Research to Outreach

- Introduction
  - Problems Associated with Fall in the Elderly
  - Current Approaches to Reducing Fall Accidents

- Research
  - Mechanisms Related to Fall Accidents in the Elderly
  - Wearable Fall Risk Assessment Tool: development using nonlinear dynamics
  - Intervention: Repeated Perturbation Training

- Outreach
  - Hemodialysis Units
  - Community-Dwelling Elderly

- Discussions
  - Future Research
Bipedal Locomotion

- Found in 1978 in Tanzania, Africa
- 70 footprints in two parallel trails
- 3.7 million years old
- Credited to Australopithecus afarensis
- Walking on slippery surfaces has been going on for awhile.

Foot Print Details
Falls in the USA - Elderly

In 2014, older adults in US experienced more than 29 million falls causing more than 7 million injuries and costing over $31 billion in annual Medicare costs.

- Every 13 seconds, an elderly is admitted to an emergency department due to falling.
- Every 20 minutes, an elderly dies due to falling.

In 2014:
- Older adults in US experienced more than 29 million falls causing more than 7 million injuries.
- Costing over $31 billion in annual Medicare costs.

Motor vehicle traffic deaths
- Number of deaths: 33,804
- Deaths per 100,000 population: 10.7

Fall Accident deaths
- Number of deaths: 30,208
- Deaths per 100,000 population: 9.0
Quality of Life

• 20% - 36% fear falling\(^1\)
• 20% die within a year after hip fracture\(^2\)
• 25% in a nursing home one year later\(^3\)


Current Fall Interventions

- **Fall Protection**
  - Personal Protective Equipment (e.g. hip pads, helmets, fall arresting harness)
- **Fall Prevention**
  - Environment control (e.g. COF)
  - Fall Risk Assessments, Training
  - Interventions (e.g. strength, endurance, balance)
  - Nutrition, cholinomimetic agent, neuro-technologies
Why do Older Adults Fall More Younger Adults?

Factors Influencing Slips and Falls
(Intrinsic Changes Associated with Aging)

1. Sensory Degradation.
4. Gait Adaptation.

More importantly, extrinsic environmental factors and how those factors interact with intrinsic conditions must be considered.

What is the relationship between these risk factors and slip and fall accidents in the elderly? And, how can we use this info to assess fall risk......

Slip and Fall Experiments
Trip and Fall Experiments

Slip and Fall Experiments
Mechanisms

The Process of Initiation, Detection, and Recovery of Inadvertent Slips and Falls

Effect
Low ADCOF

Initiation
Higher RCOF (than ADCOF)

Detection
Non Optimal Detection of Deviation of COG of Body

Recovery
Non Optimal Muscular Contraction

Possible Causes
Contamination (oil, water, etc.)

Initial Gait Characteristics
- stride length
- heel velocity

Muscle Weakness
- abrupt transition of COG of body.

Degradation of Sensing Mechanism
- proprioceptive
- vestibular
- vision.

CNS
Non Optimal
Muscular
Contraction
Fall

Muscular Weakness
- lower extremity.

Slip Initiation: Initial Gait

Initial Gait Characteristics:

Initiation
Higher RCOF (than ADCOF)

Initial Gait Characteristics
- stride length
- heel velocity

Muscle Weakness
- abrupt transition of COG of body

RCOF = F_x F_y - tan α

F_x
F_y
HC
TO
**Slip Initiation: Muscle Activation**

- **a)** Raw EMG
- **b)** HV
- **c)** IEMG
- **d)** Fz

**Detection and Recovery**

- **Detection**
  - Non Optimal
  - Detection of Deviation of COG of Body

- **Recovery**
  - CNS
  - Non Optimal
  - Muscular Contraction

**Degradation of Sensory Mechanics**
- Proprioceptive
- Vestibular

**Muscular Weakness**
- Losses extremity

**Equations**

\[ F_a = \mu \cdot F_n \]

\[ \mu = \frac{F_h}{F_v} \]

\[ F_v = F_a / \sin \theta \]

\[ \sin \theta = \frac{F_h}{F_v} \]

\[ \theta > 62 \]

\[ |\mu| > 14 \]
Upper Limb Strategy

what if this person was carrying a box?

Lower Limb Strategy

“Good the Bad and the Slippery shoes”
Slip Recovery

Recovery from a slip

Multiple Regression Equation

\[ SD = -15.785 - 0.037 \text{(vision)} - 0.204 \text{(MCT)} - 0.308 \text{(LL3)} \]

\[ R^2 = 0.413 \]

<table>
<thead>
<tr>
<th>Age Group</th>
<th>SDI (cm)</th>
<th>SHV (cm/sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Young</td>
<td>3.91</td>
<td>144.45</td>
</tr>
<tr>
<td>Old</td>
<td>3.12</td>
<td>107.63</td>
</tr>
</tbody>
</table>
**Bottom Line**

![Graph showing Initial response sequence after slip](chart)

**Summary of Gait Study Results**

- Reactive Recovery Phase was the most important for the elderly.

- Control systems exhibited a **finite time delay** between the moment a **stimulus was provided** (i.e., perturbation) and the moment the system returned a **response** (i.e., nothing happens instantaneously).

- In many situations: the responses also depended nonlinearly on the input, such that the evolution of the system in the present depended sensitively on its state in the past (e.g., muscle fatigue).

- *This nonlinear time-delay systems (autonomic motor control)* can be quantified (a model) by **nonlinear dynamics - stability assessments**.
Dynamic Stability

- Based on nonlinear dynamics theory
- Measures the resistance (i.e. stability) of the target dynamic system to small perturbations

Applications:
- Dingwell et al. (2000) applied Lyapunov exponents to show that individuals with pathological gait slows down to increase their dynamic stability.
- Granata and Lockhart (2008) applied limit cycle measures to differentiate fall-prone elderly from their health counterparts.

Stability and Variability

Gait variability & fall accidents

- Individuals with step variability fell more often than non-fallers. (Guimaraes et al., 1980)
- Gait variability is demonstrated to be linked to falls in the elderly. (Imms et al., 1979)
Dynamic Stability: Floquet

- If no perturbation,
  \[ x_{i+1} = f(x_i) \]
- If small perturbation,
  \[ \Delta x_{i+1} = \nabla f(x_i) \cdot \Delta x_i \]
- After Taylor series expansion
  \[ \Delta X_{j+1} = J \cdot \Delta X_j \]
- Eigenvalues of J
  Floquet Multiplier

Data Analysis
Dynamic Stability: Lyapunov

Stability Analysis: Overview

- Original time series data (AP acceleration, 40 gait cycles)
- Auto mutual information method
- Nearest false neighbours method
- Time delay (10 frames)
- Time-delayed coordinate method
- Reconstructed state space
- Rosenstein's algorithm (Rosenstein, 1993)

Average divergence between nearby trajectories

maxLE (0-1 gait step)

Maximum Lyapunov exponent (maxLE) by group. FO = fall-prone old; HO = healthy old; HY = healthy young (Lockhart and Liu, 2008)

Dynamic Stability: Rosenstein’s Algorithm for maxLE
Approximate Entropy: Complexity

Approximate Entropy: It is the logarithmic likelihood that the patterns of the data are close to each other and will not remain close for the next comparison within a longer pattern.

- High ApEn values indicate unpredictability and random variation
- Low ApEn indicates high predictability and regularity of time series data

If \( S_N \) is a time series of length \( N \)

\[
\text{ApEn}(N, m, d) = (N - m + 1)^{-1} \sum_{n=1}^{N-m} \text{ln} C^n_{m+1}(d) - (N - m + 1)^{-1} \sum_{n=1}^{N-m} \text{ln} C^n_m(d)
\]

Where \( m \) is the pattern length (usually chosen as 2) and \( d \) is similarity coefficient (chosen as 0.2 \% of SD of time series)

Results & Discussions

<table>
<thead>
<tr>
<th>Fall Risk</th>
<th>F</th>
<th>NF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Instrument</td>
<td>FP IMU</td>
<td>FP IMU</td>
</tr>
<tr>
<td>DFA Alpha</td>
<td>Mean 1.04 1.00 1.04 0.99</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Std Dev 0.22 0.21 0.19 0.18</td>
<td></td>
</tr>
<tr>
<td>ApEn</td>
<td>Mean 0.57 1.34 0.59 1.36</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Std Dev 0.20 0.11 0.19 0.10</td>
<td></td>
</tr>
<tr>
<td>SaEn_pos (m2,r0.2)</td>
<td>Mean 0.20 1.63 0.20 1.70</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Std Dev 0.17 0.31 0.15 0.28</td>
<td></td>
</tr>
<tr>
<td>SaEn_vel (m3, r0.25)</td>
<td>Mean 1.05 2.06 1.08 2.08</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Std Dev 0.33 0.16 0.33 0.06</td>
<td></td>
</tr>
</tbody>
</table>

Heart rate signals of old and young participant. Adapted from Lipsitz and Goldberger, 1992
Fall Risk Assessment: NSF

- Perturbation studies to identify fall prone individuals may not be practical.
- History of falling is also a good indicator of fall proneness, however, after incurring an injury.
- Fall risk assessment tools have been used to provide an early detection of fall related risks to prevent falling episodes.

- Several assessment tools for fall risk evaluation can be divided into three categories:
  - Comprehensive medical assessment
  - Institutional assessment – MORSE fall scale, STRATIFY, etc.
  - Functional assessment – Berg balance test, timed get-up and go, etc.

Fall Risk Assessment Tools

- Functional Risk Assessment Tools
  - Berg’s balance test: (Berg, 1989)
    - Subjects performing 14 basic daily activities
    - Subjective grading (0 to 4) for each activity
    - A cut off total score to differentiate fallers and non-fallers (45/56 (Berg 1989)
    - 40/56 (Riddle & Stratford, 1999)
  - Timed Get-up & Go test: (Mathias, et al., 1986)
    - Transitions between sitting and standing + Transferring
    - Overall movement time as the indicator of fall risk
    - < 10 sec, normal, and > 20 sec, fall prone (Mathias, et al., 1986; Podsiadlo & Richardson, 1991)
  - Modified gait abnormality rating scale: (VanSwearingen, et al., 1996)
  - Dynamic gait index: (Whitney, et al., 2000)

- No general agreement regarding the validity and reliability of these tests (Laessoe, et al., 2007; Perell, et al., 2001)
Problems and Needs

Current Fall Risk Assessments Problems:

- Cumbersome
- Invasive
- Expensive
- Low prediction rates with 50% sensitivity and 43% specificity

Portability and Usability of Fall Risk Assessment Technology:

- Motion capture systems are confined to laboratory
- Expensive and cumbersome – e.g., 5 seconds of kinematic data – 2 hrs.

Specific Aims

Study Objective:
To characterize fall risk of older adults using the Portable Wireless System by monitoring functional and mobility characteristics

Central Tenet:
Fall risk will be significantly higher for fall-prone elderly than their counterparts

Relevance:
Accurate fall risk assessment will allow us to help pinpoint and intervene early prior to falling episodes.

Portability and usability of fall risk assessment Technology
Instrument Reliability

**Fall Event Detection**
- 2-dimension motion feature (angular rate & body orientation)
- Fast threshold technique
- Prior to the impact detection

**IMMU**
- Portable Sensors
  - Accelerometer
  - Gyroscope
  - Temperature sensor
  - Pulsoximeter
  - Magnetometer

- Networking
  - Bluetooth
  - Zigbee
  - WiFi
  - Cellular

**Fall Risk Prediction**
- Local dynamic stability (max Lyapunov exponent)
- Floquet dynamic stability
- Gait stability Symmetry Index (GSI)

**Gait Analysis**
- Spatial (Step length)
- Temporal (stance time, swing time)
- Walking velocity
- Gait symmetry

**ADL Classification**
- Sit-to-stand/ stand-to-sit
- Lying down
- Stooping
- Walking/ Stairs climbing

**Instrument Reliability**

![Graphs showing instrument reliability](image)

- **Left Foot**
  - Vertical Force [N]
  - Heel Marker vertical direction [mm]
  - Toe Marker vertical direction [mm]
  - Angular Velocity [Deg/sec]
  - Acceleration Anterior-posterior [g]

- **Right Foot**
  - Vertical Force [N]
  - Heel Marker vertical direction [mm]
  - Toe Marker vertical direction [mm]
  - Angular Velocity [Deg/sec]
  - Acceleration Anterior-posterior [g]
## Instrument Reliability

<table>
<thead>
<tr>
<th>Gait Parameters</th>
<th>Infrared Camera System and Force Plate</th>
<th>IMU</th>
<th>ICC</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean (95% CI)</td>
<td>Test for Normality</td>
<td>Mean (95% CI)</td>
</tr>
<tr>
<td>Double Support Time [sec]</td>
<td>0.290 (0.277 - 0.304)</td>
<td>0.116</td>
<td>0.193 (0.170 - 0.215)</td>
</tr>
<tr>
<td>Gait Cycle Time [sec]</td>
<td>1.399 (1.329 - 1.468)</td>
<td>&lt; 0.001</td>
<td>1.104 (1.077 - 1.131)</td>
</tr>
<tr>
<td>L. Stance Time [sec]</td>
<td>0.692 (0.674 - 0.708)</td>
<td>0.642</td>
<td>0.642 (0.619 - 0.665)</td>
</tr>
<tr>
<td>L. Swing Time [sec]</td>
<td>0.456 (0.438 - 0.476)</td>
<td>&lt; 0.001</td>
<td>0.454 (0.440 - 0.469)</td>
</tr>
<tr>
<td>R. Stance Time [sec]</td>
<td>0.723 (0.694 - 0.753)</td>
<td>&lt; 0.001</td>
<td>0.641 (0.619 - 0.665)</td>
</tr>
<tr>
<td>R. Swing Time [sec]</td>
<td>0.399 (0.391 - 0.408)</td>
<td>0.655</td>
<td>0.456 (0.445 - 0.468)</td>
</tr>
<tr>
<td>RCOF [μs]</td>
<td>0.285 (0.183 - 0.386)</td>
<td>&lt; 0.001</td>
<td>0.285 (0.279 - 0.292)</td>
</tr>
<tr>
<td>Step Length [m]</td>
<td>0.761 (0.746 - 0.773)</td>
<td>0.003</td>
<td>0.516 (0.501 - 0.531)</td>
</tr>
</tbody>
</table>

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<th>Gait Parameters</th>
<th>Test for Normality</th>
<th>ICC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cadence [steps/min]</td>
<td>Mean (95% CI)</td>
<td>SD</td>
</tr>
<tr>
<td>Double Support Time [sec]</td>
<td>0.191 (0.156 - 0.225)</td>
<td>0.115</td>
</tr>
<tr>
<td>Foot Swing Angle [degrees]</td>
<td>31.929 (31.001 - 32.857)</td>
<td>3.052</td>
</tr>
<tr>
<td>Gait Cycle Time [sec]</td>
<td>1.136 (1.098 - 1.184)</td>
<td>0.178</td>
</tr>
<tr>
<td>L. Stance Time [sec]</td>
<td>0.664 (0.620 - 0.706)</td>
<td>0.155</td>
</tr>
<tr>
<td>L. Swing Time [sec]</td>
<td>0.472 (0.457 - 0.487)</td>
<td>0.048</td>
</tr>
<tr>
<td>R. Stance Time [sec]</td>
<td>0.663 (0.620 - 0.706)</td>
<td>0.155</td>
</tr>
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<td>0.473 (0.457 - 0.486)</td>
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<td>&lt; 0.001</td>
</tr>
<tr>
<td>Step Length [m]</td>
<td>0.761 (0.746 - 0.773)</td>
<td>0.003</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Walking Velocity [m/sec]</th>
<th>Mean (95% CI)</th>
<th>SD</th>
<th>SEM</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.917 (0.806 - 0.980)</td>
<td>0.102</td>
<td>0.015</td>
<td>0.956 (0.851 - 1.061)</td>
</tr>
</tbody>
</table>
Portable, Non-Invasive Fall Risk Assessment in End Stage Renal Disease Patients on Hemodialysis

**iPhone Demo**

Projections of Sway using tri-axial accelerometer

- Tri-axial accelerometer (LIS302DL) in iPhone can used to measure inclination with direction of gravity

\[
A = \sqrt{a_x^2 + a_y^2 + a_z^2}
\]

\[
d_x = D \times \cos \quad d_y = D \times \cos
\]

\[
d = \frac{d_z}{\cos}
\]

D = dz / cos

\[
A_x = \cos^{-1} \frac{a_x}{A} \quad A_y = \cos^{-1} \frac{a_y}{A} \quad A_z = \cos^{-1} \frac{a_z}{A}
\]
Adaptive Control: brain process which allows sensory-motor systems to maintain or recover performance given changes in relationship between the sensory input and the motor output.
“Kinetic Learning” – Repeated Perturbation

Protocol for MPT group

<table>
<thead>
<tr>
<th>Data collection</th>
<th>Data collection</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline slip</td>
<td>Training</td>
</tr>
<tr>
<td>Slip1 (15-20 min)</td>
<td>T1-T12 (35-40 min)</td>
</tr>
<tr>
<td>Data collection</td>
<td>Data collection</td>
</tr>
<tr>
<td>T1-T3 Slip</td>
<td>N1-N3 No slip</td>
</tr>
<tr>
<td>N4-N6 Slip</td>
<td>T4-T6 No slip</td>
</tr>
<tr>
<td>R1 .................. R12 Random variation of slip (T7-T12) and No slip (N7-N12)</td>
<td></td>
</tr>
</tbody>
</table>
Repeated Perturbation Study: Initiation

Mean ± 1S.D of center of mass velocity and transitional acceleration of whole body COM (TA) at heel contact from T1- T12 slip training trials (training group), and from SLIP1 and S2 trials (training and control group).

Repeated Perturbation Study: Recovery

Mean ± 1S.D of peak ankle and knee coactivity from T1- T12 slip training trials (training group), and from SLIP1 and S2 trials (training and control group).
The Bottom Line

Simulator Training

https://www.insidescience.org/video/preventing-slips-trips-and-falls
Results

- 79.3% greater reduction in injuries for DSPs trained with the Integrad™ compared to those receiving traditional training.
- Concurrent 61% greater reduction in accidents for the Integrad™ group.

Current Research
Current Research

Community Simulator Training
Community Simulator Training
The Impairment and Recovery of Dynamic Walking Stability During Virtual Environment Exposure in the Elderly

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Thank You!
Thank You!