The Design of Foam Crash Pads for Short Track Speed Skating on Boarded Rinks

S. Maw [1] and C. Johnston [2]

[1] Department of Math, Physics and Engineering, Science and Technology Faculty, Mount Royal University, Calgary, Canada

[2] Department of Mechanical and Manufacturing Engineering, Schulich School of Engineering, University of Calgary, Canada

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Presentation Overview

- Background and Introduction
- Modeling the Impacts
- Pad Design Criteria and Constraints
- Experimental Work
- Results
- Conclusions and Recommendations
- Acknowledgements

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- Why this work is important …
  - http://www.youtube.com/watch?v=Rb5zMxL_eho

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Background and Introduction

- Short track races include 500m, 1000m, 1500m and 3000m, plus 3K/5K team relays
- Mass start racing format is used
- Skaters reach speeds of over 45 kmph
- Padded boards protect skaters who fall/crash
- ISU padding specifications are of limited help (Communication No. 1512 and 1019)
- Literature is also of limited assistance
- Designs developed in Calgary since 2001

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Modeling the Impacts

- A qualitative spring model of impacts
- Spring parameters include:
  - stiffness (variable)
  - compression range (variable)
  - Orientation (variable)
- Conservation of energy formulation
- Impacting skater: $KE = \frac{1}{2} m v^2$
- KE → PE (as springs compress)

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- The different springs include …
  - Pad foam layers
  - Pad cover
  - Different tissues (bones/muscles/ligaments) in skaters
- Orientation of skater upon impact is CRITICAL

- Fundamentally, the key equation is …

$$F\,\Delta t = m\,\Delta v$$

- Assume high forces → more likely/severe injury

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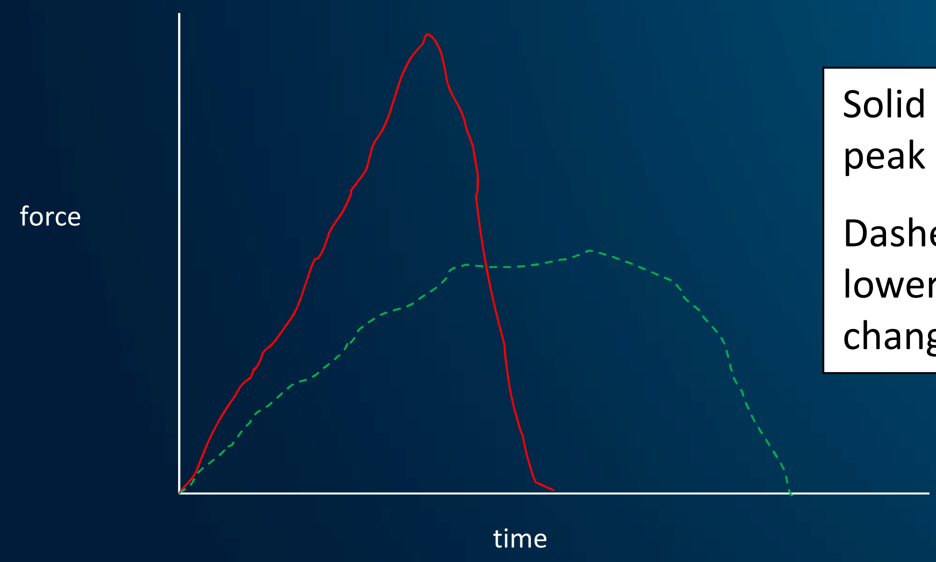
- but impact forces vary with time i.e.



Solid line – short “hard” hit, high peak force, high rate of change of F

Dashed line – longer “softer” hit, lower peak force, lower rate of change of F

- *F = f (t)* since *F = f (spring compression)* and spring compression and k values vary with time since all the springs are non-linear

- In the simplest case, with two springs in series:

  $F = k_1 x_1 = k_2 x_2$ and $k_1 / k_2 = x_2 / x_1 = PE_2 / PE_1$

  i.e. both springs experience the same force
- The weaker spring compresses more and dissipates more energy, both proportionate to the ratios of the spring constants

- But springs have elastic ranges/yield strengths
- If we exceed the elastic range of the soft tissue “body spring”, skeletal components may break, snap or crush to further dissipate remaining *KE*

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- Cases:
  - k_{body} high, k_{pad} low(er)
    - Pad compresses and absorbs more energy
    - What if pad “fully” compresses?
    - What about coefficient of restitution (COR)?
  - k_{body} low, k_{pad} high(er)
    - Body compresses and absorbs more energy
    - What if body reaches elastic limit?
    - What about full compression and COR?
- How to optimize for all types of crashes?
  - Head or feet first
  - Side of body impacts
  - Multi-body impacts

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Pad Design Criteria

- Primary - Peak deceleration
- Secondary - Bounce back
- Tertiary
  - Portability
  - Durability
  - Aesthetics
  - Purchase costs
  - Maintainability
  - Environmental costs

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Pad Design Constraints

- Pad thickness
  - Too thin is a problem i.e. 1 x 8”?
  - Too thick is a problem i.e. > 20-24”?
- Rink size
  - NHL [85’ (25.91 m) by 200’ (60.96 m)]
    vs. Olympic [30 m by 60 m]
    vs. hybrids [usually narrower and longer than NHL]
- Dissipate KE by sliding on ice
- Limit speeds or change tracks

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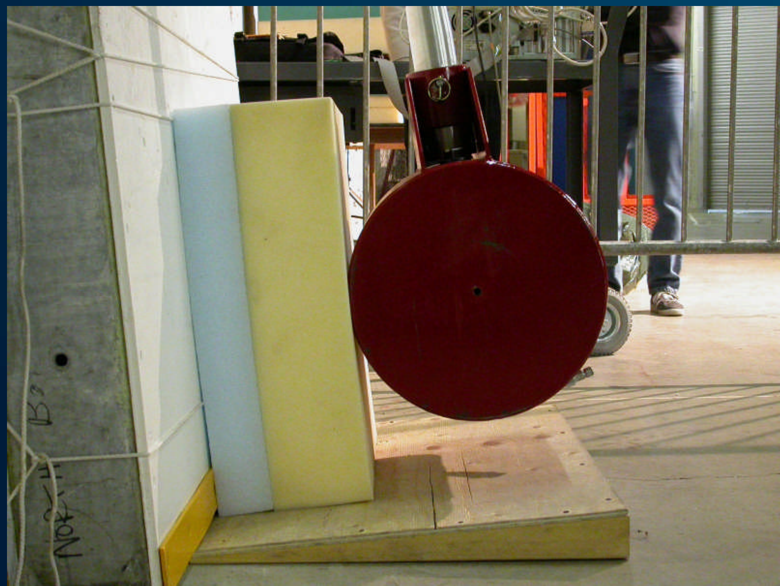
Experimental Work

- Pendulum impactor with 55 kg steel barrel
- Impact speeds of < 3 m/s to > 8 m/s
- Position (LVDT) and acceleration sensors



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- Focused on open-cell polyurethane (PU) and closed-cell polyethylene (PE) foam
- Mostly deal with vinyl-coated polyester covers with Velcro™ flaps linking pads
- Compression tests use ASTM D3574-05
  - Standard Test Methods for Flexible Cellular Materials - Slab, Bonded and Molded Urethane Foams
    - specifically Test B_1 - Indentation Force Deflection (force required to indent foam 25% of its thickness)
  - Density determined using Test A - Density

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Results and Discussion

- Foam type – open beats closed cell; no memory
- Foam density – mid-range is preferable
- Pad height – use height of boards (often 4')
- Pad length – 5-8' with pros and cons
- Pad thickness – thicker the better, but stiffness interacts with thickness so use layers
- Foam layering – softest to hardest in corners, firm in front on straights, judicious use of closed-cell foam, holes aren't worth it

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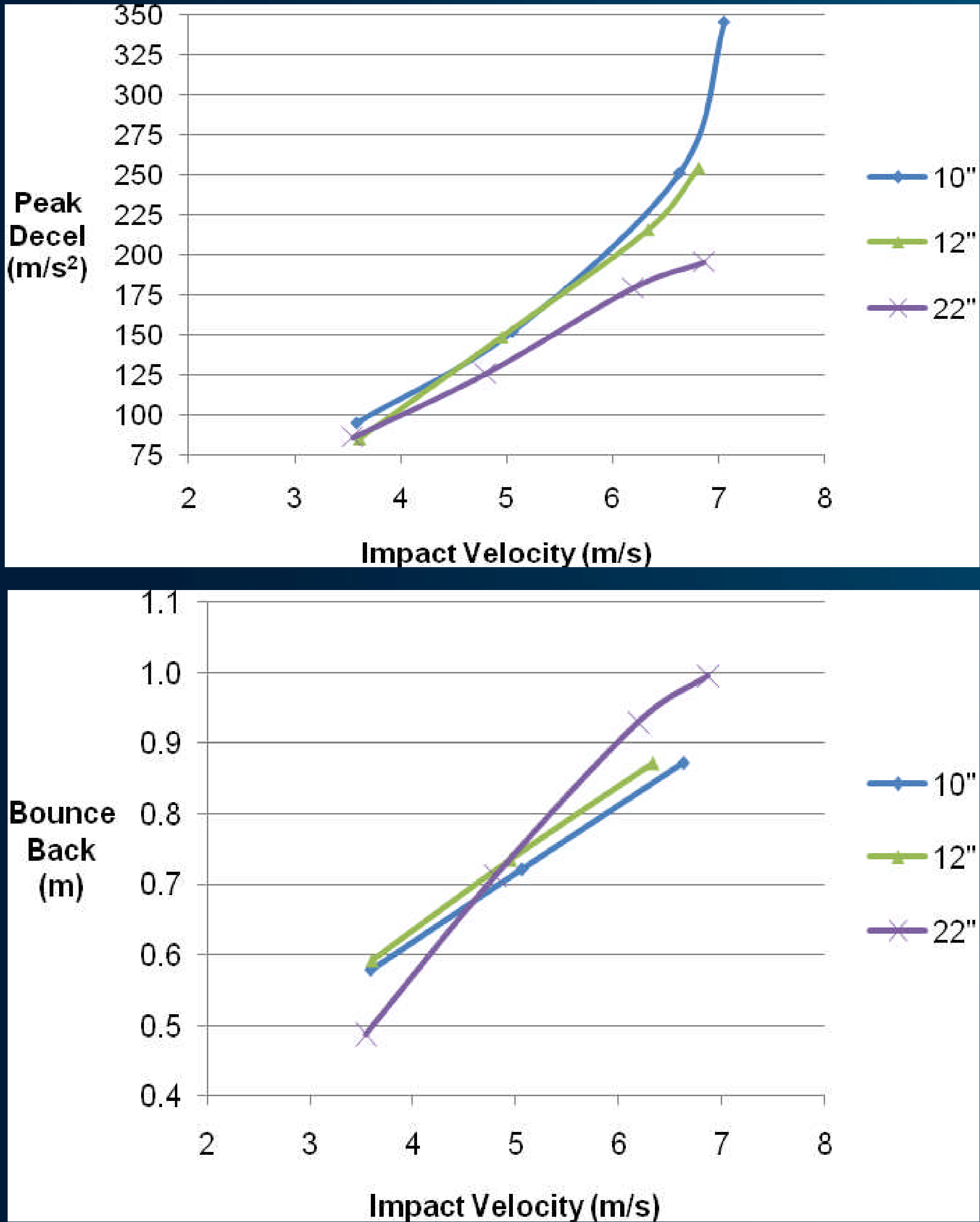

Figure 3. Peak deceleration and bounce back with respect to pad thickness (42-45 lb open cell foam). The 22” pad was a combo of two pads (10” + 12”).

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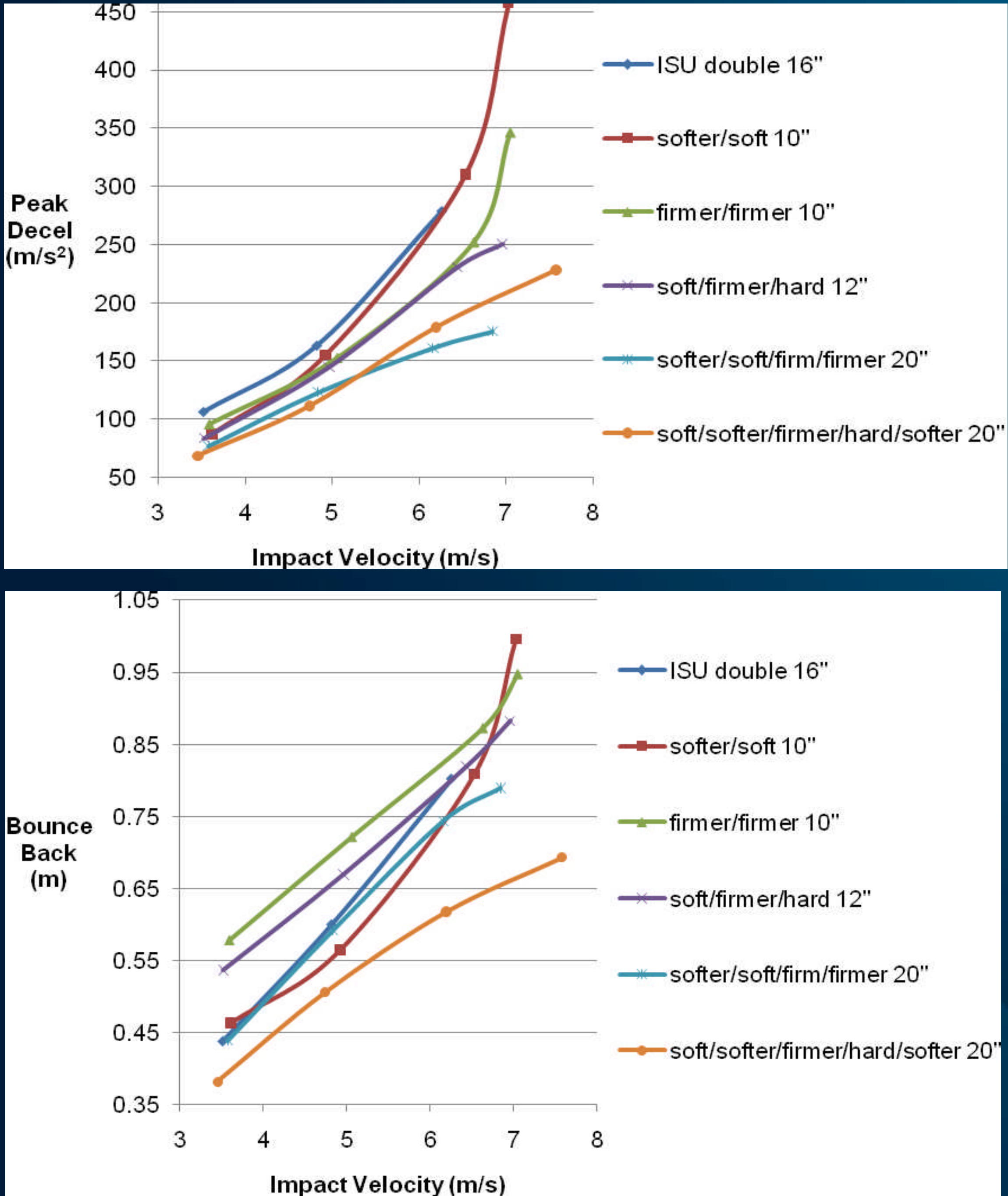

Figure 4. Peak deceleration and bounce back for pads of various thicknesses with various layers of foam. Softer = 15 lb, soft = 26 lb, firm = 32 lb, firmer = 42 lb and hard = closed cell. All points represent the average of 2-6 impact trials. Standard deviations were less than 2% for bounce back, and less than 10 m/s^2 for peak deceleration.

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- Cover material – medium density vinyl-coated polyester, slippery, matte textured, water/cold resistant and rip-stop, with handles, Velcro™ attachments, venting and heavy double zippers

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- Pad locations – thickest in corners

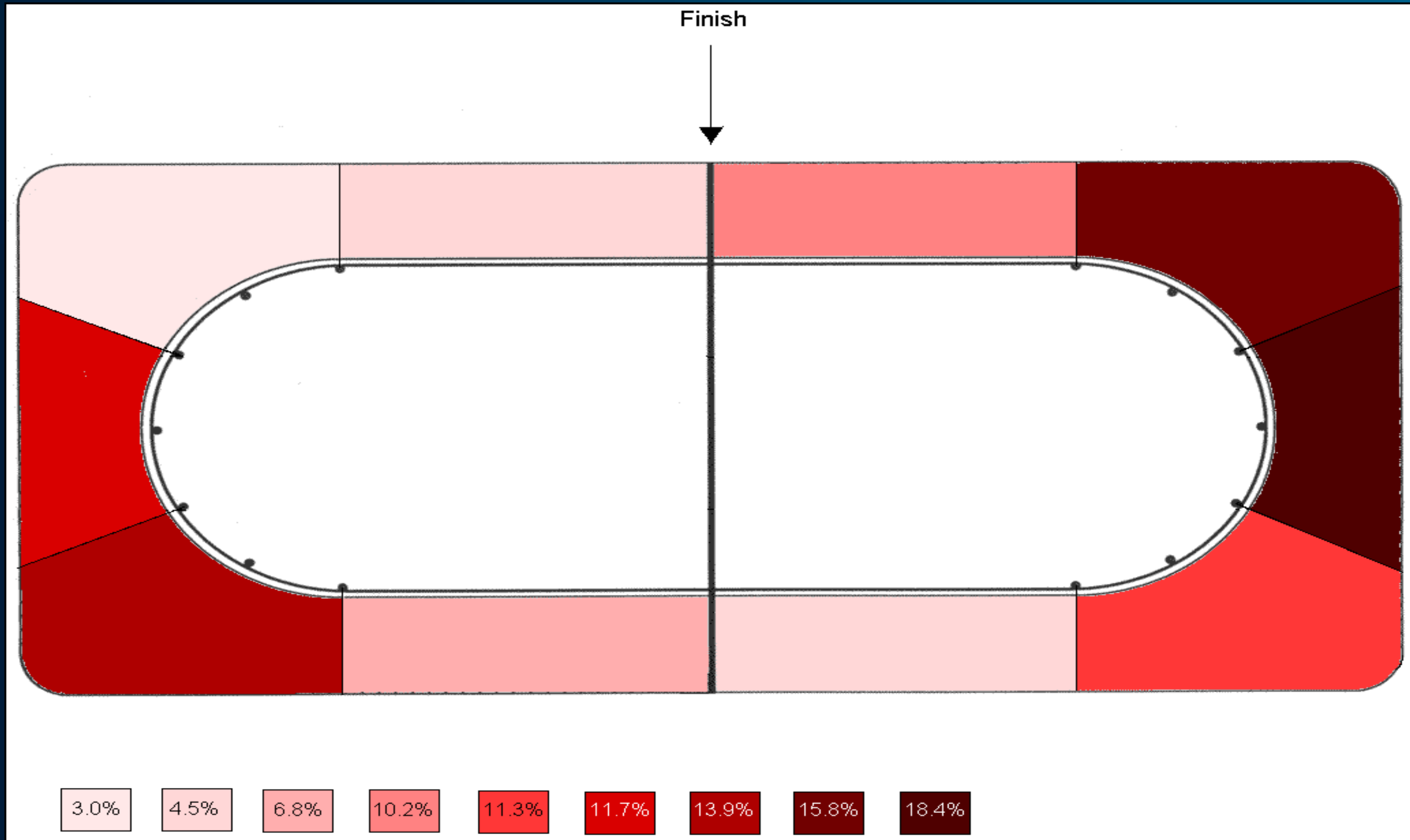

Figure 6. Relative percentage of falls around the short track rink. Darker areas are impacted more frequently.

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- Venting – on top, ≥ 1/3 total area, mesh cover

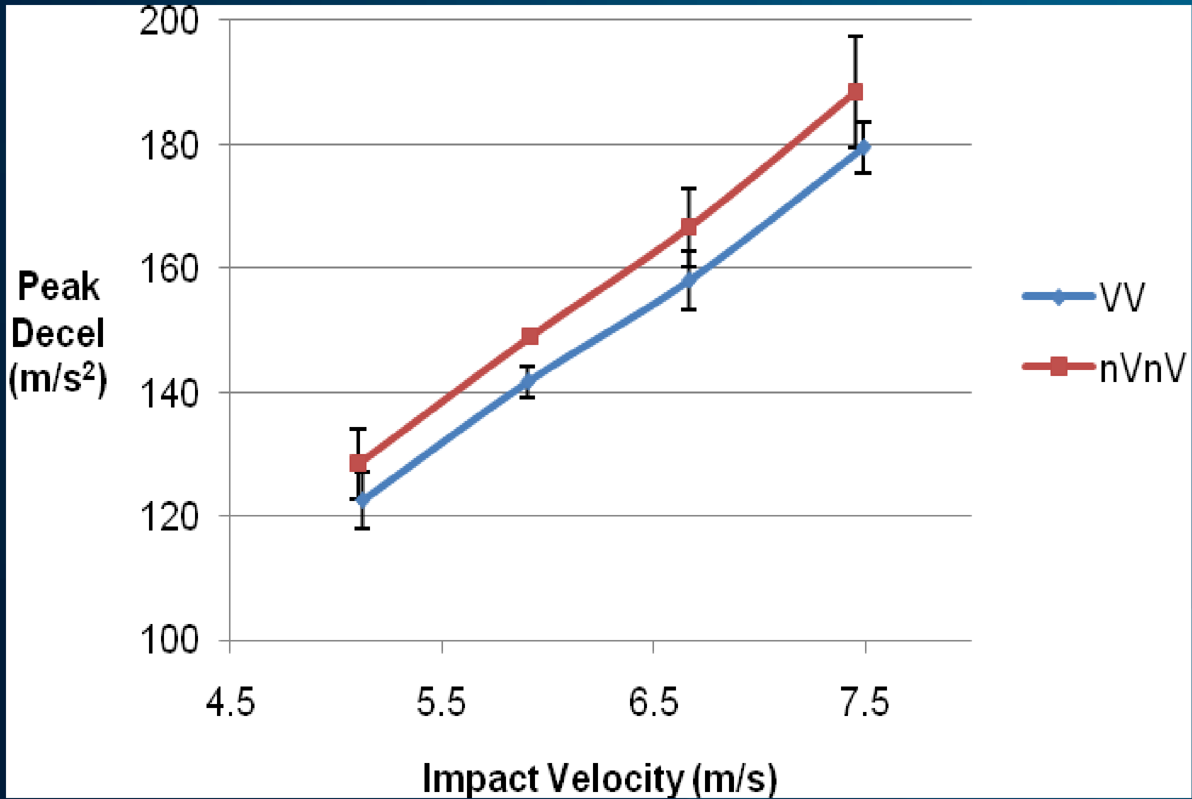

Figure 7. Effects of venting on peak deceleration. Two pads, back to back. One pair is vented (VV). The other pair is not (nVnV). Standard deviation bars are shown (3-7 impact trials for each plotted data point for VV, 2-3 for nVnV).

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- Doubling Up Pads – good, but one thicker pad is better than two thinner ones, by design
- Linking Pads Together – use Velcro™ with moderate overlap, side to side and front to back as needed

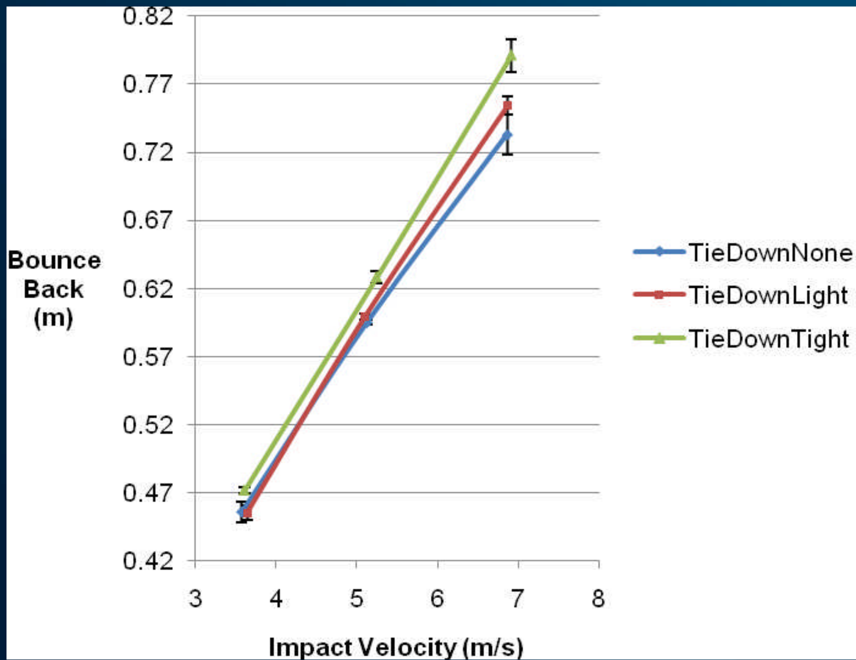

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Figure 8. Effects of front cover tightness on bounce back. Standard deviation bars are shown (2-3 impact trials for each plotted data point).

Conclusions/Recommendations

- Match pads with the expected speed and mass of skaters (KE), for the present and foreseeable future
- If top skaters will be using the facility, then safety must be the ultimate criterion as even then, risk of injury can only be reduced, not eliminated

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- Several basic rules or principles of pad system design are suggested for short track speed skating in a boarded rink:
  - teach skaters to fall properly (side impacts)
  - skate on as wide/long an ice surface as possible
  - allow for as much pad thickness as possible
  - go from soft to hard foam in the corners and firmer (but not stiff) foam elsewhere
  - use closed-cell foam sparingly
  - have vents in low friction pad covers
  - old pads do not work as well as new pads

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