Preventing falls through improved stair and handrail design

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End Falls this Fall
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Toronto Rehab Research – Who we are

• Teaching hospital fully affiliated with the University of Toronto

• Over 350 scientists, fellows, graduate students and support staff
  • Biomedical, mechanical, and electrical engineers, doctors, nurses, occupational and physiotherapists, kinesiologists, industrial designers, machinists

• 8 Research Teams:
  • Cardiopulmonary Fitness
  • Cognition
  • Communication
  • Sleep and Upper Airway
  • Neural Engineering and Therapy
  • Optimization of the Rehabilitation System
  • Mobility
  • Technology
StreetLab
Falls on stairs - Epidemiology and injury burden

Causes of Major Injury Hospitalizations in Canada, All Cases, 2009–2010

- Unintentional falls second only to MVA for all major injury hospitalizations in Canada

Major Injury Hospitalizations Due to Unintentional Falls in Canada, by External Causes of Injury, 2009–2010

- Stairs represent main location of injury

National Trauma Registry Comprehensive Data Set, 2009–2010, Canadian Institute for Health Information (2012).
Falls on stairs - Epidemiology and injury burden

- 25% of known deaths from accidents occur on stairs
- 12% of stair-related falls result in TBI
  - Significant incline in injury rates in persons over the age of 65
- Upwards of $10 Billion/per year total societal costs related to stair injuries

Numbers and age-specific rate of hospitalisations due to falls on stairs and steps by sex, Canada, 1994-2009 (n=63,638 for males, 98,686 for females)

Olsen and Barss 2012, Adapted from Statistics Canada
Stair ambulation & Independent mobility for older adults

• 55% of Canadians over the age of 55 have difficulty climbing stairs
  – One of the leading ADL challenges faced by older adults

• Stairs leading concern for older adults living in their homes
  – Solution = move, restrict living to single floor in home, yet…

• 89% of seniors want to AGE IN PLACE
How are we addressing the problem?

“Although clinical interventions are important, population health interventions that tackle the underlying determinants of falls and injuries need to be considered.” (Edwards, 2008)

- Modifiable risk factor = reduction of environmental hazards
Prevalence of priority hazards of home stairs according to seniors (Edwards & Lockett, 2003)
Two important features of the stairs for safety

• Step geometry (rise/run)
• Handrail (height, size, shape)
Step Geometry & falls

- Direct relationship between falls & size of run
  - Tread depth ↓, risk of falls ↑

Figure from Johnson & Pauls, 2012; adapted from Wright & Roys, 2008
Rise/run combination: the “7-11” debate

- Established relationship between stair steepness, length of run (going) and falls
- In Canada - a code-change proposal for minimum 280 mm run (going) dimensions for home stairs (11 inch run length)
- Current empirical evidence not enough – our research efforts directed at providing greater range of biomechanical measures to support “safer” stairs
Our “adjustable” staircases

Minimum run length

Maximum run length
Our “adjustable” staircases

- Adjusted from 8 inch to 14 inch run length, in one-inch increments
- 3 staircases of different riser heights (7 inch, 7.5 inch, 8 inch)

- Subjects ascended/descended at self-selected speed
- 20 Healthy young adults & 20 healthy older adults tested
Measure of Balance: Margin of Stability

Foot trajectory measures

Figure 1. Illustration of dynamic balance control measures (A - top) and foot trajectory measures (B - bottom) during stair descent and ascent. Step geometry features are indicated in green.
Preliminary results: Margin of Stability

- Linear relationship between run length and margin of stability; limited effect of riser height
  - Greater margin of stability with longer step length without the need to modify individual behaviour
- Slight upward shift in healthy older adults margin of stability compared to young adults
  - Reflects strategy to adopt more biomechanically stable posture at critical point when body weight is being transferred to the anteriorly placed foot
Preliminary results: Foot trajectory measures

- Linear relationship between run length and foot-to-step clearance, % of foot overhang
- Reduced slope of older adults curve; reflects strategy to maintain full foot on step despite increasing run length
  - Highlights need to provide longer step to accommodate step-to-step variability
Step Geometry: The 7-11 debate

• Preliminary findings provides greater understanding of the mechanism underlying previous injury statistics
  – I.e. Linear relationship with step geometry and biomechanical indicators of falls risk pairs with linear relationship between reported falls and run length

• Recommendations for safer stairs? Where to determine the minimum step length for homes?
Better handrail design to prevent falls

• Prerequisite for a fall:
  – Initial “loss of balance” (ie. slip, trip, misstep, collision)
  – Failure of balance-recovery mechanisms to counteract destabilization

• Handrails most effective way to respond to unexpected perturbation & prevent a fall!!
Better handrail design to prevent falls

• Well-designed handrails significantly increase the likelihood that a person can avoid or recover from balance loss and avert a fall, by making it easier for the person to:
  – Quickly and accurately reach and grasp the rail
  – Generate sufficient forces and moments on the rail to stabilize the person’s centre of mass (COM)

• Useful when other balance recovery mechanisms (i.e. stepping) are not reliable
Handrail design & fall prevention

Can handrails be designed to promote effective reach-to-grasp reactions?

• Early work by Maki et al.
  – Capacity to generate stabilizing moments & forces
  – Power grip optimal – greatest stabilizing moments/forces
  – Narrow or complex shapes requiring “pinch grip” ~50% lower forces – Not recommended
Balance recovery reactions are complex!

• To design the best handrail we need to know....

• What happens in the process of using a handrail for balance recovery when your hand is not initially on the rail?

• Which factors could influence the execution & success of this process?
Dynamic testing of handrail design

- Reach-to-grasp studies: Cylindrical or oval shape supported & most strongly recommended

Vertical angle of attack

Horizontal angle of attack

Fig. 1. Schematic drawing of the experimental apparatus.
Defining shape of handrails: “graspability” debate

- At handrail contact, the hand must be oriented appropriately, with an aperture suited for grasping
- Power grip optimal – greatest stabilizing moments/forces
  Reach-to-grasp studies: Cylindrical or oval shape most strongly recommended
- Narrow or complex shapes requiring “pinch grip” ~50% lower forces – Not recommended

- Current proposal for building standards: Defining a “graspable portion”
Using StairLab, CEAL to provide empirical evidence

- Unexpected platform perturbations induce balance loss
- “Reach-to-grasp” reaction evoked

1. Height study
   - Investigate effect of height and slope
2. Graspability study
   - Investigate shape/size during dynamic stair ambulation
Defining appropriate handrail height

1. Investigate how handrail installation height affects a user’s ability to recover from balance loss while walking on level and inclined surfaces.

2. Estimate an optimal and acceptable handrail installation height range for balance recovery on these surfaces, considering children, younger adults and older adults.
Outcomes proposed handrail work

• Do recommendations for building standards differ in context of a real fall?
• What is the optimal vs. minimum requirement to promote effective reach-to-grasp?
• Systematic evaluation of commonly used handrail design/permissible in current building codes (Canada)
Other handrail considerations

• Bilateral handrails; Handrails in corridors
  – Permanent or non-permanent installations
Bilateral handrails, Handrails in corridors

• Ready to install products: eg. Promenaid
  – “Continuous slot design allows support brackets to be installed with a simple twist anywhere you need them”

www.promenaid.com
Bilateral handrails, Handrails in corridors

- Non-permanent safety poles: eg. Safety Grip Pole Kit
How can we provide sturdy supports from the bed to the toilet?
SafetyGrip Pole Kit

- Low cost
- Strategic grip section placement and design
- Packs to a 1m (39”) long box
- Easy to reconfigure as needed
How to accomplish safer stair standards

• National Building Code of Canada (NBCC)
  – National Research Council
  – Revised every 5 years
  – Model code for provinces; Provincial Building Codes usually very similar to NBCC
How to accomplish safer stair standards

• Public consultation process for Building Code Revisions
  – All changes to the NBCC undergo public review process
  – NRC welcomes public input! Letters, emails
  – Include supporting evidence to strengthen the case
