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The driving simulator as a valid measure of driving behavior

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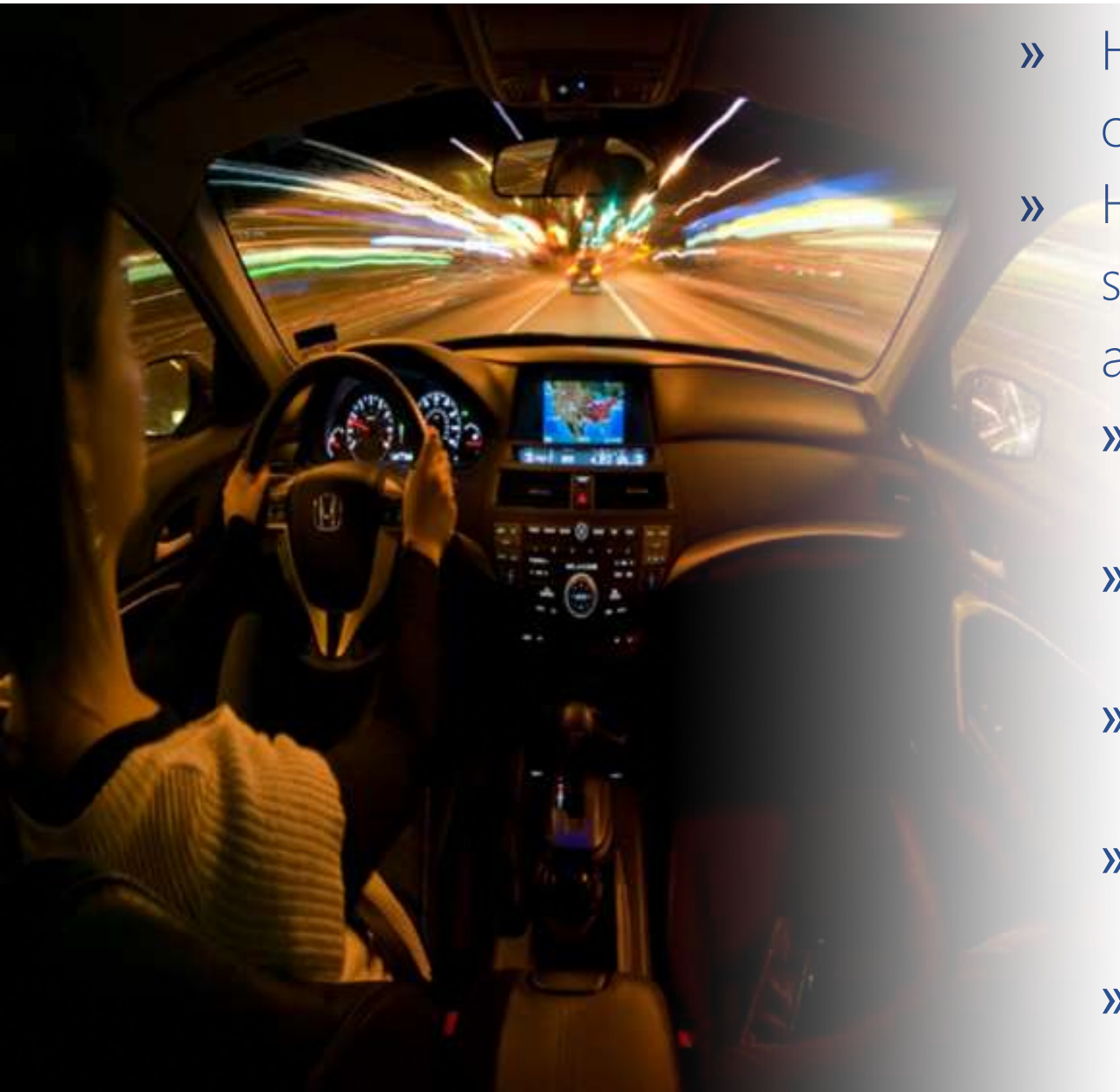
Driving Behaviour and Road Safety

- **Driving in traffic** is more than just knowing how to operate the mechanisms which control the vehicle
- Road accidents constitute a major social problem in modern societies (**eighth leading cause** of fatalities globally and **the leading cause** of fatalities for young people aged 15-29 years), in 2015:
  - 1.2 million fatalities worldwide
  - 26.000 in the European Union
  - 800 in Greece

Human factors and driving behaviour



- Human factors are the basic causes in 65-95% of road accidents
- Human factors involve a large number of specific factors that may be considered as accident causes, including:
  - **Driver dangerous action** (speeding, traffic violations etc.)
  - **Driver error or reaction** (loss of control, failure to keep safe distances, sudden braking etc.)
  - **Behaviour or inexperience** (aggressive driving, nervousness, uncertainty etc.)
  - **Driver distraction** (mobile phone use, conversation with passenger etc.)
  - **Driver impairment** (cerebral diseases, alcohol, fatigue etc.)

Types of assessing driving behavior

- Driving Simulator Experiments
- Naturalistic Driving Experiments
- On road experiments
- Surveys on Opinion and Stated Behaviour

Naturalistic driving experiments

A research method for the observation of everyday driving behaviour of road users

Advantages

- Large degree of control over the variables that affect driving behavior
- Researchers study issues that cannot be investigated in a lab

Disadvantages

- Difficult to determine the exact cause of a behaviour
- The experimenter cannot control outside factors
- Traffic incidents are very rare

On-road experiments

Studies using instrumented test vehicles to gain greater insights into the factors that contribute to road user accident risk

Advantages

- Study of actual observed behaviour

Disadvantages

- Data collection for a short period
- In response to selected interventions
- High cost

Surveys on opinion and stated behaviour

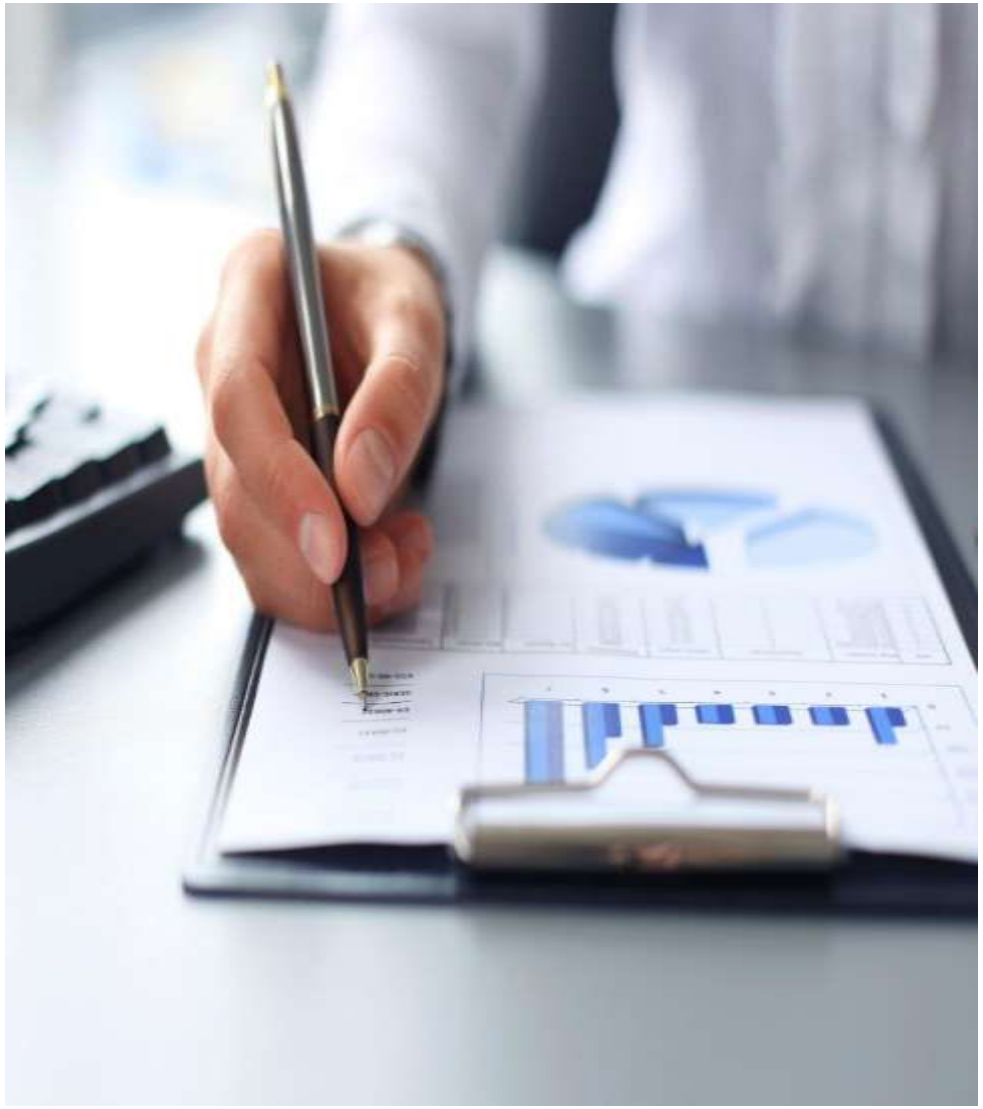
A reference questionnaire is built, based on a list of selected topics and a representative sample of population is interviewed

Advantages

- Survey design may control for external factors
- Allow to investigate new situations, outside the current set of experiences

Disadvantages

- Often hypothetical nature of questions
- Actual behaviour is not observed
- Over- or under-representation of actual behaviour



Driving simulator experiments

Examination of a range of driving performance measures in a controlled, relatively realistic and safe driving environment

Advantages

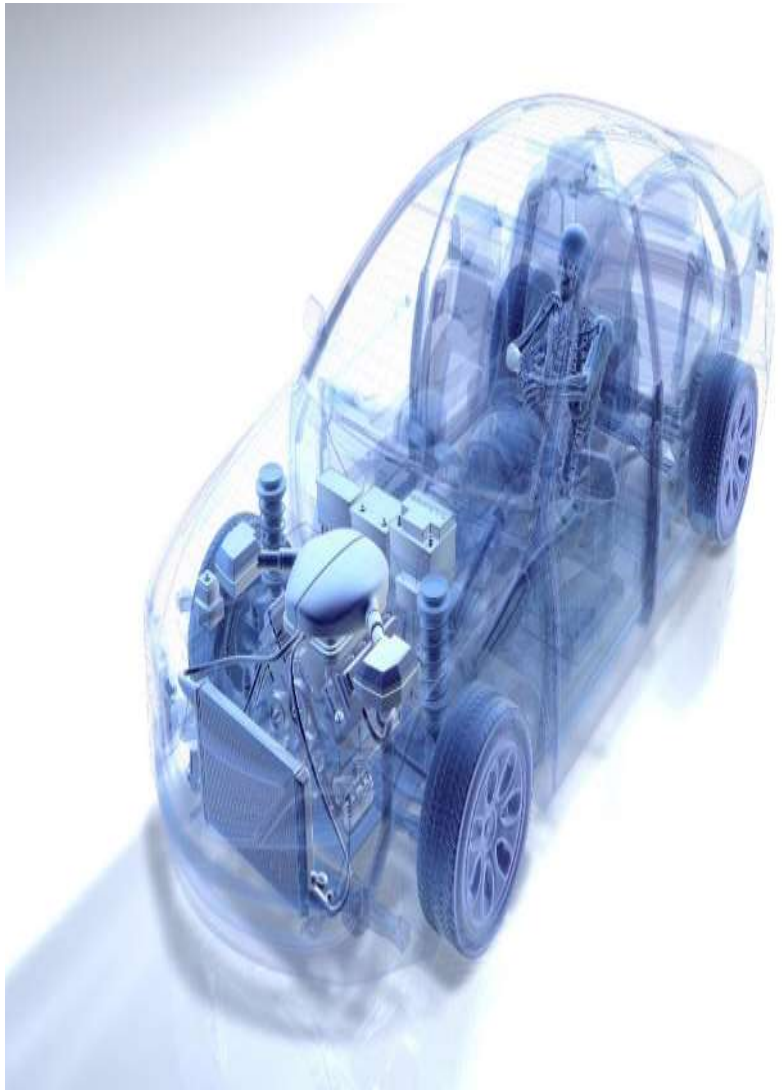
- Collection of data which would be very difficult to collect under real traffic conditions
- Exploration of any possible driving scenario
- Driving conditions are identical for all drivers

Disadvantages

- Possibility of adopting a different driving behaviour
- Simulator sickness

Driving simulator challenges - Fidelity

- **Fidelity** refers to the level of realism inherent in the virtual world
- The closer a simulator approximates real-world driving the greater fidelity it is reported to have
- The following **dimensions** of fidelity exist
  - equipment fidelity
  - environmental fidelity
  - objective fidelity
  - perceptual / psychological fidelity

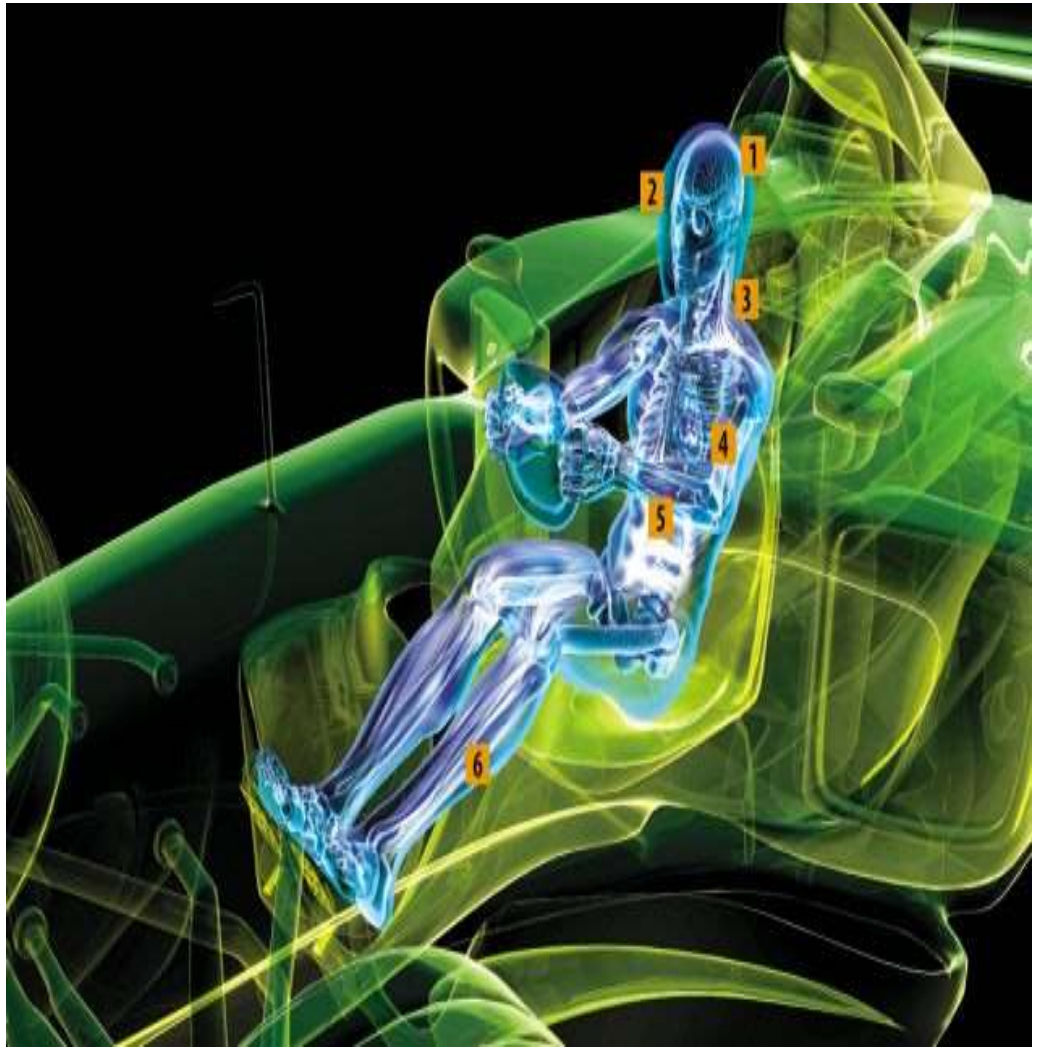


Driving simulator challenges - Validity

- **Driving simulator validity** refers to the degree to which behaviour in a simulator corresponds to behaviour in real-world environments under the same conditions

- If the numerical values are identical or near identical, **absolute validity** is achieved

- **Relative validity** is achieved when driving tasks have a similar affect on driving performance in both the simulator and real vehicles



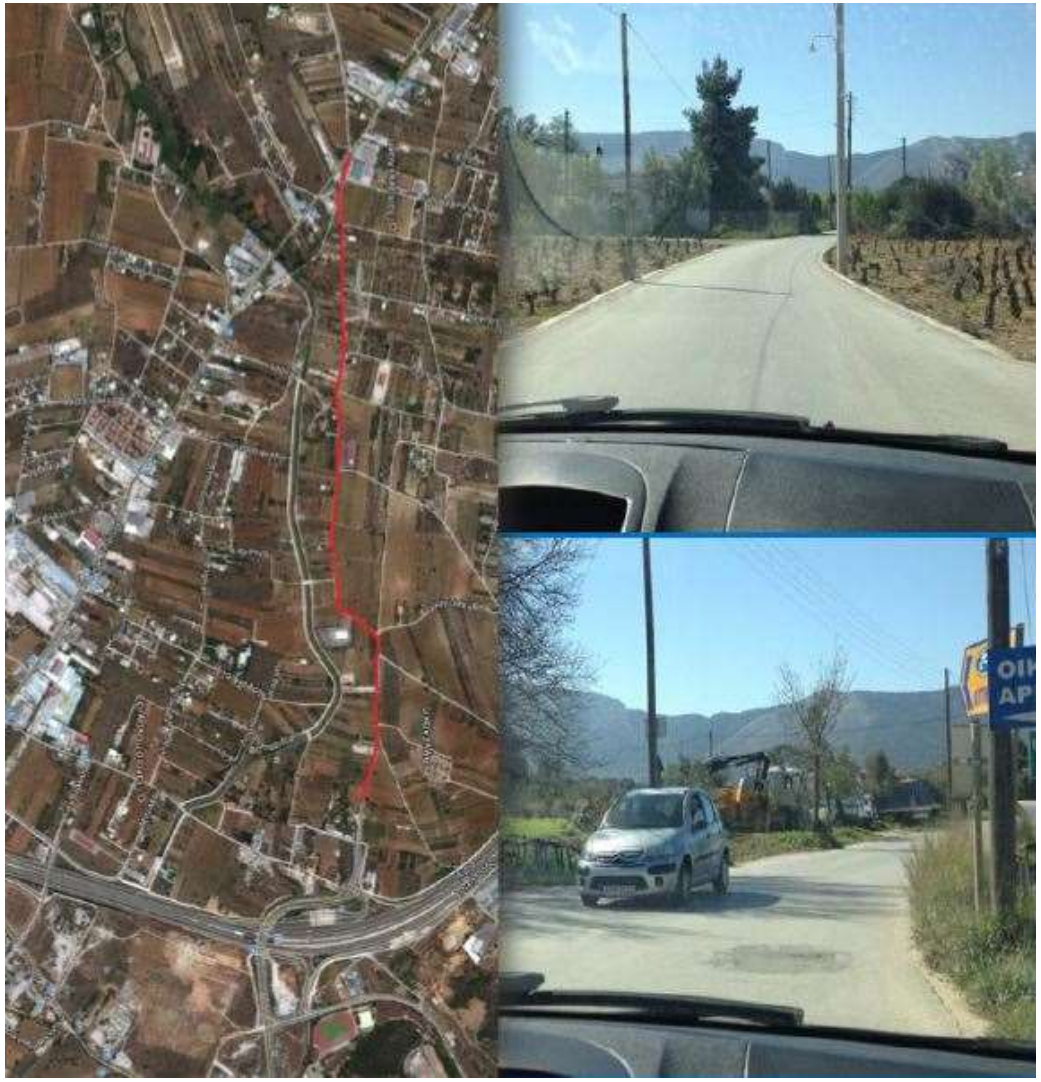
Validity experiment - Overview

Two driving scenarios have been developed in order to compare the driving performance of young drivers in simulated and on-road driving conditions

- In the **driving simulator** experiment, a rural route 2,1 km long, single carriageway and the lane width is 3m, with zero gradient and mild horizontal curves
- In the **on-road experiment** the selected route was consisted of a rural route 1,9km long, single carriageway and lane of 3,5m width

Validity experiment – Road environment

- The on-road experiment took place on the suburbs of Athens, namely in the region of **Paiania**
- Each driver performed with his/her **own car** twice every route, without any distraction source and while conversing with the passenger
- Drivers were asked to follow their **usual driving behaviour** throughout the experiment and try not to be affected by any other factors



Validity experiment - Analysis methods

Explanatory analysis

Absolute and relative values of driving performance measures were compared in order to give an overall impact of driving performance between simulated and real driving conditions

Model development

Lognormal regression models were developed for the identification of the impact of driving environment, driver characteristics as well as driving performance variables on average vehicle speed

1	Average speed (km/h)
2	Logarithm of the average speed
3	Driving on real road conditions (0:no, 1:yes (simulator))
4	(0:no, 1:yes)
5	Distance covered at each trial (km)
6	V(NO TALK) – V(TALK) speed difference between talking and not talking scenario of each driver per driving environment (km) διαφορά ταχύτητας χωρίς ομιλία με την ταχύτητα με ομιλία κάθε οδηγού για κάθε περιβαλλον
7	Ratio of speed when not talking to speed when talking (km)
8	General acceleration -positive or negative-(m/s^2)
9	Acceleration (m/s^2)-positive
10	Logarithm of the acceleration
11	Deceleration (m/s^2)-negative
12	Logarithm of the deceleration
13	Standard deviation of speed
14	Standard deviation of General acceleration
15	Standard deviation of Acceleration
16	Standard deviation of Deceleration
17	Driving Environment
18	Age
19	Gender
20	Week days driving to work
21	Cautious driving while talking to passenger
22	Conversation is risky
23	Speed Reduction by 10-20Km/h

Validity experiment - Results

Several parameters have a statistical significant effect on average speed model including

- **driver characteristics** (age, gender)
- **driving performance variables** (speed difference with and without conversation)
- **questionnaire variables**

- **Absolute values** of drivers' performance **vary** among simulated and real driving conditions
- **Relative differences** of driver behaviour at the two driving environments remain mostly the **same**

Independent Variables	Average Driving Speed			
	β_i	t	Relative Impact	
			e_i	e_i *
Driving Environment	0,069	9,797	0,0196	-3,76
Speed Difference with and without Conversation	-0,003	-2,389	-0,0052	1
Standard Deviation of Deceleration	0,019	5,194	0,0248	-4,75
Age	-0,021	-3,168	-0,0054	1,03
Gender	-0,040	-6,154	-0,0095	1,83
Week days driving to work	-0,004	-2,654	-0,0064	1,22
Cautious driving while talking to passenger	0,049	6,278	0,0063	-1,21
Conversation is risky	-0,024	-3,325	-0,0057	1,10
Speed Reduction by 10-20Km/h	-0,036	-4,737	-0,0059	1,14
R^2=0,659				

Driving performance measures (1/3)

- Driving behavior is a multidimensional phenomenon which means that no single driving performance measure can capture all effects of behavior
- The selection of the specific measures should be guided by a number of general rules related to the **nature** of the **task** examined as well as the **specific research questions**

			Distraction Source							Sample Characteristics							Driving performance measures								Statistical Analyses				
	Authors	year	cell phone	conversation	visual	music	IVIS	adv/sign signs	eat, drink, alcohol	sample size	% male	25-	26-55	55+	benefits	questionnaire	speed	lane position	reaction time	perception / situation awareness	headway	accident probability	eye glance	acceleration / deceleration	Descriptive statistics	One way ANOVA	Two way ANOVA	Repeated measures ANOVA
1	Laberge et al	2004	•	•						80	50%	•				•	•	•										
2	Drews et al	2008	•	•						96	25%	•	•		•		•	•								•		
3	Charlton	2009	•	•						112	50%	•	•	•	•	•	•				•	•					•	
4	Yannis et al	2011	•	•					•	42	48%	•			•	•	•	•	•			•						•
5	Hunton andRose	2005	•	•						111	25%				•							•				•		
6	Horbery et al	2006	•			•				31	-		•	•		•	•										•	
7	Reed-Jones et	2006	•			•				32	44%	•					•					•				•		
8	Yannis et al	2011	•			•				48	50%	•				•	•	•	•			•				•		
9	Rakauskas et al	2004	•							24	50%					•	•	•				•					•	
10	Kass et al	2007	•							49	49%	•	•	•												•		
11	Bruyas et al	2009	•							30	50%	•	•		•	•												•
12	Reimer et al	2010	•							60	60%	•			•	•	•			•				•		•		
13	Schlehofer et al	2010	•							69	36%	•			•	•											•	
14	Ma and Kaber	2005	•				•			18	50%	•				•	•	•			•					•		
15	Beeder and Kas	2006	•				•			36	-	•	•			•	•	•	•							•		
16	McKnight and Mc	1993	•				•			150	50%	•	•	•						•						•		•
17	White et al	2010		•						40	50%	•				•						•				•		•
18	Maciej et al	2011		•						33	52%	•			•	•										•		
19	Noy et al	2004			•					24	63%	•	•		•	•	•									•		•
20	Donmez et al	2006			•					28	-		•	•	•	•										•		
21	Donmez et al	2008			•					48	52%	•			•	•	•	•			•	•	•			•		•
22	Liang et al	2010			•					16	50%	•	•		•			•		•						•		•
23	Fofanova et al	2011			•					20	80%			•			•									•	•	
24	Muhrer et al	2011			•					28	50%	•	•		•	•	•				•						•	
25	Metz et al	2011			•					40	55%		•										•					
26	Kaber et al	2012			•					20	50%	•			•	•										•		
27	Zhang et al	2012			•					24	50%	•	•	•		•	•						•					•
28	Hatfield et al	2008				•	•			27	48%		•		•	•	•	•		•		•						•
29	Chisholm et al	2008				•				19	53%	•			•			•		•			•					
30	Garay-Vega et al	2010				•				17	71%	•	•		•	•							•					•
31	Young et al	2012				•				37	46%	•	•		•	•	•	•								•		
32	Hughes et al	2012				•				21	5%	•	•			•	•	•										•
33	Jamson et al	2005					•			48	-		•															•
34	Donmez et al	2007					•			29	48%	•			•	•	•							•				
35	Reyes et al	2008					•			12	50%		•		•				•					•		•		•
36	Jamson et al	2010					•			18	50%		•		•		•	•						•		•		•
37	Benedetto et al	2011					•			15	80%					•			•							•		•
38	Birrell et al	2011					•			25	56%		•			•	•				•			•		•		•
39	Terry et al	2008						•		78	55%	•	•	•		•			•		•						•	
40	Young et al	2009						•		48	60%		•		•			•					•			•		
41	Bendak et al	2010						•		12	100%	•	•			•	•						•		•	•		
42	Edquist et al	2011						•		48	63%	•	•	•	•	•		•					•			•		
43	Rakauskas et al	2008							•	45	100%	•			•											•		
44	Young et al	2008							•	26	62%	•	•	•	•		•	•									•	
45	Harrison et al	2011							•	40	50%	•	•		•	•	•					•				•		

Driving performance measures (2/3)

- Longitudinal Control Measures
  - Average Speed
  - Speed variability
  - Space headway
  - Time headway

- Lateral Control Measures
  - Lateral position
  - Lateral Position variability
  - Steering wheel control
  - Standard deviation of steering wheel angle
  - Steering wheel reversal rate
  - Lane exceedances (LANEX)
  - Time to Lane Crossing (TLC)
  - Reversal Rate (RR)

Driving performance measures (2/3)

- Reaction Time Measures
  - Reaction time
  - Brake Response Time (BRT)
  - Time to Collision (TTC)
- Gap acceptance measures
  - Number of collisions
  - Gaps accepted
- Eye movement measures
  - Glance
  - Eyes-off-road-time
  - Fixation
  - Percent Dwell Time (PDT)

Driving performance measures (3/32)

- Subjective Workload
  - NASA-task Load Index (TLX)
  - Rating Scale Mental Effort (RSME)
  - Situation Awareness Global Assessment
  - Driving Activity Load Index (DALI)
- Physiological Workload
  - Heart Rate (HR)
  - Respiration
  - Electroencephalography (EEG)
  - Skin Conductance
- Accident
  - Accident probability
- Others
  - Entropy

Driving simulator overview

- Every **experiment type** has benefits and limitations. All types of experiments should carefully follow some basic **experimental design** principles, allowing for reliable analysis of the data

- Driving simulator experiments allow the investigation of any possible driving scenario under identical conditions for all drivers

- Driving simulators provide a variety of driving performance measures

Driving simulator experiment

A common simulator experiment in the framework of two research projects:

- **Distract** - Analysis of causes and impacts of driver distraction
- **DriverBrain** - Analysis of the performance of drivers with cerebral diseases

An **interdisciplinary** research team:

- Dpt. of Transportation Planning and Engineering NTUA
- Dpt. of Neurology of the University of Athens Medical School, UoA
- Dpt. of Psychology, School of Philosophy, Pedagogy and Psychology, UoA

Sample size: 225 participants fully examined

- 154 persons > 55 years old
- (MCI = 59, AD= 25, PD= 25, Normal Controls= 45)

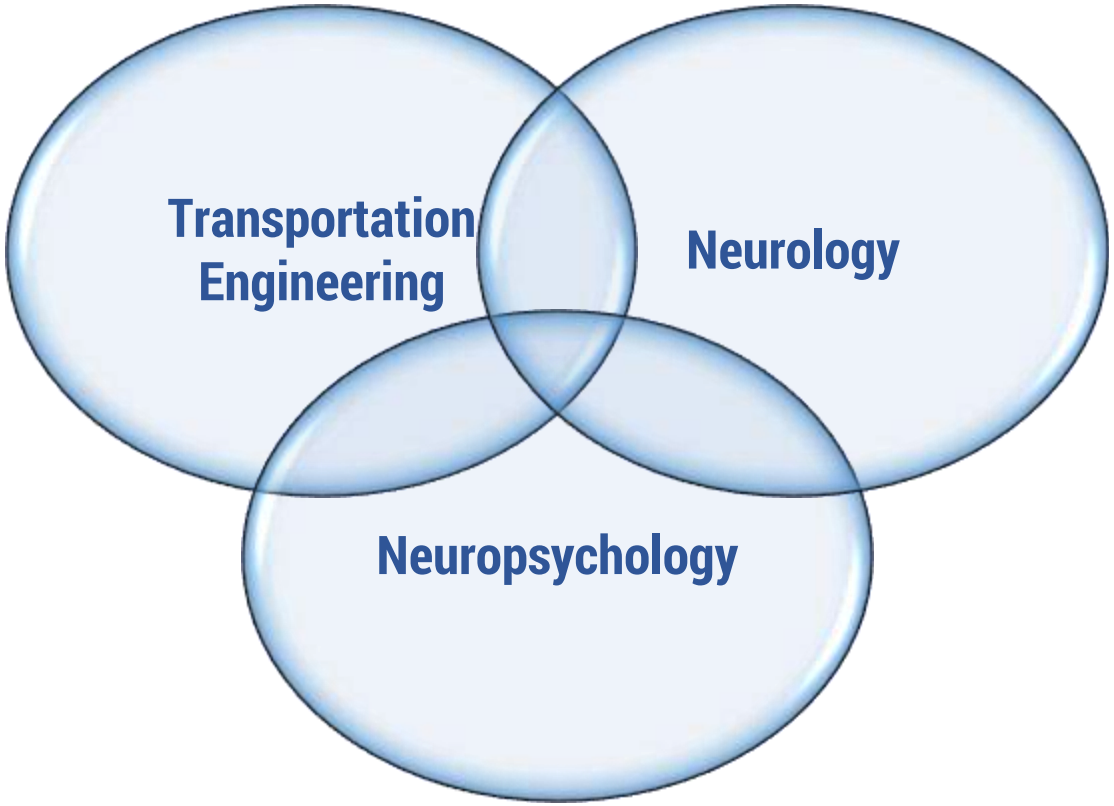
distrACT driverBRAIN

Department of Transportation Planning and Engineering, NTUA

Department of Neurology, Psychiatry and Social Medicine, UoA
Department of Psychology, UoA

Inter-disciplinary driving simulator experiment

- **Medical/neurological assessment**:
  administration of a full clinical medical, ophthalmological and neurological evaluation, in order to well document the characteristics of each of these disorders
- **Neuropsychological assessment**:
  administration of a series of neuropsychological tests and psychological - behavioural questionnaires to the participants which cover a large spectrum of Cognitive Functions: visuospatial and verbal episodic and working memory, general selective and divided attention, reaction time, processing speed, psychomotor speed etc.
- **Driving at the simulator**:
  a set of driving tasks into a driving simulator for different driving scenarios



Inclusion criteria and ethical issues

All participants should:

- have a valid driving license
- have driving experience of more than 3 years
- have driven more than 2500km during the last year
- have driven at least 10km/week during the last year
- not have important psychiatric history for psychosis
- not have any important kinetic disorder that prevent them from basic driving moves
- not have dizziness or nausea
- not be pregnant
- not be an alcoholic or had any other drug addiction
- not have any important eye disorder that prevent him from driving safely
- not have any disease of the Central Nervous System

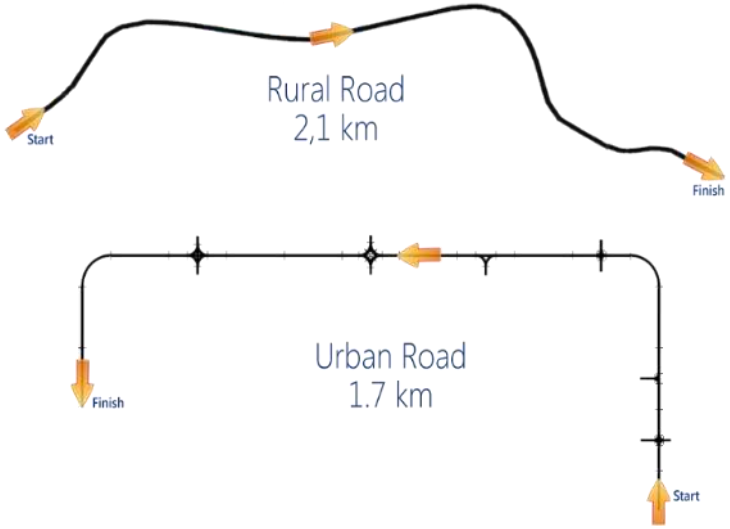
- The study was approved by the **Ethics Committee** of the University General Hospital "ATTIKON".

Driving simulator

- Quarter-cab driving simulator manufactured by the FOERST Company
- 3 LCD wide screens 42″ (full HD: 1920x1080pixels) - total field of view 170 degrees
- Validated against a real road environment

Driving assessment

- **1 practice drive** (usually 15-20 minutes)
- **1 rural route** (2,1km long, single carriageway, 3m lane width)
- **1 urban route** (1,7km long, at its bigger part dual carriageway, 3.5m lane width)
- **2 traffic scenarios** for each route:
  - Q_L: Moderate traffic conditions (Q=300 vehicles/hour)
  - Q_H: High traffic conditions (Q=600 vehicles/hour)
- **3 distraction conditions** for each route:
  - **Undistracted driving**
  - Driving while **conversing with a passenger**
  - Driving while conversing on a hand-held **mobile phone**
- **2 unexpected incidents** scheduled to occur during the trial:
  - Sudden appearance of an **animal** (deer or donkey) on the roadway
  - Sudden appearance of a **child chasing a ball** on the roadway or of a **car suddenly getting out** of a parking position.



Scenarios design

- Sequence of trials - Randomized
  - The purpose of randomization is to remove bias and other sources of extraneous variation, which are not controllable
- Full factorial within-subject design
  - 12 trials in total
  - 40 minutes of driving

	Road Traffic Conditions			
	Urban Area		Rural Area	
Distraction Sources	Low traffic	High traffic	Low traffic	High traffic
No distraction condition	★	★	★	★
Conversation with passenger	★	★	★	★
Conversation through mobile phone	★	★	★	★

Driving assessment video

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