Novel balance assessments and ‘perturbation-based’ training to reduce falls risk

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The Balance, Mobility & Falls Clinic Team

- Integrated team of clinicians and researchers within the patient care setting
- ‘Hub’ for knowledge exchange
- Accelerates...
  - new knowledge to everyday clinical practice
  - new clinical questions to scientific inquiry

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Connie Cadeau
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By the end of this presentation, participants will be able to:

- Discuss existing and emerging *research related to reactive balance control*, its link to fall risk and relevance to rehabilitation within both the elderly and neurological patient populations.

- Identify and compare existing and emerging *clinical approaches to measuring reactive balance control* with respect to safety, standardization, feasibility and clinical information gained.

- Identify *novel balance ‘perturbation’ training strategies* that can be applied to their clinical practice, to target features of reactive balance control linked to fall risk.
Fall = loss of balance (internally or externally generated ‘balance perturbation’) + failure to recover
Strategies for balance recovery

- Ankle strategy
- Hip strategy
- Step strategy

- Not a hierarchy of responses
- Stepping strategy commonly-observed reaction to loss of balance in daily life, even with small magnitude perturbations
Successful balance recovery reactions are...

- ...fast!
- ...scaled to the magnitude of the perturbation
- ...appropriate for the perturbation characteristics (e.g. direction)
- ...adaptable to environmental constraints
Reactive balance control: a critical link to falls

- Impaired execution of reactive stepping is predictive of falls
  - within community-dwelling elderly (Maki et al., 2001; Hilliard et al., 2008)
  - 6 months after discharge from stroke inpatient rehabilitation (Mansfield et al., Physiotherapy, 2015)

Video link:
https://www.youtube.com/watch?v=HKfF0rkn-8Y
The need for targeted measures of reactive balance control

Commonly-used clinical measures, that focus on volitional control, do not clearly identify individuals with impaired reactive stepping performance

Adapted from Inness et al., Phys Ther, 2014
Challenges to clinical assessment

- Of concern, reactive balance control less frequently assessed than other aspects of balance control \(\text{(Sibley et al., 2011)}\)

- Limited availability of clinical tools among the top 3 cited barriers to assessing reactive balance control \(\text{(Sibley et al., 2013)}\)

- Challenges to clinical assessment of reactive balance control could include:
  - Safety
  - Standardized protocol
  - Controlled method of perturbation
  - Quantification of response
  - Feasible to administer in a clinical setting
‘Research lab’ methods

- Safety
- Standardized protocol
- Controlled method of perturbation
- Quantification of response

Feasible for use in a clinical setting

Active Step & R-Mill – commercially-available perturbation treadmills

“FallsLab” motion platform at the Toronto Rehab Institute

Tanvi Bhatt & Clive Pai’s slip perturbation set-up at the University of Illinois, Chicago
‘Clinical’ methods: push or pull

- Safety
  - Standardized protocol
- Controlled method of perturbation
- Quantification of response
  - Feasible for use in a clinical setting

Horak, BESTest
The ‘lean-and-release’ assessment

- **Safety**
  - Overhead harness

- **Standardized protocol**

- **Controlled method of perturbation**
  - Temporally unpredictable
  - Amplitude of perturbation is controlled and measured

- **Quantification of response**
  - Video-recorded to observe and code performance
  - Force plates reveal temporal factors

- **Feasible**
  - Potential for uptake in stroke rehabilitation setting (Inness et al., 2014)
The ‘lean & release’ balance assessment

Healthy response

Foot-off time*: 273-357 msec

Foot-contact time*: 490-601 msec

Swing duration

Limb-load symmetry

Timing data reflects 95% confidence intervals of healthy elderly responses age > 65 years from Thelen et al., 2000
<table>
<thead>
<tr>
<th>Trial #</th>
<th>Pert amp</th>
<th>Limb load</th>
<th>Reactive stepping performance</th>
<th>Timing</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>% BW on cable</td>
<td>% BW on Affected left limb</td>
<td>Category</td>
<td>Assist</td>
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<tr>
<td><strong>Usual Response</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>5.1</td>
<td>42</td>
<td>Fall</td>
<td>Y</td>
</tr>
<tr>
<td>2</td>
<td>7.1</td>
<td>47</td>
<td>Fall</td>
<td>Y</td>
</tr>
<tr>
<td>3</td>
<td>7.2</td>
<td>48</td>
<td>Multistep</td>
<td>N</td>
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<tr>
<td><strong>Dual Task</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>6.2</td>
<td>42</td>
<td>Fall</td>
<td>Y</td>
</tr>
<tr>
<td><strong>Encouraged Use (block right)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>6.6</td>
<td>42</td>
<td>Fall</td>
<td>Y</td>
</tr>
<tr>
<td>6</td>
<td>6.4</td>
<td>45</td>
<td>Fall Blocked step</td>
<td>Y</td>
</tr>
<tr>
<td>7</td>
<td>7.7</td>
<td>43</td>
<td>Blocked step</td>
<td>N</td>
</tr>
</tbody>
</table>

**Comments**
* ‘slide step’, decreased foot clearance
**healthy reference values**
[Video removed]
Inability or unwillingness to step with affected limb significantly delays step initiation.

Aborted step with affected limb

Inability or unwillingness to step with affected limb significantly delays step initiation.

Step initiation time = 742 msec
(vs 350 msec healthy elderly values)
Non-paretic limb preference

[Video removed]
Decreased limb clearance

Right step not fully unloaded
Influence of dual-task

Preferred Response
Onset to Unload = 164 msec
Foot Off = 336 msec
Foot Contact = 574 msec

Dual Task
Onset to Unload = 375 msec
Foot Off = 586 msec
Foot Contact = 829 msec
Summary: characteristics of reactive stepping post-stroke

- Failed responses (assistance, “fall”)†
- Multi-step responses*
- Reluctance to step†
- Over-use of upper extremities
- Unwilling/unable to step freely with both limbs†
- Delayed timing in early preparatory phases (foot-off time)†
- Poorly controlled steps:
  - Short in duration/length
  - Decreased clearance (“slide”)†
  - Limb collisions*
  - Limb coordination/placement*

Linked to falls in the *elderly and after †stroke

Maki & McIlroy 2006; Lakhani et al., 2011; Mansfield et al., 2012; Inness et al., 2014, Mansfield et al., 2015
Considerations for assessment

• Influence of pre-perturbation weight-bearing asymmetry
• Influence of limb preference
• Influence of magnitude of perturbation (cable load)

• Changes across conditions:
  • Encouraged-use conditions - differences between preferred and non-preferred
  • Dual-task conditions - cognitive/attentional influence on responses
Evolution of assessments?
Training reactive balance control

- Task-specific ‘perturbation’ training
- Repeated exposure to external or internally generated perturbations
- Focus on speed of processing, speed of execution and rapid re-stabilization
Evidence for perturbation training

Studies within elderly, Parkinson’s disease and stroke suggests perturbation training can:

- ↓ voluntary reaction time
- ↑ reactive balance control
  - e.g. faster m. latency, reduced limb collisions, reduced multi-step reactions
- ↓ ‘in-lab’ falls & ↓ ‘real world’ falls

Marigold et al., 2005; Smania et al., 2010; Mansfield et al., 2011; Grabiner et al., 2012; Pai et al., 2014; Mansfield et al., Phys Ther, 2015
See additional video files in:
http://ptjournal.apta.org/content/90/4/476.figures-only#fig-data-additional-files
Varied perturbation methods
- External perturbations: cable pulls, push/pull by therapist, water-based perturbations, moving platforms, treadmills, lean and release
- Internal perturbations: ‘agility’ tasks

Wide range in volume of training
- Single session versus 30 sessions
- 24 perturbations versus ~1,500 perturbations across all sessions
Clinical application of perturbation training

- Collaborative approach between researchers and physiotherapists
- Neurorehabilitation setting (stroke & acquired brain injury)
Considerations for safety

- **Exclude** those with illness, injury or condition that will be exacerbated by repeated exposure to postural perturbations

- **Clinical judgement prevails** but consider:
  - Acute MSK issues
  - Recent trauma (fractures, soft tissue injury), surgery, unstable lower limb joints (knees, ankles); Acute low back or lower limb pain; OA, RA
  - Osteopenia / osteoporosis
  - Acute/unstable cardiovascular condition
  - Extreme fear of falling or anxiety
  - Acuity of brain injury
Considerations for safety

- Informed consent (with demonstration)
- Harness system to ensure safety but allow multi-planar movements
- Use of braces & splints (unstable ankles, sensory impairment)

- Graded progression
  - Internally → externally-generated
  - ‘Lean & release’ towards therapist → ‘pulling’ / ‘pushing away’
  - Predictable → unpredictable perturbations
  - Low → high amplitude perturbations
Clinical application: Training principles

- *Individualized* training based on participant’s unique dyscontrol revealed by assessment

- FITT principles (optimal parameters not yet known)

<table>
<thead>
<tr>
<th>Frequency</th>
<th>2-3 times a week, 7-10 sessions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intensity</td>
<td>Must elicit a reactive step</td>
</tr>
<tr>
<td></td>
<td>Allow for ‘success’ some of time</td>
</tr>
<tr>
<td>Time</td>
<td>20-30 minutes with rests</td>
</tr>
<tr>
<td></td>
<td>Minimum 30 ‘repetitions’ or losses of balance</td>
</tr>
<tr>
<td>Type</td>
<td>Variety of tasks and perturbations</td>
</tr>
</tbody>
</table>

- Perturbation methods

  *Internally-generated*: Voluntary tasks of sufficient challenge that evoke internal perturbations

  *Externally-generated*: Balance perturbations generated by a force outside participant’s control
Clinical application: Training principles

- **Progression**
  - Features of the perturbation (predictable vs unpredictable timing, direction, or amplitude)
  - Mobility continuum: stable, vs quasi-mobile vs mobile tasks
  - Sensory conditions (firm vs compliant surface, eyes open vs closed)
  - Cognitive challenge (single task vs dual task)
  - Environmental challenges (open vs obstacles/targets for foot placements, etc)
Internally-generated perturbation

Video removed
Internally-generated perturbation

Video removed
Externally-generated perturbation ‘lean and release’
Externally-generated perturbation ‘push and release’
Encouraged use of paretic limb
Externally-generated perturbation ‘pull’
Limb clearance & increased step length
Unpredictable perturbations

Video removed
Sensory, motor, cognitive & environmental challenges
Pilot Evaluation

- Patients with stroke and brain injury participated
- Evaluation included:
  i) perceptions of patients and therapists through structured interviews and questionnaires, respectively
  ii) pre-post outcomes on measures of reactive balance control
- Comparison of those with stroke who receive training to matched historical control cohort (Clinic database)
“...liked the challenge to my balance...feeling more solid on my feet... felt completely secure in the harness...feeling of independence...took me by surprise, like at the mall or on a streetcar...”
Physical therapist perceptions?

Confident in patient safety
Relevant to patient goals
Beneficial to pt recovery
Informed D/C recommendations
Planned future use
Ease of 7-10 Rx
Ability to delegate to PTA

Frequency of responses (n=10)

Agree or Strongly Agree
Strongly Disagree/Disagree/Neutral
Did participants benefit?

- Improved performance of reactive stepping *features linked to falls*
  - ↓ frequency of assist trials (p=0.007)
  - Faster foot-off times (p=0.09)

- Improved *balance recovery performance*

<table>
<thead>
<tr>
<th>Assessment</th>
<th>Performance on 1(^{st}) novel trial</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Assist</td>
</tr>
<tr>
<td>Pre</td>
<td>5</td>
</tr>
<tr>
<td>Post</td>
<td>1</td>
</tr>
</tbody>
</table>
Can improvement be attributed to training?

- Greater reduction in features linked to falls, for those with stroke who completed training versus matched historical control cohort

A = frequency of ‘falls’
B = frequency of ‘blocked’ steps
C = frequency with decreased foot clearance
Can improvement be attributed to training?

- Greater reduction in foot-off time (nonparetic > paretic) for individuals with stroke who completed training versus matched historical control cohort.

A = nonparetic steps

B = paretic steps
Video removed
Impaired *reactive balance control is related to increased risk for falls* within both the elderly and neurological patient populations.

Clinical *assessment should target reactive stepping*:
- Several standardized assessments are available to assess reactive stepping.
- Instrumented assessments might provide information related to underlying dyscontrol, but...
- Many characteristics of reactive stepping known to be linked to falls can be obtained by observation.

Reactive balance control can be improved with *perturbation training, which is a feasible training strategy for many populations*.