^4 \right)
\end{align*}
\] |

The 5th order minimum jerk model for reaching is widely used in robotic therapy (Flash & Hogan, 1985; Flash & Hogan, 1987).

This modified 7th order model was developed by Loureiro and colleagues as a better approximation of actual reach towards an object (Loureiro et al. 2003; Amirabdollahan et al. 2003).

This modified 5th order model is based on equations developed by Hogan and Flash to describe reaching. We have applied special inputs to the equations based on motion analysis studies to approximate functional reaching.

Original paradigm predicts straight line movements with bell shaped velocity profiles.

Modified paradigm expands to include curvature and considers movement through via points at a prescribed time with maximum curvature at the minimum Velocity.

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Apply Models to Functional Movements

3-D Kinematic Data Collection with 15-Camera Vicon Motion 524 System (120 Hz collection rate)

Upper Extremity Bilateral Model (Hinglgen et al., 2003)
Averaged Normalized XY Data & Minimum Jerk Model

In XY: MODEL Best fits Point to Point Reaching (Object Absent)

\[
\begin{align*}
    x(t) &= x_o + (x_f - x_o)(15T^4 - 6T^5 - 10T^3) \\
    y(t) &= y_o + (y_f - y_o)(15T^4 - 6T^5 - 10T^3) \\
    z(t) &= z_o + (z_f - z_o)(15T^4 - 6T^5 - 10T^3)
\end{align*}
\]
Averaged Normalized XZ Data & Minimum Jerk Model

In XZ: MODEL does not model any well

Normalized Drink Trajectories and Model (XZ Plane)

Wrist Trajectory: XZ- Movement in Frontal Plane Perpendicular to Table
The Drink Task

- Over all the curvature is captured better with the modified model especially in XZ plane
- In the XZ plane the normal mode shows no curvature for the ‘Reach’ and ‘Rest’ events

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### Implement Models on ADLER

#### Basic & Curvature and Input Adjusted

<table>
<thead>
<tr>
<th>Task</th>
<th># Events</th>
<th>Event Type</th>
<th>Cut Time</th>
<th>Object Constraints (X1, Y1, Z1)</th>
<th>Environment Constraints</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drink</td>
<td>4</td>
<td>1 – Reaching</td>
<td>1 - .4</td>
<td>1 – (40, 0, 12)</td>
<td>1 – TC = 42</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2 – Lifting</td>
<td>2 - .23</td>
<td>2 – (16.5, 0, -50)</td>
<td>2 – OMR = 60</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3 – Returning</td>
<td>3 - .4</td>
<td>3 – (16.5, 0, -50)</td>
<td>3 – OMR = 60</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4 - Retracting</td>
<td>4 - .4</td>
<td>4 – (40, 0, 7)</td>
<td>4 – TC = 28</td>
</tr>
</tbody>
</table>
Results Updated Model versus Basic and Raw data: The Drink Task

Follows the curvature pattern better

Accommodates new REST position

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Grasp Model?

\[
\begin{bmatrix}
    x_{\text{thumb}} \\
    y_{\text{thumb}} \\
    z_{\text{thumb}}
\end{bmatrix} =
\begin{bmatrix}
    c(\theta_{t1} + \theta_{t2})l_{t2} + c(\theta_{t1})l_{t1} + d \\
    s(\theta_{t1} + \theta_{t2})l_{t2} + s(\theta_{t1})l_{t1} \\
    1
\end{bmatrix}
\begin{bmatrix}
    x_{\text{index}} \\
    y_{\text{index}} \\
    z_{\text{index}}
\end{bmatrix} =
\begin{bmatrix}
    c(\theta_{i1} + \theta_{i2} - 90)l_{i2} + c(\theta_{i1} - 90)l_{i1} \\
    s(\theta_{i1} + \theta_{i2} - 90)l_{i2} + s(\theta_{i1} - 90)l_{i1} \\
    1
\end{bmatrix}
\]

\[
\beta = \sqrt{(x_{\text{index}} - x_{\text{thumb}})^2 + (y_{\text{index}} - y_{\text{thumb}})^2}
\]
Obtaining Grasp Aperture Data for Drink Task

Graph of Individual Joint Angles vs. Percent Task Completed

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Reach-to-Grasp Models?

- Looked at exponential models as well
- Not Many models with both Reaching and Grasping Implemented
- Intrinsic properties influencing grasp (finger)
- Extrinsic properties such as the features of the objects used, the goal and constraints of the task and the environmental settings
- Grasping component of the model depend on x position
- Issue – coefficients are very task specific so there is a need for identifying a general model

\[ x_2 = ae^{bx_1} + ce^{dy_1} \]
\[ y_2 = ae^{by_1} + ce^{dx_1} \]
\[ z_2 = ae^{bz_1} + ce^{dx_1} \]
\[ g_2 = ke^{pg_1} + me^{nx_1} \]
EVENT 1 GRASP APERTURE

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Training/Control Structure

- Common Training Strategies
  - Assist, Active-Assist or Assist-as-needed
    - Provide forces to assist the movement
    - Measures users effort and supply assistive forces as needed
      - “assist-as-needed” based on sensed error
      - “out forget” the human controller, else the human lets the robot do all of the work.
  - Resist or Perturbations
    - Provide forces to resist or perturb the movement
      - Forces maybe constant, viscous or vibratory
    - Typically used in later phases of recovery (stroke) to build strength and challenge task
  - Implemented using Admittance or Impedance Control

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ADLER Training Modes

Training Strategies

- Typical: Form (Guiding Forces)
  - Actively follow a desired path
  - Experience forces if deviate
  - Graded resistance along path

- Function (Minimal Guiding Forces) (New)
  - Aim for target point
  - Permitted to deviate
  - Attracted to target
  - Graded resistance along path

- Resist
- Normal (No forces)
Training Process

18 Sessions (over 6 Weeks): 1-hour/therapy

Pre-Assessment and Training
- Recruited and Consented
- Moderate to Severe Strokes

Intervention:
- ROBOT ADL: Task-Oriented, Robot-Assisted Therapy
- Control: Occupational Therapy (n=30)

2 Sessions Post-Assessment and Follow-up
- All Subjects

A1a A1b Robot Training A2 (Follow-Up) A3

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Assessment

- Common Clinical Tools Assess
  - Motor Control (e.g., Fugl-Meyer)
  - ADL Function (e.g., Barthel Index and Rancho Los Amigos Functional Hand Evaluation)

- Biomechanical Metrics
  - Range of Motion
  - Accuracy (Root Mean Square)
  - Quickness (e.g., Movement Time, Mean Velocity)
  - Stability (e.g., Movement Smoothness (peak velocity/mean velocity), % of time on task)
  - Motor Power

### Table: Biomechanical Metrics

<table>
<thead>
<tr>
<th>Metric Name</th>
<th>Definition</th>
<th>Remark</th>
</tr>
</thead>
<tbody>
<tr>
<td>ROM Area Ratio</td>
<td>The ratio of the area size of user capability space to the input device work space.</td>
<td>Reflects the user’s Movement Range in the range [0, 1]; ideally this value should be close to 1.</td>
</tr>
<tr>
<td>Reaction Time</td>
<td>The time from the jump of the target to the first significant movement by subject.</td>
<td>Reflects the human machine system response Capability (Reaction quickness).</td>
</tr>
<tr>
<td>Movement Time</td>
<td>The time between the end of the reaction time to the time after the human subject stayed within the target stably.</td>
<td>Reflects the Movement Quickness.</td>
</tr>
<tr>
<td>Movement Speed</td>
<td>Movement speed is the average speed within the movement time window.</td>
<td>Reflects the Movement Quickness in the movement time window.</td>
</tr>
<tr>
<td>Error</td>
<td>The average distance from the target position to the subject position.</td>
<td>Reflects overall performance Accuracy.</td>
</tr>
<tr>
<td>Deviation</td>
<td>The average distance from the subject position to straight target path line.</td>
<td>Reflects Movement Curvature. This metric is for Joystick only.</td>
</tr>
<tr>
<td>Peak Speed Number</td>
<td>The number of peaks in the speed profile within the movement time window.</td>
<td>Fewer PV represent fewer periods of acceleration and deceleration, making a more Smoothness movement.</td>
</tr>
</tbody>
</table>
Case Study Results

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## Case Study Result

<table>
<thead>
<tr>
<th>Evaluation Session</th>
<th>Biomechanical and Clinical Measures</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>MT (s)</td>
<td>TD (m)</td>
</tr>
<tr>
<td>Initial</td>
<td>15.78</td>
<td>2.51</td>
</tr>
<tr>
<td></td>
<td>±5.65</td>
<td>±0.46</td>
</tr>
<tr>
<td>Week 1</td>
<td>12.75</td>
<td>2.05</td>
</tr>
<tr>
<td></td>
<td>±4.01</td>
<td>±0.23</td>
</tr>
<tr>
<td>Week 3</td>
<td>8.14</td>
<td>1.88</td>
</tr>
<tr>
<td></td>
<td>±1.42</td>
<td>±0.37</td>
</tr>
<tr>
<td>Week 6</td>
<td>6.38</td>
<td>2.08</td>
</tr>
<tr>
<td></td>
<td>±0.13</td>
<td>±0.13</td>
</tr>
<tr>
<td>Follow-up</td>
<td>12.59</td>
<td>2.89</td>
</tr>
<tr>
<td></td>
<td>±1.01</td>
<td>±0.59</td>
</tr>
</tbody>
</table>

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Summary Findings: Stroke Rehabilitation

Robotics Track Record – Operational Machines

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
Challenges

- Need to optimize for recovery of function in activities of daily living and ability to improve ADL function
- Need to cope with compensatory behaviors and Bilateral function
- Need to provide affordable opportunities for intensive therapy
- Need to provide better training strategies anchored in motor learning and neuroscience theories
- Need to understand what drives recovery
Summary

There is a need to improve the results

- Improve *Control and Training Strategies* to capitalize on motor learning constructs
- Improve Motivational Construct by improving how tasks are embedded into the therapy.
- Utilize other techniques such as functional magnetic resonance imaging and diffusion tensor imaging to understand changes after robot-assisted therapy.

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New Directions

New strategies are being examined
- Error Augmentation (Patton et al)
- Gravity Assistance (Dewald et al)
- Bilateral Training and Cueing (Johnson et al)
- Exoskeletal Training Options

Use of systems at home as well
- More Home Rehabilitation Technologies
- Bilateral Training and Cueing (Johnson et al)

Use of systems with additional technologies
- Functional Magnetic Resonance Imaging
- Diffusion Tensor Imaging
- Gravity Augmentation
Acknowledgments

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- **Students in Rehabilitation Robotics Research & Design Lab /OREC**

- **Collaborators**
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  - Dr. Elaine Strachota, PhD, OT, Concordia Univ.
  - Dr. Roger Smith, PhD, OT, Univ. of Wisc, Milwaukee
  - Dr. Jack Winters, PhD, Marquette University
  - Dr. Robert Schiedt, PhD, Marquette University

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Thank – You!

Questions?