

# 人體動作平衡控制 與 梯子設計之人因考量

楊秉祥

國立交通大學 機械工程學系

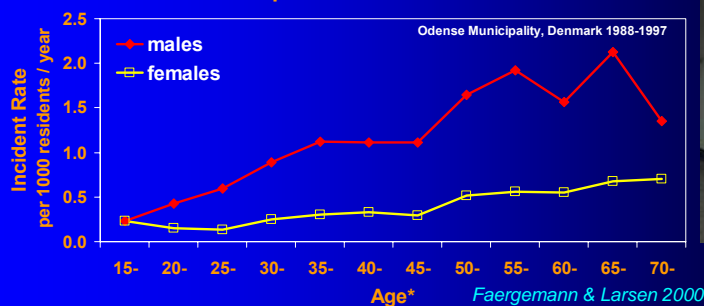


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## Falls from Ladders

- More than 17% of occupational fatal falls are from ladders (U.S. Bureau of Labor Statistics, 2001).
- More falls occur from ladders in non-occupational settings (Tsipouras et al 2001).

Non-occupational ladder/scaffold falls



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## Falls from Ladders

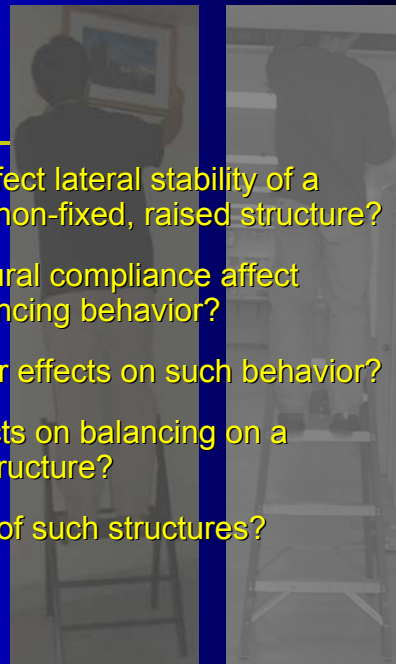
- More than 17% of occupational fatal falls are from ladders (U.S. Bureau of Labor Statistics, 2001).
- More falls occur from ladders in non-occupational settings (Tsipouras et al 2001).
- 20-27% ladder fall injuries need to be hospitalized for 7-8 days (Björnstig and Johnsson 1992; Faergemann and Larsen 2000).
- Ladder falls cause serious injuries in older adults (Björnstig & Johnsson 1992; Faergemann & Larsen 2000,2001).
- **Lateral falls** are the most frequent cause of injuries of stepladder accidents (Björnstig & Johnsson 1992).



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## Research Questions

- What are the factors that affect lateral stability of a human standing on a rigid, non-fixed, raised structure?
- How does the lateral structural compliance affect subjects' stepping and balancing behavior?
- Are there any age or gender effects on such behavior?
- Are there any learning effects on balancing on a laterally-compliant raised structure?
- Can we improve the safety of such structures?



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## Research Outline

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- Feasible lateral weight transfer on rigid structures
- Effects of unexpected structural compliance on stepping and balancing behavior
- Adaptive changes of stepping movements
- Effects of stepping strategy on system stability

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## Significance of Study

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- Insights needed to reduce fall-related injuries caused by falls from stepladders/chairs, especially in older adults.
- Developing the first study of the interaction of age and structural compliance on postural stability of stepping and balancing behavior on a raised structure.

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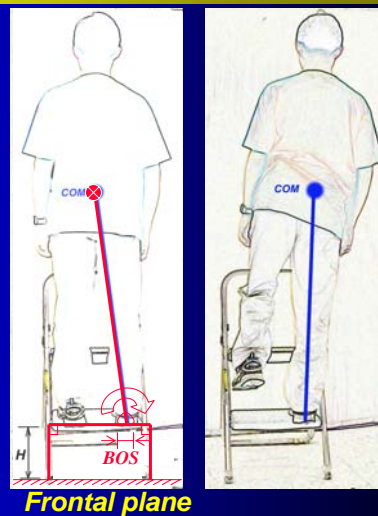
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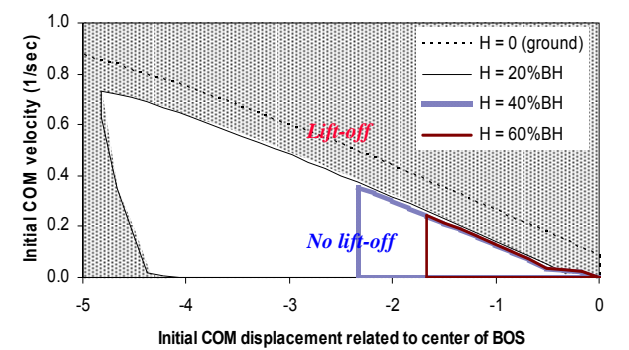
## Methods – Biomechanical model

- Lateral weight transfer movements
- Structure: rigid, planar, inverted “U” structure
- Human body: fixed-length single-segment inverted pendulum
- Rail “Lift-off”



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## Results – Effects of tread height

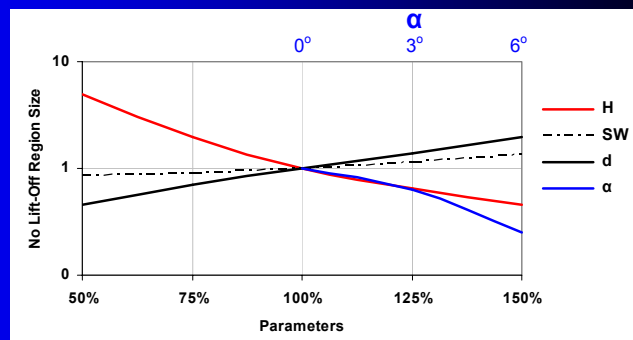
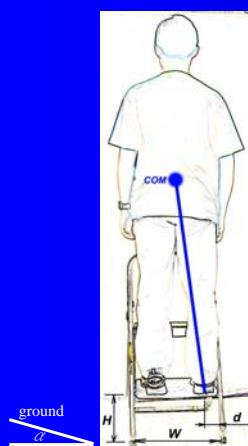


SW=15%BW,  $d=1/4W$ ,  $\alpha = 0$

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## Sensitivity Analysis

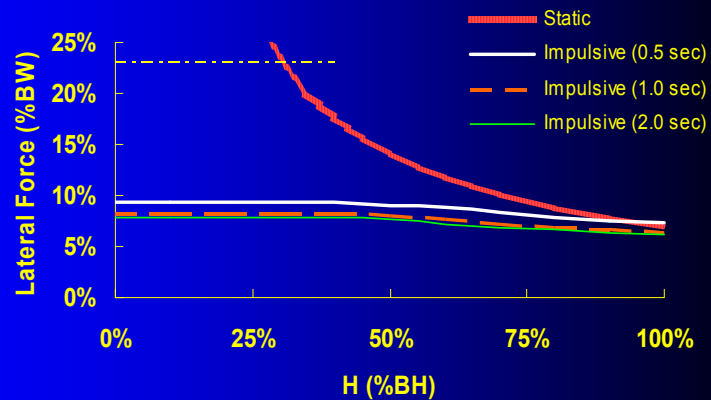


Operating point (100%):  $H=40\%BH$ ,  $SW=15\%BW$ ,  $d=1/4W$ ,  $\alpha = 0$

## Max. Allowable Lateral Force



ipsilateral pulling / contralateral pushing



## Conclusions

- Feasible lateral movements were identified.
- Most sensitive factors are tread height, ground inclination angle, and stance-foot position.
- Safety suggestions:
  - Slow weight shift
  - Avoid extreme lateral foot placement, especially on a parallel-sided structure
  - “A”-shaped stepladders need larger included angles between rails than suggested by ANSI standards



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## Hypotheses

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- Primary null hypothesis
  - *Unexpected* structural compliance of a raised structure does not affect the stepping and balancing behavior.
- Secondary null hypothesis
  - There is no age or gender difference in this behavior.

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## Experiment

- Subjects: 30 Healthy Adults (10 in each group).

	Age (yrs)	BH (cm)	BM (Kg)
Young Females (YF)	25.2 (2.0)	160.1 (5.1)	53.2 (5.5)
Young Males (YM)	26.0 (2.5)	168.5 (1.7)	71.4 (11.6)
Older Males (OM)	72.2 (2.6)	168.7 (4.3)	69.1 (8.1)

Note: no significant BH ( $p=0.92$ ) and BM ( $p=0.74$ ) differences between YM and OM

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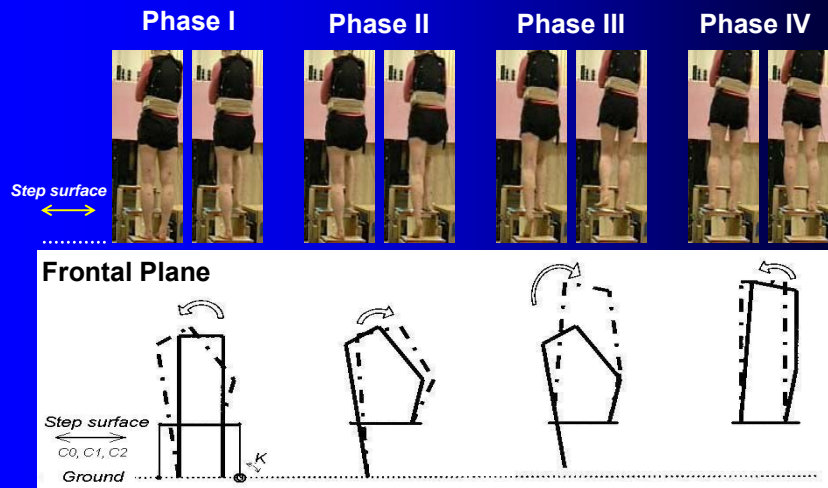
## Experiment

- Subjects: 30 Healthy Adults (10 in each group).
- Task: Forward stepping up onto a 7"-high step
  - 3 covertly assigned structural compliance x 6 trials
  - Compliance:  $C_0 < 0.01$  mm/N,  $C_1 = 0.1$  mm/N,  $C_2 = 0.2$  mm/N
- Measurements (at 100Hz)
  - Body kinematics – 10 IRED (Optotrak 3020)
  - Ground reaction forces (AMTI Force Plates)
  - Normal forces (F-scan pressure sensors)



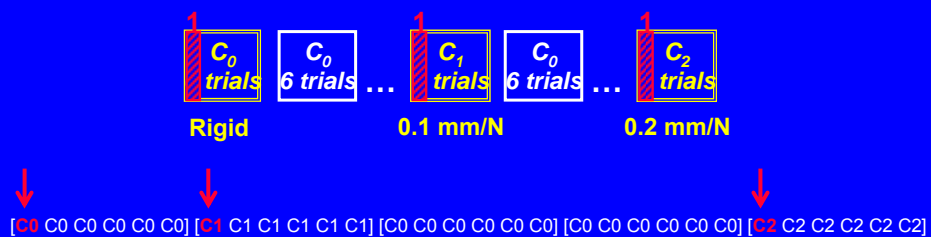


## Phases of Stepping Movements



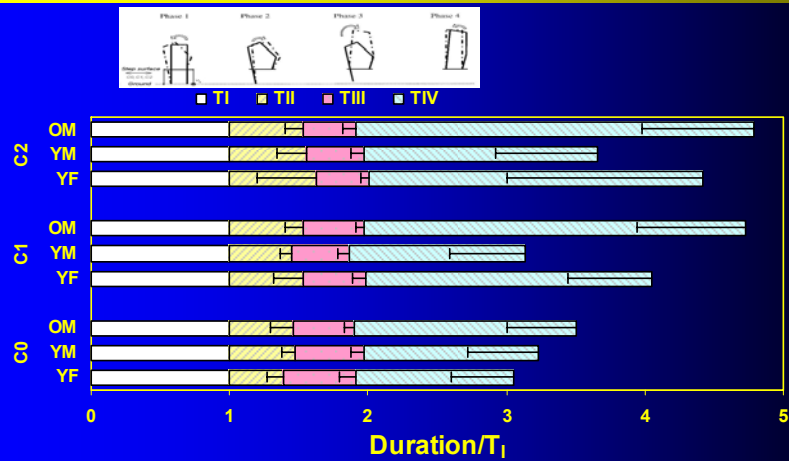
## Results

**First trial** (N=30) on each value of structural compliance

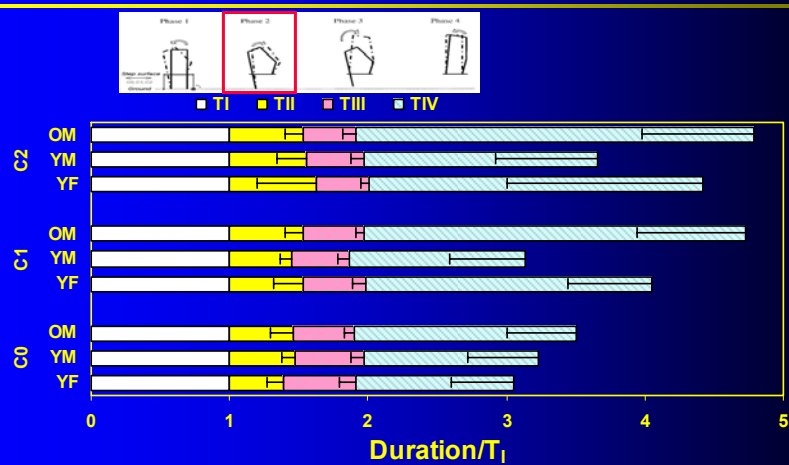


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## Effect of Compliance on Duration

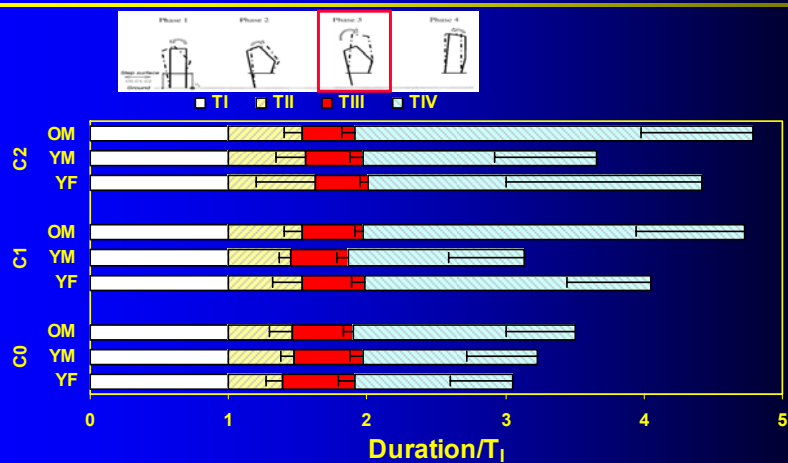
C:  $p=0.002$ ; Age:  $p<0.001$ ; Gender:  $p=0.004$ 2  
0

## Duration in Phase 2

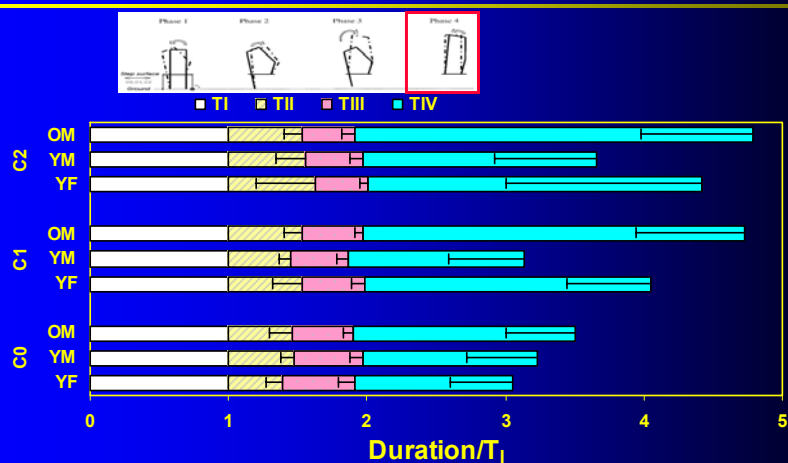
Ph2: C:  $p=0.2$ ; Age:  $p=0.63$ ; Gender:  $p=0.68$

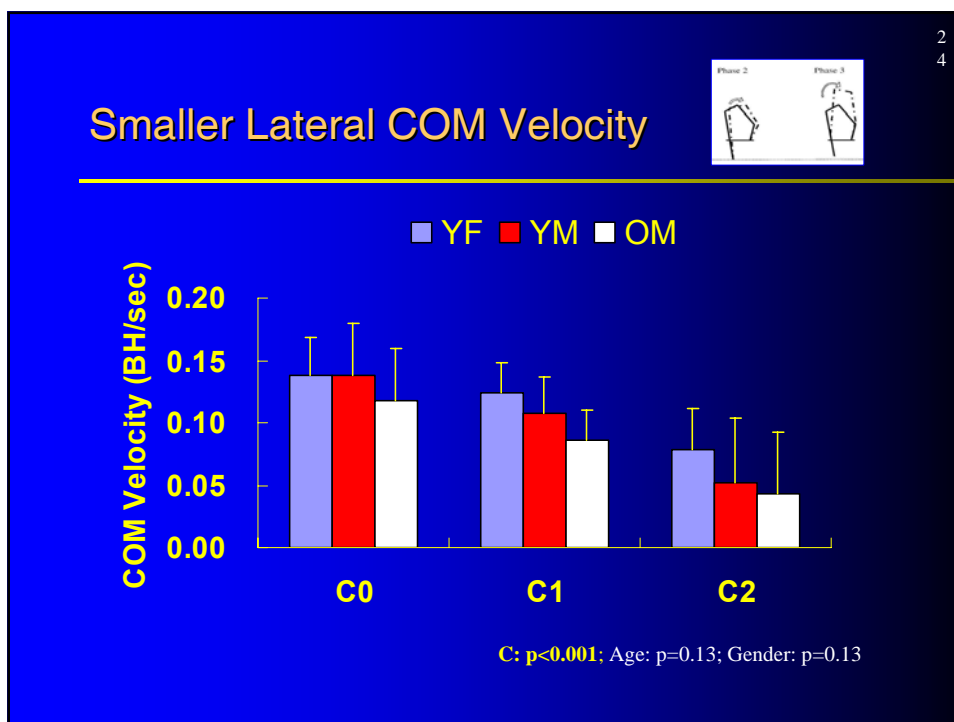
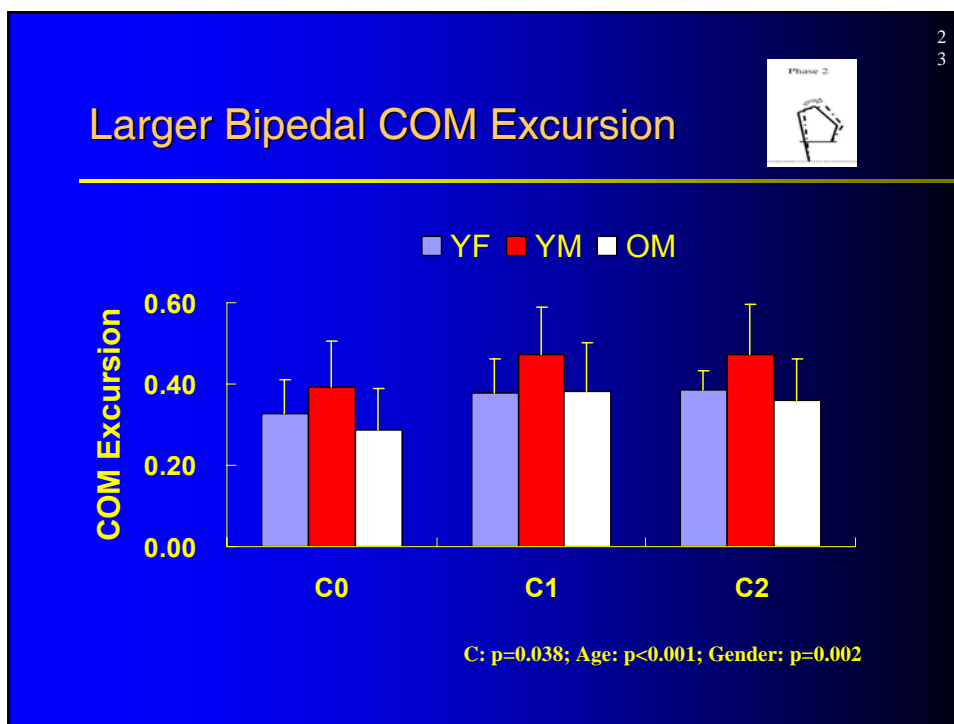
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## Shorter Unipedal Support Phase

Ph3: C:  $p=0.029$ ; Age:  $p=0.26$ ; Gender:  $p=0.75$ 2  
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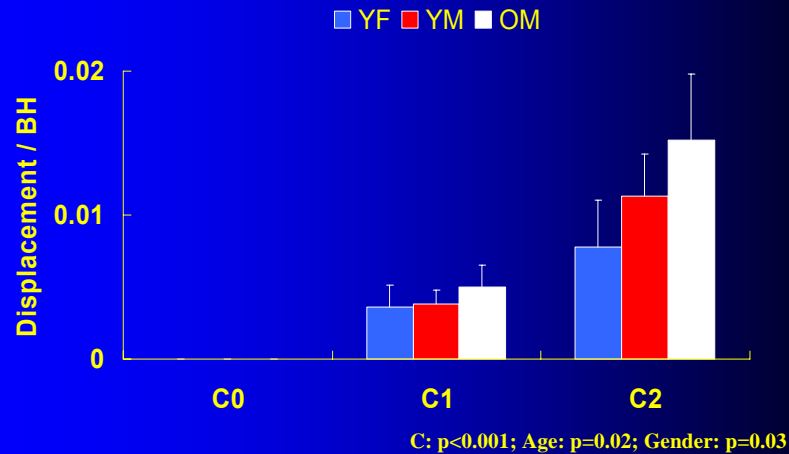
## Longer Lateral Balance Recovery

Ph4: C:  $p<0.001$ ; Age:  $p<0.001$ ; Gender:  $p=0.02$



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## Lateral Structural Displacement

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## Conclusions

- Lateral structural compliance adds 15% time for YM, 33-45% for YF, and 35-37% for OM to complete one step-up movement.
- Healthy adults were able to identify the presence of the structural compliance as they first step onto a raised structure.
- Older males needed longer time than did young adults to step up and balance on a raised structure with “unexpected” lateral compliance.

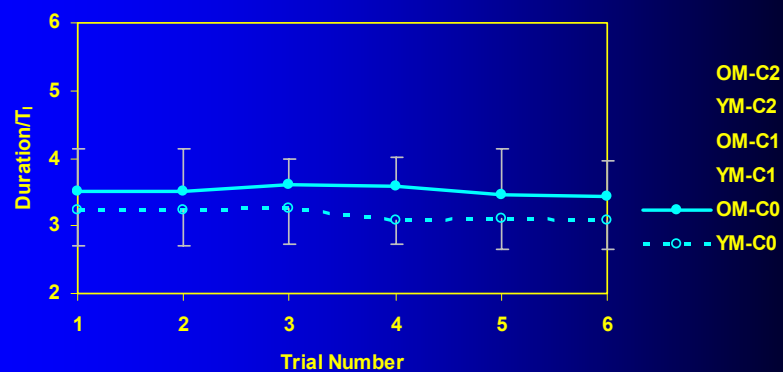
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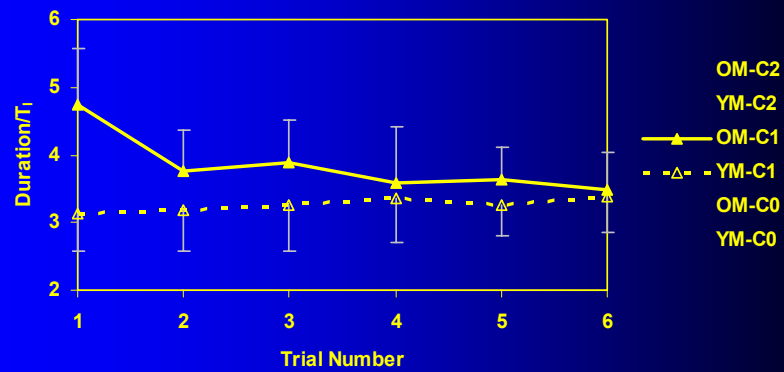
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## Results – Duration vs. Trial on C0

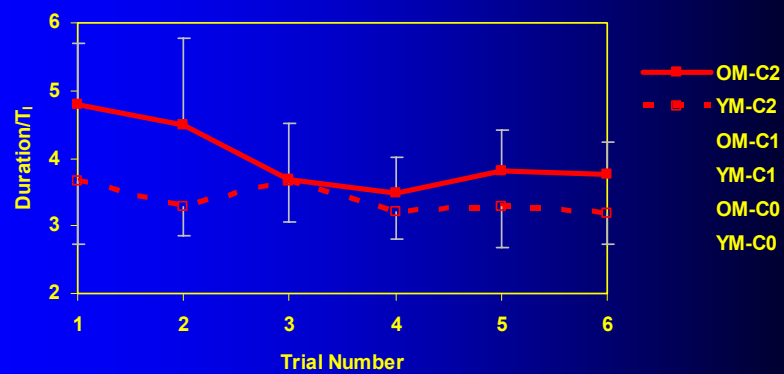


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## Results – Duration vs. Trial on C1

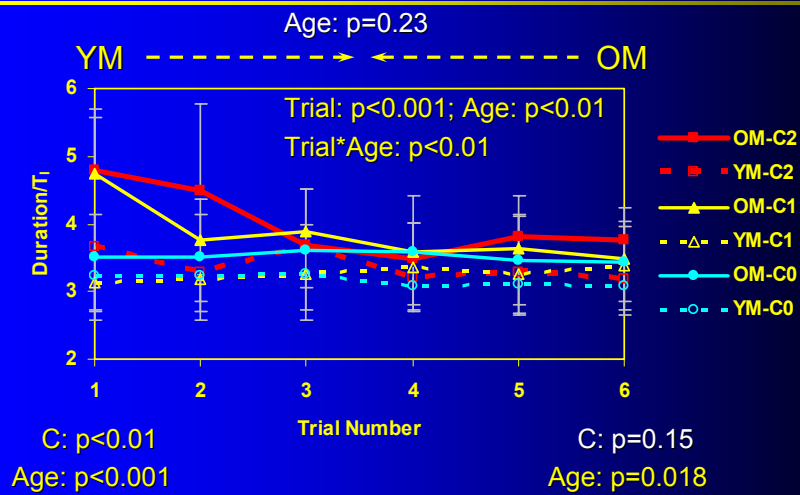
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## Results – Duration vs. Trial on C2

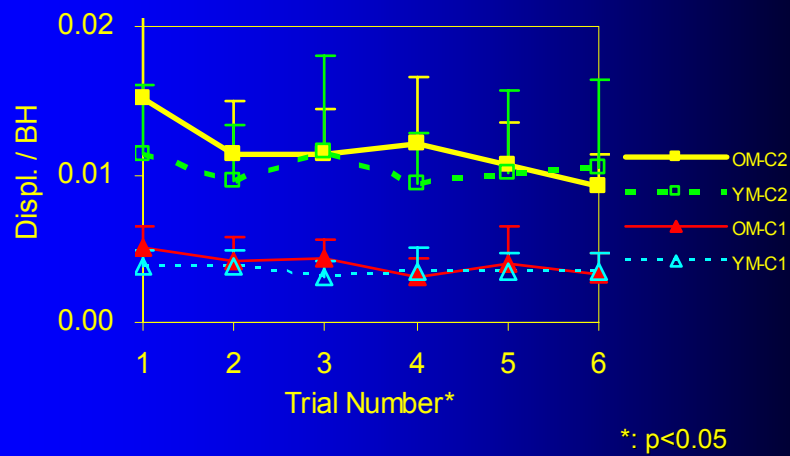


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## Results – Duration vs. Trial

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## Result – Displacement vs. Trial





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## Conclusions

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- After 5 practice trials, structural compliance did not affect the total duration.
- YM could adapt to the structural compliance within the first stepping trial.
- OM might not be able to accurately control stepping movement in the first trial; however, they are able to adapt to structural compliance within 2-3 trials.
- OM are able to compensate for most age differences in stepping movements by practice.

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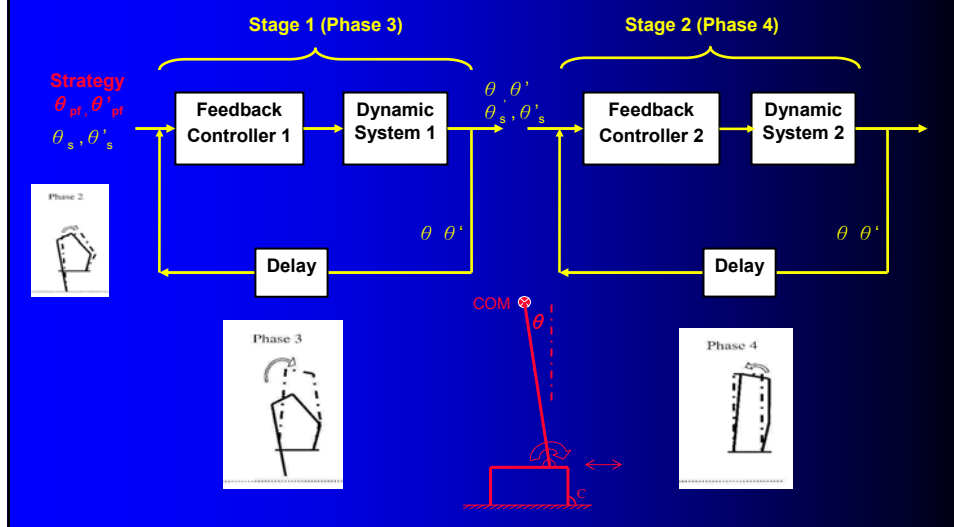
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## Hypotheses

- Primary null hypothesis
  - Stepping strategy does not affect the lateral stability of the human-compliant structure system.
- Secondary null hypothesis
  - System parameters do not affect the system stability.

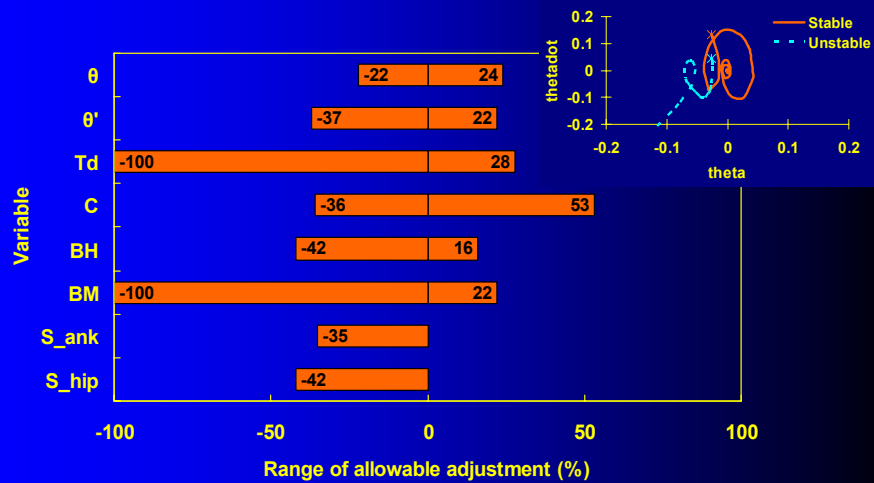
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## Biomechanical Model

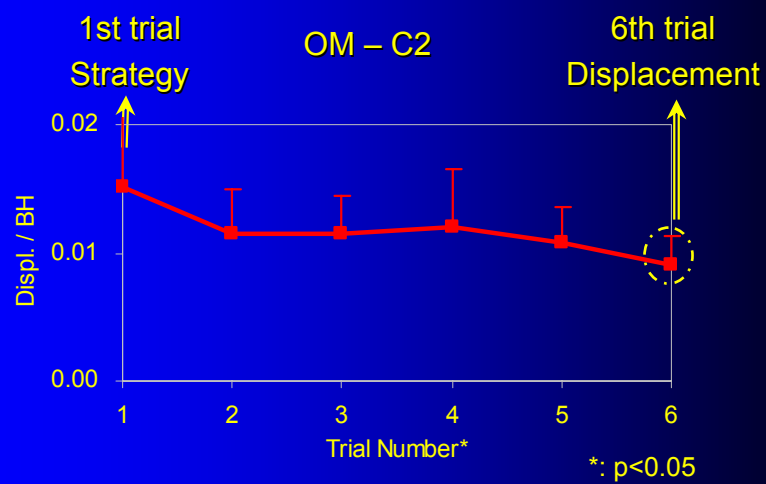


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## Allowable Adjustments of Variables

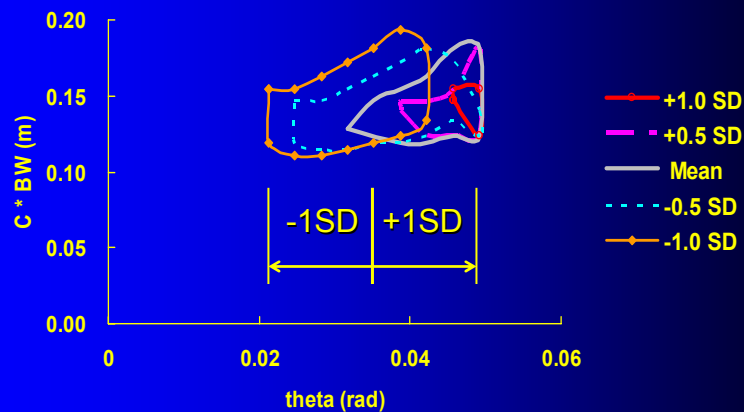
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## Max. Allowable Lateral Compliance



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## Max. Allowable Lateral Compliance

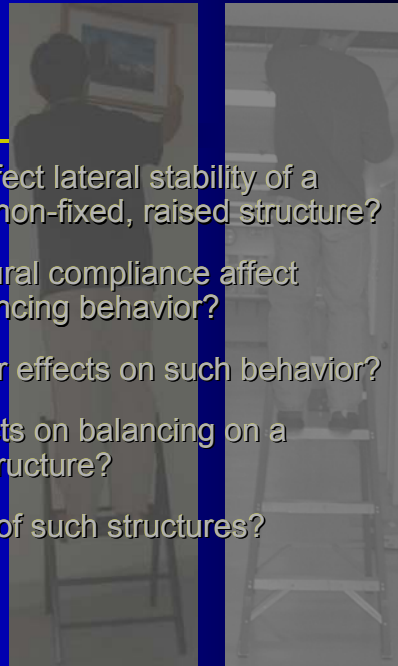
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## Conclusions

- Stepping strategy can affect the system lateral stability.
- Lateral movement of system is most sensitive to the lateral COM velocity and displacement at the trail-foot push-off.
- Allowable maximum compliance based on our experiment should be less than 0.12 m/BW (in N).
- Obesity might reduce the maximum allowable structural compliance.

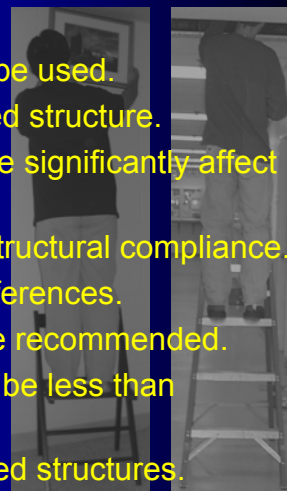
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## Concluding Remarks

- No Lift-off region is predicted.
- >10 degree "A"-shape angle should be used.
- Lateral tool force is limited on a raised structure.
- Lateral structural compliance and age significantly affect stepping and balancing behavior.
- Practice can eliminate the effect of structural compliance.
- Practice can compensate for age differences.
- Slow stepping/lateral movements are recommended.
- Lateral structural compliance should be less than 0.12m/BW.
- Obese people should use stiffer raised structures.

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## *Acknowledgements*

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