Safe Standing: A Study of Floor Mats and Insoles
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Understanding balance responses imposed by these influences on employee productivity

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***A study funded by a grant from The Boeing Company
“Anti-Fatigue”

• So, how did we ever end up with “anti-fatigue” as a term for what we stand on?
• Do different materials REALLY let us fight off “fatigue” so effectively?
• How much “anti-fatigue” is good?
• Is “anti-fatigue” the affect we are looking for - is there something more important?
• Do safety managers ACTUALLY know if they are causing other influences on the employee’s work performance?
Sometimes we do things rather impulsively…
Muscle Fatigue
Multiple possible mechanisms that may contribute.

Definitions of muscle fatigue:

- Failure to maintain the required or expected muscle force
- Decrease in the maximum force a muscle can generate
- Muscle force decreases by ~1/2 in first minute of maximal voluntary contraction (MVC)
- Fatigue in general is a feeling of tiredness, exhaustion, or lack of energy. You may feel mildly fatigued because of excessive effort at work, poor sleep, worry, boredom, or lack of exercise.
- Any illness, such as a cold or the flu, may cause fatigue, which usually goes away as the illness clears up.
- Potassium overdose, anemia, effects of medications, abnormal thyroid function, etc…
1. Motor cortex activation – level of excitation
2. Descending spinal cord motor excitation
3. Motor neuron excitability & conduction
5. Intracellular chemistry (pH, mitochondrial function)
6. Levels of ATP and sources for resupply (carbs/fats)
7. Excitation-Contraction coupling (available Ca$^{2+}$)
8. Actin and Myosin interactions for muscle contractions
9. Amount of blood flow to the muscles
10. Sometimes, it’s just psychological motivation – Bored!
Central fatigue – More realistic variables

- Known “anti-fatigue” influences - Encouragement, loud noises, Stimulants (e.g., amphetamines) increase time to fatigue, Serotonin agonist (buspirone) reduced fatigue from 26 to 16 minutes, external electrical stimulation can increase muscle force in a fatigued muscle

- … but nothing about floor mat materials objectively measuring or even having the ability to measure the level of “anti-fatigue” effects on employees.

- That is when the light bulb went off and it became clear that if we were standing on some material, it would most certainly have a potential impact on our balance, and thus our work performance and even possible safety concerns!!!
We need to think a little more on this...
However, those applied forces are absorbed by the body in ways not readily apparent to the worker or managers.

But the body will and must react in the performance of doing work!
Interaction of Foot Structure & the Insoles
Help is needed to rationalize the multiple choices of floor mats and insoles?

Understanding how people react to certain floor mats and insoles would improve safety OR we just can just keep on guessing at this point. Safety is not about guessing!!!
Balance Factors in Standing

- A person’s COM must be kept within the body’s BOS
- Holding a weight out to the right side shifts the COM to the right and to the outside of the right foot, the very edge of the BOS
- To negotiate that new challenge, the person will lower the weight closer to their side or try to widen their base of support to maintain a safe standing position
- Material under the person will influence that adjustment and balance response …
• 1\textsuperscript{st} and most important is the sensory information from the lower extremities in the form of pressure and proprioception

• 2\textsuperscript{nd} is the visual right reflexes that provide confirmation of the first set of information

• 3\textsuperscript{rd} is the vestibular system that provides an orientation in three planes of motion but is actually a slower reacting system
Figure 15.3. Plot showing the center of pressure during standing posture in which sway was voluntarily controlled by the subject.
Two Independent Studies Designed

Two studies approached this question with the first one using the three floor mats (hard, medium, and soft densities).

A second study utilized three insoles (same three ranges of materials)

Two randomized control trial studies were designed to answer the question:

• What are the affects balance reactions on different density floor mats and insoles?
• Was balance affected when putting material against the foot or against the footwear?
• What balance variables were affected and to what degree?
The purpose of this study was to investigate the influence of three different ergonomic mats and insoles on an individual’s:

- multidirectional reaction time (RT)
- Movement velocity (MVL)
- Initial endpoint excursion (EPE)
- Maximum excursion (MXE)
- Directional control (DCL)
- While being challenged at 100% of one’s limits of standing stability.
Definitions

• Reaction Time (RT): in seconds between the command to move and the pt’s first movement
• Movement Velocity (MVL): the average speed of a person’s COP movement in degrees/sec
• Initial endpoint Excursion (EPE): the percent distance towards the designated target considered to be the point at which the initial movement toward the target ceases and standing adjustments are made by the individual
• Maximum Excursion (MXE): the maximum distance achieved during the trial towards the designated target
• Directional Control (DCL): the accuracy of movement in the intended direction (towards the target) in percent indicating the efficiency of that movement
Subjects

Inclusion Factors

- Age 20 – 59
- No ambulatory devices (canes – walkers)
- No balance related pathologies
- Both genders included
- No limitations to height or weight

Exclusion Factors

- Over Age 60 or under 20
- Use of ambulatory devices
- Balance pathology (i.e. vestibular, neurological, muscular/motor control issues)
- Visual impairments that would preclude responding to the screen icon or lighted targets
- Unable or unwilling to complete initial 2 minute training session
Study Methods (con’t)

- **Pre-test Questionnaire each subject completed:**
  - Age
  - Weight
  - Height
  - Gender
  - Shoe size
  - Hours standing/day
  - Distance walked/day
  - Standing discomfort
  - Shoe replacement experience

- **Post-test Questionnaire each subject completed:**
  - Level of perceived firmness of mat or insole
  - Characterized level of firmness
  - Perceived shock absorption
  - Perceived affect on balance reactions
  - Would they recommendation mat or insole? (Y/N)
• Repeated Treatment design: Also referred to as Within-Subject design, controlled by an order randomization of each trial (i.e. ABCD, BCDA, CDAB, etc.)

• Availability Sampling: Also referred to as Convenience Sampling, a method of randomly choosing subjects who are available and willing to participate

• Standardized Pre-Training Session: to practice shifting their balance, recognizing target prompts, and standing postures during the testing. Those subjects who could not complete the training session were excluded from the study

• Randomization of Trials:
  • Subjects were assigned a number as they entered the study. Each number was pre-assigned a given randomized order for testing of the following conditions below (A – D):
    – A = control for both studies (standardized safety shoe)
    – B = soft density mat - medium density insole
    – C = medium density mat - hard density insole
    – D = hard density mat - soft density insole

*Measures of density were established using the Shore A /D scales and Asker C meter purchased from HOTO Instruments, Northbrook, IL. Both instruments also had certificates of calibration for each respective scale
Balance Data of Subjects

DOB: 7/24/1972  
Referral Source: Amer. Inter. College  
Height: 5'10"  
Comments: B - C - A - D  
Test Time: 12:49:38 PM

**LIMITS OF STABILITY TEST**

<table>
<thead>
<tr>
<th>Transition</th>
<th>RT (sec)</th>
<th>MVL (deg/sec)</th>
<th>EPE (%)</th>
<th>MXE (%)</th>
<th>DCL (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 (F)</td>
<td>0.40</td>
<td>4.5</td>
<td>101</td>
<td>103</td>
<td>91</td>
</tr>
<tr>
<td>2 (RF)</td>
<td>1.26</td>
<td>4.6</td>
<td>94</td>
<td>111</td>
<td>87</td>
</tr>
<tr>
<td>3 (R)</td>
<td>0.52</td>
<td>5.0</td>
<td>47</td>
<td>83</td>
<td>76</td>
</tr>
<tr>
<td>4 (RB)</td>
<td>0.78</td>
<td>3.6</td>
<td>86</td>
<td>86</td>
<td>70</td>
</tr>
<tr>
<td>5 (B)</td>
<td>0.51</td>
<td>2.6</td>
<td>88</td>
<td>88</td>
<td>77</td>
</tr>
<tr>
<td>6 (LB)</td>
<td>1.61</td>
<td>3.7</td>
<td>68</td>
<td>86</td>
<td>84</td>
</tr>
<tr>
<td>7 (L)</td>
<td>1.07</td>
<td>4.9</td>
<td>79</td>
<td>96</td>
<td>74</td>
</tr>
<tr>
<td>8 (LF)</td>
<td>0.73</td>
<td>4.8</td>
<td>107</td>
<td>107</td>
<td>88</td>
</tr>
</tbody>
</table>

100% LOS

**Graphs:**
- Reaction Time (RT)
- Movement Velocity (MVL)
- Endpoint & Max Excursions (EPE & MXE)
- Directional Control (DCL)
### Limits of Stability Test

**DOB:** 7/24/1972  
**Referral Source:** Amer. Inter. College  
**Height:** 5'10"  
**Comments:** B - C - A - D  
**Test Time:** 12:49:38 PM

#### Transition | RT (sec) | MVL (deg/sec) | EPE (%) | MXE (%) | DCL (%)
--- | --- | --- | --- | --- | ---
1 (F) | 0.40 | 4.5 | 101 | 103 | 91
2 (RF) | 1.26 | 4.6 | 94 | 111 | 87
3 (R) | 0.52 | 5.0 | 47 | 83 | 76
4 (RB) | 0.78 | 3.6 | 86 | 86 | 70
5 (B) | 0.51 | 2.6 | 88 | 88 | 77
6 (LB) | 1.61 | 3.7 | 68 | 86 | 84
7 (L) | 1.07 | 4.9 | 79 | 96 | 74
8 (LF) | 0.73 | 4.8 | 107 | 107 | 88

#### Reaction Time (RT)

<table>
<thead>
<tr>
<th>sec</th>
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<th>Back</th>
<th>Right</th>
<th>Left</th>
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<td>0.73</td>
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<td>0.81</td>
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<td>1.21</td>
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<td>0.88</td>
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#### Movement Velocity (MVL)

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<th>deg/sec</th>
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<td>4.7</td>
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<td>4.1</td>
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#### Endpoint & Max Excursions (EPE & MXE)

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#### Directional Control (DCL)

<table>
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<th>Forward</th>
<th>Back</th>
<th>Right</th>
<th>Left</th>
<th>Comp</th>
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<tr>
<td>80</td>
<td></td>
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</table>
Computerized Balance Testing
Balance Display and Targets

Go and Move Cursor to Target.
### Material Compression Profiles

<table>
<thead>
<tr>
<th>Shore Scale</th>
<th>A</th>
<th>A*</th>
<th>Shore Scale</th>
<th>A</th>
<th>Asker C*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control A (Slip-Grip Shoe)</td>
<td>42</td>
<td></td>
<td>Control A (Slip-Grip Shoe)</td>
<td>42</td>
<td></td>
</tr>
<tr>
<td>Mat B soft</td>
<td>18</td>
<td>10</td>
<td>Insole B medium</td>
<td>32</td>
<td>40-44</td>
</tr>
<tr>
<td>Mat C hard</td>
<td>72</td>
<td>75-78</td>
<td>Insole C hard</td>
<td>90</td>
<td>95-98</td>
</tr>
<tr>
<td>Mat D medium</td>
<td>47</td>
<td>45-48</td>
<td>Insole D soft</td>
<td>15</td>
<td>30-36</td>
</tr>
</tbody>
</table>

Table 3. Standardized testing of study floor mats and insoles in the Shore A/D/Asker C scales. *indicates results from the Precision Testing Laboratories, Nashville, TN
Overall Results of Independent Testing for Durometers of Floor Mats

- Mat B (soft) Shore "A" <10* - <10*
  Asker "C" 32 – 36

- Mat C (hard) Shore "A" 74 – 78

- Mat D (medium) Shore "A" 45 – 49

- ***Mat A was control (just Slip grip shoes)
### Overall Profile for Floor Mats

#### Descriptive Statistics for Subjects (N = 55 Mat)

<table>
<thead>
<tr>
<th>Variables</th>
<th>Mean (SD)</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mat Study</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Age</td>
<td>33.98 (14.34)</td>
<td>20-59</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>67.23 (4.03)</td>
<td>61-76</td>
</tr>
<tr>
<td>Weight (lbs)</td>
<td>164.43 (35.21)</td>
<td>98-232</td>
</tr>
<tr>
<td>Hours/Day</td>
<td>6.64 (2.55)</td>
<td>0-11</td>
</tr>
<tr>
<td>Hours on Feet</td>
<td>6.18 (2.99)</td>
<td>1-15</td>
</tr>
</tbody>
</table>
## Overall Results for Floor Mats

Mean comparisons of Mats A, B, C, and D with dependent variables ($N = 55$)

<table>
<thead>
<tr>
<th>Variable</th>
<th>F</th>
<th>P</th>
<th>Mat A</th>
<th>Mat B</th>
<th>Mat C</th>
<th>Mat D</th>
</tr>
</thead>
<tbody>
<tr>
<td>RT</td>
<td>1.11</td>
<td>.34</td>
<td>.73 (.2)</td>
<td>.75 (.2)</td>
<td>.90 (1.1)</td>
<td>.74 (.21)</td>
</tr>
<tr>
<td>MVL</td>
<td>2.54</td>
<td>.06</td>
<td>5.69 (1.6)</td>
<td>5.37 (1.4)</td>
<td>5.53 (1.5)</td>
<td>5.43 (1.5)</td>
</tr>
<tr>
<td>EPE$^a$</td>
<td>3.74</td>
<td>.01</td>
<td>80.83 (13.4)</td>
<td>82.21 (12.5)</td>
<td>78.74 (10.7)</td>
<td>77.85 (9.8)</td>
</tr>
<tr>
<td>MXE$^b$</td>
<td>5.03</td>
<td>.01</td>
<td>96.74 (10.4)</td>
<td>99.51 (13.3)</td>
<td>94.89 (9.2)</td>
<td>94.40 (11.9)</td>
</tr>
<tr>
<td>DCL</td>
<td>1.39</td>
<td>.25</td>
<td>75.90 (9.7)</td>
<td>77.83 (8.7)</td>
<td>75.63 (11.1)</td>
<td>76.11 (10.1)</td>
</tr>
</tbody>
</table>

$^a$ Mat B (soft) was significantly larger than both Mats C and D.

$^b$ Mat A (control) was significantly larger than Mat D (medium)

$^b$ Mat B (soft) was significantly larger than Mat C (hard)

(Greenhouse Geisser adjustment was used for variable F RT, MXE, DCL)
Independent Testing Results for Insoles Durometers

- Insole B
  Shore "A" <10* - <10*  
  (medium) 
  Asker "C" 40 - 42

- Insole C
  Shore "A" 95 - 98  
  (hard) 
  Asker "C" 73 – 74

- Insole D
  Shore "A" <10* - <10*  
  (soft) 
  Asker "C" 30 – 36

***Insole A was control (just Slip grip shoes)
Overall Profile for Insoles

Insole Study (N = 45)

Variables | Mean (SD) | Range
--- | --- | ---
Age | 34.36 (14.60) | 21-59
Height (cm) | 66.98 (4.05) | 60-76
Weight (lbs) | 163.34 (35.59) | 98-232
Hours/Day | 6.64 (2.79) | 0-11
Hours on Feet | 6.39 (2.75) | 1-13
Overall Results for Insoles & Mats

- Mean comparisons for Mat B, Insole B, and Insole D ($N = 45$)

<table>
<thead>
<tr>
<th>Variable</th>
<th>F</th>
<th>P</th>
<th>Mat B</th>
<th>Insole B</th>
<th>Insole D</th>
</tr>
</thead>
<tbody>
<tr>
<td>RT</td>
<td>0.51</td>
<td>.60</td>
<td>0.75 (0.2)</td>
<td>0.78 (0.2)</td>
<td>0.79 (0.2)</td>
</tr>
<tr>
<td>MVL</td>
<td>0.65</td>
<td>.52</td>
<td>5.37 (1.4)</td>
<td>5.31 (1.8)</td>
<td>5.68 (1.6)</td>
</tr>
<tr>
<td>EPE</td>
<td>0.38</td>
<td>.69</td>
<td>82.21 (12.5)</td>
<td>82.39 (12.5)</td>
<td>84.12 (9.5)</td>
</tr>
<tr>
<td>MXE</td>
<td>1.36</td>
<td>.26</td>
<td>99.51 (13.3)</td>
<td>95.84 (13.9)</td>
<td>96.21 (8.9)</td>
</tr>
<tr>
<td>DCL$^b$</td>
<td>3.04$^a$</td>
<td>.05</td>
<td>77.83 (8.7)</td>
<td>78.94 (7.2)</td>
<td>81.35 (4.1)</td>
</tr>
</tbody>
</table>

- Insole D is larger than Mat B ($P = .054$)

- $^b$ indicates that the Assumption of Homogeneity of Variance was violated. No adjustment was made.

- Homogeneity of Variance = The assumption of homogeneity of variance is that the variance within each of the populations is equal. This is an assumption of analysis of variance (ANOVA). ANOVA works well even when this assumption is violated except in the case where there are unequal numbers of subjects in the various groups. If the variances are not homogeneous, they are said to be heterogeneous.
Subjects’ Perception I

Perception of Insoles

<table>
<thead>
<tr>
<th>Insole A</th>
<th>Insole B</th>
<th>Insole C</th>
<th>Insole D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shock Absorption</td>
<td>Comfort</td>
<td>Fit in Shoe</td>
<td></td>
</tr>
<tr>
<td>7.18</td>
<td>7.17</td>
<td>7.23</td>
<td>7.17</td>
</tr>
<tr>
<td>5.74</td>
<td>5.68</td>
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<td>5.61</td>
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<tr>
<td>5.10</td>
<td>5.27</td>
<td>6.00</td>
<td>7.15</td>
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</table>

Rating Scale
Insole Affect on Balance and Arch Support

Subjects’ Perception II

AffectBalance

Arch Support

<table>
<thead>
<tr>
<th>Insole</th>
<th>AffectBalance</th>
<th>Arch Support</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>6.77</td>
<td>6.16</td>
</tr>
<tr>
<td>B</td>
<td>5.73</td>
<td>6.54</td>
</tr>
<tr>
<td>C</td>
<td>5.93</td>
<td>4.34</td>
</tr>
<tr>
<td>D</td>
<td>6.78</td>
<td>6.12</td>
</tr>
</tbody>
</table>
Subjects’ Recommendations

Subject Recommendations

Insole A
Insole B
Insole C
Insole D

Recommend Percent Preference for Each Insole

Subjects' Recommendations
Reaction Times of Subjects

Reaction Times

- Insole D
- Floor Mat B

Insole Compared to Floor Mat

Seconds

RT - F  RT - RF  RT - R  RT - RB  RT - B  RT - LB  RT - L  RT - LF

Insole D: Light Blue
Floor Mat B: Dark Grey
Movement Velocities of Subjects

Insoles vs. Floor Mat

Degrees per second

Insole D vs. Floor Mat B

MVL - F  MVL - RF  MVL - R  MVL - RB  MVL - B  MVL - LB  MVL - L  MVL - LF
Subjects’ First Attempt to Change Balance

First Attempt to Change Balance

- Voluntary Stop to Balance
- Insole D
- Floor Mat B

Percentage

Voluntary Stop to Balance

- EPE - F
- EPE - RF
- EPE - R
- EPE - RB
- EPE - B
- EPE - LB
- EPE - L
- EPE - LF

EPE - RF
Maximum Attempt to Reach Target

100% of Limits of Standing Stability
Directional Control of Subjects

Directional Control

Accuracy of Reaching Target

DCL - F  DCL - RF  DCL - R  DCL - RB  DCL - B  DCL - LB  DCL - L  DCL - LF

Insole D  Floor Mat B

Directional Control of Subjects
Balance Control

**Sensory**

Where am I?

- Determination of Body Position
- Compare, Select and Combine Senses
- Visual System
- Vestibular System
- Somato Sensation
- Environmental Interaction

**Motor**

What am I going to do?

- Choice of Body Movement
- Select and Adjust Muscle Contractile Patterns
- Ankle, Thigh
- Trunk, Neck
- Eye, Head
- Generation of Body Movement
Choice of floor mats OR insoles can influence balance reactions and thus affect a worker’s performance.

Body is influenced to make muscle and balance changes quickly to complete work related tasks safely and efficiently.
Six subjects agreed to have surface electrodes applied to the leg muscles during the balance testing. This allowed us to monitor electrical muscle activity (EMG) while on the different floor mats. Same EMG responses were monitored while placing the different insole materials in the footwear. Even though it was a small sample, the result showed lower EMG activities on the softer materials (floor mat and insoles) less work of the leg muscles.

Anyone interested in funding that study would be greatly appreciated. The information would be important for manufacturers and safety managers.
Salient Points from the study

- Safety initiatives should think about soft floor mats and/or insoles since they demonstrated a statistically significant improvement in directional control in balance reactions within a specific range of softness (durometer).

- Although it was a surprise to the researchers, softer materials within a specific durometer range of 30 to 36 – Asker C scale were shown to have the most significant benefit to three dynamic standing balance reactions.

- Most important balance reaction variable as it relates to work environments, performance, and productivity was directional control (DCL) with softer insoles showing a near statistically significant benefit.

- Among the softer materials, the best interaction for balance and standing, the approach to placing the material as close to the surface of the feet, in the footwear, with a slight contour at the arch and depression at the heel area (insole D) was better than placing the cushioning under the footwear.
1. **Balance Master.**


Questions - Discussions

Safety and productivity concerns typically sustain each other.

Both soft mats and/or insoles have benefits but cost – benefit considerations but it appears that softer is the way to go!
Thank you for attending!

Please remember to submit an evaluation on the mobile app.