Systematic Behavioural Analysis of Pedestrian and Autonomous Vehicle Interactions using Virtual Immersive Reality Environment

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Problem Statement

- **AVs are expected to be on the streets in near future**
  - Potential to fundamentally altering urban travel patterns and behaviours
  - Urban areas need to be prepared to benefit from these changes
- Bloomberg Philanthropies Survey:

> “We asked a subset of 30 cities about the barriers to moving forward on AV pilots, policy, and plans. These cities told us they are struggling to find the human and financial capacity to deliver more projects, and the right actions are not yet clear or urgent enough.”

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Solution

- To rethink conventional urban policies, designs and plans

Some possible changes (NACTO)

- Reducing streets' lane width
- Increasing public spaces
- Sidewalk and bike lane width
- Restrictions on roads based on real-time demand
- Managing traffic gaps
- Setting lower speed limits

Project Overview

- **Objective:** To explore the features of future streets and AV traffic characteristics that influence pedestrian movement
- **Approach:** Quantifying the effects of specific traffic parameters and streets' geometric designs on pedestrians' walking behaviour in different conditions
- **Method:** Design an experiment in Virtual Immersive Reality Environment

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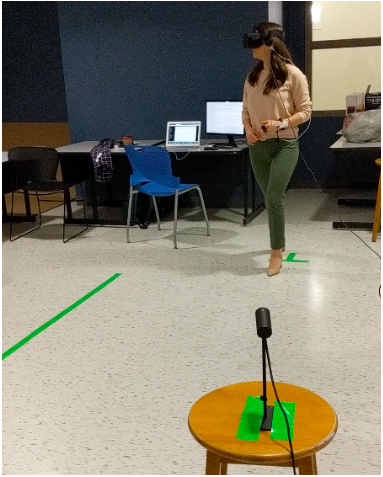
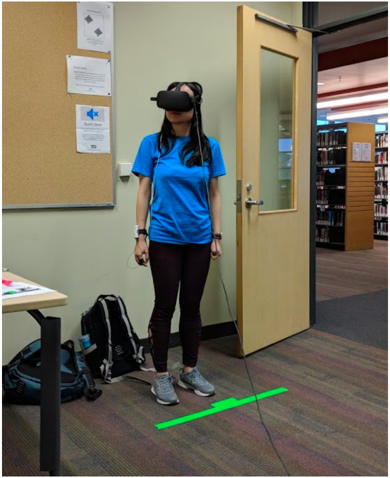
Virtual Immersive Reality Environment

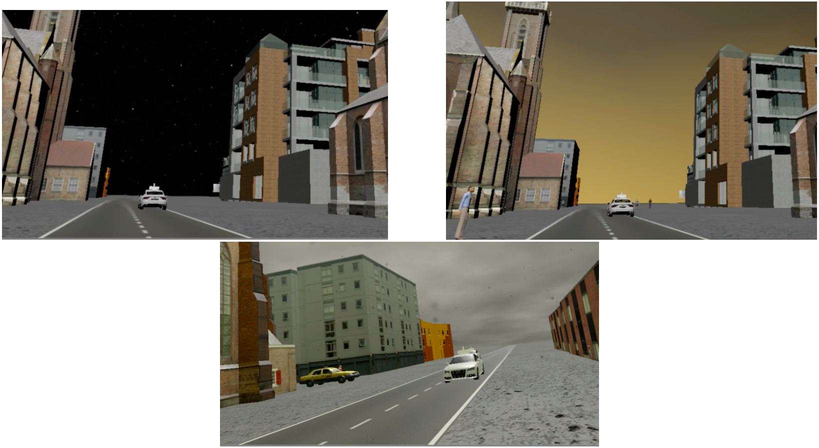
VIRE (Farooq, Cherchi, Sobhani, 2018)

- 3D scenarios are created based on theoretical experiment design
- Traffic movement is represented using an agent based simulation
- Positions and interactions of dynamic objects are projected onto Head Mounted Display
- Immersive and responsive environment
- Responses from users are recorded





Participants using VIRE



Street views in VIRE

Scenarios

- Each scenario is defined as a combination of designed multi-level factors (independent variables)

<table>
<tr><th>Variable</th><th colspan="10">Levels</th></tr>
<tr><td>Speed limit (km/h)</td><td colspan="3">30</td><td colspan="4">40*</td><td colspan="3">50</td></tr>
<tr><td>Lane width (m)</td><td colspan="3">2.5</td><td colspan="4">2.75</td><td colspan="3">3*</td></tr>
<tr><td>No. of breaking levels</td><td colspan="3">1</td><td colspan="4">2</td><td colspan="3">3</td></tr>
<tr><td>Minimum Gap (s)</td><td colspan="3">1</td><td colspan="4">1.5</td><td colspan="3">2*</td></tr>
<tr><td>Flow rate (veh/hr)</td><td colspan="3">530</td><td colspan="4">750</td><td colspan="3">1100</td></tr>
<tr><td>Road type</td><td colspan="3">1-way</td><td colspan="4">2-way</td><td colspan="3">2-way & median</td></tr>
<tr><td>AV penetration rate %</td><td colspan="2">0</td><td colspan="2">25</td><td colspan="2">50</td><td colspan="2">75</td><td colspan="2">100</td></tr>
<tr><td>Time of day</td><td colspan="5">Day</td><td colspan="5">Night</td></tr>
<tr><td>Weather</td><td colspan="5">Clear</td><td colspan="5">Snowy</td></tr>
</table>

- Changes in speed limit, lane width, no. of braking levels and Minimum Gap, are limited to scenarios with 100% AVs

*Current standards for residential urban streets in Canada

Dependant Variable

Automatically Measured

- Pedestrian comfort: required waiting time before crossing
  Cox Proportional Hazard Model
- Stress level: Galvanic Skin Response (GSR)
  Binary Logit Model
- Pedestrian safety: Post Encroachment Time (PET)
  Binary Logit Model

Experiment Design

- Testing all combinations of factor levels is impossible
- A subset of all combinations should be selected
- **D-Optimal Design:** attribute level combinations are sought to be as such to minimize parameter covariances in the model
- Prior information on model parameters required: demo design
- D-Optimal design for:
  - **Cox Proportional Hazard Model with three covariates** Schmidt and Schwabe (2017)
  - 9 covariates are involved in our design

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Experiment Setup

- D-Optimal Designs are developed for each dependent variable
- 100 scenarios are selected based on their overlap in different designs and weights.
- Participants are asked to fill a questionnaire on their:
  - sociodemographic information
  - walking habits
  - previous VR experience
  - health condition

Number of trials for each participant:

- **Adults** 15 scenarios, 2 times each
- **Adolescents** 15 scenarios, no repetitions

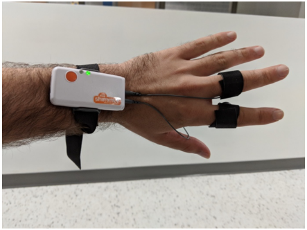
A Sample of Scenarios

No	Speed Limit	Lane Width	Minimum Gap	Number of Braking Levels	Mean Arrival Rate	Road Type	Day or Night	Weather	AV %
1	30	2.75	2	1	750	Two way	Day	Clear	100
2	30	3	1.5	1	1100	Two way	Night	Clear	100
3	30	3	1	2	750	One way	Day	Clear	100
4	30	2.5	1.5	3	750	One way	Day	Clear	100
5	40	2.75	1.5	3	750	One way	Day	Clear	100
6	30	2.5	1.5	3	750	Two way	Night	Snowy	75
7	30	3	1.5	1	1100	Two way with median	Day	Snowy	25
8	50	2.5	1	3	1100	Two way	Day	Clear	50
9	50	2.75	1.5	1	1100	Two way with median	Day	Snowy	25
10	40	3	1.5	2	530	Two way with median	Day	Clear	50

A sample of experimented scenarios

Stress Level sensors

- **GSR Sensors**
  - Skin resistance between two reusable electrodes attached to two fingers of one hand.
  - In response to internal and external stimuli, sweat glands become more active, increasing skin conductance and thus decreasing skin resistance.
- **PPG to HR**
  - capture a PPG signal and convert it to estimate heart rate (HR),
  - Using the PPG ear clip



Shimmer GSR+ Sensor

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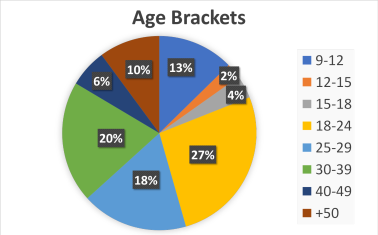
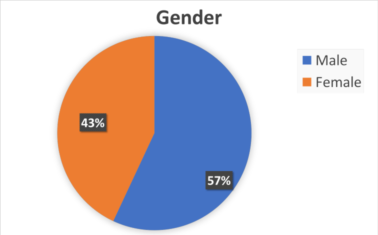
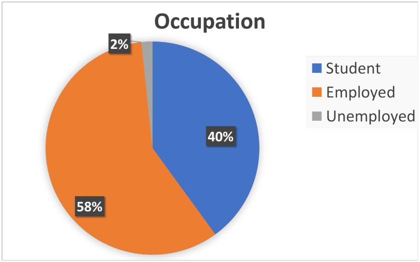
Sociodemographic Characteristics

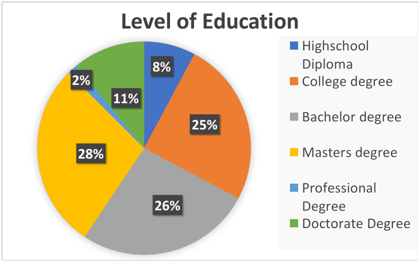
- Campaign: June 15 – August 30
- 102 participants so far
  - Adults: 66
  - Adolescents: 36
  - 57% used virtual reality before



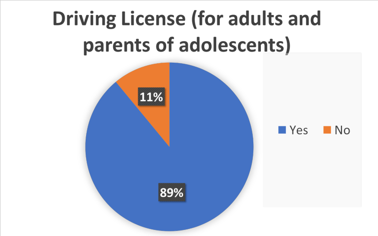


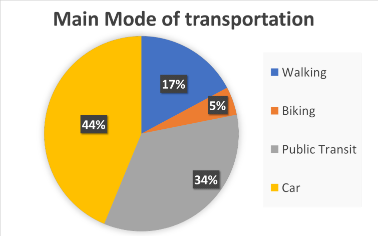
Adults Sociodemographic

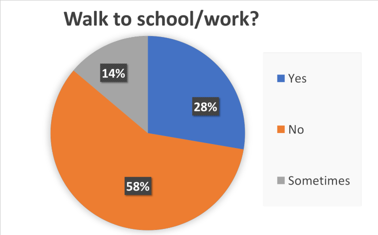




Transporation Information







Compare Means-Sociodemographic

Variable	Level	Wait Time(s)	PET(s)
Gender	Male	9.7	1.9
	Female	6.1	1.6
Age	18-24	6.8	1.4
	25-29	10.1	1.6
	30-39	13.1	1.9
	40-49	11.1	1.8
	Over 50	15.3	1.8
Occupation	Student	7.2	1.4
	Employed	10.1	1.9
Education	Highschool Diploma	5.2	1.2
	College degree	8.1	1.6
	Bachelor Degree	6.5	1.4
	Masters Degree	7.1	1.8
	Professional Degree	15.4	2.3
	Doctorate Degree	9.3	1.6
Previous VR experience	Yes	7.6	1.6
	No	8.4	1.7

Compare Means-Transportation Information

Variable	Level	Wait Time(s)	PET(s)
Driving Licence	Yes	8.3	1.9
	No	6.2	1.5
Main Mode	Bike	11.1	1.8
	Car	10.1	1.7
	Public transit	7.0	1.6
	Walking	8.1	1.7
Walk to work	Yes	8.3	1.8
	Sometimes	7.4	1.6
	No	8.3	1.7
Walk for shopping	Yes	7.9	1.7
	Sometimes	9.7	1.9
	No	6.9	1.4

Compare Means (Experiment Factors)

Variable	Level	Wait Time(s)	PET(s)
Speed Limit	30	9.9	2.2
	40	7.1	1.8
	50	6.2	1.4
Lane Width	2.5	7.8	1.6
	2.75	7.8	1.7
	3	7.7	1.6
Minimum Gap	1	8.2	1.5
	1.5	7.6	1.7
	2	7.6	1.8
Mean Arrival Rate	530	7	1.5
	750	7.7	1.4
	1100	8.6	1.1

Compare Means (Experiment Factors) (continued)

Variable	Level	Wait Time(s)	PET(s)
Braking Levels	1	7.6	1.7
	2	8.2	1.6
	3	7.4	1.8
Road Type	One-Way	7.1	1.9
	Two-Way	8.4	1.4
	Two-Way with median	7.9	1.5
AV%	0	6.2	1.6
	25	7.0	1.7
	50	6.9	1.5
	75	6.0	1.6
	100	7.9	1.9
Weather	Clear	8.1	1.7
	Snowy	7.2	1.8
Time	Day	8.0	1.9
	Night	7.4	1.8

Preliminary Hazard Model for Waiting time

- Negative Coefficient means longer waiting times

	coef	exp(coef)	se(coef)	z	Pr(>|z|)	
Arrival Rate	-8.91E-04	9.99E-01	2.10E-04	-4.246	2.18E-05	***
Gender: Female	-8.41E-01	4.31E-01	4.03E-01	-2.089	0.036682	*
Education :College	7.97E-01	2.22E+00	2.53E-01	3.155	0.001605	**
Education: Doctorate	-1.74E+00	1.75E-01	3.97E-01	-4.394	1.11E-05	***
Driving Licence: Yes	-8.70E-01	4.19E-01	2.68E-01	-3.242	0.001186	**
mode: PublicTransit	1.94E+00	6.96E+00	3.96E-01	4.903	9.45E-07	***
mode: Walking	2.35E+00	1.05E+01	4.04E-01	5.817	5.99E-09	***
walk to work: Sometimes	1.20E+00	3.30E+00	3.26E-01	3.666	0.000246	***
walk to work: Yes	6.18E-01	1.86E+00	3.71E-01	1.668	0.095365	.

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Summary

- Virtual Immersive Reality Environment is used to capture pedestrians' reactions to different traffic, road geometric design and environmental conditions
- Modeling results for Cox Proportional Hazard model showed that factors such as arrival rate, gender, level of education, walking to work and main mode of transportation have significant impact on waiting time

Future Work

- Model safety measure (PET) and stress level (GSR)
- Expanding the data set to cover different areas in the city
- Expanding the data set to elderly and disabled participants

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