Towards Effective Design Treatment for Right Turns at Intersections with Bicycle Traffic

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TOWARD EFFECTIVE DESIGN TREATMENTS FOR RIGHT-HOOK CRASHES AT INTERSECTIONS WITH BICYCLE TRAFFIC

PSU FRIDAY SEMINAR
FEBRUARY 5, 2015

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Mafruhatul Jannat, PhD ’15, OSU
Jennifer Warner, MS ’15, OSU
Ali Razmpa, MS candidate, GRA, PSU
Crash Review (2007-2011), Statewide

4,072 reported bicycle-involved crashes
504 (12.3%) typed as a “potential” right-hook crash
Potential Right Hook Crash, 504, 12%

Bicycle-Car Crash, 3568, 88%
Right-Hook Severity Summary

- PDO: 4.2%
- A: 5.8%
- B: 61.7%
- C: 27.8%
- K: 0.6%
Driveway, 133, 26%

Intersection, 371, 74%
Traffic Signals, 267, 72%
Minor Stop, 88, 24%
4-Way Stop, 14, 4%
No Control, 2, 0%
Right-Hook Crash Scenarios (Intersection with bike lane)

onset of the green indication

at a stop sign

cyclist passing motorist

motorist passing cyclist

Latter portion of green indication
Right-Hook Crash Scenarios (Intersection with bike lane)

onset of the green indication

at a stop sign

cyclist passing motorist

motorist passing cyclist

Latter portion of green indication
# Methodology

<table>
<thead>
<tr>
<th>Simulator Experiment 1</th>
<th>Field Validation</th>
<th>Simulator Experiment 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Experimentally verify the influence of four factors that potentially contribute to right-hook crashes.</td>
<td>• Validate through field observations the motorist-bicyclist interaction exhibited in Simulator Experiment 1.</td>
<td>• Evaluate the effectiveness of four categories of treatments to mitigate right-hook crashes.</td>
</tr>
</tbody>
</table>
OSU Driving Simulator

View from outside the car

View from inside car w/bicycle
ASL Mobile Eye-Tracker

Scene & Eye Camera

Computer & Control Unit
Simulator Experiment 1

Purpose:
• Examine motorist behavior in response to four factors that potentially contribute to right-hook crashes.

Research Objectives:
• Determine how motorists’:
  • visual attention
  • situational awareness
  • crash avoidance
• is influenced by the experimental factors.
## Experiment 1 – Independent Variables

<table>
<thead>
<tr>
<th>Name of the Variable</th>
<th>Levels</th>
</tr>
</thead>
<tbody>
<tr>
<td>Relative position of bicyclist</td>
<td>None</td>
</tr>
<tr>
<td></td>
<td>One (1) bicyclist riding in front of the motorist in an adjacent bicycle lane to the right</td>
</tr>
<tr>
<td></td>
<td>One (1) bicyclist coming from behind the motorist in an adjacent bicycle lane to the right</td>
</tr>
<tr>
<td>Speed of bicyclist</td>
<td>Lower (12 mph)</td>
</tr>
<tr>
<td></td>
<td>Higher (16 mph)</td>
</tr>
<tr>
<td>Presence of oncoming vehicular traffic</td>
<td>None</td>
</tr>
<tr>
<td></td>
<td>Three (3) vehicles</td>
</tr>
<tr>
<td>Presence of conflicting pedestrian</td>
<td>None</td>
</tr>
<tr>
<td></td>
<td>One (1) pedestrian walking towards the motorist</td>
</tr>
</tbody>
</table>
Experiment I – Experimental Drives

Start Line

Finish Line

RT 1

RT 2

RT 3

656 ft.

1312 ft.

656 ft.

1312 ft.
Experiment 1 – Data Acquisition

Participants:
• 67 Participated
• 16 Simulator Sickness
• 51 Usable
• 1,071 total-right turn scenarios

Data:
• Visual attention
• SAGAT responses
• Observed crashes
• Position and speed of vehicles, bicycles, and pedestrians
Visual Attention – Areas of Interest (AOIs)
Visual Attention – Avg Total Fixation Durations (ATFD)

- Pedestrian: 3.69 sec
- Bicyclist: 0.32 sec
- Signal overhead: 0.23 sec
- Signal_side: 0.11 sec
- RV mirror: 0.34 sec
- Side mirror: 0.46 sec
- Oncoming veh: 2.26 sec

(Chart showing average and range of fixation durations for different objects.)
Mean percentage of correct responses to situation awareness (SA) queries for different intersection conditions

<table>
<thead>
<tr>
<th>Levels of Situation Awareness (SA)</th>
<th>Percent Correct Response to Queries</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base Condition</td>
<td>61%</td>
</tr>
<tr>
<td>Opposing Veh</td>
<td>70%</td>
</tr>
<tr>
<td>Bike Ahead</td>
<td>63%</td>
</tr>
<tr>
<td>Bike Behind</td>
<td>48%</td>
</tr>
<tr>
<td>Level 1 SA</td>
<td></td>
</tr>
<tr>
<td>Level 2 SA</td>
<td>41%</td>
</tr>
<tr>
<td>Level 3 SA</td>
<td>39%</td>
</tr>
<tr>
<td>Overall SA</td>
<td>37%</td>
</tr>
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<td></td>
<td></td>
</tr>
<tr>
<td>Level 2 SA</td>
<td>37%</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>Level 3 SA</td>
<td>39%</td>
</tr>
<tr>
<td></td>
<td>38%</td>
</tr>
<tr>
<td></td>
<td>42%</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>Overall SA</td>
<td>49%</td>
</tr>
<tr>
<td></td>
<td>46%</td>
</tr>
<tr>
<td></td>
<td>42%</td>
</tr>
</tbody>
</table>

Levels of Situation Awareness (SA): Base Condition, Opposing Veh, Bike Ahead, Bike Behind

Oregon State University
Mean percentage of correct responses to situation awareness (SA) queries for different intersection conditions

Levels of Situation Awareness (SA)

<table>
<thead>
<tr>
<th>Levels of SA</th>
<th>Base Condition</th>
<th>Opposing Veh</th>
<th>Bike Ahead</th>
<th>Bike Behind</th>
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<tr>
<td>Level 1</td>
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<td>38%</td>
<td>42%</td>
<td>42%</td>
</tr>
<tr>
<td>Overall</td>
<td>54%</td>
<td>49%</td>
<td>46%</td>
<td>42%</td>
</tr>
</tbody>
</table>
Crash Avoidance: Time-to-Collision (TTC)

- Simulator:
  - Time-to-collision is a continuous value that changes in time
  - Bikes in simulator do not change speed.

- Field
  - Post-encroachment time (PET) is a discrete time measurement
Crash Avoidance: Crashes

From 1,071 right turns, 26 collisions observed:
• 66% did not check mirror before turning
• 5% looked but didn’t see
• 18% assumed the bike would yield or there was enough time
Crash Avoidance: Time To Collision (TTC)

Scenario: Bicyclist (16 mph) behind, three oncoming vehs, and no ped
Crash Avoidance: Time To Collision (TTC)

Scenario: Bicyclist (16 mph) behind, three oncoming vehs, and no ped

TTC (s)
Crash Avoidance: Near-Crashes

From 408 right turns, 28 near-collisions observed:
• 58% did not check mirror before turning
• 23% looked but didn’t see
• 19% assumed bike would yield or there was enough time
Field Validation

- November 5, 2014 to February 12, 2015
- All days of week
- 144 hours

- Extraction of 43 events with measured PET < 5 seconds
Comparison of All Field and Simulator PET/TTCs

PET/TTC (s)

0-0.9 1-1.5 1.5-2 2-2.5 2.5-3 3+

Frequency

0 5 10 15 20 25 30

0% 10% 20% 30% 40% 50% 60% 70% 80% 90% 100%

Field Simulator
Simulator Experiment 2

**Purpose:**
- Examine motorist behavior in response to four different categories of right-hook crash treatments

**Research Objectives:**
- **Identify engineering countermeasures** that will reduce frequency and severity of RH crashes
- **Evaluate and compare** these countermeasures
- **Provide guidance to ODOT** regarding the selection of design countermeasures
Experiment 2 - Independent Variables

**SIGNAGE**

- ODOT OR10-15b “Turning Vehicles Yield to Bicycles”

**PAVEMENT MARKINGS**

- Dashed white bike line with stencil, single line
- Dashed white bike line with stencil, double line
- Dashed green bike lanes with white outline
- Full green bike lane with dashed white outline

**CURB RADIUS**

- Larger curb radii, 30ft
- Smaller curb radii, 10ft

**PROTECTED INTERSECTIONS**

- With islands
- With islands and green pavement markings
Experiment 2- Experimental Drives

**Diagram Description:***
- **RT1** and **RT2** are located at the starting point.
- **RT3** and **RT4** are located at the finish line.
- Distances:
  - 2153 ft. from RT1 to RT2
  - 1077 ft. from RT1 to RT4
  - 1077 ft. from RT2 to RT3
  - 1077 ft. from RT3 to RT4

---

**Related Logos:**
- Portland State University
- Oregon State University
Experiment 2- Data Acquisition

Participants:
- 46 Participated
- 18 Simulator Sickness
- 28 Usable
- 616 total-right turn scenarios

Data:
- Observed crashes
- Visual attention
- Position and speed of vehicles, bicycles, and pedestrians
Experiment 2- Visual Attention... ATFD
Experiment 2 - Visual Attention... ATFD
Experiment 2 - Visual Attention... ATFD

Average Total Fixation Duration, by Signage Treatment Level

- Dutch Intersection Island
- Dutch Intersection Pavement Marking
- Signage
- Pavement Marking
- Signal
- Turning Vehicle
- Rear-mirror
- Side-mirror
- Bicyclist
- Bicyclist in Rear-mirror
- Bicyclist in Side-mirror

Duration (sec)

S0
S1
Experiment 2 - Visual Attention... ATFD

Average Total Fixation Duration, by Signage Treatment Level

- Dutch Intersection Island
- Dutch Intersection Pavement Marking
- Signage
- Pavement Marking
- Signal
- Turning Vehicle
- Rear-mirror
- Side-mirror
- Bicyclist
- Bicyclist in Rear-mirror
- Bicyclist in Side-mirror

Duration (sec)

0.00 0.25 0.50 0.75 1.00 1.25 1.50 1.75 2.00 2.25 2.50 2.75

S0
S1
Experiment 2- Visual Attention... Motorist Fixation on Bicyclist

<table>
<thead>
<tr>
<th>Frequency of fixation</th>
<th>Signage</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>S0</td>
</tr>
<tr>
<td>Total (n)</td>
<td>296</td>
</tr>
<tr>
<td>Fixated</td>
<td>228</td>
</tr>
<tr>
<td>%</td>
<td>77%</td>
</tr>
</tbody>
</table>
Experiment 2 - Crash Avoidance
Experiment 2 - Crash Avoidance

Distribution of TTC Values by Treatment D Level

- Frequency
- TTC Value (sec)
- Cumulative Frequency
- D0
- D1
- Cumulative Frequency, D0
- Cumulative Frequency, D1
Experiment 2- Crash Severity
Final Comparison

• Each treatment was evaluated based on the following:

• Visual attention
  • Measurable change in longer AFTD towards bicycle targets

• Crash avoidance
  • Frequency of low and moderate TTC observations

• Crash severity
  • Speed of turning vehicles and variance of speed
<table>
<thead>
<tr>
<th>Performance Measures</th>
<th>S1</th>
<th>PM1</th>
<th>PM2</th>
<th>PM3</th>
<th>PM4</th>
<th>C1</th>
<th>PI1</th>
<th>PI2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Visual Attention</td>
<td>✓</td>
<td></td>
<td>✓</td>
<td></td>
<td></td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Crash Avoidance</td>
<td></td>
<td>✓</td>
<td></td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Potential Crash Severity</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Survey</td>
<td>n/a</td>
<td></td>
<td>✓</td>
<td></td>
<td></td>
<td>n/a</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Symbols: ✓ = Present, × = Absent, * = Partially Present, ** = Highly Present.
Recommendations

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ODOT OR10-15b
“Turning Vehicles Yield to Bicycles”

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Acknowledgements

**PhD Student:**
- Mafruhatul Jannat, PhD ’15, OSU

**MS Students:**
- Jennifer Warner, MS anticipated spring 2015, OSU
- Ali Razmpa, MS anticipated spring 2016, PSU

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- Amy Wyman, UHC anticipated spring 2017, OSU
- Kayla Fleskes, BSCE anticipated spring 2016, OSU
- Katie Mannion, BSCE anticipated spring 2016, OSU
- Amber Meeks, BSCE anticipated spring 2018, OSU
Questions?

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