

Visual Occlusion to Assess the Demands of Driving and Tasks: the Literature

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Topics to Be Covered

Initial references on visual occlusion method to assess demands of primary driving task to provide context for current research to provide insights into the method

Current work at UMTRI

Assume that other recent work (TNO, German U studies, Japan, etc.) will be covered by others

Why Was the Occlusion Method Originally of Interest?

Driving is a visual task. If the vehicle operator cannot see, they cannot drive. Therefore, determining how often the driver needs to look at the road and for how long provides a basis for determining the visual demand (workload) of driving. Presumably, any time in excess of those limits is available for other purposes, such as interacting with in-vehicle system, though operating at the limits of performance provides a slim safety margin for unexpected events.

How Did the Idea Originate?

Senders, et al (1972) - Highway Research Record, p .16

"Some of our theoretical notions arose from some personal observations made by the senior author while driving on a straight road with little oncoming traffic. A heavy rain resulted in the windshield wipers being about to clear only a small sector of about 20 degrees behind the blade, so that visual conditions for the driver were somewhat analogous to those which would be presented by a radar sweep. The wiping speed was independent of the speed of the car. The driver became aware of a "psychological speed limit." Up to that speed, there was no anxiety; above that speed the driver became anxious and had to slow down."

How Can Occlusion Be Implemented?

1. Eyes Closed Method

"close your eyes whenever you can"
 on surface, the most natural method
 no control over open or closed durations
 not commonly used

Recording methods

1. stopwatch - challenging if not for isolated events,
2. video - requires laborious frame-by-frame analysis
3. EOG - no reports of use, requires skill

2. Motorcycle Helmet with Visor

operated by footswitch, 1 glance/depression
 method used by Senders
 visor was pneumatically controlled
 helmet was bulky
 translucent visor avoided light accommodation
 required an air system
 viewing time was accurately controlled
 problems (when visor was closed)

Senders' Helmet



3. Wiper in Heavy Rain

only a brief glimpse of the road is available
 after each sweep
 poor experimental control of viewing time
 times can be readily measured
 rain on windshield keeps scene
 illumination constant
 naturalistic approach
 original stimulus for occlusion measures
 no evidence of use in relation to occlusion

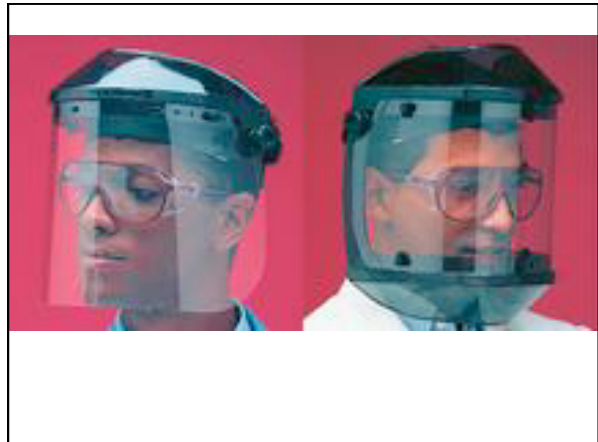
4. LCD goggles

normally translucent, allowing light to pass, milky when closed
 often operated by footswitch
 not very comfortable to wear
 some narrowing of field of view due to frame
 readily purchased (product from Translucent Technologies - www.interlog.com/~milgam)
 Good software control
 Can control each eye separately
 3 ms switching time
 used by UMTRI in pilot tests



5. LCD Face Shield

Approach used by TTI
 Custom made
 Framework is for welder's or woodworking face shield
 Some concerns about on-head power levels

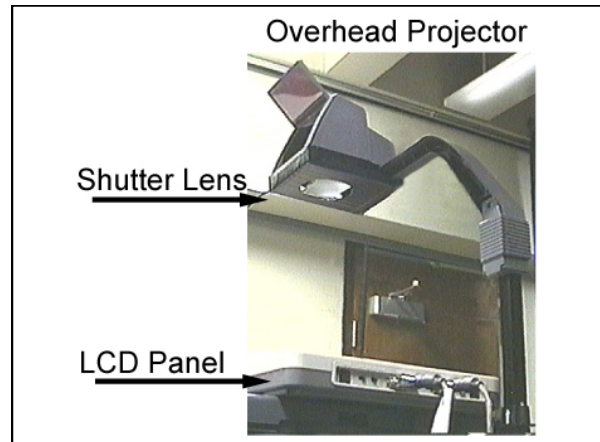


6. Scene Control in Simulator Using Shutter

Pressing button causes shutter (from LCD goggles) to block image from projector

Used by UMTRI and Mourant

scene luminance decreases if image is blocked



7. Scene Control Using Simulator Software

Pressing button cuts signal to image generator

Done in simulator software

Need special mods for simulator code

Used in current UMTRI simulator

Feature will be in KQ/Hyperion simulator

Replaced image can be gray, checkboard, etc.

8. Turn Headlights Off while Driving

naturalistic equivalent

not done yet

rise/fall of times of lights do not allow for precise control of durations (periods of vision and no vision),

Could to shutter lights

even if it is very dark, some natural scene illumination is always available

Dangerous to do on a real road

not discussed in literature

no one has tried this

9. Full Windshield LCD

replace entire windshield with LCD (now technically feasible)
 expensive to implement
 critical that if LCD fails (loss of power, etc.), it fails in the clear state
 should provide results equivalent to LCD goggles and face shield
 not discussed in literature
 no one has tried this

Conclusions

Lots of Possible Methods

Only a few have been tried
 Fewer have been compared

| Experiment | subjects | occlusion | Location, speeds |
|--|---------------------|--|--|
| Senders, Kristofferson, Levison, Dietrich, and Ward (1966) -experiment 1 | 2 men assumed young | keep eyes closed as long as possible (single event, time with watch) | unopened expressway 1963 Ford Falcon convertible with top down 10, 20, 30, 40 mi/hr 7 trials/subject |
| Senders, Kristofferson, Levison, Dietrich, and Ward (1966) -experiment 2 | 2 men assumed young | keep eyes closed as long as possible (single event, time with watch) | unopened expressway 1964 VW convertible with top up 10, 20, 30, 40, 50 mi/hr |
| Senders, Kristofferson, Levison, Dietrich, and Ward (1966) -experiment 3 | 2 men assumed young | face shield, 0.5 s viewing time, self-chosen occlusion | 10, 20, 30, 40, 50 mi/hr |

| | | | |
|--|---------------------|--|---|
| Senders, Kristofferson, Levison, Dietrich, and Ward (1966) -experiment 4 | 3 men assumed young | presumed use of face shield, 0.5 s viewing time, self-chosen occlusion | 10, 20, 30, 40, 50 mi/hr increase limit experiment |
| Senders, Kristofferson, Levison, Dietrich, and Ward (1967b) - experiment 1 | 5 young men | face shield, 0.25, 0.5, 1.0 s viewing times 1.0 -9.0 occlusion times | unopened expressway, lane width unknown, ->subject selected speed to drive see also Senders, Kristofferson, Levison, Dietrich, and Ward (1967a) |
| Senders, et al. (1967b) -experiment 2 | 3 young men | face shield 0.5 s viewing time ->subject-selected occlusion time | unopened expressway, lane width unknown, fixed speeds (22-60 mi/hr) see also Senders, et al (1967a) |

| | | | |
|---|-------------|---|---|
| Senders, et al. (1967b) -experiment 3 | 4 young men | face shield 0.5 s viewing time ->subject-selected occlusion time | formula 1 type test track 3 speeds (22, 25, 30 mi/hr) see also Senders, et al (1967a) |
| Senders, et al. (1967b) -experiment 3 | 3 young men | face shield 0.5 s viewing time occlusion times of 0.5, 1.0, 1.5, 2.0, 3.0 s | formula 1 type test track ->subject selected speed see also Senders, et al (1967a) |
| Senders, and Ward, (1969) - experiment 1 | 2 drivers | face shield, 0.5 viewing time, occlusion times unclear | varied tire pressure and steering free play |

| | | | |
|--|-------------------------------------|--|--|
| Senders, and Ward (1969) - experiment 2 | 2 drivers | face shield, 0.5 viewing time, self-chosen occlusion times | drive on city street in traffic |
| Safford (1971)-pilot experiment | 2 young men | self chosen eye closure | drive on lightly traveled interstate 50 mi/hr, with or without traffic in sight |
| Safford (1971) | 5 or 6 young (varies with analysis) | face shield, self chosen duration | open road, with or without variable speed lead vehicle (50 mi/hr) with and without carbon monoxide see also Weir and Rockwell, 1973; Rockwell and Weir, 1974. |

| | | | |
|--------------------------------|---|---|---|
| Farber and Gallagher (1972) | 6 young men | face shield w/ & w/o filters to simulate dusk, night; 0.5 s looks | slalom on unopened expressway, 30 or 45 mi/hr |
| Hicks and Wierwille (1979) | 30 young (25 men, 5 women), 6/condition | blank road scene, visible for 0.2 s | driving simulator with curving roads and motion, 55 mi/hr |
| Blaauw (1984) -experiment 1 | 6 experienced drivers | LCD goggles self chosen look durations and occlusion durations | 80 km/hr on used, 4-lane road under full moon, low beams only, no road lighting, straight, 1000 m radius curves, 200 m curves, various pavement markers |

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|--------------------------------------|-----------------------|--|---|
| Blaauw (1984) -experiment 2 | 6 experienced drivers | LCD goggles self chosen look durations and occlusion durations | similar to experiment 1 but lane marking treatments combined with either raised centerline markers or roadside posts |
| Godthelp (1984) experiment 7 of 9 | 6 young men | visor, 0.55 s looks | 20, 40, 60, 80, 100, 120 km/hr unused 4-lane divided hwy, 3.5 m wide lanes see also Godthelp, Milgram, and Blaauw (1984) for additional analysis |
| Godthelp (1984) experiment 8 of 9 | 6 young men | visor, 0.25, 0.5, 1.0, 2.0, 4.0 duration | 20, 60, 100 km/hr unused 4-lane divided hwy, 3.5 m wide lanes |

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|---|---|--|---|
| Godthelp and Kappler (1988) | 6 young men | LCD goggles, 0.55 s duration, self-chosen occlusion duration | 20, 40, 60, 80, 100 km/hr, unused 4-lane highway, 3.5 m lanes 3 vehicles (normal, understeer, oversteer) |
| van der Horst and Godthelp (1989) | unreported | unreported device or duration, self-chosen occlusion | 20, 60, 100 km/hr straight highway lane widths 2.05, 2.55, 3.05, 3.55 m original paper may have details**get it |
| Krammes, Brackett, Shafer, Ottesen, Anderson, Fink, Collins, Pendelton, and Messer (1995) -experiment 1 | 40 drivers (both sexes), 7 young, 18 middle, 15 old (55+) | LCD face shield (fixed), 0.5 s viewing time | 3, 6, 9 degree of curvature, 20 and 45 degree deflection angle, course at abandoned airport driven at 45 mi/hr (72.5 km/hr) |

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|--|---|---|--|
| Krammes, Brackett, Shafer, Ottesen, Anderson, Fink, Collins, Pendelton, and Messer (1995) -experiment 2 | 15 drivers (both sexes), 5 young, 5 middle, 5 old (55+) | LCD face shield (fixed), 0.5 s viewing time | 6, 9, 12 degree of curvature, 45 and 90 degree deflection angle, course at abandoned airport driven at 45 mi/hr (72.5 km/hr) see also Shafer (1996); Shafer, Brackett, and Krammes (1995) |
| Mourant and Ge (1997) | 8 young subjects | self-chosen duration | driving simulator with curving roads, 33 or 100 km/hr, 6 or 9 deg curves, 45 or 90 deg deflection, 0 or moderate oncoming traffic |
| Fitzpatrick, Wooldridge, Tsimhoni, Collins, Green, Bauer, Parma, Koppa, Warwood, Krammes and Poggioli (1998) | 24 subjects, 8 young, 8 middle, 8 older (55+) | blank road scene, 0.5 s visible | driving simulator with curving roads (3, 6, 9, 12 degrees of curvature, 20, 45, 90 degree deflection angles) 45 mi/hr, 12 foot lanes replicates and expands Krammes, et al. (1995) |

Senders Model

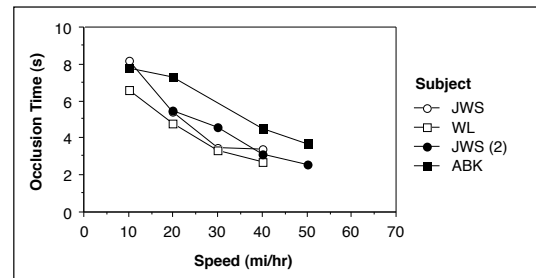
$$U(T_d) = H \cdot D [1 - e^{-(V/D + 1/F)T_d}] + K_n V^2 (T_d)^{1.5} \leq U_d$$

Where

- U(T_d) = uncertainty at the end of the occlusion interval
- H = information density of the road in bits/mile
- D = weighting constant per mile
- F = Forgetting rate parameter
- K = constant
- V = velocity in miles/second

Senders First 2 Preliminary Experiments

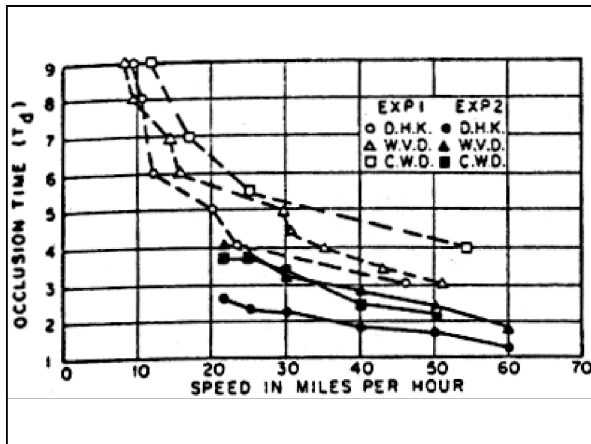
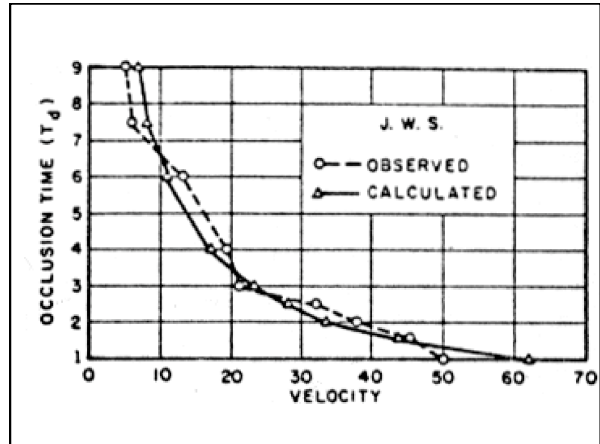
Single eye closure timed with stopwatch
Very few trials and subjects



Role of Look Duration

0.25 s was the practical minimum that drivers could use
 There was little difference in occlusion durations between look durations of 0.5 and 1.0 seconds

Note: Natural road fixations are about 0.5 s, but not exactly.



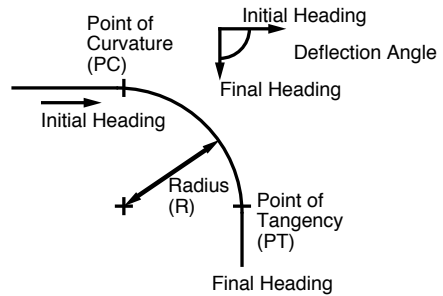
Conclusions about Early Work

Idea was unique and compelling
 Early studies involved few subjects
 Large individual differences
 Time between looks was key
 No performance difference over wide range of look durations
 Mostly studies on road
 Roads had no traffic
 Visual demand was directly related to speed
 Senders had a quantitative model

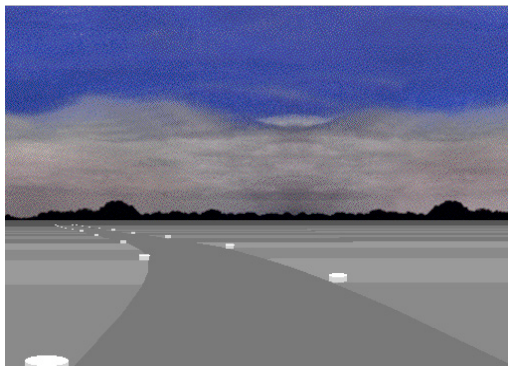
**Some Recent Relevant UMTRI Work
Tsimhoni and Green (1999)**

1. What is the relationship between visual demand, radius of curvature, and curve length?
2. Is visual demand correlated with ratings of demand?
3. How do the relationships change as a function of age?

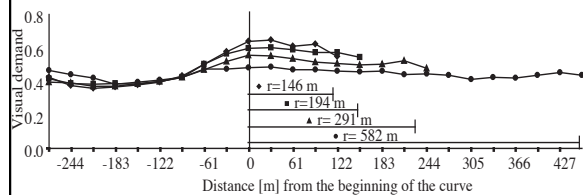
Visual Occlusion Method to Determine the Visual Demand of Driving



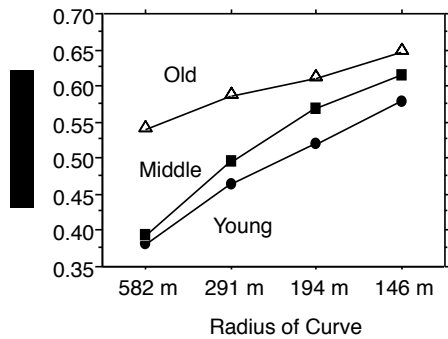
Example Left Curve



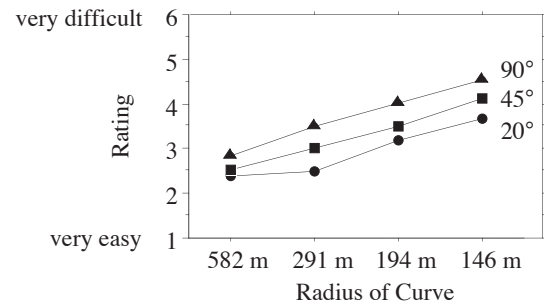
Visual demand of driving a curve



Interaction between Curvature & Age



Rating vs. Radius of Curvature



So,

The occlusion method is very sensitive to changes in road geometry on a moment-to-moment basis.

There is a quantitative relationship between curve radius and demand as measured by occlusion.

Note: We replicated in the simulator work conducted on a test track and on the road.

Conclusions

1. There are many methods for achieving occlusion.
2. Subject samples have been small in most studies.
3. Between subject variability is large.
4. Replication of specific values between studies is limited.
5. Most studies involve roads without traffic.
6. Above about 0.25 s, the look duration does not matter too much (for empty roads).
7. The measure of demand seems to be the number of looks over time.
8. Road viewing times commonly used are typically 0.5 sec. Should this be occlusion time in task occlusion study?
9. Look and occlusion times are inversely proportional to speed.
10. A strong point of Senders work is his theoretical model of information demand.

Issues Addressed

- How does the visual demand of driving affect **driving performance** while concurrently completing a display-intensive in-vehicle task?
- How does visual demand affect the **time to complete** an in-vehicle task?
- How do visual demand and task duration affect **glance behavior**?

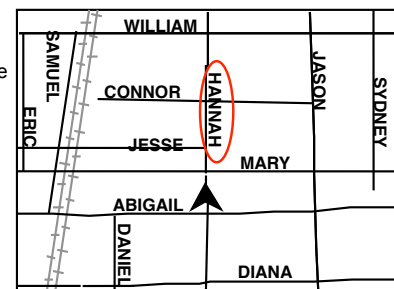


Experimental Design

- 16 subjects
 - Age (2) : young (<30 yrs), old (>65 yrs); and Gender (2)
- Within-subjects variables:
 - In-vehicle task (3): (short, medium, long)
 - Visual demand of driving (5): no driving, straight, wide, moderate, sharp curve
 - Measured visual demand using the visual occlusion technique for each subject on all the curvatures

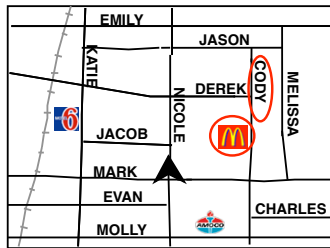
Task 1 - Short

What street are you on?



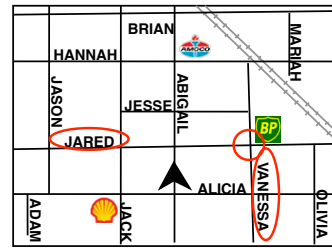
Task 1 - Medium

What street is the fast food restaurant on?

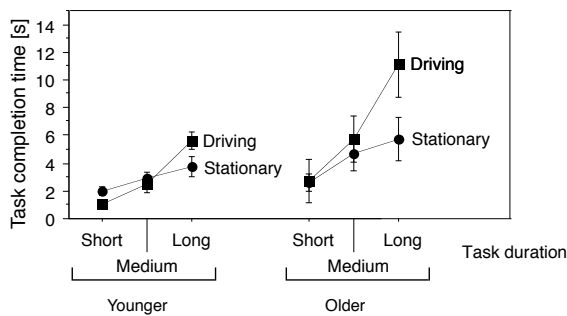


Task 1 - Long

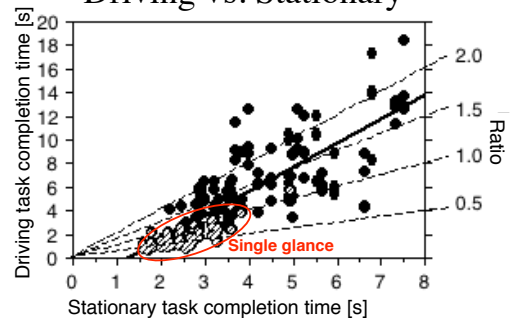
What street intersects with Vanessa at a gas station?

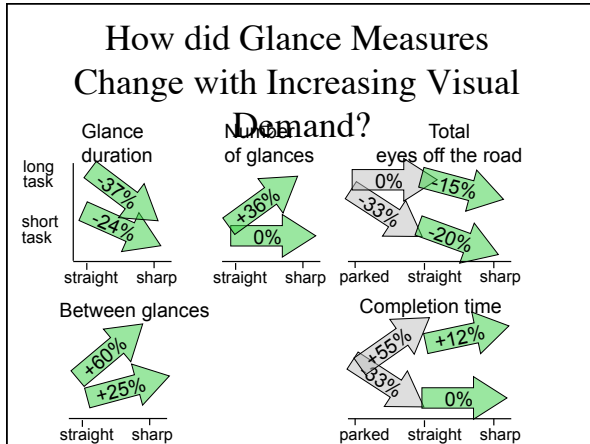


Task Completion Time

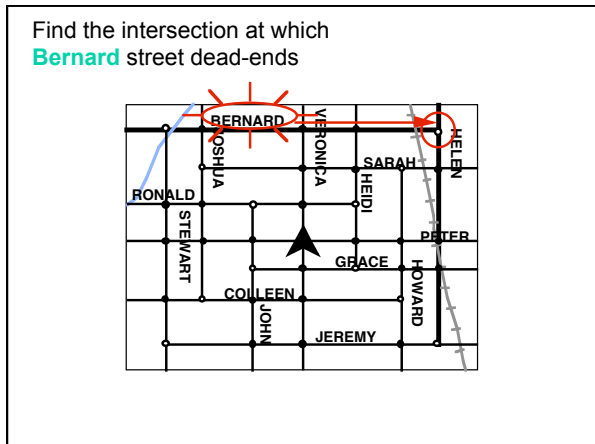
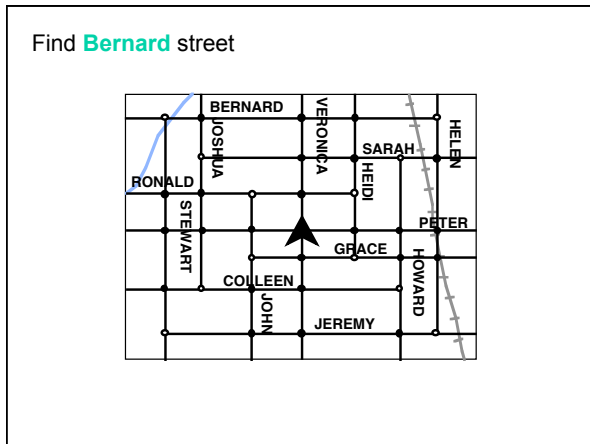


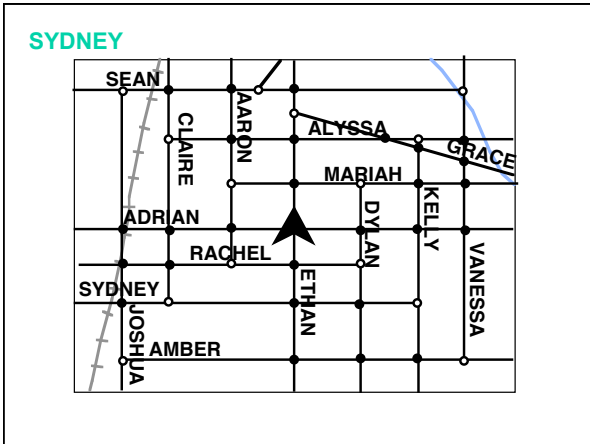
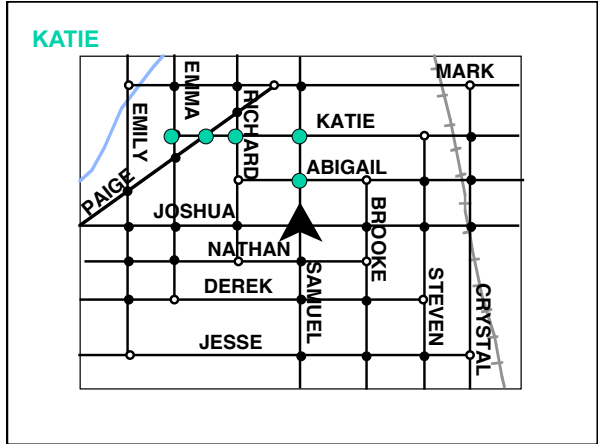
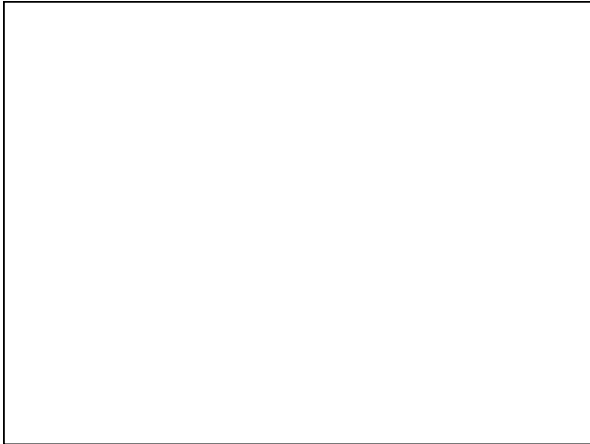
Task Completion Time Ratio: Driving vs. Stationary

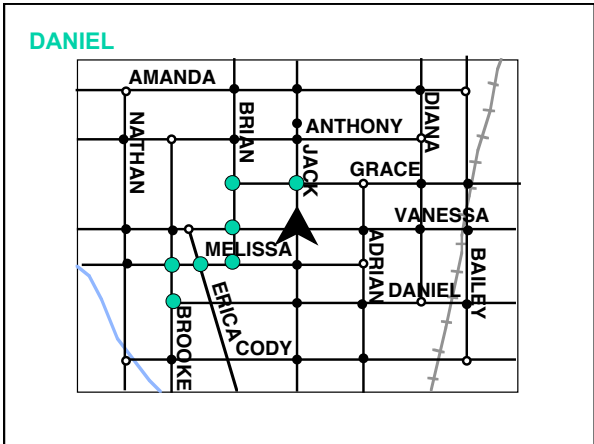
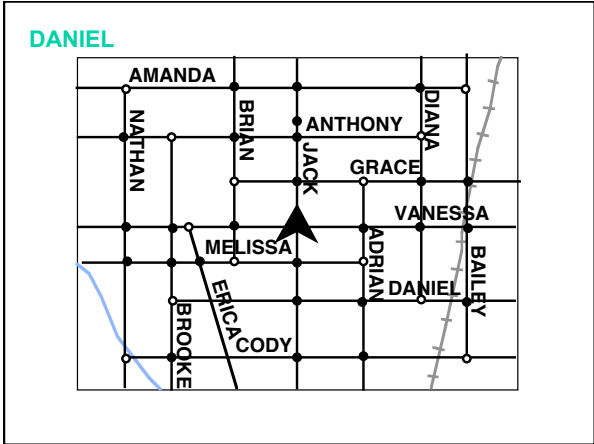
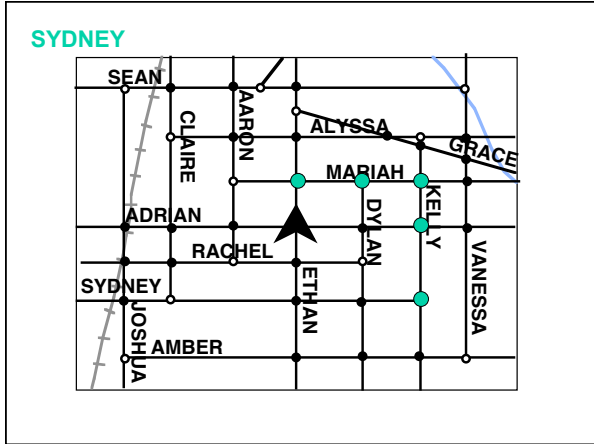


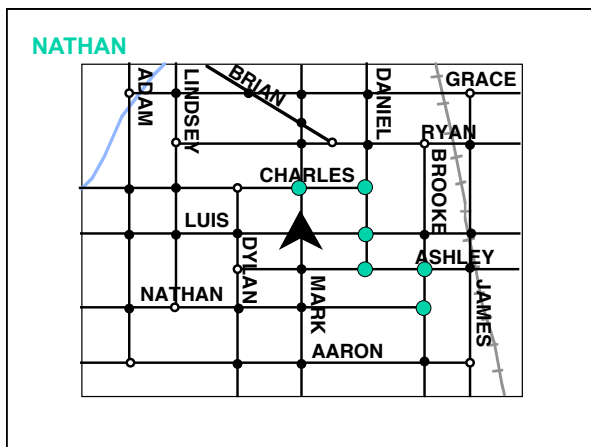
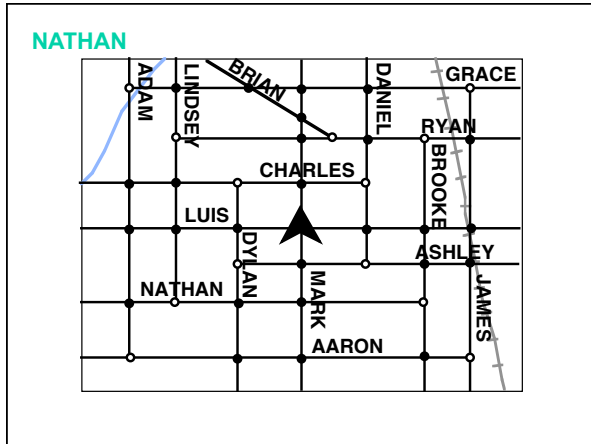


- #### A Demonstration of Work in Progress What It Takes to for a Task to Not Be Readily Partitioned (Omer Tsimhoni's dissertation)
- Using task occlusion at varying intervals to model the effect of task demands and road demands on glance behavior while driving
 - Main task: Plan a route to a given intersection on an electronic map while counting the number of intersections.
 - Subtasks:
 - Find the street name
 - Find where the street dead ends
 - Plan a route while counting intersections you pass









Extra images

| Test Course Content | | | | | |
|----------------------------|----|---|-----|-----|-----|
| <hr/> | | | | | |
| | | Curve Radius [m] (Degree of Curvature) | | | |
| | | 582 | 291 | 194 | 146 |
| | | 3 | 6 | 9 | 12 |
| Degree of Inflection | 20 | D | F | G | A |
| | 45 | H | E | J | M |
| | | 90 | B | L | C |
| | | | | | K |

| Drivers (n=24) | | |
|----------------|-----|-------|
| <hr/> | | |
| Age | Men | Women |
| 18-24 | 4 | 4 |
| 35-54 | 4 | 4 |
| 55+ | 4 | 4 |

Mean glance duration vs. visual demand to show that there is a correlation to the in-vehicle task
 Talk about the way it was done: the subject drove and pressed a key whenever they wanted to view the display (voluntary task occlusion with "loading task")