Occupational Science & Occupational Therapy
UNIVERSITY OF TORONTO

UHN Toronto Rehabilitation Institute

ROCKET FAMILY UPPER EXTREMITY CLINIC CONFERENCE

APPLICATION OF ROBOTICS IN UPPER LIMB REHABILITATION POST-STROKE: EXPERIENCES OF DEVELOPING A ROBOTIC SYSTEM

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TORONTO, ON, CANADA
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Outline

1. Stroke rehabilitation in Canada
2. Currently-available robotic technologies for upper limb rehabilitation
3. Clinical evaluation and implementation of robotics
4. Considerations for development and implementation of upper limb robotic rehabilitation system

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Current state of stroke rehab

- Repetitive, labour intensive
- Limited 1:1 therapist-patient time
- Lack of quantitative measures
- Economic pressures
- Disparity in access
- Home rehab is self-directed with little professional or quantitative feedback

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On rehab services, 5th Ed (2015)

HEART & STROKE FOUNDATION — CANADIAN Stroke BEST PRACTICE RECOMMENDATIONS

- Inpatient - early, “adequate” intensity, goal-directed, tailored, task-oriented, coordinated, early discharge planning
- Therapists recommended to spend 80% of time in direct patient care; 6:1
- Minimum 3 hours direct task-specific therapy, 5 days/week
- Lack of outpatient and community-based rehab

On system implications, 5th Ed (2015)

HEART & STROKE FOUNDATION — CANADIAN Stroke BEST PRACTICE RECOMMENDATIONS

“Robotics are an emerging and developing area and stroke rehab programs *should begin to build capacity* to integrate robotic technology into stroke rehab therapy *to appropriate patients* as the research evidence suggests, and *in the future* incorporate this therapy as part of comprehensive therapy *where available*.”

(http://www.strokebestpractices.ca/index.php/stroke-rehabilitation/part-two-providing-stroke-rehabilitation-to-maximize-participation-in-usual-life-roles/management-of-the-arm-and-hand-following-stroke/)

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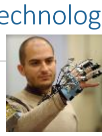
Robotic technologies for upper limb rehab


PolyU Rehab Sleeve, HK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Center for Applied Biomechanics and Rehabilitation Research, USA

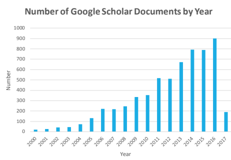
Robotic technologies for upper limb rehab

Search terms:

(rehabilitation or therapy) and (arm or "upper limb" or "upper extremity") and robotics and stroke

- **PubMed**: 527 results
- Reviews: 76*
- **Scopus**: 1176 results
- Reviews: 113*

* Not all systematic and related to therapy outcomes



6250 documents (since March 2017)
"CRISPR" 139,000 documents (since March 2017)

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Robotic technologies for upper limb rehab

What is the added value of robotics?

- Better quantify performance changes – can be superior to current clinical measures
- Motivating, engaging games and interfaces – encourage, provide real-time feedback
- Adaptive/intelligent systems – do not need therapists to be constantly present
- Therapists can focus on functional activity training and community integration, less on repetitive activities (robots don't get tired!)

What can we buy if we had the money?*

- Arm Robot – "MIT Manus" – R&D began 20+ years ago, MIT Mechanical Engineering, Hermano Krebs
- **Arm Robot** – Elbow/shoulder, about $70 - 80K
- **Wrist Robot** – Pronation/ supination, flexion/extension, radial/ulnar deviation
- **Hand Robot** (with Arm Robot) – Grasp, release, pinch

INMOTION ROBOTS Redefining Recovery™

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What can we buy if we had the money?*

- R&D history – 15+ years in Switzerland, USA and Netherlands
- **ArmeoPower** - Robotic arm exoskeleton, about $340K
- **ArmeoSpring** - Exoskeleton with integrated spring mechanism, about $60K
- **ManovoSpring** – Grasp/release
- **ArmeoBoom** - Overhead sling, suspension system, about $17K



Hocoma

What can we buy if we had the money?*

motorika

ReoGo

- UL rehabilitation, all stages of recovery
- 5 modes - passive support → guided motion
- Developed in Israel
- 3D repetitive arm movements, fully motorized robotic arm
- About $ 85K

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What can we buy if we had the money?*

Armotion

- Swiss company
- Moderate and severe neurologic or orthopedic conditions
- Has passive and active assist modes, force feedback and force multiplier
- Visual feedback with daily activity related games

REHA TECHNOLOGY FOR A BETTER LIFE


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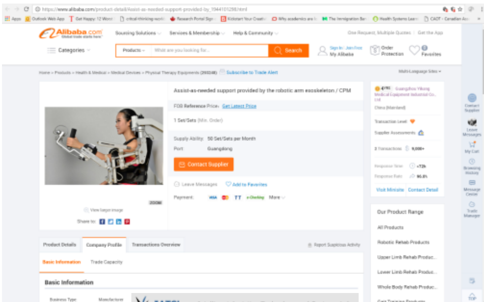

Clinical evaluation and implementation

Electromechanical and robot-assisted arm training for improving activities of daily living, arm function, and arm muscle strength after stroke (Cochrane Systematic Review, Mehrholz et al, 2015)

- RCTs – Electromech/robot-assisted vs other rehab, placebo, no treatment
- 34 trials (1160 stroke survivors)
- Improves
  - Arm muscle strength
  - Arm function
  - Generic ADLs

Clinical evaluation and implementation

(Mehrholz et al, 2015, cont.)

- Adverse events rare
- Drop out rate comparable to comparison groups
- ***Evidence quality rated as “low”
- Variability in type of treatment, intensity, duration, amount, participants

Clinical evaluation and implementation

Effects of Robot-Assisted Therapy for the Upper Limb After Stroke: A Systematic Review and Meta-analysis (Veerbeek et al, 2017)

- RCTs – Robot-assisted vs non-robotic treatment
- 44 trials (1362 stroke survivors), 38 trials in meta-analysis (N=1206)
- Improves
  - Motor control (e.g. Fugl-Meyer Assessment) – significant but small changes
  - Muscle strength (note: negatively effects tone)
- No effect
  - Upper limb capacity (e.g. Wolf Motor Function Test)
  - Basic ADLs

Clinical evaluation and implementation

(Veerbeek et al. cont.)

- No serious adverse events
- ***Evidence quality on PEDro Scale – median was 6 – indicating "high quality" (scale 0-10)
- Subgroup analyses

Clinical evaluation and implementation

What are some of the unknowns?

- Which treatment modalities? → *For which patients and when?*
- What treatment intensity and duration?
- How do we tailor our treatment programs?
- What control strategies and feedback approaches?
- How can we measure changes better? Statistical vs clinical significance
- How can we transfer motor recovery gains to functional performance in daily life?
- Is it cost-effective???

Clinical evaluation and implementation

Implementation barriers

- Convincing clinical evidence still lacking
- Few are commercially available
- Still high cost – initial purchase, training, maintenance
- Technology complexity – needs high usability e.g. set-up, programming
- Safety – not consistently reported in studies
- How to best use them in practice?

Development and implementation considerations

AIRR robotic system development

Development and implementation considerations

- Applied evidence-based approach in design of robotic system
- Observational sessions, international survey, and individual and group feedback sessions with OTs and PTs → desirable features for robotic system intervention

What do therapists want?

Lu, E. et al. (2011). Disability & Rehabilitation: Assistive Technology

Objectives:
- To understand current rehabilitation methods and aims
- To define features desirable in upper limb rehabilitation robot

Methods:
- Online questionnaire with 85 questions distributed to professional therapist organizations & listservs
- Analysis based on descriptive statistics

What do therapists want?

Data analyzed for 233 respondents:
- Mainly from Australia, Canada, USA
- Mainly physiotherapists (72%) and occupational therapists (27%)

Main approaches to upper limb rehabilitation:
- Repetitive task training (88%)
- Motor relearning (76%)
- Neurodevelopmental/Bobath (65%)
- Use of robot assisted (6%)

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What do therapists want?

Desired robot features
- Facilitate many arm movements
- Be usable in a seated position
- Give biofeedback to the user
- Have virtual ADL
- Useful for clients to use at home
- Adjust resistance based on client performance
- Modular
- Maintain proper joint alignment

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Understanding clinical applicability and implementation issues

Lu, E., et al. (2012). Paladyn. Journal of Behavioural Robotics

Wang, R.H., et al. (2012). Canadian Stroke Congress

Objectives:
- To gain therapists' feedback on prototype haptic robot, AI controller and gaming environments

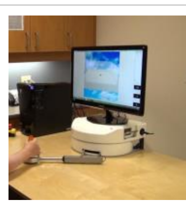
Methods:
- Focus group (n=7) and individual feedback sessions (n=6) with OTs and PTs
- Thematic analysis to identify themes related to design, clinical needs and solutions.

Understanding clinical applicability and implementation issues

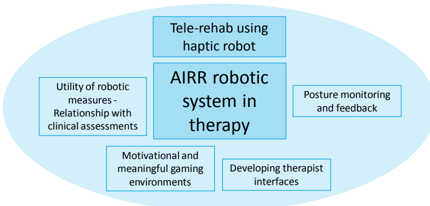
Value-added features	Major design concerns	User characteristics	Features of therapist training programs
Ability to work with patients in lower levels of recovery with haptics Capacity to customize activity parameters for changing abilities Potential to quantitatively document improvements	Need to monitor/correct postural compensations – *solutions identified* Limitations of 2D therapy – when evaluating cost trade-off of 3D system and haptics, *opted for haptics*	Consideration for cognition, visual-perceptual abilities and pain precautions	Shorter is better (1-2 hours) Short documented instructions and demonstrations Hands on "play" with system Learn basics and a few specialists to help Intuitive interface

AIRR Robotic System

- 2 degree of freedom, end effector robot for shoulder and elbow therapy
- Haptic – resistance and assistance
- Lightweight and portable
- Low cost
- Self-contained unit
- Adaptive – vary exercise challenge
- Robotic data: e.g. range of motion, movement speed, error, smoothness



AIRR Robotic System



AIRR Robotic System therapy evaluation

Wang, R.H., et al, (in preparation)

Purpose: To evaluate an outpatient program for older adult chronic stroke survivors that uses the AIRR robotic system, individualized goal setting, and homework exercises

Objectives:

1. To evaluate program in improving upper limb movement function and goal achievement
2. To evaluate satisfaction with program (e.g. overall therapy program, robot, service delivery)

AIRR Robotic System therapy evaluation

Study design:

- Multiple single subject study design (A1-Baseline, B-Therapy, A2-Baseline, F/U-Follow-up)
- Surveys and interviews

Participants:

- Inclusions: 60 years+, at least 6 months post-stroke, arm recovery stages 3-5 (out of 7) on Chedoke-McMaster Stroke Assessment
- Exclusions: other upper limb neurological or musculoskeletal conditions, shoulder subluxation/pain limiting active treatment

AIRR Robotic System therapy evaluation

Procedures

- Assessments: demographics, robotic, upper limb function
- Intervention: customized 8-week program: goal setting using Goal Attainment Scaling, robot exercises 1 h x 3 x / week and homework
- Surveys, interviews after program completion
- 1 follow-up session after 4 weeks

AIRR Robotic System therapy evaluation

Outcome measures

- Robot measures collected throughout study: range of motion (ROM) and movement smoothness (MSm), speed (MS), error (ME)
- Clinical measures collected throughout study: Fugl-Myer Assessment–Upper Extremity (FMA-UE), Action Research Arm Test (ARAT), Motor Activity Log (MAL-14)
- Goal Attainment Scaling (GAS)
- Satisfaction: items from Quebec User Evaluation of Satisfaction with Technology (QUEST2.0) scale and Outpatient Service Satisfaction Survey (UHN-OSS)

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AIRR Robotic System therapy evaluation

1) Waypoint exercise

2) Bouncing ball game

3) Paddle game

4) Boat game

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AIRR Robotic System therapy evaluation

Participants:

- n=11 (9 participants completed study, 2 withdrawn)
- Age range 60-73
- 3 female
- Post-stroke range: 10 months to 23 years

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AIRR Robotic System therapy evaluation

Preliminary Results (*first 6 participants):

- Visual analysis of robotic data shows trends toward increases in ROM and MSm, and possible increases in MS and decreases in ME
- Minimal clinically important differences (MCID) were achieved for 4 of 6 participants on FMA-UE
- 5 of 6 participants achieved their goals on GAS
- MCID not found for ARAT
- Analysis of MAL-14 is pending
- Satisfaction was high (QUEST2.0 average: 4.6/5, UHN-OSSS: 4.8/5)

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Interview feedback

Positive aspects and facilitators to participation	• Experienced improvements in arm abilities • Supportive team of staff and family • Feedback on movement and progress from staff and robot were beneficial
Robotics as part of therapy program	• Combination of therapy with robot and therapist appreciated
Challenges or barriers to participation	• Session frequency too high • Goal setting and self-motivation to participate in therapy can be challenging • Transportation to appointments can be difficult or unreliable • Missing appointments due to holidays, acute illness, weather
Areas for improvement	• Occasional hardware and software issues with robot • Further gamification and more games needed • Robot hand hold or arm support needs better design • Need to ensure clinical staff understand automatic adaptations of system • Therapy sessions schedule needs revision • More can be offered for wrist and hand therapy • Continued psychosocial support beyond therapy trials

AIRR Robotic System therapy evaluation

Conclusions

- Preliminary findings suggest that the program shows promise to benefit older adults with chronic moderate upper limb disability after stroke
- Further data analysis and study completion are pending

Utility of robotic measures

(*Zariffa, J. et al, in preparation*)

Predictive modeling of upper limb rehabilitation in stroke patients using robotic data

Objectives:

- Identify a model that can be used to accurately predict clinical assessment outcomes based on a set of robotic metrics
- Assess the model's ability to track the patient's rehabilitation over time

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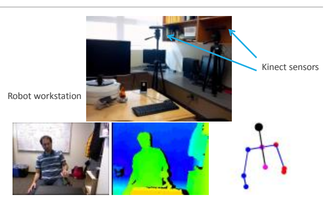
Postural monitoring and feedback

Taati, B. et al (2012). Biomedical Robotics and Biomechatronics (BioRob)

Dolatabadi, E. et al (2017). Pervasive Health (submitted)



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…Work in progress

- Input from clinicians and stroke survivors is needed for useful and usable intervention
- Simultaneous development of multiple robotic system components is needed - robot hardware, application software, interactive therapy activities with feedback, and therapist interfaces to operate system and make use of data
- Robotic systems used in stroke rehab are complex interventions - need to examine implementation as adjuncts to current therapy, integration into clinical practice and settings, practice and delivery models
- Need to develop multi-site studies to examine efficacy and effectiveness of interventions using robotics

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