Passive Safety of Standing Passengers in Public Transportation

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Accessibility, Comfort & Ergonomics

Passive Safety & Protection

Injury risk assessment & simulation

Orthopedic surgery & Rehabilitation

Motion Analysis & Physiology

Emergency situation Pre-crash – Balance ...

A thematic continuum dedicated to human mobility modeling: a physical and biomechanical approach
Context and Objectives

• Problematics: Standing passengers in public transportation are vulnerable: in the case of a sudden deceleration
  • They may be subjected to movements of great amplitude
  • Possible injuries due to impacts on interior fittings
• … A worsening problem:
  – More and more standing passengers ↔ “open spaces”, improved accessibility, …
  – An aging population
  – Road traffic more and more complex,
    • share the traffic with road vehicles,
    • especially at crossroads
Context and Objectives

Objectives [SafeInteriors project]
- Determine trends of standing occupants kinematics under emergency braking conditions
- Evaluate injury risk when head impacts a grab pole during a crash

Recommendations to designers concerning interior layout and acceleration/braking features of public transports
Standing occupants kinematics
Emergency braking: need to perform testing with live human subjects

Importance of the reactivity in the kinematics
Standing occupants kinematics: *methods*

Volunteers are standing on a mobile platform initially still.

The platform is suddenly moved towards the subject without notice.

Platform acceleration pulse measured for 6 tests and the theoretical corridor defined for urban and peri-urban trams.

Launching cart

Mobile platform

Impulse

Breaking

Displacement

Stop

**Displacement**

**Breaking**

**Impulse**

**Displacement Stop**
Standing occupants kinematics: **methods**

- 10 young healthy males
  - Individual protection (harness, mattress, net)
- 6 configurations mixing orientation of body and use of a buttock support and grabpole

- Surface markers on head, hip, ankles
- Video recording @250 fps
- Tracking of markers provides their trajectories and velocities
- Questionnaires filled by the subjects (to evaluate their filling of desequilibrium…)

![Images of standing occupants in various configurations](image-url)
Standing occupants kinematics: results

- Example
Standing occupants kinematics: results

- Example of head tangential velocities vs horizontal displacement

<table>
<thead>
<tr>
<th></th>
<th>min</th>
<th>max</th>
</tr>
</thead>
<tbody>
<tr>
<td>Head velocity (m/s)</td>
<td>0.45</td>
<td>3.6</td>
</tr>
<tr>
<td>Excursion (m)</td>
<td>0.3</td>
<td>2.38</td>
</tr>
</tbody>
</table>
Standing occupants kinematics: results

- **Kinematics trends:**
  - Subjects forced to perform steps to preserve their balance
  - Different strategies
    - some subjects prepare themselves before the pulse and make steps to resist the forced motion.
    - others try to keep their torso upright without resisting and finish their course in the foam mattress
    - crossing the legs / making “chassé” lateral steps (sideward facing)
  - Influence of the direction
    - Rearward facing configuration is the most critical
      - all the subjects finish their course in the mattress
    - Sideward facing situation is also critical for some subjects
    - Forward facing situation is easier to control for subjects
  - Duration of the pulse seems to have a great effect on balance recovery
  - Use of a buttock rest increases the stability (even in the sideward direction)
  - Use of a grab pole provides a good restraint effect and limits the excursion of the body
Toward the simulation of the balance recovery kinematics

- **Principle**
  - A human body representation is placed in a close loop with a controller
  - At each time-step, the best control actions that will zero the CoM velocity is decided and applied.
Toward the simulation of the balance recovery kinematics

- **Principle**
- **Control actions**
  - Moving the center of pressure
  - Rotating the upper body
  - Making a step
Toward the simulation of the balance recovery kinematics

- Principle
- Control actions
- Example of results
Evaluation of Head Injury Risk

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Evaluation of Head Injury Risk

What is the risk of head injury when impacting a grabpole during a crash or an emergency braking?

- Statistics identify the head as the most exposed part of the body.
- Grab poles are the most common furniture in standing areas.
Evaluation of Head Injury Risk: methods

- Head impact initial conditions

**REFERENCE SCENARIO**

« What is the most common way to impact a grabpole? »
- Passenger standing 25 to 50cm from a pole
- Lack of reaction prior to impact with a grabpole

**SAFEINTERIORS BACKGROUND**

- Reference scenario
- Multi-body simulations

**CRASH PULSE**

- Impact velocity: 5.23m/s
- Head angle: 24.5°
- Impact height: 1.75m
- Head Offset: 0

**STANDARD IMPACT CONDITIONS**

- Theoretical pulse and accepted corridor
Evaluation of Head Injury Risk: \textit{methods}

\begin{align*}
\text{STANDARD IMPACT CONDITIONS} & \quad \downarrow \\
\text{EFFECT OF PARAMETERS ON INJURY RISK} & \quad \downarrow \\
\text{PHYSICAL TESTING} & \quad \text{Component test on a rig} \quad \downarrow \\
\text{NUMERICAL TESTING} & \quad \text{Equivalent FEM} \quad \downarrow \\
\left[ \frac{1}{t_2 - t_1} \int_{t_1}^{t_2} \text{adt} \right]^{2.5} (t_2 - t_1) & = 0.75446 \times \text{HIC} + 166.4 \\
\text{INJURY RISK EVALUATION} & \quad \downarrow 
\end{align*}
Evaluation of Head Injury Risk: methods

PHYSICAL TESTING

EVALUATION TOOL: FMVSS201 HEADFORM
Hybrid III headform without nose
Assessing interiors in automotive industry

VERTICAL TEST RIG
1 – Headform with its fixings
2 – Grabpole
3 – Honeycomb
4 – Grabpole structure
5 – Motorized sled
6 – Release arm
7 – Free Fall sled
8 – High-speed camera
9 – Test rig guides
Evaluation of Head Injury Risk: methods

NUMERICAL TESTING

ALTAIR FREE MOTION HEADFORM
- Aluminum skull (Rigid Body)
- Hyperelastic foam skin (Law 42)

GRABPOLE FEM
- Shell elements (2D)
- Size: 2200 x 35mm (wall thickness: 2mm)
- Stainless steel 304 through Johnson-Cook Law

Validation through experimental results

ACCELERATION OF THE HEAD

\[ a(t) \]
Evaluation of Head Injury Risk: results

**GENERAL TREND**
- Linear relation between HICd and impact velocity
- Values of HICd $\rightarrow$ moderate injury risk: 20% chance to sustain an AIS2+ injury

\[ \text{AIS = Abbreviated Injury Scale} \]
Evaluation of Head Injury Risk: results

- Strong effect of the impact height

Tall passengers are more at risk: 20% chance to sustain an AIS3+ injury

![Graph showing the relation between impact height and HICd](image)
Conclusion & Perspectives

• Standing passengers submitted to an emergency braking
  – Analysis of volunteers kinematics shows that subjects achieve different performance levels
  – Rearward facing configuration is demonstrated to be the most critical situation
  – Use of grabpole or buttock rest allows to reduce the excursion on the platform
  – Head velocity may reach up to 3.6 m/s
    • could be higher for elderly passengers due to large modification of reaction time, joint mobility and muscular power
    • May induce moderate injuries when head impacts a grab pole
Conclusion & Perspectives

• Standing passengers submitted to a crash deceleration
  – Lack of reaction (duration of the pulse is too short)
  – Case of head impact against a grab pole
    • Injury evaluation with a simple and repeatable methodology
    • Moderate injury risk
      – However some populations are more at risk
        » Tall passengers: risks are much higher when impact takes place where the grabpole is the most rigid (close to its fixings)
        » Elderly passengers
    • Need to still reduce injury risk to allow the full evacuation of the vehicle after a crash.
• Limitations
  – no fully adapted criteria: HICd takes into account only linear accelerations
  – only one kind of population
• Another scenarios could be investigated
  • Impacts against a rigid structure of the vehicle, falls, …
Thank you
Any questions?

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