Measurement of Head Acceleration and Angular Rate Experienced by Aerobatic Pilots

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Outline

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Introduction

• Automotive industry utilizes accelerometer technology in impact testing
• Plastic-molded ear plugs
• In-ear accelerometers measure accelerations at head-level
• Recent research in race car drivers, football players, boxers, and rodeo riders
Introduction

- Aerobatic pilots exposed to wide range of G’s
- Non-impact acceleration, but can cause neuro-vestibular symptoms
- G-meter only records Gz values
- +Gz’s: gray-out, black-out, and G-induced loss of consciousness
- -Gz’s: head fullness, headache, vision changes, decreased heart rate, arrhythmias, and red-out
Problem

- No tri-axial accelerations previously published
- Actual forces experienced at head-level during aerobatic flight have never been characterized
- Vertigo or gait abnormalities may represent G-induced vestibular dysfunction (GIVD) or “the wobblies”
- Thought to be associated with high - G’s
- Sxs may lead to safety of flight or career-limiting effects
Specific Aims

• 1) Measure the magnitude of linear accelerations and angular rates experienced at head-level by aerobatic pilots
• 2) Compare data obtained at head-level to that of the plane
Background

- Muller: first case report of G-induced vestibular dysfunction (GIVD) or “the wobblies”
- 41 year old aerobatic pilot
- Reported spinning sensation with nausea after -7 G maneuver
- Pilot had unsteady gait and fine horizontal nystagmus upon exiting the airplane
- Diagnosed with Benign Paroxysmal Positional Vertigo (BPPV) and treated using the Epley maneuver
- Against medical advice, the pilot continued to fly and completed the aerobatic competition without recurrence

Background

• Authors proposed GIVD similar to post-traumatic BPPV
• Rather than a blunt force, G forces could cause otoconia displacement
• May be related to head movements during G exposure
• Complex area of study warrants further investigation

Background

• Muller: survey during the World Aerobatics Championships in 1998
  ▫ “More than 75% of team members from the U.S., Britain, Australia, Russia, Switzerland, Hungary, and Slovakia had experienced at least one episode of GIVD”
  ▫ Only French team stated GIVD was infrequent
• Williams et al conducted a survey among a wide range of civilian aerobatic pilots in 1996
  ▫ 12.7% of respondents (mean peak -8 Gz) reported persistent vertigo after aerobatic flight with exposure to negative G’s
• Doesn’t include pilots with vestibular problems early in their careers/those involved in fatal mishaps


Methods

Diversified Technical Systems (DTS) designed and built tri-axial accelerometers, angular rate sensors, data recorders, and software
Methods
Methods
Results

- Complete readings from both plane and pilot for a 10-minute practice run were successfully collected from five subjects.
- Max pilot and plane linear accelerations and angular velocities highly correlated (correlation coefficients: 0.77, 0.91, 0.91, 0.90, 0.88)
Comparison of mean linear acceleration and angular velocity for pilot v plane

<table>
<thead>
<tr>
<th>Axis</th>
<th>Pilot (95% CI)</th>
<th>Plane (95% CI)</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Positive linear x (G)</td>
<td>4.76 (3.2 to 6.3)</td>
<td>8.24 (3.8 to 12.7)</td>
<td>0.100</td>
</tr>
<tr>
<td>Negative linear x (G)</td>
<td>-6.90 (-8.1 to -5.7)</td>
<td>-7.86 (-13.1 to -2.7)</td>
<td>0.635</td>
</tr>
<tr>
<td>Positive linear y (G)</td>
<td>2.28 (1.9 to 2.6)</td>
<td>10.44 (2.0 to 18.9)</td>
<td>0.053</td>
</tr>
<tr>
<td>Negative linear y (G)</td>
<td>-4.80 (-11.1 to 1.45)</td>
<td>-9.82 (-20.3 to 0.6)</td>
<td>0.316</td>
</tr>
<tr>
<td>Positive linear z (G)</td>
<td>5.30 (3.4 to 7.2)</td>
<td>13.96 (1.6 to 26.4)</td>
<td>0.129</td>
</tr>
<tr>
<td>Negative linear z (G)</td>
<td>-5.88 (-9.9 to -1.9)</td>
<td>-19.4 (-39.5 to 0.7)</td>
<td>0.149</td>
</tr>
<tr>
<td>Positive angular x (deg/s)</td>
<td>277.42 (196.6 to 358.2)</td>
<td>460.66 (305.1 to 616.2)</td>
<td>0.013</td>
</tr>
<tr>
<td>Negative angular x (deg/s)</td>
<td>-384.66 (-404.6 to -364.7)</td>
<td>-425.64 (-649.3 to -201.9)</td>
<td>0.653</td>
</tr>
<tr>
<td>Positive angular y (deg/s)</td>
<td>255.98 (172.7 to 339.2)</td>
<td>190.46 (121.0 to 259.9)</td>
<td>0.154</td>
</tr>
<tr>
<td>Negative angular y (deg/s)</td>
<td>-282.64 (-335.4 to -229.8)</td>
<td>-185.68 (-281.1 to -90.3)</td>
<td>0.058</td>
</tr>
<tr>
<td>Positive angular z (deg/s)</td>
<td>294.22 (184.0 to 404.4)</td>
<td>154.1 (111.4 to 196.8)</td>
<td>0.014</td>
</tr>
<tr>
<td>Negative angular z (deg/s)</td>
<td>-382.8 (-473.1 to -292.5)</td>
<td>-137.68 (-220.1 to -55.6)</td>
<td>0.004</td>
</tr>
</tbody>
</table>
Example Plot: Resultant accelerations of pilot v plane for a test run.
Results

• Pilot accelerometer Gz’s highly correlated to G-meter: 0.79 for +Gz and 0.76 for –Gz
• Plane accelerometer Gz’s correlated with removal of test run 1: 0.70 for +Gz and 0.99 for -Gz
• No reported GIVD from 10 to -6 G’s as recorded by each aircraft’s G-meter
Discussion

• First Aim
  ▫ Data successfully collected during five practice runs at the 2009 US National Aerobatic Championships

• Second aim
  ▫ Max and min parameter comparison
  ▫ Paired t-tests of mean value for each parameter
  ▫ G-meter comparison
    · Test run 1 plane accelerometer recorded very extreme values
    · May have been valid, but could have been fleeting
    · Increased sample size to see if values are plausible
Discussion

- No similar studies in aerobatic pilots
- Dr. Watkins: peak resultant linear acceleration for the bull rider was 26 G’s/bareback rider was 46 G’s
- Dr. Mathers: bareback riders exposed to twice the level of accelerations as bull riders
- Max G’s were 27.6, 17.5, and 24.9 while max angular rates were 2109.7, 2864.7, and 2228.7 deg/s in the x, y, and z axis respectively
- Rough stock riders are exposed to higher positive G’s and angular velocities several orders of magnitude higher than those of the aerobatic pilots
- Aerobatic pilots represent unique population to study negative G’s
Discussion: Limitations

- Small sample size
- Only males
- Subjects do not include air show performers who may pull varying amounts of G’s
- Confidence intervals demonstrated wide ranges and several included zero
- Test run one plane accelerometer values
- Flat surface not always available for airframe accelerometer
- Equipment settings
  - Less sampling
  - Only values for specified time collected
  - Angular acceleration
  - Could sync with video
- No comparison among pilots
Future Applications

- Experimental sensors are capable of measuring a large array of forces that have not been routinely captured from G-meter data.
- Further data collection may capture values associated with neurovestibular effects such as GIVD.
- Once values for neurovestibular effects are quantified, clinical models can be devised to predict adverse effects for certain non-impact head-level accelerations and angular rates.
- Mitigation strategies can then be developed and employed to prevent such occurrences.
Conclusion

• Head-level data can be successfully collected and correlated using tri-axial accelerometers and angular rate sensors
• Aerobatic pilots experience a large range of linear accelerations, which appear to be well correlated to their aircraft.
• Future work in this field may involve clinical modeling of G-effects based on head-level accelerations and angular rates.
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References

Questions?