Enabling participation through rehabilitation engineering

Waterloo Smarter Health Seminar Series
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What we will talk about

• Magnitude of disability
• Biopsychosocial model of disability
• Implications for rehab engineering
• Examples from Bloorview MacMillan
Magnitude of disability

Prevalence in Canada

A profile of disability in Canada, Statistics Canada, 2001
Magnitude of disability

A profile of disability in Canada, Statistics Canada, 2001
Magnitude of disability

US Census Bureau, 2003
Magnitude of disability

World (Millions)

600

9.3%

6476

Disability
Without disability

United Nations, 2004
Aging population

No. people Over 65 (USA)

2002: 34.7 M
2030: 69.4 M

US Department of Health and Human Services, Administration on Aging, 2002
Economic numbers

$29 Billion loss per year (industry & businesses)

Time away to care for aging parents

MIT Age Lab, 2004
Economic numbers

Assistive technology industry

$2.87 Billion

Biopsychosocial model of disability

WHO ICF 2001
WHO ICF: Goals

- **scientific basis** for consequences of health conditions
- **common language** to improve communications
- **comparison of data** across:
  - countries
  - health care disciplines
  - services
  - time
- **systematic coding scheme** for health information systems
Principles of ICF

Human Functioning - not merely disability
Universal Model - not a minority model
Integrative Model - not merely medical or social
Interactive Model - not linear progressive
Parity - not etiological causality
Context - inclusive - not person alone
Cultural applicability - not western concepts
Operational - not theory driven alone
Life span coverage - not adult driven
Principles of ICF

Human Functioning  
• Body functions  
  & structures

  limitation

  restriction

disability
Principles of ICF

Universal Model vs. Minority Model

Everyone may have disability
Continuum
Multi-dimensional

Certain impairment groups
Categorical
Uni-dimensional

“LABELS”
Principles of ICF

Universality

How far you go in life depends on you being tender with the young, compassionate with the aged, sympathetic with the striving and tolerant of the weak and the strong. Because someday in life you will have been all of these.

George Washington Carver (1864-1943)
“I refuse to see myself within a defective framework. I don’t accept the defect label because I have no legs. I see myself as a person with a non-mainstream body function.”

Dr. Gregor Wolbring
Principles of ICF

Medical versus Social Model

- PERSONAL problem vs SOCIAL problem
- personal adjustment vs environmental manipulation
- behaviour vs attitude
- individual adaptation vs social change
Principles of ICF

Interactive model

Disability

Health Condition (disorder/disease)

Body function&structure (Impairment)

Activities (Limitation) <-> Participation (Restriction)

Environmental Factors

Personal Factors
Principles of ICF

- Products
- Close milieu
- Institutions
- Social Norms
- Culture
- Built-environment
- Political factors
- Nature

Health Condition (disorder/disease)

Environmental Factors

Personal Factors

Body function & structure (Impairment)

Activities (Limitation)

Participation (Restriction)

Close milieu

Institutions

Social Norms

Culture

Built-environment

Political factors

Nature

Products

Principles of ICF
Principles of ICF

- Health Condition
  - disorder/disease

- Environmental Factors

- Personal Factors
  - gender
  - age
  - other health conditions
  - coping style
  - social background
  - education
  - profession
  - past experience
  - character style

- Body function & structure (Impairment)

- Activities (Limitation)

- Participation (Restriction)

- Environmental Factors

- Personal Factors
Principles of ICF

“If I had to say that there is one most difficult thing about being a teen in a wheelchair, it would be that I still feel there is a constant battle to "belong." By belong, I mean to feel that I am a part of my community, my school, to have a feeling of being welcome, and to never ever again feel the need to question my own self value, worth, or ability. As a teen, this is one of the most complicated and painful parts of being in a wheelchair.”

- Eileen, seventeen year old high school senior living with a spinal cord injury
Sometimes the worst thing about having a disability is that people meet it before they meet you.
Principles of ICF
Implications for rehabilitation engineering

Embracing a biopsychosocial model
Rehabilitation Engineering

“... is the application of science and technology to improving the quality of life for people with disabilities.”

James Reswick, 1st RESNA President
Assistive Technology

"Any item, piece of equipment, or product system, whether acquired commercially off the shelf, modified, or customized, that is used to increase, maintain, or improve functional capabilities of individuals with disabilities.

Embracing a biopsychosocial model of disability

Intelligent systems
Intelligent system

Information

Child

Context

Activities
Intelligent system

Child

Context

Activities
Intelligent system

Child

Context

Activities
Dynamic intelligent system

- Child
- Context
- Activities

Time
Dynamic intelligent system

Child

Context

Activities

Time
Dynamic intelligent system
Dynamic intelligent system
Dynamic intelligent system

Outputs
Inputs
Time

\[ y = f(\theta, x, t) \]

Free parameters
Intelligent system

Transfer onus of learning human-machine interface from child to machine

Human functioning
Intelligent system

Individual is ok

Depart from minority model
Accommodate any user ability
Psychosocial model
Intelligent system

Context-aware

Personal factors
Environmental factors
Intelligent system

Sensors

Interface
Dynamic intelligent system

Disability is dynamic

- Disease progression
- Environmental change
- Developmental change

Interactive model

Life span coverage
Dynamic intelligent systems

1. Transfer onus of learning
2. Individual is ok
3. Look at context
4. Disability is dynamic

Developmental
Ecological relevance
Body – Activity - Participation

ICF

Devices
Assessments
Interventions
Examples from paediatric rehabilitation

- Non-contact communication aid
- Aspirometer
- Augmented environments
- Mechanomyography
- Fractal gait
Non-contact communication

- Brain computer interface
- Gesture interface
Brain-computer interfaces
Brain-computer interfaces

EEG → BCI

Control
Communication

Bereitschaft (readiness potential)
Brain-computer interfaces

Expressions of preference

“No”
Brain-computer interfaces

Expressions of preference

“Yes”
Gestural interface
Gestural interface
Gestural interface
Gestural interface

- I am in pain
- Can you read me a story?
- I want my mommy
- When can I go home?
Context – speech act prediction

- Cultural background
- Medical condition
- OT Assessment
- Time of day
- Recent utterances
- SLP Assessment
- Ventilator dependence

Predictor

Probable next utterances
Noncontact communication

Context

Gestures

Thoughts

Intelligent system

Facial

Fine/gross

Navigation

Messages
Examples from paediatric rehabilitation

- Non-contact communication aid
- Aspirometer
- Augmented environments
- Mechanomyography
- Fractal gait
Detection of aspiration
Detection of aspiration

Vibration sensor
Synchronized (time stamped) X-ray video & accelerometry
Videofluoroscopy
Detection of aspiration


Detection of aspiration

- 3 Features: stationarity, normality, dispersion

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<table>
<thead>
<tr>
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<tbody>
<tr>
<td>+ve predictive value</td>
<td>93%</td>
</tr>
<tr>
<td>-ve predictive value</td>
<td>58%</td>
</tr>
<tr>
<td>Sensitivity</td>
<td>83%</td>
</tr>
<tr>
<td>Specificity</td>
<td>81%</td>
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</table>
Aspirometer
Aspirometer
Examples from paediatric rehabilitation

- Non-contact communication aid
- Aspirometer
- Augmented environments
- Mechanomyography
- Fractal gait
Augmented environments

Real, physical environment

+

Virtual objects

Information (cues)  Enhanced properties
Augmented environments
Virtual music instrument
Augmented environments
Virtual music instrument
Augmented environments

Virtual music instrument
Examples from paediatric rehabilitation

- Non-contact communication aid
- Aspirometer
- Augmented environments
- Mechanomyography
- Fractal gait
Mechanomyography
Mechanomyography
Mechanomyography
Mechanomyography
Mechanomyography

\[ p_0 + p_d(t) \]
Mechanomyography

Mechanomyography
Mechanomyography

Classifier

Motor programs

MMG

MMG

MMG

MMG
Examples from paediatric rehabilitation

- Non-contact communication aid
- Aspirometer
- Augmented environments
- Mechanomyography
- Fractal gait
Temporal fractals

Fluctuations vs. Scale

Strides vs. Seconds
Measurement

• Any time-varying, quasi-periodic gait variable
Measurement

Period of measurement: = 10 minutes
Number of strides: = 500
Context: outside of laboratory
Healthy gait

• Scaling exponent – close to 1.0
  – What does this mean?
Healthy gait

• Robust dynamics
  – Speed
  – 1000+ strides
  – 1 hour of walking

• Obliterate dynamics
  – Scramble time series
  – Walk to metronome
  – Walk on a treadmill
Physiological hypotheses

1. Efficiency - energy expenditure
2. Stability/balance
3. Adaptability – response to perturbations
4. Hierarchical synthesis of multiscale input
   -> multiscale control output
Physiological hypotheses

- Proprioceptive
- Visual
- Auditory
- Vestibular
Pathological gait

![Bar graph showing scaling exponents for different groups: HD, CP, Elderly, ALS, PD, Control. The scaling exponent values range from 0.1 to 1.0. HD has the lowest scaling exponent, and Control has the highest.](image-url)
Pathological gait

- Diminished dynamics – implications
  - Less stable
  - Less energy efficient
  - Prone to falls
  - Less adaptable
  - More periodic


# Fractal vs. conventional thinking

<table>
<thead>
<tr>
<th>Topic</th>
<th>Fractal</th>
<th>Conventional</th>
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</thead>
<tbody>
<tr>
<td>Information</td>
<td>Fluctuations</td>
<td>Absolute values</td>
</tr>
<tr>
<td>Fluctuations</td>
<td>“ordered”</td>
<td>Random</td>
</tr>
<tr>
<td>Periodicity</td>
<td>Bad!</td>
<td>Good</td>
</tr>
<tr>
<td>Data</td>
<td>100’s strides</td>
<td>&lt;10 strides</td>
</tr>
<tr>
<td>Analysis</td>
<td>Temporal dynamics</td>
<td>Summary statistics</td>
</tr>
<tr>
<td>Perspective</td>
<td>System</td>
<td>Localized</td>
</tr>
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Interventions

• **Implications**
  – Repetitive, periodic training (e.g. treadmill) – not good!
  – Walking while listening to computer generated music – bad?
  – Need to consider CONTEXT of walking
  – Intervention: Entrain healthy dynamics?
Interventions

• Fractal gait training

Fractal timing

Entrained dynamics?

Fractal velocity pattern
Interventions

- Walking in context

  Sensory stimuli
  Collective vs. individual walking
  Other cognitive processes (e.g. talking)
Other PRISM Lab Projects

• Evidence-based approach to written productivity
• Electroactive polymers
• In-place health care & remote activity monitoring
• Self-selected expressions of functional intent
What we have talked about

• Magnitude of disability

• Biopsychosocial model of disability

• Implications for rehab engineering

• Examples from Bloorview MacMillan
The Future

- “Developmental” technology – dynamic
- Context-aware, context-dependent solutions (in-place health monitoring)
- Novel actuation/sensing materials
The Future

• Fractal rehabilitation – outcomes and interventions

• Intersection of micro- and macroscopic biomedical engineering

• Evidence-based medicine & policy
# Body Functions and Structures

<table>
<thead>
<tr>
<th>Mental functions</th>
<th>Structures of the nervous system</th>
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<tbody>
<tr>
<td>Sensory functions and pain</td>
<td>The eye, ear and related structures</td>
</tr>
<tr>
<td>Voice and speech functions</td>
<td>Structures involved in voice and speech</td>
</tr>
<tr>
<td>Functions of the cardiovascular, haematological, immunological and respiratory systems</td>
<td>Structures of the cardiovascular, immunological and respiratory systems</td>
</tr>
<tr>
<td>Functions of the digestive, metabolic and endocrine systems</td>
<td>Structures related to the digestive, metabolic and endocrine systems</td>
</tr>
<tr>
<td>Genitourinary and reproductive functions</td>
<td>Structures related to the genitourinary and reproductive systems</td>
</tr>
<tr>
<td>Neuromusculoskeletal and movement-related functions</td>
<td>Structures related to movement</td>
</tr>
<tr>
<td>Functions of the skin and related structures</td>
<td>Skin and related structures</td>
</tr>
</tbody>
</table>
Activities and Participation

1. Learning & Applying Knowledge
2. General Tasks and Demands
3. Communication
4. Movement
5. Self Care
6. Domestic Life Areas
7. Interpersonal Interactions
8. Major Life Areas
9. Community, Social & Civic Life
Environmental Factors

1. Products and technology
2. Natural environment and human-made changes to the environment
3. Support and relationships
4. Attitudes
5. Services, systems and policies
Augmented environments
Community mobility rehabilitation
Augmented environments

Community mobility rehabilitation