Fall Prevention in the Elderly, from Research to Reality

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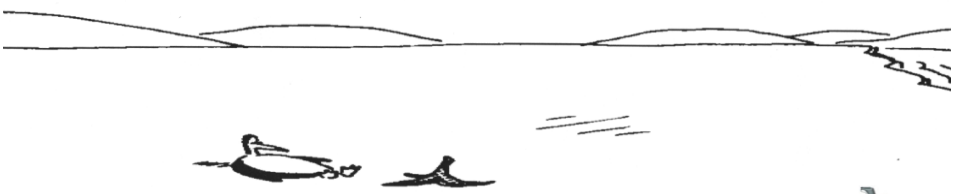


ARIZONA STATE UNIVERSITY

LOCOMOTION LABORATORY

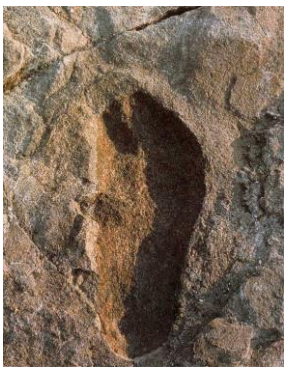
AZNHA 2018 Conference, Aging2.0 Phoenix AZ, 8-24-2018

Research to Outreach

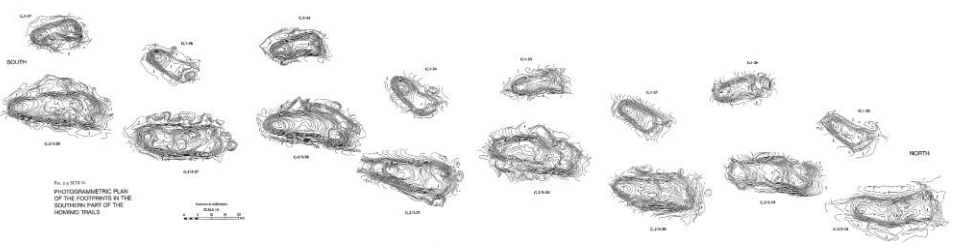
- Introduction
  - » Problems Associated with Fall in the Elderly
  - » Current Approaches to Reducing Fall Accidents
- Research
  - » Mechanisms Related to Fall Accidents in the Elderly
  - » Wearable Fall Risk Assessment Tool: development using nonlinear dynamics
  - » Intervention: Repeated Perturbation Training
- Outreach
  - » Hemodialysis Units
  - » Community-Dwelling Elderly
- Discussions
  - Future Research

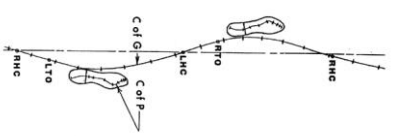
Bipedal Locomotion

- 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

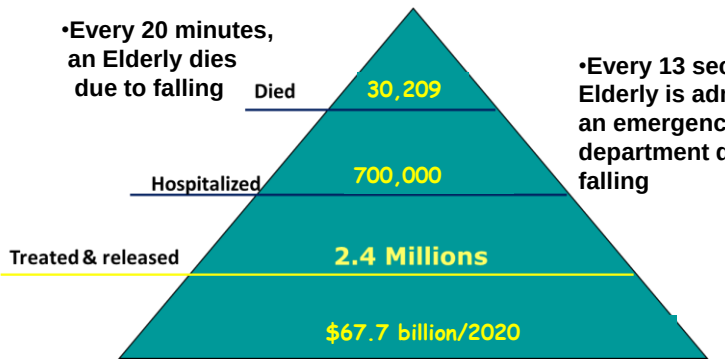




Falls in the USA - Elderly

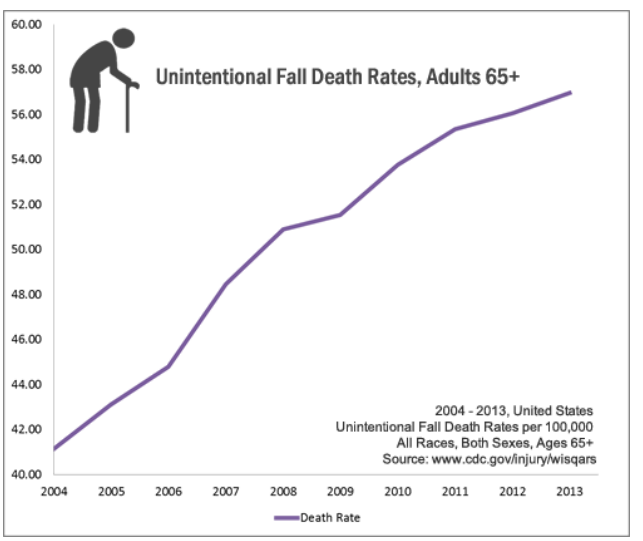
In 2014, older adults in US experienced more than 29 million falls causing more than 7 million injuries and costing over $31 billion in annual Medicare costs

•Every 20 minutes, an Elderly dies due to falling



•Every 13 seconds, an Elderly is admitted to an emergency department due to falling

Fatal and Nonfatal Fall Injuries Among People 65+ in 2015 (CDC)



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

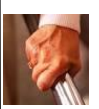
Quality of Life

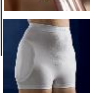
- 20% - 36% fear falling[1]
- 20% die within a year after hip fracture[2]
- 25% in a nursing home one year later[3]

1. Vellas BJ, *Age & Aging*, 1997; Friedman SM, *JAGS*, 2002
2. Lu-Yao GL, *AJPH*, 1994
3. Magaziner, *J Gerontology: Medical Sciences*, 2000

Current Fall Interventions

Fall Protection





Personal Protective Equipment (e.g. hip pads, helmets, fall arresting harness)

Fall Prevention

Environmental control (e.g. COF)

Fall Risk Assessments, Training Interventions (e.g. strength, endurance, balance)

BRAIN

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.
2. Cognitive Impairment.
3. Muscle Weakness.
4. Gait Adaptation.

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

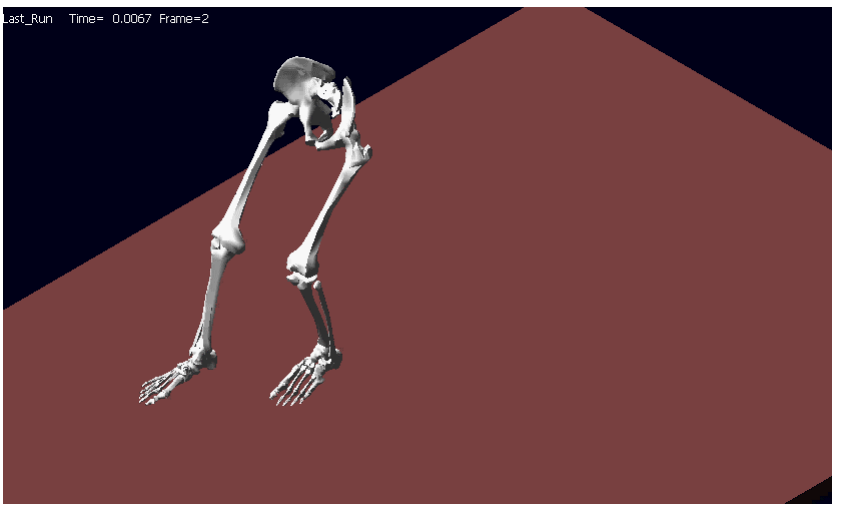
What is the relationship between these risk factors and slip and fall accidents in the elderly? And, how can we use this info to assess fall risk……

Slip and Fall Experiments

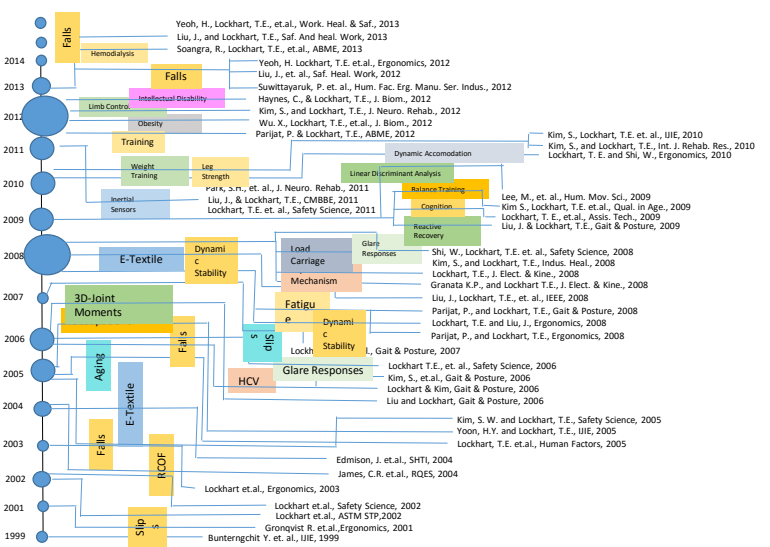
Trip and Fall Experiments

Slip and Fall Experiments

Slip and Fall Experiments

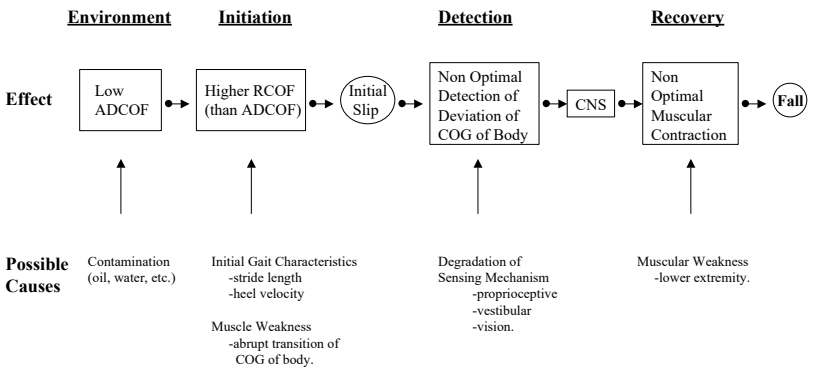


Prior Work on Falls



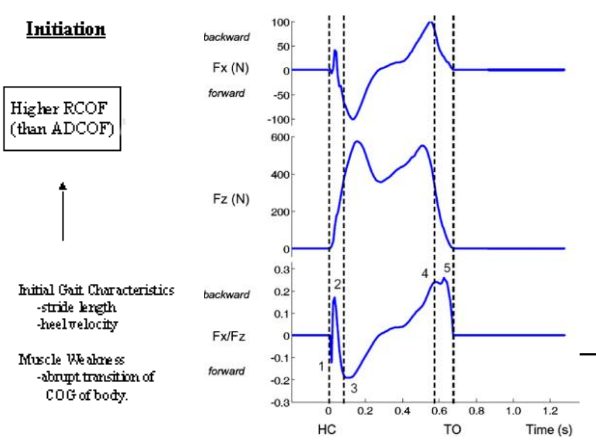
Mechanisms

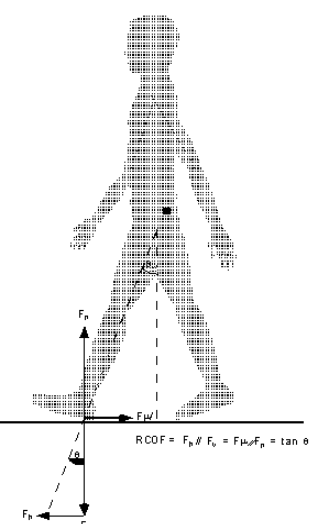
The Process of Initiation, Detection, and Recovery of Inadvertent Slips and Falls



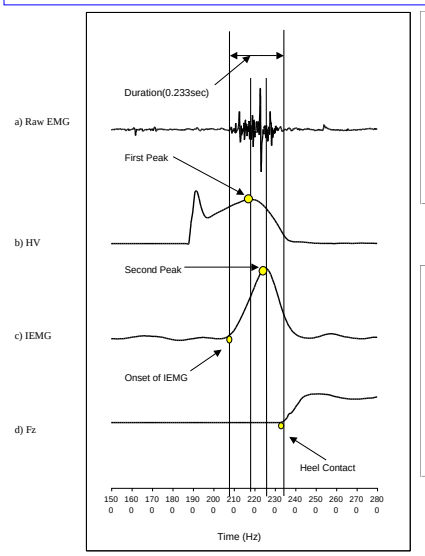
Slip Initiation: Initial Gait

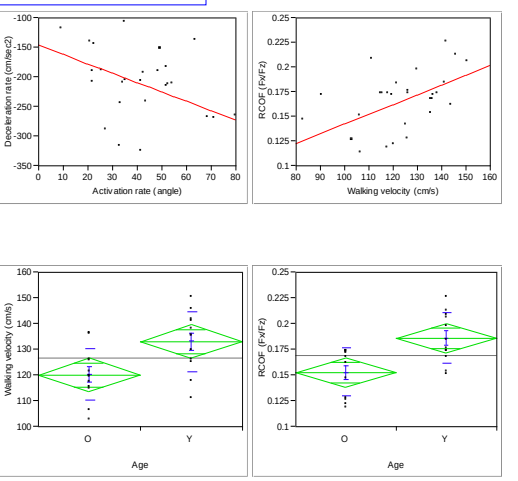
Initial Gait Characteristics:





Slip Initiation: Muscle Activation





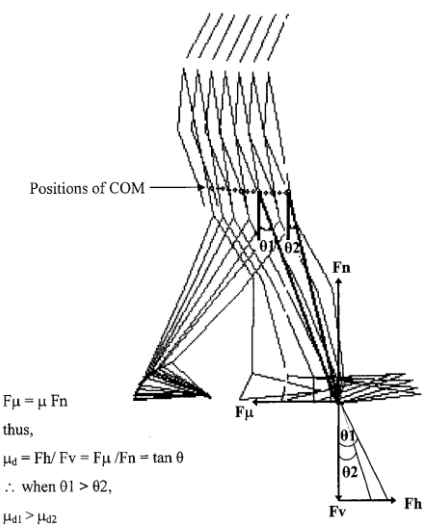
Detection and Recovery

Detection | **Recovery**

Non Optimal Detection of Deviation of COG of Body ↔ CNS ↔ Non Optimal Muscular Contraction ↔

Degradation of Sensing Mechanism
- -proprioceptive
- -vestibular
- -vision.

Muscular Weakness
- -lower extremity.



$F\mu = \mu Fn$

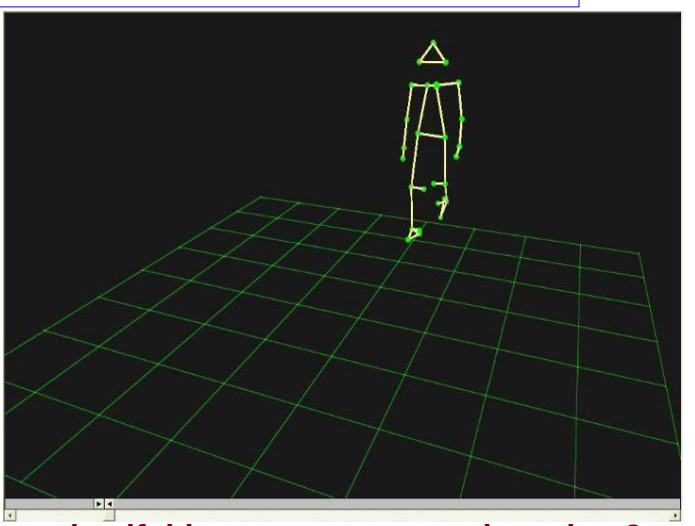
thus,

$\mu_d = Fh/Fv = F\mu/Fn = \tan\theta$

$\therefore$ when $\theta 1 > \theta 2$,

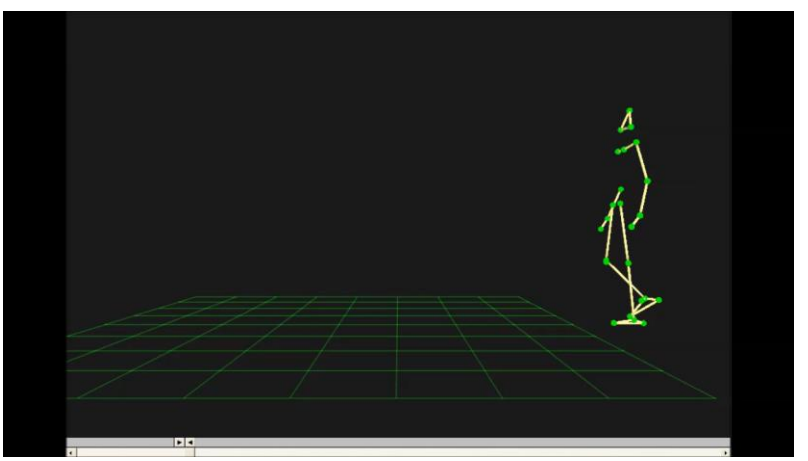
$\mu_{d1} > \mu_{d2}$

Upper Limb Strategy



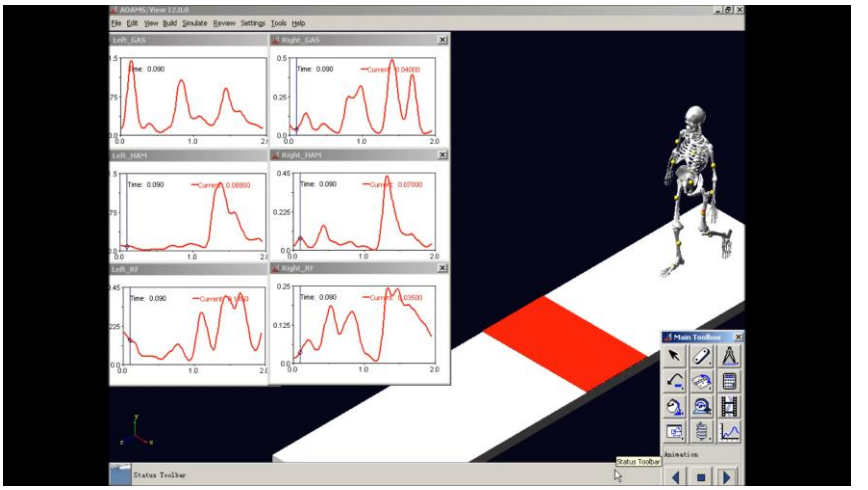
what if this person was carrying a box?

Lower Limb Strategy

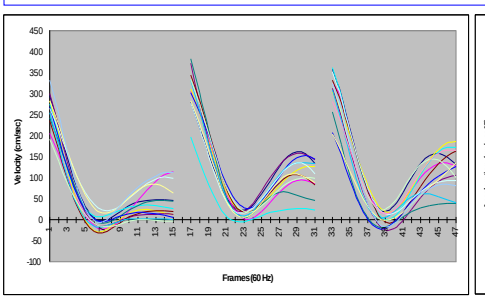


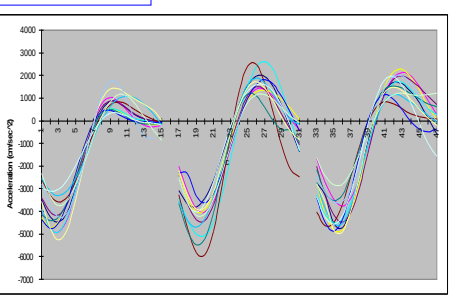
“Good the Bad and the Slippery shoes”

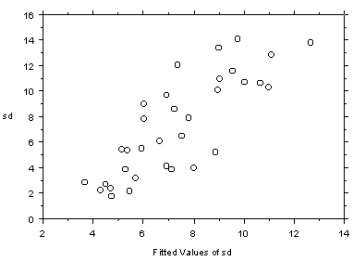
Slip Recovery



Recovery from a slip





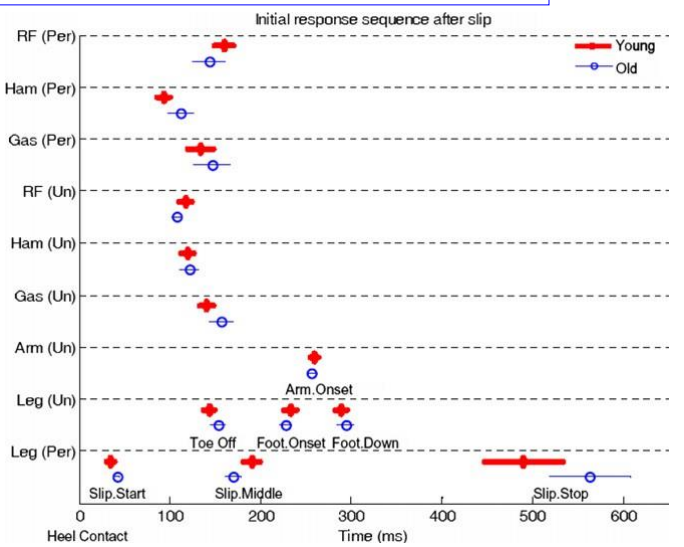


Multiple Regression Equation

SD = -15.785 -.037 (vision) + .204 (MCT) - .308 (LLI) R^2 = .413

Age Group	SDI (cm)	SHV (cm/sec)
Young	3.91	144.45
Old	3.12	107.63

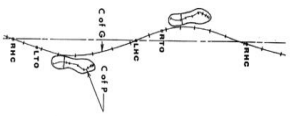
Bottom Line



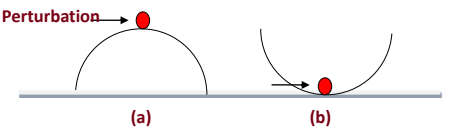
Summary of Gait Study Results

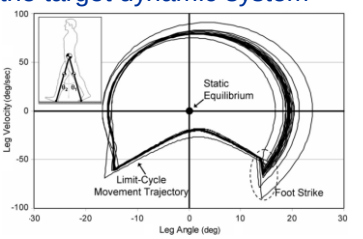
- **Reactive Recovery Phase was the most important for the elderly.**
- Control systems exhibited a **finite time delay** between the moment a **stimulus was provided (i.e., perturbation)** and the moment the system returned a **response (i.e., nothing happens instantaneously)**.
- In many situations : 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.

» Lockhart and Liu (2008) applied Lyapunov to differentiate fallers and non-fallers.

Stability and Variability

Gait variability & fall accidents

Inability to ambulate in a repetitive & stable manner

↓

Gait pathology

↓

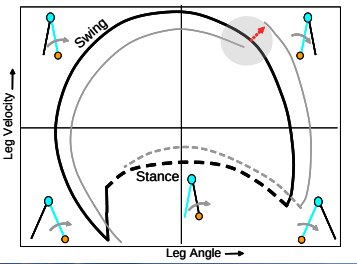
Fall accidents

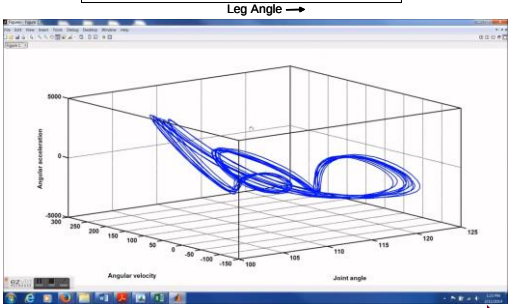
•Individuals with step variability fell more often than non-fallers. (Guimaraes et al., 1980)

•Gait variability is demonstrated to be linked to falls in the elderly. (Imms et al., 1979)

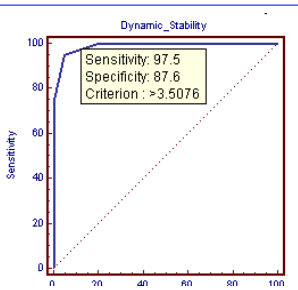
Dynamic Stability: Floquet

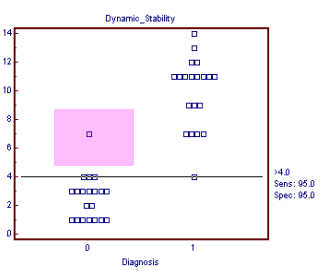
- If no perturbation,
  $x_{i+1} = f(x_i)$
- If small perturbation,
  $\Delta x_{i+1} = \nabla f(x_i) \cdot \Delta x_i$
- After Taylor series expansion
  $\Delta X_{j+1} = \boldsymbol{J} \cdot \Delta X_j$
- Eigenvalues of J
  Floquet Multiplier

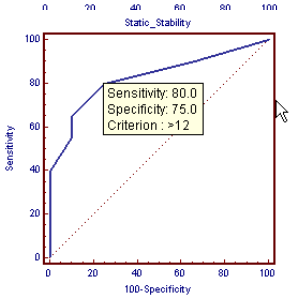


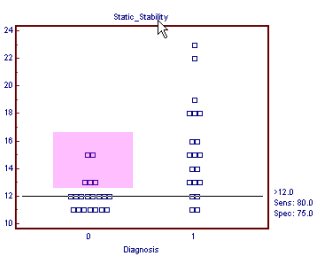


Data Analysis

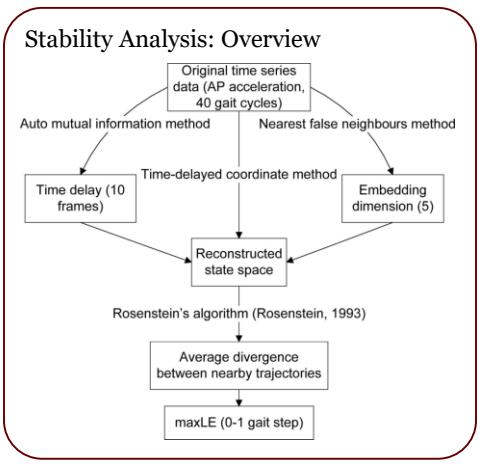


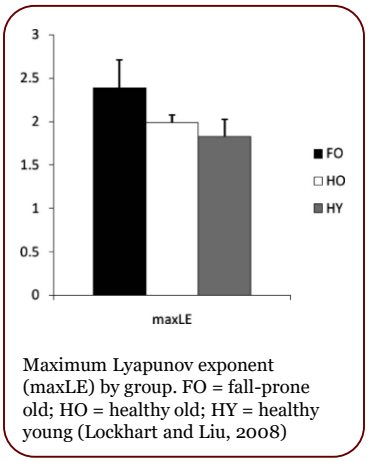






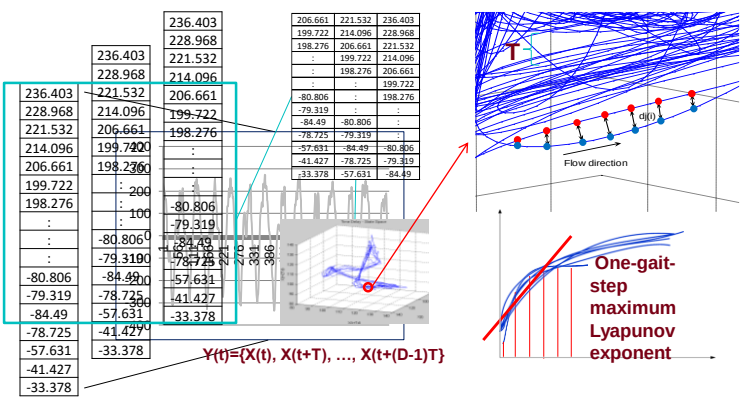
Dynamic Stability: Lyapunov





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

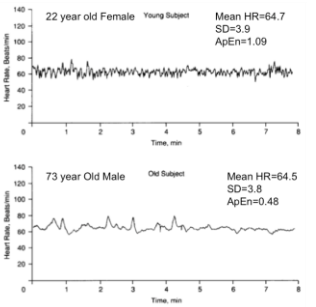


Approximate Entropy: Complexity

ApEn quantifies regularity and complexity of a system (Pincus, 1994)

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**



Heart rate signals of old and young participant. Adapted from Lipsitz and Goldberger, 1992

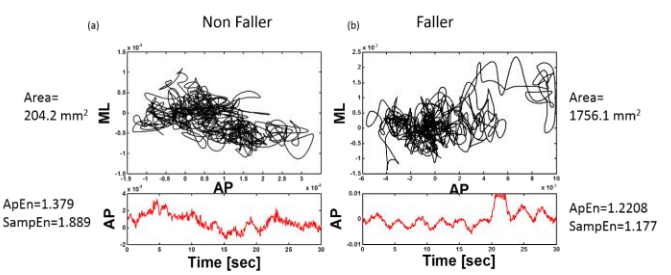
If S_N is a time series of length N

$$ApEn(N,m,d) = (N-m+1)^{-1} \sum_{i=1}^{N-(m-1)} lnC_i^m(d) - (N-m)^{-1} \sum_{i=1}^{N-m} lnC_i^{m+1}(d)$$

17

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



		Fall Risk			
		F		NF	
		Instrument		Instrument	
		FP	IMU	FP	IMU
DFA_Alpha	Mean	1.04	1.00	1.04	0.99
	Std Dev	0.22	0.21	0.19	0.18
ApEn	Mean	0.57	1.34	0.59	1.36
	Std Dev	0.20	0.11	0.19	0.10
SaEn_pos (m2,r0.2)	Mean	0.20	**1.63**	0.20	**1.70**
	Std Dev	0.17	0.31	0.15	0.28
SaEn_vel (m3,r0.25)	Mean	1.05	2.06	1.08	2.08
	Std Dev	0.33	0.16	0.33	0.06

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.

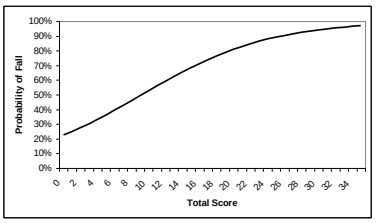
Fall Risk Assessment Tools

- 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)
  - » Postural-Locomotor-Manual Test (Ingvarsson, et al., 1986)
- 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.**

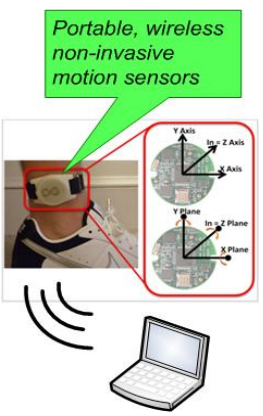
Specific Aims

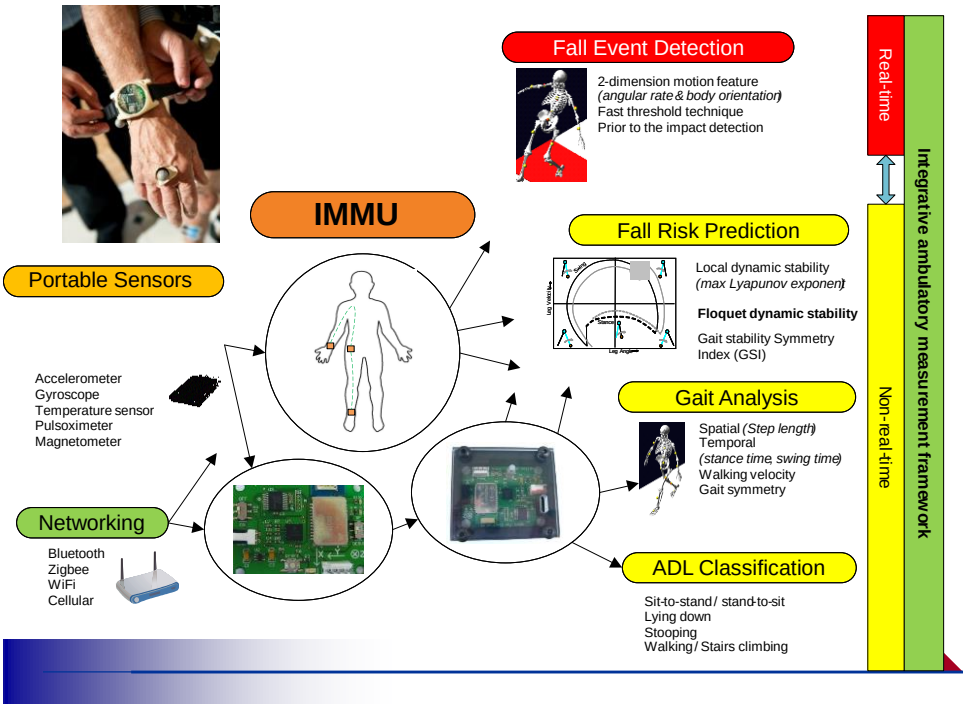
Study Objective:
To characterize fall risk of older adults using the Portable Wireless System by monitoring functional and mobility characteristics

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

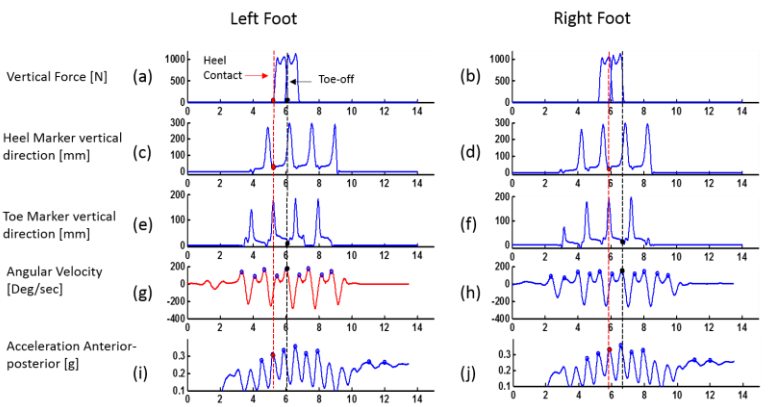
Relevance:
Accurate fall risk assessment will allow us to help pinpoint and intervene early prior to falling episodes.

Portability and usability of fall risk assessment Technology





Instrument Reliability

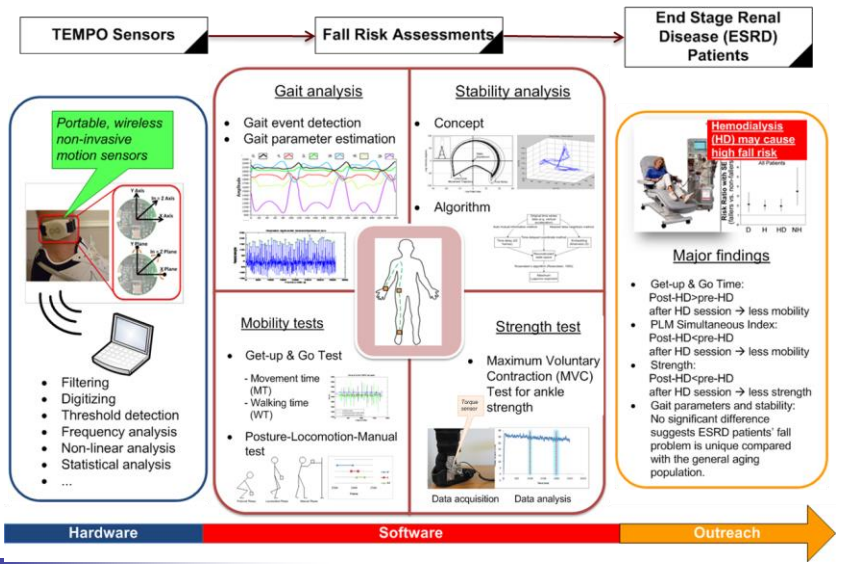


Instrument Reliability

Gait Parameters	Infrared Camera System and Force Plate		IMU		ICC
	Mean (95% CI)	Test for Normality	Mean (95% CI)	Test for Normality	
Double Support Time [sec]	0.290 (0.277 - 0.304)	0.116	0.193 (0.170 - 0.215)	0.665	0.473
Gait Cycle Time [sec]	1.399 (1.329 - 1.468)	< .0001	1.104 (1.077 - 1.131)	0.016	< .001
L. Stance Time [sec]	0.692 (0.674 - 0.709)	0.642	0.642 (0.619 - 0.665)	0.008	0.873
L. Swing Time [sec]	0.456 (0.438 - 0.476)	< .0001	0.454 (0.440 - 0.469)	< .0001	0.249
R. Stance Time [sec]	0.723 (0.694 - 0.753)	< .0001	0.641 (0.619 - 0.663)	0.014	0.551
R. Swing Time [sec]	0.399 (0.391 - 0.408)	0.655	0.456 (0.445 - 0.468)	< .0001	0.232
RCOF [n/a]	0.285 (0.183 - 0.386)	< .0001	0.285 (0.279 - 0.292)	0.479	0.024
Step Length [m]	0.761 (0.746 - 0.777)	0.003	0.516 (0.501 - 0.531)	0.001	< .001

Gait Parameters	Test				Re-Test				ICC
	Mean	(95% CI)	SD	SEM	Mean	(95% CI)	SD	SEM	
Cadence [steps/min]	107.617	(103.158 - 112.075)	14.665	2.211	111.702	(108.024 - 115.379)	12.096	1.824	0.727
Double Support Time [sec]	0.191	(0.156 - 0.225)	0.115	0.017	0.183	(0.149 - 0.217)	0.112	0.017	0.647
Foot Swing Angle [degrees]	31.929	(31.001 - 32.857)	3.052	0.460	32.063	(31.056 - 33.071)	3.313	0.499	0.788
Gait Cycle Time [sec]	1.136	(1.088 - 1.184)	0.158	0.024	1.089	(1.047 - 1.130)	0.137	0.021	0.635
L. Stance Time [sec]	0.664	(0.624 - 0.704)	0.133	0.020	0.633	(0.603 - 0.663)	0.100	0.015	0.728
L. Swing Time [sec]	0.472	(0.457 - 0.487)	0.048	0.007	0.456	(0.427 - 0.484)	0.093	0.014	0.412
Single Stance Time [sec]	0.394	(0.360 - 0.427)	0.111	0.017	0.350	(0.322 - 0.378)	0.091	0.014	0.717
R. Stance Time [sec]	0.663	(0.625 - 0.702)	0.126	0.019	0.633	(0.601 - 0.664)	0.105	0.016	0.646
R. Swing Time [sec]	0.473	(0.461 - 0.486)	0.042	0.006	0.450	(0.427 - 0.474)	0.078	0.012	0.027
RCOF [n/a]	0.287	(0.278 - 0.296)	0.029	0.004	0.284	(0.272 - 0.295)	0.038	0.006	0.612
Step Length [m]	0.521	(0.497 - 0.545)	0.079	0.012	0.522	(0.499 - 0.546)	0.078	0.012	0.927
Stride Length [m]	1.042	(0.994 - 1.089)	0.157	0.024	1.045	(0.998 - 1.092)	0.155	0.023	0.927
Walking Velocity [m/sec]	0.917	(0.886 - 0.948)	0.102	0.015	0.956	(0.911 - 1.001)	0.148	0.022	0.606

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

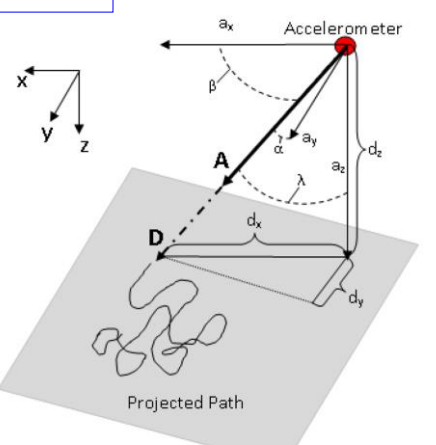
$$A = \sqrt{a_x^2 + a_y^2 + a_z^2}$$

$$a = \cos^{-1}\frac{a_x}{A} \quad b = \cos^{-1}\frac{a_y}{A} \quad g = \cos^{-1}\frac{a_z}{A}$$

dz=Height of iPhone

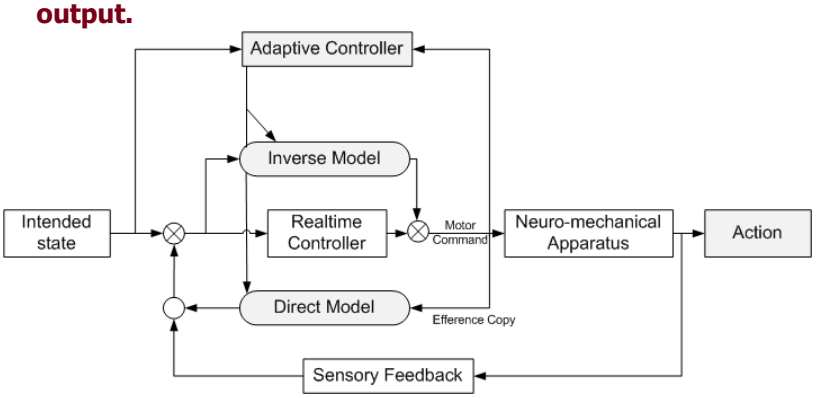
$$D = d_z / \cos g$$

$$d_x = D * \cos a \quad d_y = D * \cos b$$



After the perturbation ?

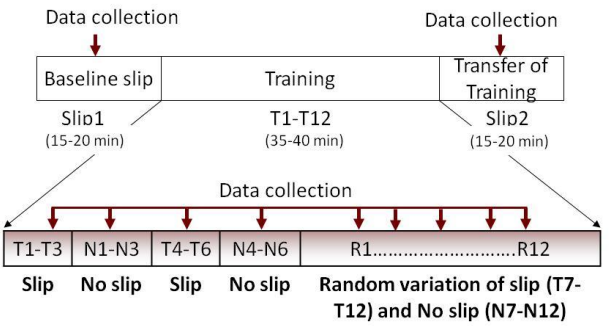
Adaptive Control: brain process which allows sensory-motor systems to maintain or recover performance given changes in relationship between the sensory input and the motor output.



NOVA Science Now

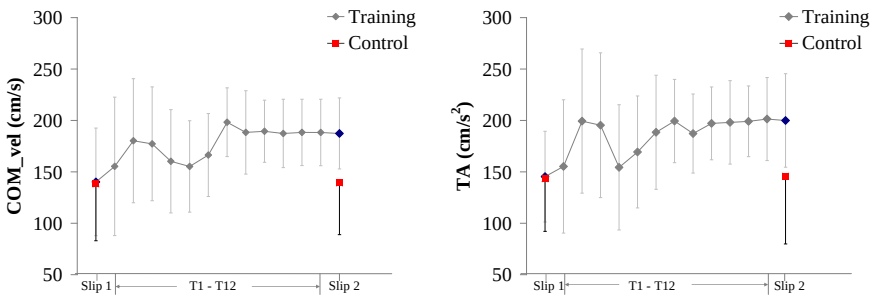
"Kinetic Learning" –Repeated Perturbation

Protocol for MPT group



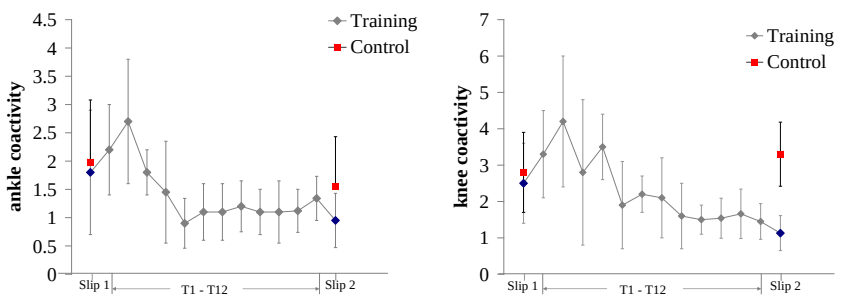
"Kinetic Learning" –Repeated Perturbation

Repeated Perturbation Study: Initiation



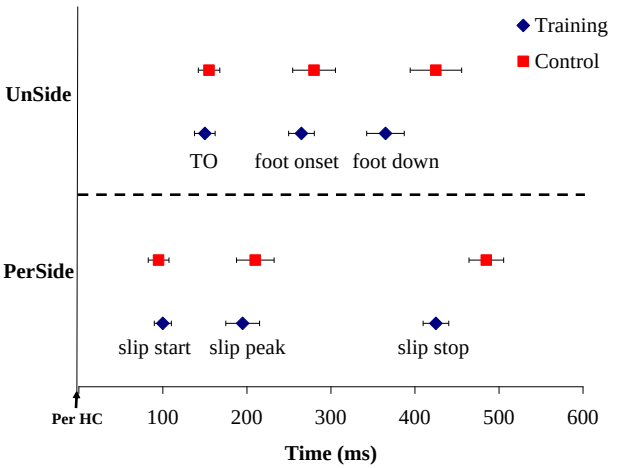
Mean ± 1S.D of center of mass velocity and transitional acceleration of whole body COM (TA) at heel contact from T1- T12 slip training trials (training group), and from SLIP1 and S2 trials (training and control group).

Repeated Perturbation Study: Recovery

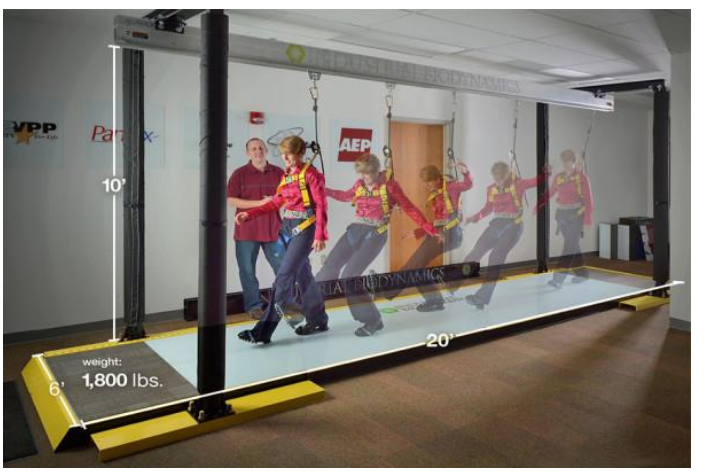


Mean ± 1S.D of peak ankle and knee coactivity from T1- T12 slip training trials (training group), and from SLIP1 and S2 trials (training and control group).

The Bottom Line



Simulator Training



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

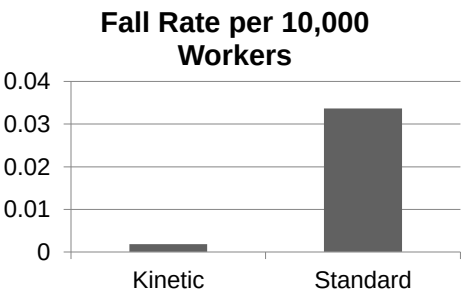
UPS Integrad

Training

[redacted]

Results

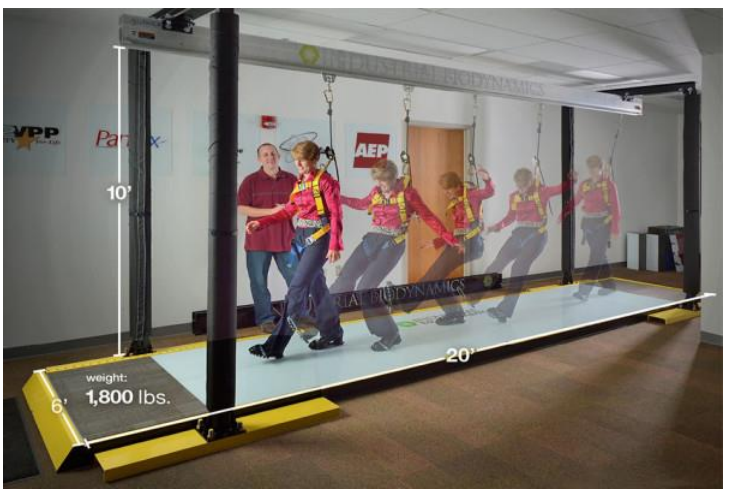
- 79.3% greater reduction in injuries for DSPs trained with the Integrad™ compared to those receiving traditional training.
- Concurrent 61% greater reduction in accidents for the Integrad™ group.



Current Research

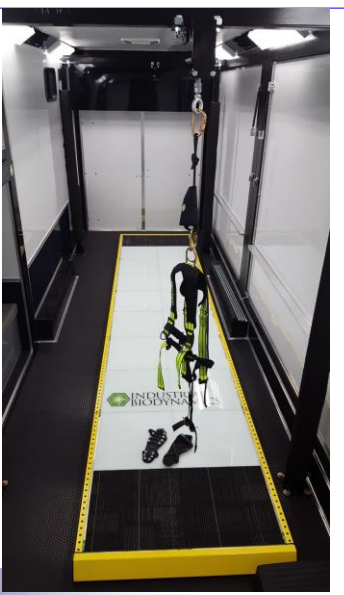
Current Research

Community Simulator Training

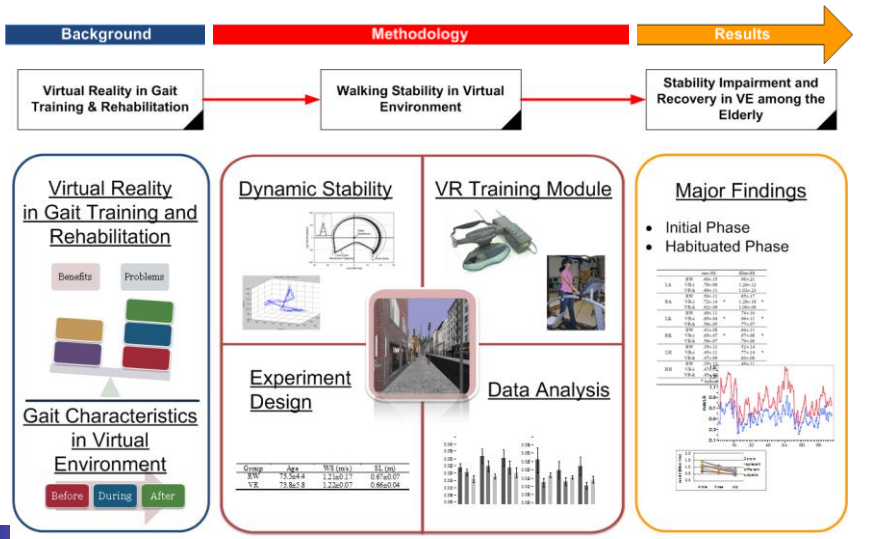


Community Simulator Training

Community Simulator Training



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



Thank You!

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Thank You!