Assessment of the Older Patient with Gait and Balance Problems

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University of Iowa
43rd Annual Refresher Course for the Family Physician
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Balance and Gait Disorders

- Nothing to Disclose
Balance and Gait Disorders - OUTLINE

- Introductory remarks about locomotion
- Normal Balance/gait
- Balance Building
- Balance/gait anatomy & physiology
- Changes of balance/gait with age and fall risk
- Common balance/gait disorders in the elderly
- Fall Prevention
INTRODUCTION
Balance and Gait

- Walking is unique- each one of us has our unique finger (foot) prints
- Bipedalism is essentially a human endeavor
Evolution of Bipedalism

- Human evolution:
  - Split from chimpanzees 6 Mya
  - Between about 3-6 Mya: combined humanlike (biped) and apelike (arboreal, etc) locomotion
  - Around 4 Mya: mostly bipedal (Lucy)
  - Since about 2 Mya: became fully bipedal
  - Since 200,000: homo sapiens
    - Same skeleton as now
    - We are all ONE SPECIES (so far)
  - Evolution ongoing!
Benefits of Bipedalism

- Makes it easier to pick fruits and other food from low-lying branches
- Frees hands for carrying food, tools, or babies
- Enables early humans to appear larger and more intimidating
- Helps early humans cover wide, open landscapes quickly and efficiently
- Side effect: back pain
Balance and Gait

- Balance: ability to stand up and remain upright against the force of gravity (equilibrium)
- Gait: generation of rhythmic stepping movements to advance in space (locomotion)
Balance and Gait Disorders, BGD

Epidemiology

- BGD prevalent especially in the elderly, making them among the most common complaints in neurology
- Prevalence of BGD in persons older than 65 years is 14% and jumps up to about 50% in persons over age 85
- Psychogenic BGD is seen in up to 40% of patients with psychogenic movement disorder (Baik & Lang 2007)
Falls

- One third of community dwelling persons > 65 will fall at least once per year
- 15% of these falls associated with serious injury

NORMAL BALANCE/GAIT
Basic walking pattern

- Gait cycle:
  - Stride
  - Swing

Walking is a series of losing balance and regaining it
- We are always one step away from falling
Balance and Gait Exam

- Walk on own or with aid
- Wide Base (ataxia)
- Steady (unsteady: ataxia)
- Walk on toes/heel (motor)
- Romberg (sensory)
- Tandem (testing all)
- Turn > 5 steps (parkinsonism)
BALANCE BUILDING
<table>
<thead>
<tr>
<th>Cortical</th>
<th>Subcortical White Matter</th>
<th>Psychological is “over the top”</th>
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<tbody>
<tr>
<td>Basal Ganglia</td>
<td></td>
<td>10 Parkinsonian, Ataxic, Slow, Spastic</td>
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<tr>
<td>Thalamus</td>
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<td>Cerebellum</td>
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<td>8 Parkinsonian</td>
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<td>Brainstem</td>
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<td>7 ataxic</td>
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<tr>
<td>Peripheral Nerve</td>
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<td>5 ataxic</td>
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<td>4 Spastic</td>
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<tr>
<td>Muscle</td>
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<td>3 Sensory ataxia</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2 waddling</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1 Waddling</td>
</tr>
</tbody>
</table>
Anatomy & Physiology of Balance/Gait

HOW DOES THE BALANCE/GAIT SYSTEM WORK?
Physiology-Spinal Cord
Central Pattern Generator, CPG

Stimulate in animals
Imaging human supraspinal locomotor centers in brainstem and cerebellum

BOLD signal changes superimposed for standing, walking, and running. Color-coding as shown in the right upper corner.

Jahn. Neuroimage 2008
Red Nucleus-Dentatorubrothalamic tract

Figure. MRI of patient showing hyperintense lesion (arrow) in area of left dorsomedial red nucleus (TR 2,222 msec; TE 80 msec).

Felice, 1990

Contrapulsion

Karimi & Fattal, 2004
Cerebellum

1- Coordination Role
compares external with internal signals

3- Modulates activity of descending tracts

<table>
<thead>
<tr>
<th>Stance</th>
<th>Swing</th>
</tr>
</thead>
<tbody>
<tr>
<td>cerebellectomy</td>
<td></td>
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</tbody>
</table>

Motor cortex

GP
VL
Thalamus
SubT
Red
SC
RF
VN
CS,RbS,TS,RS,VS
CPG

2-VOR

DSCT
SOCP
VSCT
SRCP
Floor 8: Basal Ganglia

- Parkinsonism
  - Tremor, Rigidity, Bradykinesia, Postural instability

- Balance/Gait
  - Slow
  - Stooped
  - Reduced step height
  - Reduced step length
  - Reduced arm swing
  - Multiple steps to turn
  - Hesitation /freezing
  - Festination
Location of White Matter Signal

Same amount of white matter signal
- Top bad gait (contiguous & symmetrical)
- Bottom: good gait

Top: bad gait- more signal
CHANGES IN BALANCE/GAIT WITH AGE
Sensory and Motor Changes with Age

- Vision
- Vestibular
- Proprioception
- Muscles
- Joints
- Central Changes

- All degrade over time in the elderly
Changes with Age

- Higher foot variability: reduced stepping accuracy
- Increased mediolateral sway (specially when walking and talking)
- Slower initiation of stepping plan and adjustments
- Compared to young, who fixated on target 3 steps ahead, elderly fixated closer to target (can be improved with training)

Uiga, Ageing Research Rev 2015
Sensory Changes with Age

- Vision declines
  - cataract, glaucoma, macular djd
- Decline in joint position sense
  - Aging
  - disease- DM, ETOH, vitamin, chemotherapy
- Loss of vestibular (hair cells) with aging
  - One third > 70 have vestibular impairment
- Exercise Can help neuropathy and vestibular system!

Fattal. BGD 2015
Sturnieks. Neurophysiologie Clinique 2008
Motor System Changes with Age

- **Bulk**
  - Loss of lean muscle mass after mid 20s!
  - In quad area: 40% loss in elderly (especially fast twitching)

- **Strength**
  - > 40-50s decline
  - 50% loss by age 80

- **Torque production (peak and rate) reduced**
  - 14% of community dwelling women lack calf muscle strength enough to support their weight

Motor System Changes with Age

- Strength important for recovery after perturbed balance
- Fall risk correlates with hip/knee/ankle weakness
- Strength can be maintained at higher level with physical activity

Sensory Integration of Information, Changes with Age

- Reduced ability to integrate information to adjust balance

- Reaction time:
  - Loss of brain mass (10%) and loss of myelin (slow conduction)
  - Increase by 25%
  - Especially slow with dual tasks or stepping

- Do NOT text and walk/stairs at any age

Gait Changes with Age

- Reduced gait speed
- Slightly widened stance
- Stooped posture
- Reduced arm swing
- Reduced stride (shorter steps)
- Increased double-limb stance (increased time with both feet on ground)
- Increase variability of gait parameters (fall risk)
Fall Risk Increases with Age

- **Input:**
  - Inaccurate sensory input (vision, proprioception)

- **Central:**
  - Impaired central sensori-motor integration
  - Slowed reaction time (dual tasks)

- **Output:**
  - Reduced torque generation (weak muscle, stiff joints)
  - Variable steps/inaccurate foot placement
  - Slow response
  - Need > 1 step to adjust

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Boonsinsukh, Horak. Phys Ther 2012
Tropea. IEEE 2015
Age related mechanisms of slip initiated falls

Critical time to slip initiation:
1- Shortly after **heel contact** (where only edge of heel is in contact) Peak 3
2- At **toe off** (only tip of shoe is in contact with ground) Peaks 4,5
Age related mechanisms of slip initiated falls

- Velocity of heel at heel contact was faster!
- Slower transitions between different velocities
- Plantar flexion strength reduced (at toe off)
- Abnl vision/tactile assessment of surface (input), so do not correctly plan and modulate ahead of time and limited ability to modulate fast (at heel contact time to avoid slip is only 100-110 ms; but response latencies in elderly 120-200 ms)
  - Training improves psychophysics
  - Look 10-15 feet ahead!

COMMON BALANCE/GAIT DISORDERS IN ELDERLY
Gait Pattern in Elderly: concept of Cautious Gait

- 50% or more can have abnormal Balance/Gait
- 60% to 70% of those have an abnormal gait related to a known cause
- 10% to 20% have no known cause, termed “cautious” gait

Note: 10-20% of 85-year-olds have no gait impairment (Jahn et al 2010)
Common Causes of BGD in Elderly

- Cautious Gait
- Polyneuropathy (Diabetes, Alcohol)
- Cervical myelopathy (arthritis)
- Ataxia (alcohol, medications, vitamin, familial)
- Inactivity
- Polypharmacy
  - More than four, sure to fall
- Post inner ear infection
- Parkinsonism: Parkinson, vascular, etc
- Frontal lesions (stroke/tumor)
- Hydrocephalus: NPH (Over diagnosed, 2/million)
Causes of Subjective Sense of Imbalance with Normal Exam

- Post “labyrinthitis”/chronic subjective dizziness
- Inactivity/polypharmacy
- Cautious gait
- Early parkinsonism
- Stroke: mid pons, posterolateral thalamus
- Orthostatic tremor
- Migraine related (very rare-in middle age)
FALL PREVENTION
Fall Prevention

- Currently there is strong evidence that both the number of falls and the number of fallers can be reduced by structured intervention
  - Physical training reduced falls
  - Home safety evaluation by OT
  - Anti slip shoe devices
  - Vitamin D in deficient patients
  - Reduce medications
  - Sensory optimization: Cataract

- The most effective approach: multicomponent
  - Strength, balance, flexibility, endurance

Comparison of number of falls in community-living elderly exposed to intervention with different types of exercise interventions vs. controls reported in a variety of RCTs.

### Exercise interventions for preventing falls in elderly in the community

<table>
<thead>
<tr>
<th>Study</th>
<th>Exercise (n)</th>
<th>Control (n)</th>
<th>Rate Ratio (mean with 95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Multi-component exercise on group bases versus control</td>
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<tr>
<td>Ballard 2004 ([33])</td>
<td>13</td>
<td>13</td>
<td>0.38 [0.12, 1.20]</td>
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<tr>
<td>Barnett 2003 ([32])</td>
<td>76</td>
<td>74</td>
<td>0.80 [0.36, 1.80]</td>
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<tr>
<td>Boehmer 1997 ([34])</td>
<td>79</td>
<td>78</td>
<td>0.61 [0.45, 0.94]</td>
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<tr>
<td>Bonint 2005 ([35])</td>
<td>111</td>
<td>130</td>
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<td>Carter 2002 ([36])</td>
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<tr>
<td>Forsgren et al. 2006</td>
<td>04</td>
<td>06</td>
<td>0.79 [0.39, 1.66]</td>
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<tr>
<td>Lord 1995 ([37])</td>
<td>75</td>
<td>94</td>
<td>0.95 [0.58, 1.55]</td>
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<tr>
<td>Lord 2003 ([38])</td>
<td>259</td>
<td>283</td>
<td>0.78 [0.62, 0.99]</td>
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<tr>
<td>Lundh 2007 ([39])</td>
<td>217</td>
<td>220</td>
<td>0.93 [0.65, 1.39]</td>
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<tr>
<td>Meads 2005 ([40])</td>
<td>144</td>
<td>94</td>
<td>0.41 [0.37, 0.62]</td>
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<tr>
<td>Rebelo et al. 2000</td>
<td>31</td>
<td>28</td>
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<td>Skelton 2005 ([41])</td>
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<td>31</td>
<td>0.69 [0.50, 0.96]</td>
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<td>Suzuki 2004 ([42])</td>
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<tr>
<td>Werderstyn 2006 ([43])</td>
<td>39</td>
<td>28</td>
<td>0.53 [0.26, 1.09]</td>
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<td><strong>Subtotal (95% CI)</strong></td>
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<td>0.78 [0.53, 1.18]</td>
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### Multi-component exercise on individual bases in home versus control

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<tr>
<td>Campbell 1997 ([44])</td>
<td>116</td>
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<td>0.60 [0.51, 0.70]</td>
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<td>Campbell 1999 ([45])</td>
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<td>Lox 2007 ([46])</td>
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<td>0.67 [0.55, 0.80]</td>
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<tr>
<td>Roberts 2001 ([47])</td>
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<td>119</td>
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<td><strong>Subtotal (95% CI)</strong></td>
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<td>0.66 [0.53, 0.82]</td>
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### Group Tai Chi exercise versus control

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<th>Exercise (n)</th>
<th>Control (n)</th>
<th>Rate Ratio (mean with 95% CI)</th>
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<td>Li 2005 ([48])</td>
<td>95</td>
<td>93</td>
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<td>Voss 2007 ([49])</td>
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<td>137</td>
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<tr>
<td>Hutt 1996 ([50])</td>
<td>72</td>
<td>64</td>
<td>0.67 [0.41, 1.10]</td>
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<tr>
<td>Hutt 2003 ([51])</td>
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<td>141</td>
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<tr>
<td><strong>Subtotal (95% CI)</strong></td>
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<td>0.63 [0.50, 0.78]</td>
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</table>

### Group gait, balance and functional exercise versus control

<table>
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<th>Study</th>
<th>Exercise (n)</th>
<th>Control (n)</th>
<th>Rate Ratio (mean with 95% CI)</th>
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<td>Cossio 2002 ([52])</td>
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<td>Lin-Rehbein 2004 ([53])</td>
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<td>McMurdo 1997 ([33])</td>
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<td>48</td>
<td>0.53 [0.20, 1.30]</td>
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<tr>
<td><strong>Subtotal (95% CI)</strong></td>
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<td>0.73 [0.54, 0.97]</td>
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</table>
Comparison of number of falls in community-living elderly exposed to intervention with home hazard assessment followed by risk factor reduction vs. controls reported in a variety of RCTs.

### Environmental interventions for preventing falls in elderly living in the community

<table>
<thead>
<tr>
<th>Study</th>
<th>Exercise (n)</th>
<th>Control (n)</th>
<th>Rate Ratio (mean with 95% CI)</th>
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<td>Home safety versus no home safety</td>
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<tr>
<td>Campbell 2005</td>
<td>190</td>
<td>193</td>
<td>0.50 (0.42, 0.62)</td>
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</tr>
<tr>
<td>Cumming 1999</td>
<td>264</td>
<td>266</td>
<td>0.86 (0.72, 1.03)</td>
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<tr>
<td>Day 2002 (2)</td>
<td>543</td>
<td>547</td>
<td>0.97 (0.81, 1.16)</td>
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<tr>
<td>Lin 2007</td>
<td>50</td>
<td>50</td>
<td>0.46 (0.22, 0.95)</td>
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<tr>
<td>Nikolau 2003</td>
<td>101</td>
<td>179</td>
<td>0.55 (0.50, 0.65)</td>
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<td>Stevens 2001</td>
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<td>Home safety versus no home safety in high risk individuals</td>
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<tr>
<td><strong>Subtotal (95% CI)</strong></td>
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<td><strong>0.59, 0.77</strong></td>
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<td>Home safety with occupational therapist versus no home safety</td>
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<td>Campbell 2005</td>
<td>190</td>
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<td>Nikolau 2003</td>
<td>101</td>
<td>179</td>
<td>0.69 (0.50, 0.95)</td>
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<tr>
<td>Fightills 2011</td>
<td>85</td>
<td>77</td>
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<tr>
<td><strong>Subtotal (95% CI)</strong></td>
<td><strong>0.69</strong></td>
<td><strong>0.55, 0.86</strong></td>
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<td>Home safety versus no home safety in elderly with severe visual impairment</td>
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<tr>
<td>Campbell 2005</td>
<td>190</td>
<td>193</td>
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<td><strong>0.42, 0.82</strong></td>
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<td>Visual assessment/eye examination with intervention if necessary versus no intervention</td>
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<tr>
<td>Cumming 2007</td>
<td>309</td>
<td>307</td>
<td>1.57 (1.15, 2.06)</td>
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<td><strong>1.19, 2.46</strong></td>
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Figure 3. Comparison of number of falls in community-living elderly exposed to drug withdrawal, cataract surgery and Podiatry/shoe assessment vs. controls reported in a variety of RCTs.
Figure 5. Comparison of number of falls in community-living elderly exposed to intervention with individualized multifactorial interventions vs. controls reported in a variety of RCTs.


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Other Interventions

- **Stress/depression/anxiety**
  - Fear of falling
  - Depression increases fall risk
- **Sleep**
  - Inattention increases fall risk
- **Diet**
  - Avoid vitamin deficiencies
Summary

- You can diagnose a gait problem by detailed physical exam
- You can do something about it
  - Activity
  - Polypharmacy
  - Cataract
  - Shoes
  - Home safety evaluation
  - Stress
  - Sleep
  - Diet
Thank you
Age related mechanisms of slip initiated falls

- Young persons can adapt within one step of stepping on slippery surface
- Older persons require additional step to adjust
- With reduced quality of sensory input, central response may be deficient

- If perceive surface as risky, a person adjusts their gait
  - Reduce step length
  - Reduce heel speed
Age related mechanisms of slip initiated falls

- So older person should be safer right? Well, ..
  - velocity of heel at heel contact was faster!
  - Also older persons have slower transitions between different velocities
  - Plantar flexion strength reduced (at toe off)
  - Abnl psychophysics (abnl vision/tactile assessment of surface) so do not modulate ahead of time and limited ability to modulate fast (at heel contact time to avoid slip is only 100-110 ms; but response latencies in elderly 120-200 ms)
    - Training improves psychophysics
    - Look 10-15 feet ahead!

Top floors 9, 10

- Parkinsonian:
  - Slow
  - Multiple steps to turn
  - Reduced step height

- Ataxic:
  - Wide
  - Irregular
  - Unsteady

- Spastic:
  - Stiff
Vision and Medications

- **Anticholinergic (antihistamine, antipsychotic, TCA):**
  - Blurry vision, Diplopia, Loss of accommodation (cycloplegia)

- **Erectile Dysfunction medications:**
  - Blurry vision, Photophobia, Change in color perception

- **Benzodiazepines, SSRIs, alpha blockers (tamsulosin, terazosin):**
  - Blurry vision

- **NSAID < 1% blurry vision**
Age related mechanisms of slip initiated falls

- Slip risks:
  - Floor contamination (water, ice):
    - Lower dynamic Coefficient of Friction, COF
  - Slope
  - Psychophysics:
    - Discrepancy between perception of surface and its properties versus actual reality of surface (example poor vision cannot see the ice or poor sensation cannot sense the slippery surface)

Age related mechanisms of slip initiated falls

- Slip initiation and detection
  - With reduced quality of sensory input, central response may be lacking in appropriate adjustments ahead of time

- Fall Recovery
  - With musculoskeletal limitations, cannot generate strong enough and fast enough counterbalance adjustments to prevent fall
In Summary:
Because basically the whole of the neuraxis, from the peripheral nerves up to the cortex, is involved in posture control and locomotion (Azevedo et al 2007), dysfunction in any part of the neuraxis can produce a balance and gait disorder referable to that level of dysfunction.

You can diagnose a neurological disorder by observing gait!
INTERACTION OF BALANCE/GAIT WITH COGNITION/EMOTION
Cognition & Gait: slow gait now… slow cognition later

- Lower gait speed predicts lower cognitive scores (Fitzpatrick et al 2007; Verghese et al, 2007b)
  - Cognitive decline over 3- to 5-year period (Inzitari et al 2007; Verghese et al 2007a; 2007b)
Cognition & Gait: slow gait now….

- Gait can slow down up to a decade before diagnosis of MCI
- Patients who develop MCI: their gait slowed by 2 cm/s/year versus 1 cm/s/year in those who did not develop MCI (Buracchio et al, 2010)
Cognition & Gait: slow gait now….

- Gait can slow down up to a decade before diagnosis of MCI
- Patients who develop MCI: their gait slowed by 2 cm/s/year versus 1 cm/s/year in those who did not develop MCI (Buracchio et al, 2010)
- A slower gait by a difference of 10+ cm/s seems clinically meaningful to predict cognitive decline six years down the line (Marquis et al, 2002)
Cognition & Gait: slow cognition now...

- Cognitively impaired patients have BGD (Beurskens and Bock 2012)
  - amnestic mild cognitive impairment (MCI) patients walk slower than controls (Montero-Odasso et al, 2014)

- Executive dysfunction predicts decline in gait:
  - Decline in speed over 3 years (Atkinson et al 2007)
  - risk of falls over 3 years (Chen et al 2012)
New: Motoric Cognitive Risk Syndrome

- Motoric Cognitive Risk syndrome, MCR
  - new term in elderly to capture gait/cognition interplay (Verghese et al, 2013).

- MCR:
  - slow gait (below sex/age norms by $\leq 1$ standard deviation)
  - subjective cognitive complaints with preserved ability to perform activities of daily living and no dementia (using DSM criteria).

- 9 years of followup (Verghese et al, 2014):
  - MCR prevalence was 9%
  - Dementia developed in 14-25% of MCR patients
  - MCR increasing risk of dementia by two fold
Cognition & Gait: Dual Task

- Gait parameters deteriorate during dual versus single tasks, especially for more complex cognitive tasks (Li et al, 2014)

- Balance and gait disorders that are most affected by dual tasks are those at the top of the balance building (namely floor 8-10+) (Jahn et al 2010)

- Dual tasks affect balance and gait parameters, especially when the cognitive task taps into executive or memory functions rather than being a simple manual reaction-time task (Mesure et al 2001; Springer et al 2006; Allali et al 2007; 2008; Delval et al 2008; Hausdorff et al 2008; Van Iersel et al 2008; Hall et al 2009; Plotnik et al 2009)
  - Alzheimer (Sheridan et al 2003)
The reason dual tasks influence balance and gait is hypothesized by Vandenbossche (2012) to be attributed to the direct and indirect gait pathways.

- Direct automatic responses via the basal ganglia
- Indirect pathways are the controlled responses regulated by the frontal lobe
- A demand or pressure on the frontal pathway due to compromised cognitive abilities leads to deterioration in gait, such as development of freezing gait

Do not Text and Walk
Cognition & Gait: Falls

- Falls correlate with frontal lobe executive dysfunction (Holtzer et al 2007) including in patients with MCI (Delbaere et al 2012)
- Falls correlated with executive and visuospatial dysfunction in progressive supranuclear palsy patients (Kim et al, 2014)
- **Stopping walking while talking** is a marker of future falls (Lundin-Olsson et al 1997)
Cognition & Gati: Texting

- Texting while walking: growing evidence that even in young healthy adults this can be a hazard (Plummer et al, 2014; Marone et al, 2014)
- Certainly is a hazard to combine texting and driving.
Emotion & Gait

- Stress can cause alternation in balance/gait pattern: typically people walk slower.
- Depression causes slow speed, small steps, increased fall risk (Launay et al, 2013)
- Schizophrenic patients walk slower, with shorter stride and have ataxic features, such as difficulty with tandem
Figure 4. Comparison of number of falls in community-living elderly exposed to intervention with generalized multifaceted interventions vs. controls reported in a variety of RCTs.

Multiple interventions for preventing falls in elderly living in the community

Study | Exercise (n) | Control (n) | Rate Ratio (mean with 95% CI) | Rate Ratio (mean with 95% CI)
--- | --- | --- | --- | ---
Exercise and vitamin D versus no intervention in patients with visual impairment
Campbell 2005 | 92 | 95 | 1.15 [0.82, 1.61] | 1.15 [0.82, 1.61]
Subtotal (95% CI) | | | | 1.15 [0.82, 1.61]
Exercise and fall preventive advice versus no intervention
Hill 2000 | 99 | 40 | 0.89 [0.71, 1.10] | 0.89 [0.71, 1.10]
Subtotal (95% CI) | | | | 0.89 [0.71, 1.10]
Exercise, education and risk assessment versus no intervention
Shumway-Cook 2007 | 226 | 227 | 0.75 [0.52, 1.09] | 0.75 [0.52, 1.09]
Subtotal (95% CI) | | | | 0.75 [0.52, 1.09]
Exercise, education and home safety intervention versus no intervention
Clemson 2004 | 100 | 147 | 0.69 [0.50, 0.96] | 0.69 [0.50, 0.96]
Subtotal (95% CI) | | | | 0.69 [0.50, 0.96]
Exercise, nutrition, vitamin D and Calcium versus no intervention
Swannenburg 2007 | 102 | 10 | 0.19 [0.05, 0.68] | 0.19 [0.05, 0.68]
Subtotal (95% CI) | | | | 0.19 [0.05, 0.68]


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Age related mechanisms of slip initiated falls

- Heel strike: Ground reaction forces (GRF)
  - Fv Vertical: COM and downward momentum of swing leg
  - Ft Transverse: lateral momentum (ex if out toeing walk)
  - Fh Horizontal (shear): in direction of walking (forward)

Age related mechanisms of slip initiated falls

- No slip: GRF opposed by frictional force (FF) (resistance characteristics of foot-surface)
  - FF depends on applied force and Coefficient of friction (COF)
    - COF: static and dynamic

- Slip: FF < Fh

Age related mechanisms of slip initiated falls

Critical time to slip initiation:
1- shortly after heel contact (where only edge of heel is in contact)
   Peak 3
2- Toe off (only tip of shoe is in contact with ground) Peaks 4,5

In normal ground walking, typical horizontal (Fx) and vertical (Fz) ground reaction forces and required coefficient of friction (Fx/Fz) during one stance phase; HC and TO mark the instants of heel contact and toe off.

Video
Video
Video
Video
Video:
Video:

Weak Gluteus Medius
(Excessive hip movement)
Video
Video
Video
Video post procedure
Balance and Gait Disorders - OUTLINE

- Introductory remarks about locomotion
- Normal Balance/gait
- Balance Building
- Balance/gait anatomy & physiology
- Changes of balance/gait with age and fall risk
- Common balance/gait disorders in the elderly
- Balance/gait interaction with cognition & emotion
White Matter and Gait

In a study of 701 elderly pts, gait speed (measured 4m walk) was followed over mean of 4.7 yrs

White matter volume is associated with slowing gait speed over time

Willey. J of Neurology, Nov 2012
Balance Building

- Each component of the balance/gait system, i.e. each floor, gives a unique pattern of BGD that is identifiable and localizable. Thus the concept of GAIT LEVEL (akin to sensory level)

- BGD due to floors 1-8 are **stereotypical**
- BGD due to floor 9-10 (including psychogenic) **vary**
Evolution of brain to support balance

- Fire control about 800,000 yr ago
- Cooking: extract nutrients
- Nutrition and the Brain
  - Brain expansion 800,000-200,000
- Left Africa and populated the world: 60,000
Evolution of Brain

- Language ~100,000
  - FOXP2 gene
- Art ~ 77,000
  - Blombos Cave, S.Africa, 1991
- Religion (bury dead) ~50,000
- Music ~ 44,000
- Control of grain, breeding about 12,000
- Writing ~ 4000 BC (Sumer- Iraq)
Human Evolution

- http://humanorigins.si.edu/evidence/human-family-tree
- http://humanorigins.si.edu/evidence/human-evolution-timeline-interactive

Smithsonian Institute
Balance and Gait

- Balance and gait abilities in humans depend on a hierarchal system of muscles, nerves, and interconnected central nervous system structures that is amazingly similar to that seen all way “down” to the snail!
- Walking is not an aimless process and is essential for survival of animal and human.
- For this reason, disorders of balance and gait have serious consequences to the inflicted.
Balance and Gait

- Although arthritic and orthopedic illness can cause balance and gait problems
- Most balance/gait disorders are neurological
- Thus important to examine balance/gait
  - Balance/Gait can be the only thing that is abnormal on exam
  - Examples: midline cerebellar, early NPH, cautious gait of elderly, cervical myelopathy, etc
Normal Gait

- Steady
- Rhythmic
- Good Speed
- Good arm swing
- Good turns 1-2 steps
- Narrow base of support
- Can walk on toes/heels
- Romberg
- Tandem
Balance Scales: not good at identifying type of balance disorder

- Activity Specific Balance Scale (ABC)
  - Questionnaire
  - Not related to falls
- Berg
  - Clinician rating
- Tinetti
  - 93% of fallers identified

Anatomy of Balance and Gait System
A Skyscraper Analogy
## Balance & Gait Building of 10 floors

10
9
8
7
6
5
4
3
2
1
## Balance & Gait Building

<table>
<thead>
<tr>
<th>Structure</th>
<th>Floor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cortical</td>
<td>10</td>
</tr>
<tr>
<td>Subcortical White Matter</td>
<td>9</td>
</tr>
<tr>
<td>Basal Ganglia</td>
<td>8</td>
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<tr>
<td>Thalamus</td>
<td>7</td>
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<tr>
<td>Cerebellum</td>
<td>6</td>
</tr>
<tr>
<td>Brainstem</td>
<td>5</td>
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<tr>
<td>Spinal Cord</td>
<td>4</td>
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<tr>
<td>Peripheral Nerve</td>
<td>3</td>
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<tr>
<td>Neuromuscular jn</td>
<td>2</td>
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<tr>
<td>Muscle</td>
<td>1</td>
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</tbody>
</table>

Floors 1-8 are stereotypical
<table>
<thead>
<tr>
<th>Structure</th>
<th>Number</th>
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<tbody>
<tr>
<td>Cortical</td>
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<td>Brainstem</td>
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<td>Spinal Cord</td>
<td>4</td>
</tr>
<tr>
<td>Peripheral Nerve</td>
<td>3</td>
</tr>
<tr>
<td>Neuromuscular jn Muscle</td>
<td>2</td>
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<tr>
<td>Muscle</td>
<td>1</td>
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</tbody>
</table>

Wide means ataxic; also tend to be unsteady
Think drunk
<table>
<thead>
<tr>
<th>Structure</th>
<th>Steps to Moves</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cortical</td>
<td>10</td>
</tr>
<tr>
<td>Subcortical White Matter</td>
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<td>Basal Ganglia</td>
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<td>Thalamus</td>
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<td>Cerebellum</td>
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<td>Brainstem</td>
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<td>Spinal Cord</td>
<td>4</td>
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<tr>
<td>Peripheral Nerve</td>
<td>3</td>
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<tr>
<td>Neuromuscular Junction</td>
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<tr>
<td>Muscle</td>
<td>1</td>
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</tbody>
</table>

Steps to Moves: >5

Steps to Turns: >5
## Balance Building

<table>
<thead>
<tr>
<th>1</th>
<th>2</th>
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<tr>
<td><strong>Cortical/Subcortical – Cerebral, variable patterns</strong></td>
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<tr>
<td><strong>Basal Ganglia – Parkinsonism</strong></td>
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<tr>
<td><strong>Thalamus – rare ataxia/astasia</strong></td>
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<tr>
<td><strong>Cerebellum – ataxia</strong></td>
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<tr>
<td><strong>Brainstem – rare ataxia</strong></td>
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<tr>
<td><strong>Spinal Cord – spastic</strong></td>
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<td><strong>Peripheral Nerve – sensory ataxia</strong></td>
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<tr>
<td><strong>Neuromuscular junction</strong></td>
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<tr>
<td><strong>Muscle – waddling</strong></td>
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</tbody>
</table>
Balance/Gait System

Cerebral (Cortical/Subcortical)

Basal Ganglia

Thalamus

Cerebellum

Brainstem

Spinal cord

CPG

VN

Sensory feedback

Output Locomotion
Brainstem

**Locomotor Regions**
MLR, DLR & VLR, SLR, CLR
PPN

- Cerebellum
- Thalamus
- Basal Ganglia
- Cerebral (Cortical/Subcortical)

**Afferent Inputs:**
- Sensory feedback

**Efferent Outputs:**
- Vestibulospinal
- Reticulospinal
- Corticospinal
- Rubrospinal
- Tectospinal

Contribute to:
- Postural control
- Head stability
- Limb tone

**Central Pattern Generator (CPG):**

**Output Locomotion**

**Sensory feedback**
Historical List of Names of Cerebral BGD

- Astasia-abasia (Blocq, 1888)
- (Bruns) Frontale ataxie-1892
- Trepidante abasie (Petrén, 1901)
- Marche à petits pas (Marie, 1902)
- Corticale Apraxie (Heilbronner, 1905)
- Innervatory apraxia (Kleist, 1907)
- Limb-kinetic apraxia (Westphal, 1907)
- Gait apraxia (Gerstmann & Schilder, 1926)
- Trunk apraxia (Sittig, 1929)
- Frontal disequilibrium (Van Bogaert & Martin, 1929)
- Arteriosclerotic parkinsonism (Critchley, 1929)
- Senile gait (Critchley, 1931, 1948; Koller, 1983, 1985)
- Magnetic, repellent, & trunk apraxia (Denny-Brown, 1958)
- Slipping clutch syndrome (Denny-Brown, 1958)
- Pure Akinesia (Imai and Narabayashi, 1974)
- Axial apraxia (Lakke, 1985)
- Akinetic parkinsonism (FitzGerald, 1989)
- Lower half parkinsonism (Thompson, 1987)
- Lower body parkinsonism (FitzGerald, 1989)
- Primary progressive freezing gait (Achiron, 1993)
- Gait ignition failure (Atchison, 1993)
- Subcortical disequilibrium (Nutt, 1993)
- Subcortical gait disorders (Nutt, 1993)
- Frontal gait disorders (Nutt, 1993)
- Nonspecific disequilibrium of the elderly (Fife, 1993)
- Higher level gait disorder (Tyrrell, 1994)
- Vascular parkinsonism (Zijlmans, 1995)
- Frontal lobe gait disorder (Thompson, 2001)
- Gait apraxia-term revisited (Della Sala, 2002)
- Ignition apraxia, disequilibrium apraxia or mixed (Liston, 2003)
- Vascular higher level GD (Martin and O'Neill 2004)
- Psychogenic disadaptation (Mourey et al 2004)
- Elderly with cautious gait of unknown origin (Giladi 05)
- Senile paraplegia (Thompson 07)
- Parkinsonian ataxia (Thompson 07)
- Mild parkinsonian signs concept (Louis & Bennett 07)
- Higher level Gait Disorder (Huber-Mahlin et al, 2010)
- Higher level Gait Disorder (Giladi 2013)
Location of Cortical (Frontal) Areas Associated with Balance & Gait

Premotor

1º Motor

Supplementary Motor Area

Grabowski, 2002
Cortical-Subcortical Connections

Brainstem

CPG

Sensory feedback

Output Locomotion

Locomotion

Cortical-Subcortical Connections

Frontal

Limbic/Paralimbic

Parietal

Basal Ganglia

Thalamus

Cerebellum

Brainstem

CPG
Location of Subcortical White Matter Signal Associated with BGD

Red areas: statistically significant difference in signal abnormality between good & bad gait score
1- **Frontal** (80-90% sensitive) & **Parietal** (Bi-100% specific)
2- **Contiguous** with ventricles
3- **Symmetrical**

Benson, 2002
Vision Changes with aging

- Visual acuity
  - Bi and tri focal (affect stairs/outdoors)
- Reduced peripheral vision
- Reduced contrast sensitivity (trip)
- Dark adaptation
- Depth perception (multiple falls)

<table>
<thead>
<tr>
<th>floor</th>
<th>name</th>
<th>rhythm</th>
<th>Base width</th>
<th>Step height</th>
<th>Steps to turn*</th>
<th>Arm swing</th>
<th>Romberg</th>
<th>Tandem</th>
</tr>
</thead>
<tbody>
<tr>
<td>9-10 c/sc</td>
<td>Variable can be only cautious</td>
<td>+/- Non-rhythmic</td>
<td>+/- WIDE</td>
<td>+/- reduced</td>
<td>+/- Multiple</td>
<td>Reduced +/- asymmetric</td>
<td>+/- abnl</td>
<td></td>
</tr>
<tr>
<td>8 BG</td>
<td>Parkinsonism</td>
<td>Festination (only on this floor!)</td>
<td>reduced</td>
<td>Multiple ≥ 5 even &gt;10</td>
<td>Reduced +/- asymmetric</td>
<td>Early is nl</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7 thalm</td>
<td>Ataxia Astasia</td>
<td>Bit wide</td>
<td></td>
<td></td>
<td></td>
<td>+/- positive¶</td>
<td>Min abnl</td>
<td></td>
</tr>
<tr>
<td>6 cbllm</td>
<td>Ataxia</td>
<td>Non-rhythmic</td>
<td>WIDE</td>
<td></td>
<td></td>
<td></td>
<td>abnl</td>
<td></td>
</tr>
<tr>
<td>5 BS</td>
<td>Mild ataxia</td>
<td>Bit wide</td>
<td></td>
<td></td>
<td></td>
<td>+/- positive¶</td>
<td>Min abnl</td>
<td></td>
</tr>
<tr>
<td>4 cord</td>
<td>Spastic</td>
<td>Bit wide</td>
<td></td>
<td></td>
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<td>+/- min abnl</td>
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<tr>
<td>3 vestib</td>
<td>cautious</td>
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<td></td>
<td></td>
<td>Positive¶</td>
<td>Min abnl</td>
<td></td>
</tr>
<tr>
<td>3 nerve</td>
<td>Sensory ataxia</td>
<td>Non-rhythmic</td>
<td>WIDE</td>
<td></td>
<td></td>
<td>Positive</td>
<td>abnl</td>
<td></td>
</tr>
<tr>
<td>1-2 m/n-m</td>
<td>waddling</td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>

Empty boxes mean normal except steps to turn: can be normal at 1-2 or minimally abnl at 3-4 in BGD floors 1-7. ¶ Lateropulsion
Abnormal Tractography in elderly with cautious gait and abnormal postural reflex vs elderly controls
Vision Changes with aging

- Visual acuity
  - Bi and tri focal (affect stairs/outdoors)
- Reduced peripheral vision
- Reduced contrast sensitivity (trip)
- Gaze sensitivity
- Dark adaptation
- Depth perception (multiple falls)
Vision

- Presbyopia
- Cataract
- Glaucoma
- Macular degeneration
- DM
- HTN
Common types of visual impairments in older adults and their effects on activities of daily living.

<table>
<thead>
<tr>
<th>Condition</th>
<th>Visual effect</th>
<th>Effect on function</th>
</tr>
</thead>
<tbody>
<tr>
<td>Presbyopia</td>
<td>Inability to see small objects, small print, at close proximity</td>
<td>Need for multifocal lenses that may interfere in depth perception</td>
</tr>
<tr>
<td>Cataract</td>
<td>Blurred vision, Glaring of bright light</td>
<td>Limits mobility as may run into objects, limits night driving, limits ability to read instructions</td>
</tr>
<tr>
<td>Glaucoma (open angle)</td>
<td>Affects peripheral vision</td>
<td>Creates “tunnel” vision and limits object perception in visual fields</td>
</tr>
<tr>
<td>Macular degeneration</td>
<td>Affects central vision: distortion of lines, white spots, color perception</td>
<td>Limits recognition of objects, colors, and visual fields</td>
</tr>
</tbody>
</table>

I-ADL: The top three activities reported to be the most difficult to perform are heavy housework (18.9%), traveling beyond walking distance (14.7%), and grocery shopping (13.6%)

Reed-Jones. Maturitas 2013
<table>
<thead>
<tr>
<th>Medication or pharmacologic class of medications</th>
<th>Ocular adverse effect(s)</th>
<th>Additional comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amiodarone (anti-arrhythmic)</td>
<td>Bilateral corneal deposits may occur, causing lens opacities and/or halo vision. Although rare, optic neuropathy may lead to blindness.</td>
<td>Minimal corneal deposits in patients taking &lt;200 mg/day; Almost all patients develop corneal deposits at doses &gt;400 mg/day.</td>
</tr>
<tr>
<td>Anticholinergics (e.g. antihistamines, antipsychotics, tricyclic antidepressants)</td>
<td>Blurred vision, diplopia, cyclopiaplegia</td>
<td></td>
</tr>
<tr>
<td>Anti-malarials (e.g. Chloroquine, Hydroxychloroquine)</td>
<td>Corneal deposits, blurred vision, accommodation disturbances, visual field defects, maculopathy, retinopathy</td>
<td>Corneal deposits occur in nearly all patients at therapeutic doses. Other effects (maculopathy, retinopathy) are rare and associated with long-term, high-dose therapy.</td>
</tr>
<tr>
<td>Anti-epileptics (e.g. carbamazepine, phenytoin, topiramate)</td>
<td>Blurred vision, diplopia, lens opacities, nystagmus</td>
<td>Ocular adverse effects of phenytoin are related to the concentration of phenytoin in the plasma.</td>
</tr>
<tr>
<td>Corticosteroids (topical or systemic)</td>
<td>Cataracts, increased intraocular pressure (IOP), decreased vision</td>
<td>Risk of cataracts is increased in patients who have been on doses of 15 mg/day of prednisone or its equivalent for more than one year. Elevation of IOP is more common with topical corticosteroids.</td>
</tr>
<tr>
<td>Cardiac glycosides (e.g. digitals, digirops)</td>
<td>Blurred or yellow vision, decreased visual acuity, changes in visual fields, halo vision</td>
<td></td>
</tr>
<tr>
<td>Non-steroidal anti-inflammatory medications (e.g. diclofenac, diflunisal, ibuprofen, ketorolac, naproxen)</td>
<td>Blurred vision, abnormal vision including visual field defects, diplopia</td>
<td>Incidence of these effects are rare (&lt;1%) for most of these agents.</td>
</tr>
<tr>
<td>Phosphodiesterase Type 5 inhibitors (e.g. sildenafil, tadalafil, vardenafil)</td>
<td>Blurred vision, changes in color perception, and photophobia</td>
<td>Ocular effects are dose-dependent.</td>
</tr>
<tr>
<td>Tamoxifen (antineoplastic, estrogen receptor antagonist)</td>
<td>Corneal opacities, cataracts, color perception changes, retinopathy</td>
<td>More likely in patients taking doses that are higher than normal.</td>
</tr>
</tbody>
</table>
Vision in research

- Difference in gaze behavior (transfer of gaze to and from target, fixation on target, viewing pattern)
- Increased lateral sway, decreased stepping on target when having concurrent visual tracking task
Vision: Obstacle Negotiation

- Fewer preparatory saccades
- Higher foot variability
- Reduced stepping accuracy
- Slower initiation of stepping plan and adjustments
- Higher risk of stepping error
- Compared to young, who fixated on target 3 steps ahead, elderly fixated closer to target
- Earlier gaze transfer away from target (can be improved with training)

Uiga, Ageing Research Rev 2015
Proprioception

- Arguably the most important for standing balance

- Sensory structures in muscles, tendons, joints, skin provide feedback about joint position, movement, touch
  - Muscle: stretch sensitive receptors
  - Muscle-tendon interface: Golgi tendon organs
  - Joint mechanoreceptors
  - Skin (cut and s/q):
    - Meissner (stroking) and Pacinian (vibration); Merkel disk (pressure); Ruffini endings (skin stretch)

Motor System Changes with Age

- Strength important for recovery after perturbed balance
  - Need high peak torque generation and speed of generation
- Fall risk correlates with knee extension, dorsiflexion of ankle and hip strengths
- Strength can be maintained at higher level with physical activity

Sensory Integration of Information, Changes with Age

- Reduced ability to integrate information to adjust balance
- Example: during on/off proprioception perturbation (vibration) or vision changes
- Reaction time:
  - Loss of brain mass (10%) and loss of myelin (slow conduction)
  - Increase by 25%
  - Especially slow with dual tasks or stepping

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Uiga, Ageing Research Rev 2015
Proprioception Changes with Age

- **With aging:**
  - Loss of muscle spindle sensitivity
  - Pacinian and Meissner receptors loss (reduced vibration and touch perception)
  - Decline in joint position sense

- **Disease:**
  - Arthritis, Diabetes, Alcohol, vitamin deficiency, chemotherapy, etc

- **Falls:**
  - Strong correlation with neuropathy

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Changes in Balance with Aging

- Increased postural sway especially laterally when standing (fall risk)
- Reduced ability to lean forward
  - Decline in functional reach
- Stepping:
  - Impaired ability to generate rapid steps in different directions or generate long step
  - Slower lift off and landing
  - Worse in fallers

Changes of Gait Speed with Age

- Balance and gait scores drop over time and falls increase
- By age 60, we lose 1% of gait speed per year
  - ~1 cm per yr (Jahn et al 2010)
  - 6 cm/sec over 4 yrs (Beavers et al, 2013)
- Walking while talking
  - Increase mediolateral sway (LaRoche et al, 2014)
- Loss of 10 cm/s in speed is associated with 12% increase in mortality (Beavers et al, 2013)
Falls: Perturbations and Age

- Step more frequently
- Require multiple steps to recover
- Protective stepping is less successful
- Increased risk for obstacle contact

Reasons:
- Inadequate step length
- Inaccurate foot placement
- Reaction time
- Central integration
- Torque generation (weak muscle, stiff joints)

Cane/Training can help

Boonsinsukh, Horak. Phys Ther 2012
Tropea. IEEE 2015
Figure 5. Comparison of number of falls in community-living elderly exposed to intervention with individualized multifactorial interventions vs. controls reported in a variety of RCTs.
Gait Pattern in Elderly: concept of Cautious Gait

- 80% to 90% of the elderly have walking impairments
  - 60% to 70% of those have an abnormal gait related to a known cause
  - 10% to 20% have no known cause, termed “cautious” gait

- Note: 10-20% of 85-year-olds have no gait impairment (Jahn et al 2010).