How Can we Evacuate Individuals with Disabilities from High Rise Buildings Safely and Efficiently?

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Evacuation Needs

http://highriseoperations.com/2012/04/truck-company-operations-at-high-rise-fires/

http://www.foxnews.com/story/0,2933,579922,00.html
EMS – An occupation with Significant MSD Risks

  - Relative risk: 5.8 relative to health services
  - 43% Strains/Spains, 20% of injuries to the back
  - Back strain accounted for 78% of lost days.

EMS – An occupation with Significant MSD Risks

  - Sprains, strains, and muscular pain account for 60% of the injuries suffered by firefighters while performing non-fire emergency tasks, such as EMS and other rescue operations
  - Most common location – private residence where stairs and heavy patients are contributing factors.
  - 63% of injuries were back injuries
Study Objective

- To evaluate different types of **stair descent devices** that can be used to evacuate individuals with motor disabilities from high-rise buildings.
  - Biomechanical Demands
  - Physiologic Demands
  - Efficiency

Prior Work

- Adams and Galea (2010)
  - Decreased task performance times when using a **track-type device** vs:
    - manually carried stair-chair,
    - an ambulance cot,
    - or a drag mattress
  - The physical demands on the responders were not quantified.

Adams and Galea, 2010, Pedestrian and Evacuation Dynamics Conference, NIST, Maryland USA
Track-Chair Comparison Study

• Fredricks et al., 2006
  – Compared two track chairs
  – Modeled with the 3DSSPP
  – Substantial differences between two track-type chairs
    • Spine Compression
    • Spine Shear
  – Used two operators (leader/follower)
    • Load sharing


Study Aims

1. To quantify the differences among types of existing evacuation devices with regards to the physical demands placed on firefighters.

2. To quantify the variation in evacuation times, including occupant preparation for transport and the stair descent process, across different evacuation devices.
Study Aims (Continued)

3. To determine the impact of environmental factors including:
   • the width of the stairs,
   • the sense of urgency,

4. To assess usability issues with each of the evaluated devices through video analysis and a structured interview process.

Study Aims (Continued)

5. To understand the consumer’s perspective.
**Approach**

- Evaluate physical demands experienced by seasoned FF as they roll/slide stair descent devices down flights of stairs.

- Physical Demands are measured using:
  - Electromyography (EMG)
  - Heart Rate
  - Self Report

**Task**

- Secure occupant in device
- Transport the occupant down three flights of stairs.
  - Through two landings
Experimental Design

- Factors considered
  - Device Design
  - Staircase Width
  - Urgency

Device Type

- 3 Main Categories
  - Hand-carried devices
  - Devices with stair descent tracks
  - Sled type devices
Track-Type Devices

- Long Track (Garaventa)
- Rear Facing (Glider)
- 2-Wheeled (Evac+Chair)
- Narrow (AOK)
- Standard (Ferno EZ-Glide)
Sled-Type Devices

- Roll-up (Med Sled)
- Corrugated (Evacuslyde)
- Wheeled Subway Sled
- Inflatable (Hovel Jack)
- Hardshell (Lifeslider)
- Fabric Mat (ResQmat)

Hurricane Sandy Hits NYC
Staircase Width

- Based on NFPA 101-2009 describing staircase widths based on occupant load:

<table>
<thead>
<tr>
<th>Category</th>
<th>Width (inches)</th>
<th>Capacity (persons)</th>
<th>Code</th>
</tr>
</thead>
<tbody>
<tr>
<td>Narrow</td>
<td>36</td>
<td>&lt; 50</td>
<td>7.2.2.2.1.2 (A)</td>
</tr>
<tr>
<td>Medium</td>
<td>44</td>
<td>&lt; 2000</td>
<td>7.2.2.2.1.2 (B)</td>
</tr>
<tr>
<td>Wide</td>
<td>56 (52)</td>
<td>&gt;= 2000</td>
<td>7.2.2.2.1.2 (B)</td>
</tr>
</tbody>
</table>
**Staircase Width**

**Urgency**

- Controlled via instructions given to the subject prior to each run.
  - **non-urgent** - “you can take as much time as you need during this descent”
  - **urgent** - “the situation requires you leave the building as quickly as possible.”
    - Repeating recorded message “This is an urgent condition”
Participants-

• Recruited from a population of firefighters
• Twelve subjects/study- male
  – Height: 183 cm (175 – 196 cm)
  – Weight: 88 kg (71 – 111 kg)
  – Age: 36 yrs (24 – 61 years)
  – Experience: 9 yrs (1.5 – 23 years)
• Signed IRB approved consent documents

Occupant

• Rescue Randy
  – Control for size, shape, weight
  – 73 kg (160 lbs)
Measures

- Duration of evacuation
- Electromyography
  - Erector Spinae,
  - Latissimus Dorsi,
  - Deltoid,
  - Biceps
- Heart Rate
- Perceived exertion ratings
- Spine motion
- Usability information via post study interview.

Perceived Exertion Ratings

- “How hard physically was this task for you?”
  - 0  Not at All
  - 1  Very Easy
  - 2  Fairly Easy
  - 3  Moderate
  - 4  Somewhat Hard
  - 5  Hard
  - 6
  - 7  Very Hard
  - 8
  - 9
  - 10 Very, Very Hard
Descent Speed Results

Looking Across Studies: Descent Speed as a function of Staircase Width

\[ p < 0.001 \]
**Stair Descent Speeds: Hand-Carried Devices (44” Staircase Width)**

![Bar chart showing stair descent speeds for various devices and styles.]

- **Manual Carry**
- **Basic Stair Chair**
- **Fabric Seat**
- **Extended Handle**


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**Stair Descent Speed by Track-Type SDDs: 44 and 52 inch staircase widths**

![Bar chart showing stair descent speeds for various track types.]

- **Standard**
- **Long-Track**
- **Rear-Facing**
- **Narrow**
- **2-Wheel**

Chair Style


**Stair Descent Speed by Sled SDDs:**
44 and 52 inch Staircase Widths

- **p values** (Width <0.001 Device <0.001 Device x width = 0.553)

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**Heart Rate Results**
**Heart Rate – Percent Max – Hand Carried SDDs**

![Bar chart showing heart rate data for different types of hand-carried stair descent devices.](chart1.png)

**Heart Rate – Percent Max – Track-type SDDs**

![Bar chart showing heart rate data for different track types of stair descent devices.](chart2.png)
Heart Rate – Percent Max
Sled Type SDDs

Results – Muscle Use
Hand-Carried SDDs – Stair Data Mean*time, (44” Width)

![Bar chart showing % maximum EMG x time for Erector Spinae and Latissimus Dorsi across different conditions: Ex (Extended), BC (Basic), FS (Fabric Seat), MC (Manual Carry).]

BC = Basic / FS = Fabric Seat / Ex = Extended Handles / MC = Manual Carry

Track Type SDDs: Stair Data Mean*time (1.12 and 1.32m):

![Bar chart showing % maximum EMG x time for Erector Spinae and Latissimus Dorsi across different track types: Std (Standard), LT (Long-Track), 2-W (2-Wheel), Nar (Narrow), RF (Rear-Facing).]

2-W = 2-Wheel / Nar = Narrow / Std = Standard / RF = Rear-Facing / LT = Long-Track
Latissimus
Dorsi

Narrow Chair

Track Type SDDs: Landing
(1.12 and 1.32m): Arm Muscles - 90th percentile

<table>
<thead>
<tr>
<th>Muscles</th>
<th>Std</th>
<th>Nar</th>
<th>2-W</th>
<th>LT</th>
<th>RF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deltoid</td>
<td>0.30</td>
<td>0.40</td>
<td>0.50</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bicep</td>
<td>0.20</td>
<td>0.30</td>
<td>0.40</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

2-W = 2-Wheel / Nar = Narrow / Std = Standard / RF = Rear-Facing / LT = Long-Track
**Sled-Type SDDs: Stair Data Erector Spine (Back) Muscles**

<table>
<thead>
<tr>
<th>SLED TYPE / EVACUATOR ROLE</th>
<th>% maximum EMG</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fabric Mat Follower</td>
<td>0</td>
</tr>
<tr>
<td>Inflatable Follower</td>
<td>5</td>
</tr>
<tr>
<td>Inflatable Leader</td>
<td>10</td>
</tr>
<tr>
<td>Fabric Mat Leader</td>
<td>15</td>
</tr>
<tr>
<td>Wheeled Leader</td>
<td>20</td>
</tr>
<tr>
<td>Hard Shell (Leader)</td>
<td>25</td>
</tr>
<tr>
<td>Roll-up Follower</td>
<td>30</td>
</tr>
<tr>
<td>Corrugated Leader</td>
<td>35</td>
</tr>
<tr>
<td>Corrugated Roll-up Follower</td>
<td>40</td>
</tr>
</tbody>
</table>
**Sled-Type SDDs: Landing Data**

**Latissimus Dorsi Muscles**

<table>
<thead>
<tr>
<th>SLED TYPE / EVACUATOR ROLE</th>
<th>% maximum EMG</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fabric Mat (Follower)</td>
<td>10</td>
</tr>
<tr>
<td>Corrugated (Follower)</td>
<td>15</td>
</tr>
<tr>
<td>Inflatable (Follower)</td>
<td>20</td>
</tr>
<tr>
<td>Roll-up (Follower)</td>
<td>25</td>
</tr>
<tr>
<td>Hard Shell (Follower)</td>
<td>30</td>
</tr>
<tr>
<td>Roll-up (Leader)</td>
<td>35</td>
</tr>
<tr>
<td>Inflatable (Leader)</td>
<td>40</td>
</tr>
<tr>
<td>Corrugated (Leader)</td>
<td>45</td>
</tr>
<tr>
<td>Wheeled (Leader)</td>
<td>50</td>
</tr>
<tr>
<td>Fabric Mat (Leader)</td>
<td>55</td>
</tr>
</tbody>
</table>

**Bicep Muscles**

<table>
<thead>
<tr>
<th>SLED TYPE / EVACUATOR ROLE</th>
<th>% maximum EMG</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inflatable (Leader)</td>
<td>10</td>
</tr>
<tr>
<td>Fabric Mat (Leader)</td>
<td>15</td>
</tr>
<tr>
<td>Corrugated (Leader)</td>
<td>20</td>
</tr>
<tr>
<td>Roll-up (Leader)</td>
<td>25</td>
</tr>
<tr>
<td>Inflatable (Leader)</td>
<td>30</td>
</tr>
<tr>
<td>Hard Shell (Leader)</td>
<td>35</td>
</tr>
<tr>
<td>Roll-up (Leader)</td>
<td>40</td>
</tr>
<tr>
<td>Inflatable (Follower)</td>
<td>45</td>
</tr>
<tr>
<td>Corrugated (Follower)</td>
<td>50</td>
</tr>
<tr>
<td>Wheeled (Follower)</td>
<td>55</td>
</tr>
<tr>
<td>Fabric Mat (Follower)</td>
<td>60</td>
</tr>
<tr>
<td>Roll-up (Follower)</td>
<td>65</td>
</tr>
</tbody>
</table>
Objective Measures - Analysis Summary

<table>
<thead>
<tr>
<th>Device</th>
<th>Positives</th>
<th>Negatives</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hand-Carried</td>
<td>Less Expensive Higher Physical</td>
<td>Demands Slower – Unless lead person can face forward</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Track-type</td>
<td>Reduced Back muscle use – Faster</td>
<td>Latissimus use – on stairs, landings</td>
</tr>
<tr>
<td>Sled-type</td>
<td>Low muscle demands on stairs.</td>
<td>Transfer in/out, High demands on Landing</td>
</tr>
</tbody>
</table>

Hand-Carried SDDs-Interviews

<table>
<thead>
<tr>
<th>Device:</th>
<th>Basic Stair Chair</th>
<th>Extended Handle Stair Chair</th>
<th>Fabric Seat</th>
<th>Manual Carry</th>
</tr>
</thead>
<tbody>
<tr>
<td>Positive Comments</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Lighter</td>
<td>Easier to set up</td>
<td>Handy</td>
<td>Easy, quick, gets job done</td>
</tr>
<tr>
<td></td>
<td>Smaller</td>
<td>All components lock</td>
<td>Easy to have in small bag</td>
<td>Can hold weight against chest</td>
</tr>
<tr>
<td></td>
<td>Easy operation</td>
<td>Wider</td>
<td>Easy operation</td>
<td>No rocking</td>
</tr>
<tr>
<td></td>
<td>More Portable</td>
<td>Natural position</td>
<td>Occupant torso up, away from body</td>
<td>Arms around occupant</td>
</tr>
<tr>
<td></td>
<td>Works in narrow spaces</td>
<td>Foot spacing better</td>
<td>Can keep arms straight</td>
<td>Less anxiety</td>
</tr>
<tr>
<td></td>
<td>Can keep arms straight</td>
<td>Hands shoulder-width apart</td>
<td>Can keep arms straight</td>
<td>More secure</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Synchronizing better</td>
<td>Can go faster</td>
<td>Requires less room to make turn</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>OK for 1-2 floors</td>
</tr>
<tr>
<td>Negative Comments</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Too narrow</td>
<td>Width makes it difficult to turn corners in tight spaces</td>
<td>Cumbersome to get occupant on it</td>
<td>Difficult to grip occupant, especially larger individuals</td>
</tr>
<tr>
<td></td>
<td>Hard to lift</td>
<td>Handle height</td>
<td>Straps get in the way</td>
<td>Stressful, especially for operators in turnout gear</td>
</tr>
<tr>
<td></td>
<td>Footing a problem</td>
<td>Difficult to lift higher</td>
<td>Handles hurt hands</td>
<td>Limits dexterity</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Difficult clearing steps during urgent condition (arms are at 90-degrees)</td>
<td>Need to use wider stance</td>
<td>Cannot see stairs</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Not sturdy enough</td>
<td>Cannot stop on stairs or landing to rest</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Cannot stop on steps or landing to rest</td>
<td>Cannot stop on stair to rest</td>
</tr>
</tbody>
</table>
### Track-type SDDs - Interviews

#### Device: Narrow 2-Wheel Standard Long Track Rear Facing

**Pros**
- Works well in narrow space
- Easy to move from track to wheel
- 4 wheels (available when on landing)
- Liked tracks
- Easy to pull back (easy to prepare for the stairs)
- Brakes (has a brake system)
- Smooth ride
- Easy (to get) around corners
- Simple, Fast effort to operate: maneuverability, and steering
- Good wheel placement - patient weight is between you and the wheels
- Moved easily on stairs
- Good for apt building and for lay people to use
- Handle bar with curve
- Didn’t have to bend over as much
- Easier to operate
- 4 wheels on landing
- Easy to use (tracks) caught (gripped) stairs well
- Sturdy, Wider
- Easy to steer
- Easy to turn on landing
- Doesn’t take off on you
- Liked brake
- Tracks can stop device
- More controlled speed
- Simp easy to put on but a little cumbersome
- Descent was smooth
- Had control on stairs
- Liked patient facing me - can observe patient
- When tilt patient back, (their) legs don’t get in way so (I) can make a tighter turn
- Treads easy to control

**Cons**
- Narrow device
- Rocks a lot with larger patient
- Tended to tilt sideways
- Slides sideways
- No place to kick it back like on hand truck
- Hand position limits balance
- Takes a little time to get used to
- Hard to maneuver corner on narrow staircase
- Can’t put (rear) wheels down at end of stairs (when on landing)
- (Rear) Wheels not in fixed down position
- On landing, bar in front of wheels got in way
- More difficult to set up
- Noisy – minor issue
- Lap swivel belt hard to use
- Most difficult to use
- Rough (difficult) transition from stairs to landing
- Braking system is counter intuitive
- Handle too low
- Operator’s foot got caught on back bar with weight of patient on his toes
- Hard to maneuver because of length
- Have to change hand position while in motion
- Requires large radius for turning
- Required a lot of lifting at turns and therefore more energy
- No second set of wheels to put device down (during turns)
- Patient faces you - may be uncomfortable for patient

### Sled Type SDDs - Interviews

#### Device: Corrugated Fabric Mat Hard Shell Inflatable Roll-up Wheeled

**Positive Design Features**
- 2-Handle straps – good length
- Easy to get around corner
- Low profile
- Wide Strap- Good length
- Good Friction
- Easy to get around corner
- None
- More rigid – less lateral swing
- Easy to get around corner
- Friction from material

**Negative Design Features**
- Length makes getting around corner tough
- None
- Lack of control
- Hard to turn
- Strap could slip
- Top heavy-
- tendency to tip
- Hard to get around corner
- Bulky
- Could slide to fast
- Long thin strap difficult to grip*
- Position of single operator in front of patient / Bending
- Head-end swing on landing, Awkward to push down on patient’s legs

**% that would Recommend**
- Fire service / Building owners
  - 42% / 67%
  - 50% / 58%
  - 0% / 25%
  - 0% / 25%
  - 58% / 58%
  - 8% / 25%
Consumer Opinion Study

• 2 Components
  – First Impressions
    • Collect initial perceptions of the 13 devices used in the prior studies
    • Asked which, if any, devices they would like to try
  – Post descent impressions
    • Participants will be taken down 2 flights of stairs in up to 5 different devices.

Initial Impression Survey

Transfers
Safety
Security
Nervousness
**Initial Impression Survey**

1. How easy would it be for you to transfer into the device?
   - very difficult / difficult / somewhat difficult / somewhat easy / easy / very easy

2. How easy would it be for you to transfer out of the device?
   - very difficult / difficult / somewhat difficult / somewhat easy / easy / very easy

3. How safe would you feel riding in this device?
   - very unsafe / unsafe / somewhat unsafe / somewhat safe / safe / very safe

4. How securely do you think the straps would hold you?
   - very unsecurely / unsecurely / somewhat unsecurely / somewhat securely / securely / very securely

5. How nervous would you be about riding in the device?
   - very nervous / nervous / a little nervous / not at all nervous

---

**Post-Ride Survey**

1. How easy was it for you to transfer into the device?
   - very difficult / difficult / somewhat difficult / somewhat easy / easy / very easy

2. How easy was it for you to transfer out of the device?
   - very difficult / difficult / somewhat difficult / somewhat easy / easy / very easy

3. How safe did you feel riding in this device?
   - very unsafe / unsafe / somewhat unsafe / somewhat safe / safe / very safe

4. How securely did the straps hold you in the device?
   - very unsecurely / unsecurely / somewhat unsecurely / somewhat securely / securely / very securely

5. After having ridden in this device, how nervous would you be if we asked you to repeat the ride in the device?
   - very nervous / nervous / a little nervous / not at all nervous

6. For an emergency evacuation, were you sufficiently comfortable riding in the device? (Y/N)
After the completion of all rides selected by a participant...

- Which of these devices would be acceptable to you for emergency evacuation from a multi-story building?
- Are there any specific design features you liked or disliked about the devices you rode in today? Please explain.
- Is there anything else you would like to tell us about the devices you have seen today?

Participants

- **Total**
  - 14 participants
    - 8 male
    - 6 female
- **Age range**
  - 29 – 63 years (avg. 49.2 years)
- **Weight**
  - 106 – 365 lb (avg. 208.6 lb)
**Participants**

- **Disabilities**
  - Amputation, arthritis, CVA, diabetes, hearing impairment, low back pain, low vision, paraplegia, quadriplegia, post-polio, spina bifida
- **Mobility aids**
  - Cane, walker, manual wheelchair, powered wheelchair, prostheses

**Initial Impressions**

- **Transfers In/Out** - Easiest for Carry-Type and 4 wheeled track type
**Initial Impression**

- **Safety**
  - Concern over carrying full weight
  - Raised edges of Hardshell and Inflatable added to safety

- **Nervousness**

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6/12/2019
Which of these devices would be acceptable in emergency evacuation situation?

Post-Ride

- **Transfer in and out**
  - Same or improved
- **Nervousness**
  - Same or improved
- **Security**
  - Same or improved
- **Safety**
  - Less safe (2)
  - Unchanged (5)
  - More safe (2)
- **Trial use**
  - Opinion changed in half of instances
Consumer preference (acceptable) rating vs. operator % maximum heart rate

Overall Study Limitations

- Weight of the occupant in FF trials
- Relatively short duration evacuations
Key points re: 2019 Standard

- Performance tests broadened to apply to any design type
- Content broken up into 2 sections
  - Section 1
    - Terminology, Description, & Performance
  - Section 2
    - Inspection, Installation, & Maintenance
Key points re: 2019 Standard

• Section 1
  – Occupant features
  – Weight capacity
  – Stability
  – Maneuverability

Key points re: 2019 Standard

• Section 2
  – Storage location
  – Inspection schedule
  – Maintenance
Weight Capacity

• Occupant features
  – Weight capacity
    • 350 lb (159 kg), min.
  – Test method
    • 1.5 x weight capacity
      – 350 lb, test at 525 lb

Figure D1. Isometric view – Metal sample test dummy assembly
**Weight Capacity**

- Occupant features
  - Weight capacity
    - 350 lb (159 kg), min.
  - Test method
    - 1.5 x weight capacity
      - 350 lb, test at 525 lb

**Stability**

- Stability
  - Configuration for travel on **Horizontal Surfaces**
    - Forward: 10 degrees
Stability

• Stability
  – Configuration for travel on **Horizontal Surfaces**
    • Forward: 10 degrees
Stability

- Stability
  - Configuration for travel Downward
    - Forward: 32.5 degrees

Maneuverability

- Perform 180-degree turn through code-compliant stairway and landing
- Device loaded with mannequin
- Contact with partitions is allowed
Key points re: 2019 Standard

- Section 1
  - Occupant features
  - Weight capacity
  - Stability
  - Maneuverability

Key points re: 2019 Standard

- Section 2
  - Storage location
  - Inspection schedule
  - Maintenance
Summary re ANSI/RESNA ED-1

- 2019 Edition has been approved by RESNA and ANSI
- Covers devices made available January 1, 2020 and after
- Devices of any design type can be tested for compliance
- Sec 01 for Performance
- Sec 02 for Installation & Inspection

Summary- Evacuation Tests

- Track-type devices preferred
  - Evacuation speed
  - Physical Demands
  - Ingress / Egress for occupant
- If a hand-carried device is used - device width and handles should support lead person descending facing forwards.
- Sled-type devices – acceptable for evacuator but getting in/out is a concern for the occupant.
Acknowledgement

- Federal Emergency Management Agency Assistance to Firefighters Grant Program
  - 2009-EMW-FP-01944

Questions?

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