Adaptive NeuroRehab Systems Lab

UHN Toronto Rehabilitation Institute
The Kite Research Institute

Institute of Biomedical Engineering
UNIVERSITY OF TORONTO

REL
RehabilitationEngineeringLaboratory

Digital Functional Assessment*

***for humans**

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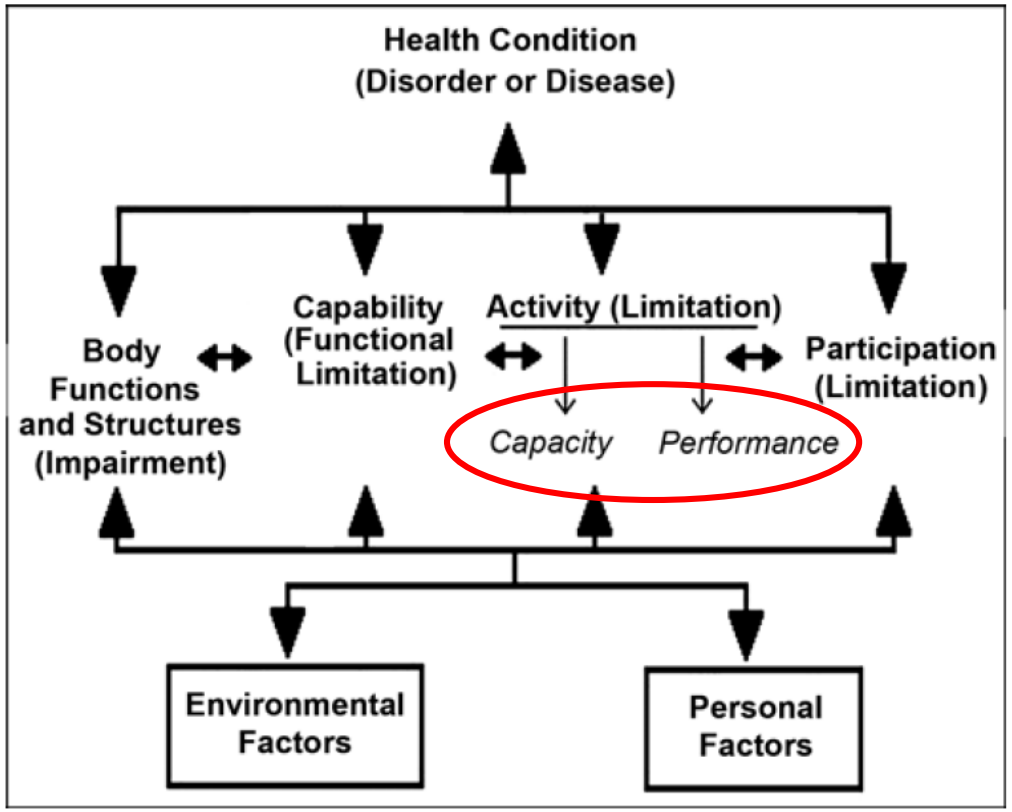
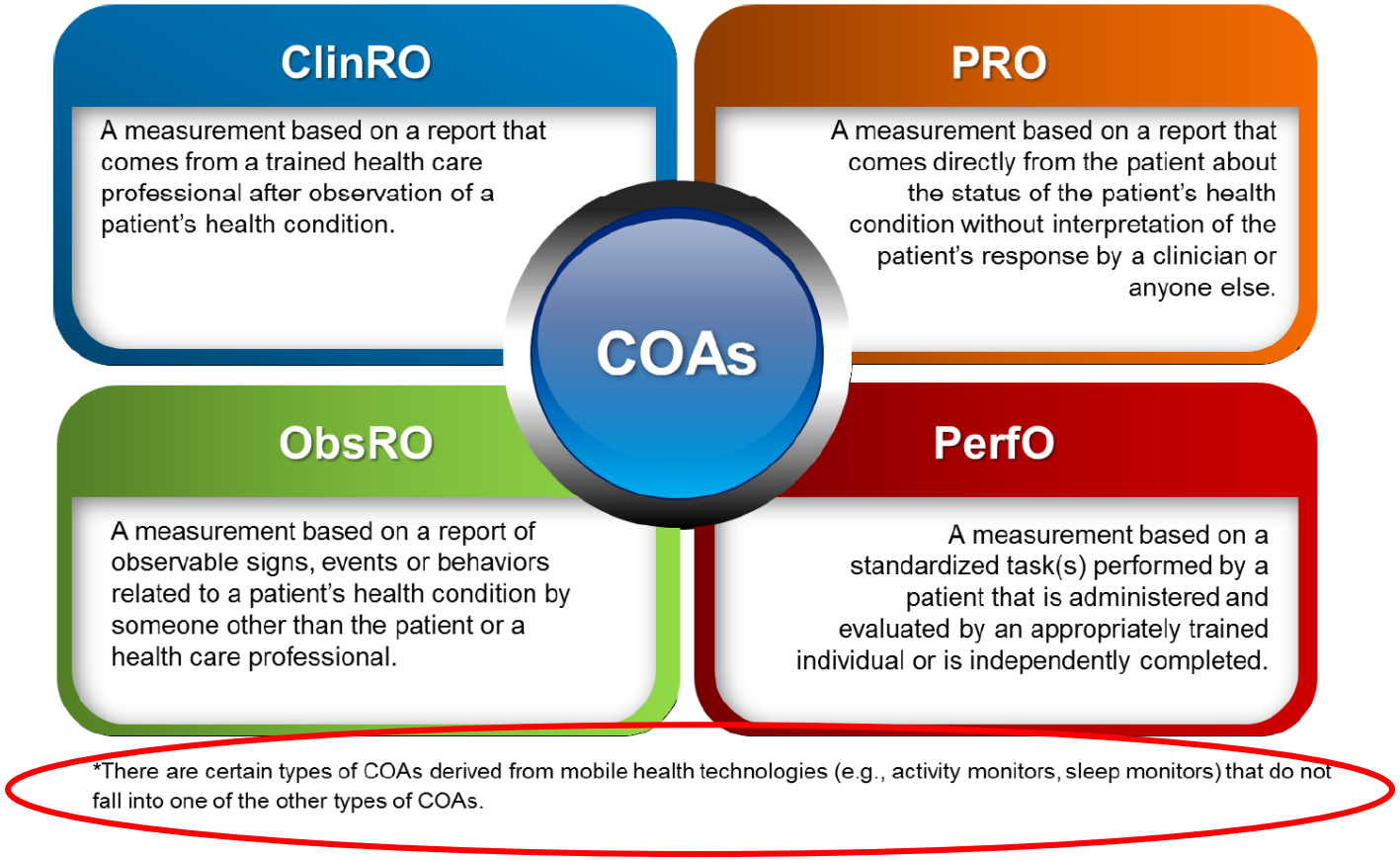
Motivation



Marino, *Journal of Rehabilitation Research & Development*, 2007.



Motivation

Strengths

- Locations
- Frequency
- Continuous values
- Objective

Weaknesses

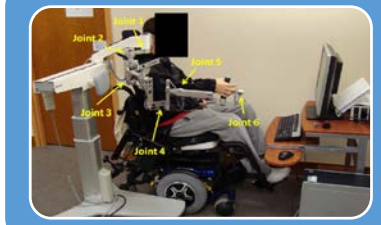
- Complexity
- Cost
- Compliance and quality control (wearables)

Opportunities

- Multi-modal
- Integration into electronic health records
- Large-scale data collection

Threats

- Validation
- Variety
- Transparency



Robotic Platforms

Wearables

Motion Capture

Digital Questionnaires

Robotic Platforms

Study	Sensor or Platform	Metric	Evaluation	Result
LOWER EXTREMITY				
Bolliger et al., 2008	Lokomat	Isometric lower extremity muscle force	Intra- and inter-rater reliability (n = 14; mixed pop)	Fair-to-good
Domingo and Lam, 2014	Lokomat	Static position sense	Discriminant and criterion validity, test-retest reliability (n = 23)	Valid and reliable
Galen et al, 2014	Lokomat	Isometric lower extremity peak torques	Responsiveness (n = 18)	Changes observed after intervention; non-linear relationship to motor score changes
Chisholm et al., 2016	Lokomat	Kinesthesia	Discriminative and criterion validity, test-retest reliability (n = 17)	Valid and reliable
Dambreville et al., 2019	Robotic ankle-foot orthosis	Ankle proprioception	Discriminative validity, test-retest reliability (n = 15)	Valid and reliable

Study	Sensor or Platform	Metric	Evaluation	Result
UPPER EXTREMITY				
Zariffa et al., 2012	ArmeoSpring	Multiple features (ROM, smoothness, grip)	Multilinear regression models (R^2) (n = 14)	Good prediction of GRASSP, ARAT, and SCIM
Rudhe et al., 2012	ArmeoSpring	Movement workspace	Criterion validity, test-retest reliability (n = 8)	Fair-to-good reliability, correlation with SCIM self-care
Prochazka and Kowalczewski, 2015	ReJoyce	RAHFT	Criterion validity, responsiveness, test-retest reliability (n = 13)	Well correlated with ARAT, responsive and reliable
Keller et al., 2015	ARMin	Multiple features (kinematic, kinetic, timing)	Criterion validity, inter- and intra-rater reliability (n = 5)	Reliability of different metrics ranges from weak to good. Several had good correlation with MMT, GRASSP, and VLT
Smith et al., 2019	Custom wrist apparatus + EMG	Hyperreflexia, proprioception, strength	Discriminant validity, responsiveness, multilinear regression. (n = 20)	Inter-group differences, responsive to intervention, predictive of myelopathy clinical scores
Grasse et al, 2019	Suite of custom devices	Hand and wrist force and ROM	Discriminant and criterion validity, test-retest reliability, MDD (n = 15)	Reliable, variable validity across metrics

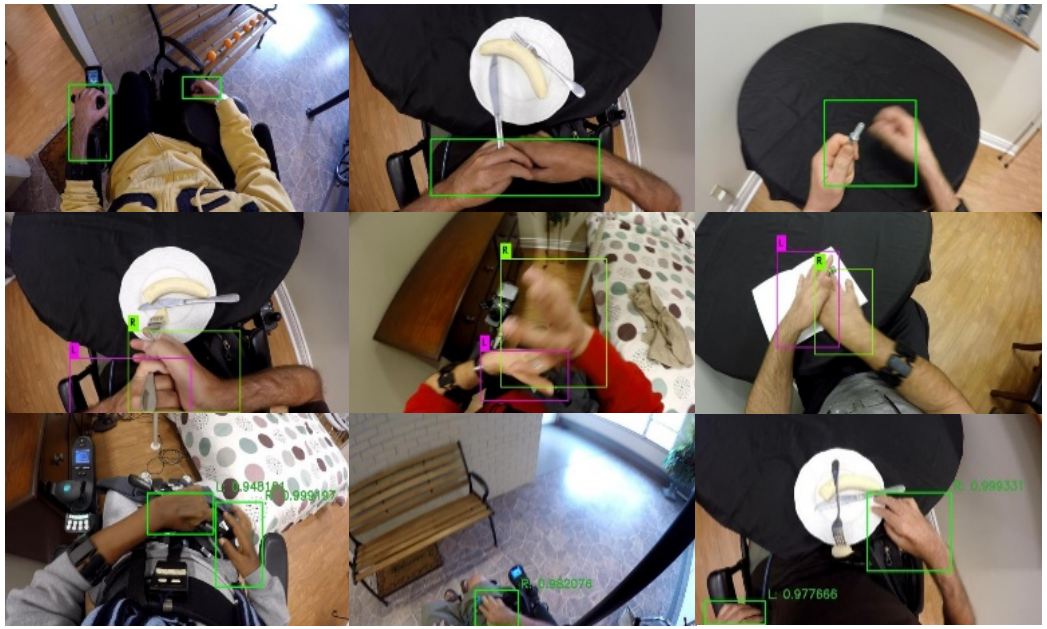
Wearables

Study	Sensor or Platform	Metric	Evaluation	Result
LOWER EXTREMITY				
Galen et al., 2011	Instrumented insoles	Gait kinematics	Responsiveness (n = 18)	Changes observed after intervention;
Werner et al., 2020	IMUs	Gait kinematics	Clustering, criterion validity (n = 29)	Correlations of select features with 6MWT

Study	Sensor or Platform	Metric	Evaluation	Result
UPPER EXTREMITY PART 1				
Maskimovic and Popovic, 1999	Customer goniometer-based apparatus	Movement classification	Classification accuracy (n = 16)	46-100%
Oess et al., 2012	Sensorized gloves	Hand kinematics	Accuracy, reliability, feasibility (n = 4)	Accurate, reliable, feasible
Brogioli et al., 2016	IMUs	Amount of UL activity	Responsiveness, discriminant validity (n = 31)	Decreasing differences in UL activity between tetraplegic and paraplegic participants over time
Popp et al., 2016	IMUs	Detection of active propulsion	Classification accuracy self- vs attendant propulsion (n = 21)	82-93%
Brogioli et al., 2017	IMUs	Amount of UL activity	Discriminant and criterion validity (n = 30)	Correlation with motor scores and SCIM, differences between tetraplegic and paraplegic individuals.
Lonini et al., 2017	Accelerometer + environmental RFID	Detection of stand-to-reach events	Classification accuracy (n = 10)	98%
Schneider et al., 2018	IMUs	Quality of wheeling movements	Reliability (n = 63)	2-3 days of recording required for reliable measurement

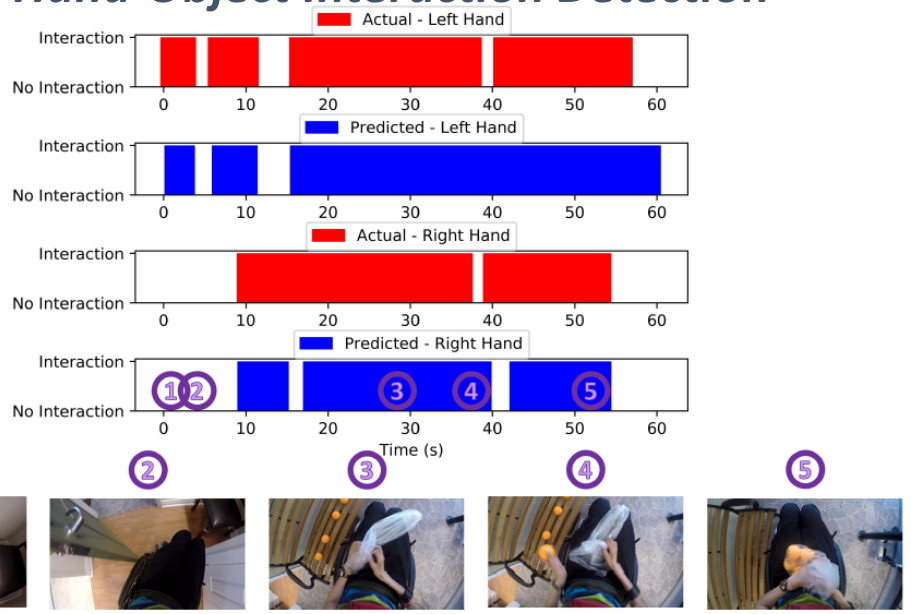
Study	Sensor or Platform	Metric	Evaluation	Result
UPPER EXTREMITY PART 2				
Likitlersuang et al., 2019	Egocentric camera	Hand-object interactions	Criterion validity (F1-score vs. manual annotations) (n = 9)	0.73-0.74
Bandini et al., 2020	Egocentric camera	Hand-object interactions	Criterion validity (F1-score vs. manual annotations) (n = 3)	0.76
Dousty and Zariffa, 2020	Egocentric camera	Grasp types used	Clustering of video frames showing similar grasping postures (n = 1)	Moderate accuracy
Su et al., 2020	Sensorized gloves	Hand kinematics	Discriminative and criterion validity (n = 98)	Differences between healthy an myelopathy groups. Relationship with JOA scores.
Dousty and Zariffa, 2021	Egocentric camera	Tenodesis grasp use	Classification accuracy (n = 17)	Accurate detection of presence of tenodesis grasp at person-level
Bravi et al., 2021	IMUs	Shoulder ROM	Criterion validity, inter-rater reliability (n = 8)	Reliable; valid for most movements

Hand Detection



Postural Estimation

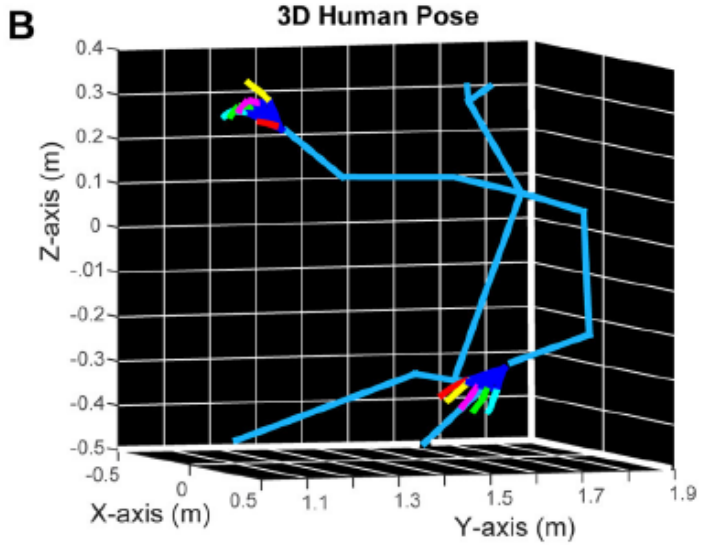
Hand-Object Interaction Detection

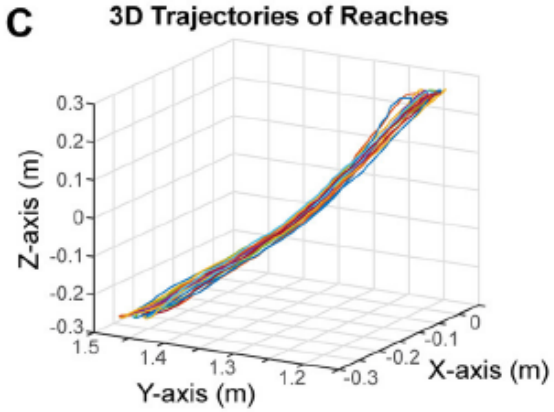


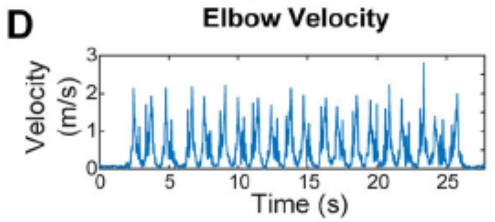
Motion Capture and Biomechanics

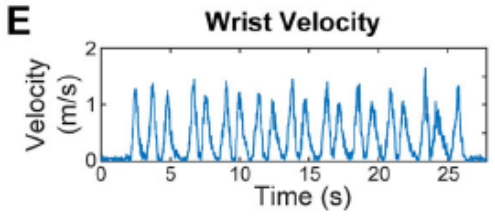
Study	Sensor or Platform	Metric	Evaluation	Result
Yozbatiran et al., 2010	Inclinometer, force sensor	Balance and leg force metrics	Validity and reliability (n = 21)	Correlations between changes in leg force and ISNCSCI elements. Variable reliability.
Cacho et al., 2011	Marker-based motion capture	Reaching kinematics	Validity (n = 20)	Some correlations between kinematic variable and ISNCSCI, FIM, SCIM.
Manella et al., 2017	Marker-based motion capture	Oscillations during drop test	Test-retest reliability, criterion validity (n = 40)	Reliable and valid
Colombo Zefinetti et al., 2020	Kinect v2 (multiple)	Wheelchair propulsion kinematics	Reliability, discriminant validity (n = 60)	Results comparable with Vicon for different levels of impairment
Nithiatthawanon et al., 2020	Load cell	Lower limb loading ability	Prediction of functional mobility and fall history (n = 90)	Thresholds identified to predict independent mobility and fall risk

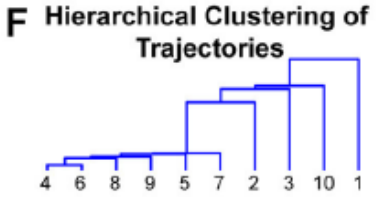
Digital Functional Assessment not yet used in SCI: Markerless motion capture

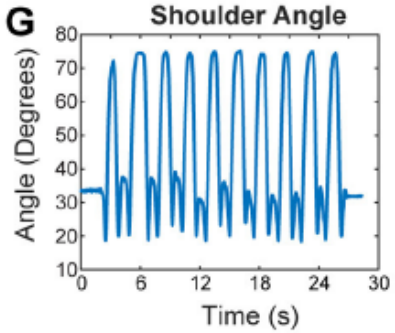


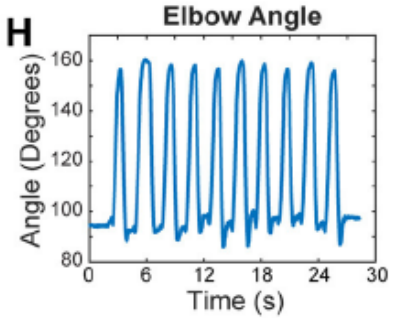












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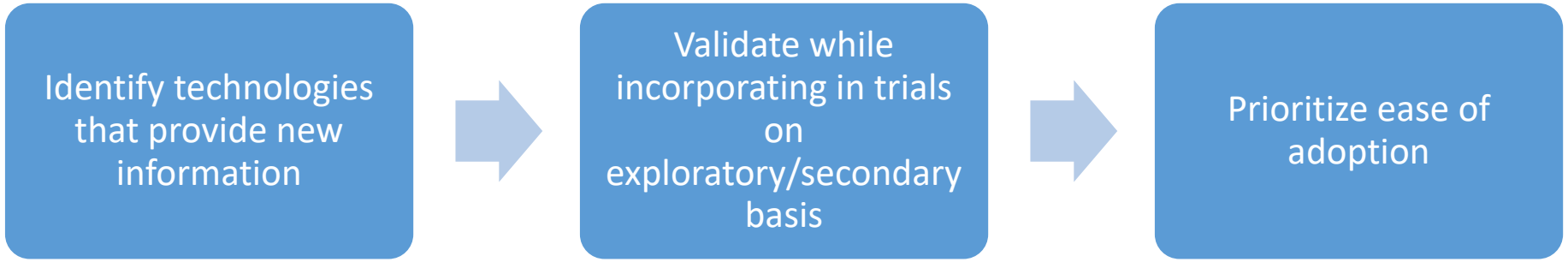
Computer-Assisted Testing and mHealth

Study	Sensor or Platform	Metric	Evaluation	Result
Jette et al., 2012	Computer Adaptive Testing (CAT)	Spinal Cord Injury – Functional Index	Precision and reliability of CAT vs full item bank (n = 855)	Acceptable psychometric properties of CAT version
Jia et al., 2020	App	ICF elements	Rasch analysis (n = 112)	Set of categories with good fit to Rasch model

Roadmap to use in practice and clinical research

- Inter-disciplinary technical development
- Emphasis on role and complementarity of information
- Progressive acceptance through use as secondary outcome measures
- Standardization of methods and larger validation studies
- Ease of access and use
- Integration into digital infrastructure (EHRs)



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