University of Toronto
Department of Computer Science

Can Autonomous Vehicles Be Safe and Trustworthy?

Effects of Appearance and Autonomy of Unmanned Driving Systems

Presenter: Yasaman Rohanifar

MSc Student, Department of Computer Science
DGP Lab, University of Toronto

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About this paper

- 2015 International Journal of Human–Computer Interaction
- HCI for Elderly and Smart Vehicle Interaction
- 29 Citations

About the Authors:

- Jae-Gil Lee
- Ki Joon Kim
- Sangwon Lee
- Dong-Hee Shin

Department of Interaction Science, Sungkyunkwan University, Seoul, Korea

Introduction

Eliminating human involvement from driving can threaten safety!

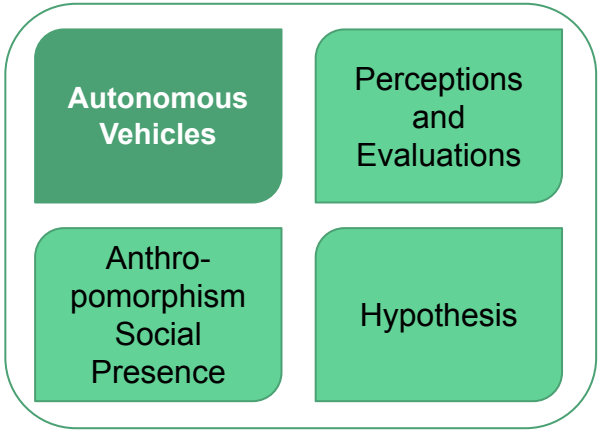
Efforts to build advanced sensors, sophisticated algorithms to increase the safety of the unmanned driving systems.

NO emphasize on psychological aspects of autonomous driving systems

Design methods that lead users to believe that driverless system's decisions are indeed **safe** and **trustworthy**

Use of **anthropomorphic cues** (human-like appearance, high autonomy) to induce greater safety and trust

Background



- Vision systems for lane, stop line detection, perceptual abilities.

- More research has been focused on the technology itself, not the driver's perceptions of vehicle trustworthiness and safety.

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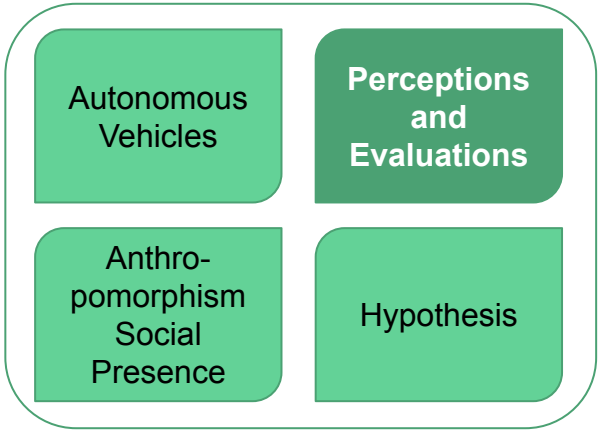
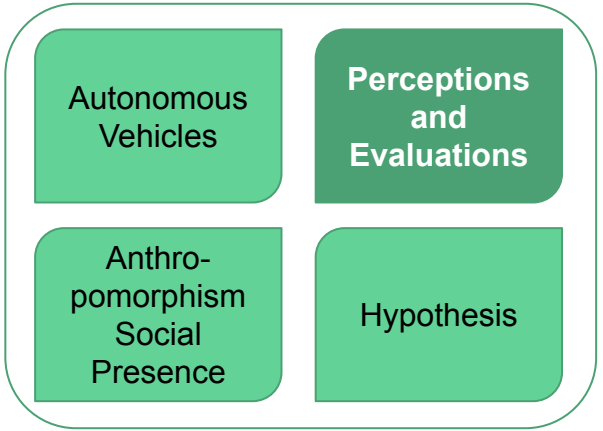
Background



Trust

- Use, misuse, and disuse of automation depends on **trust**
    - Website or advertisement ➔ increase usage and purchase
    - Sales effectiveness and customer-service provider relationship
    - Promoting acceptance of autonomous vehicles

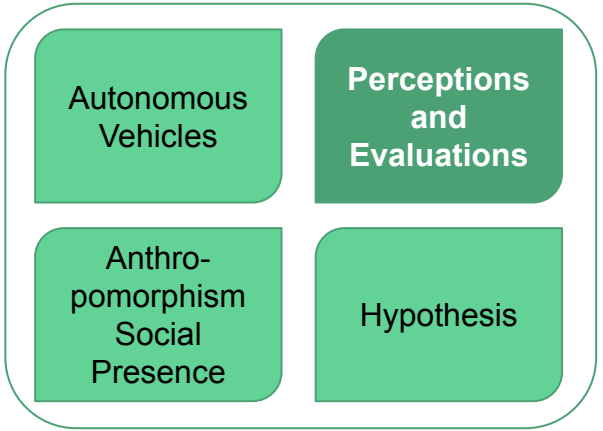
Background



Perceived Safety

- Users' perception of safety and the feeling of **"being cared of"**plays an equally important role along with increased safety measures done by technologies.
- Perception of safety in humans:
  - A decrease in the perception of danger
  - Increase in the level of comfort
  - User's belief in unmanned driving system's competence
    - To adapt to complex traffic rules
    - To drive in constantly varying conditions
    - Avoiding unpredictable risk

Background



High Intelligence

- Systems with great intelligence are granted more rights
- So, first of all, the system must be PERCEIVED as intelligent enough

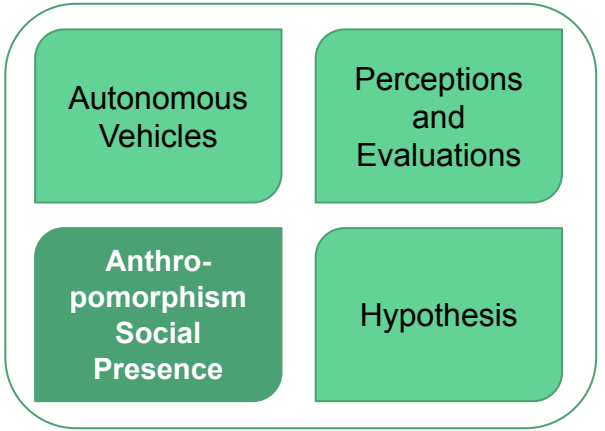
Trust, **safety**, and **intelligence**
useful indicators of success and acceptance of autonomous vehicles

Background

Anthropomorphism is the attribution of human-like characteristics (e.g. human forms, voices, behaviors) to inanimate, artificial agents such as computers and robots.

Source: Animal Anthropomorphism

Source: Disney Anthropomorphism



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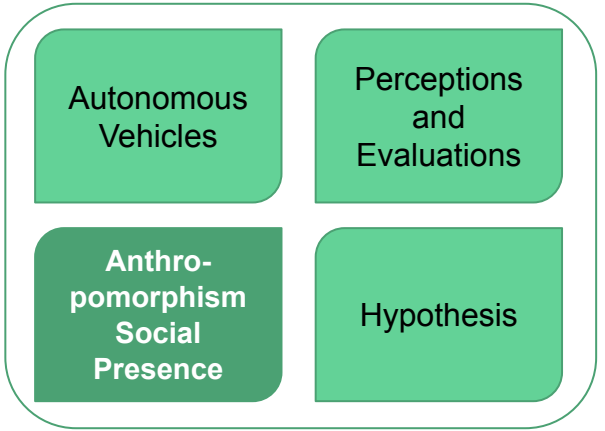
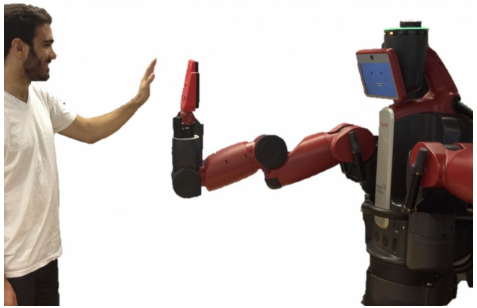


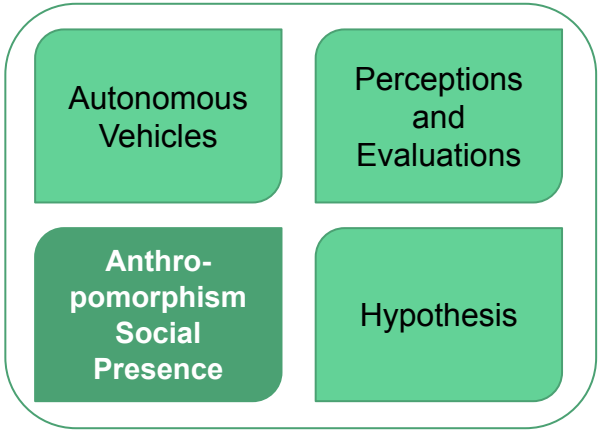
Psychology of Human-Robot Interaction

- Characteristics, process, and nature of Human-Robot interaction similar to Human-Human interaction.
- Individuals **mindlessly** apply social rules and expectations when they interact with computers with anthropomorphic cues
  - Assigning human specialties to computers
  - Applying social exchange theory in interaction with robots
  - Form a team relationship with computers



Source: Robot High Five

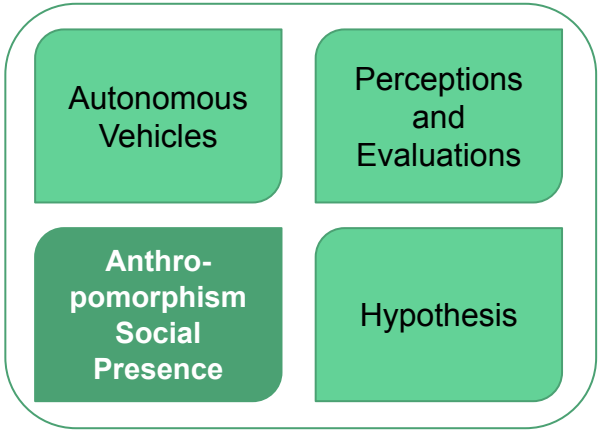
Background



- **Anthropomorphic cues**
  - Increase feelings of **social presence**
  - Keeps the inauthenticity of nonhuman agents to be unrecognized
  - Makes robots to be experienced as actual social actors.
  - More **meaningful social interactions** with robots
  - Ultimately affecting how humans **perceive** and **evaluate** the system and its performance.

Source: Anthropomorphic Cues

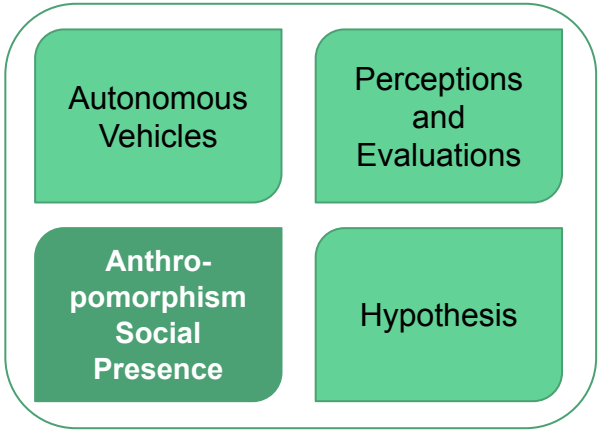
Background



- **Human physical characteristics**
  - Human facial expressions and bodily forms
  - Sense of **resemblance** and **familiarity** allows **Self-knowledge** to be more accessible
  - Morphological resemblance to humans
    - Greater social acceptance
    - Evoking positive psychological and behavioral changes in its human interactions

Source: Ex-Machina

Background

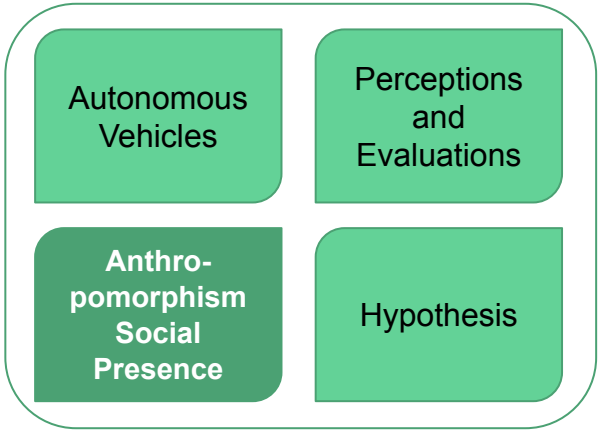


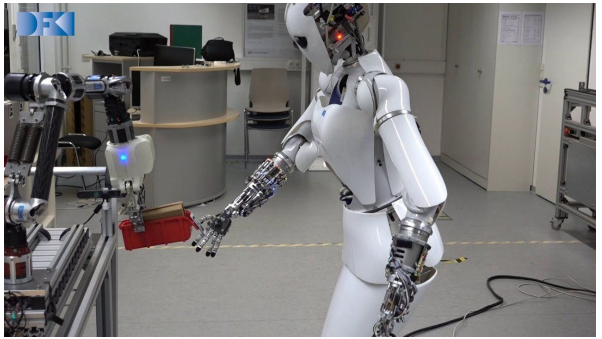
- **Autonomy**
  - technological capabilities to act on behalf of humans without direct human intervention and control, allows for full or partial replacement of the functions typically executed by human actors.

- Levels of autonomy ➔ Extension to unmanned driving systems:
  - Information acquisition ➔ Capture road and passenger information via sensors
  - Information Analysis ➔ Assess, diagnose, and integrate the collected information
  - Decision Selection ➔ Decisions in the best interest of passenger safety and satisfaction
  - Action Implementation ➔ Operate and control the vehicles according to the decisions

Background

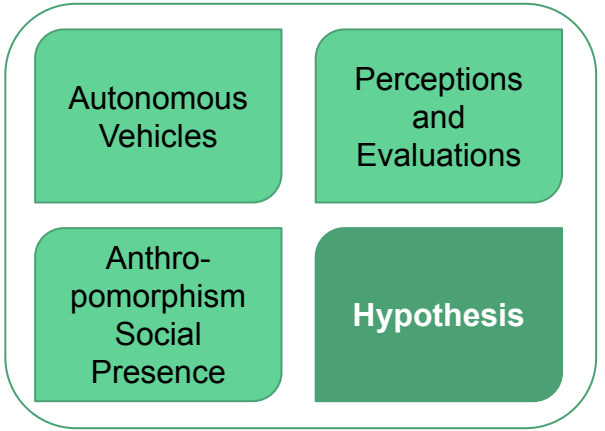
- **Human-like appearance** + **high autonomy**
  Enhance the system's similarity to humans
  Sense of independent agency
  - Triggers the social presence heuristic
  - Feelings of social presence enhanced by a robot's social cue
    - Greater perception of **trust** and **intelligence**
    - Inducing greater enjoyment, attachment, and satisfaction.





Source: Human-Like Autonomous Robot

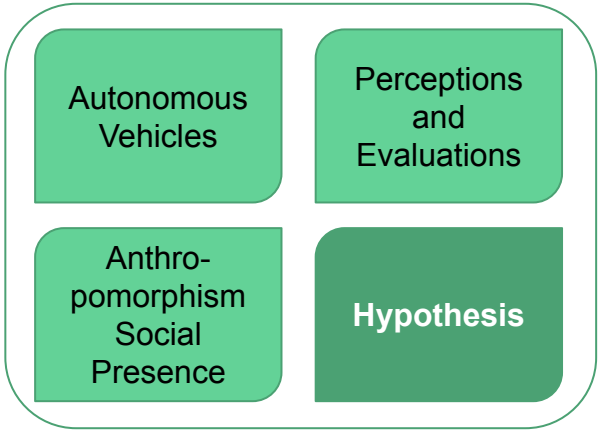
Background

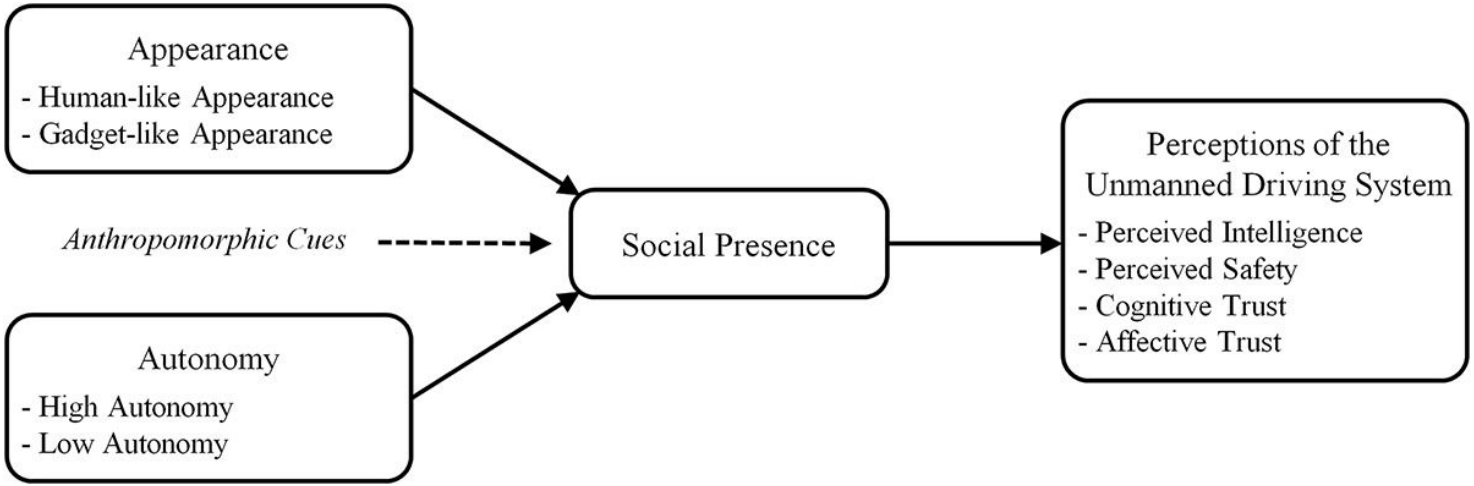


H1(a/b): An unmanned driving system with a) human-like appearance and b) high autonomy will induce greater feelings of a social presence than with a system with a gadget-like appearance and low autonomy.

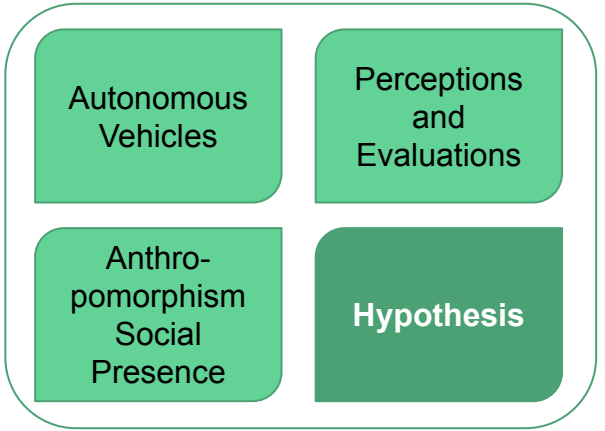
H2: A higher level of social presence in an unmanned driving system will induce positive user perceptions such as perceived intelligence and safety as well as cognitive and affective trust in the system.

Background


Autonomous Vehicles
Perceptions and Evaluations
Anthro-pomorphism Social Presence
Hypothesis


Appearance
- Human-like Appearance
- Gadget-like Appearance
Anthropomorphic Cues
Autonomy
- High Autonomy
- Low Autonomy
Social Presence
Perceptions of the Unmanned Driving System
- Perceived Intelligence
- Perceived Safety
- Cognitive Trust
- Affective Trust

Background

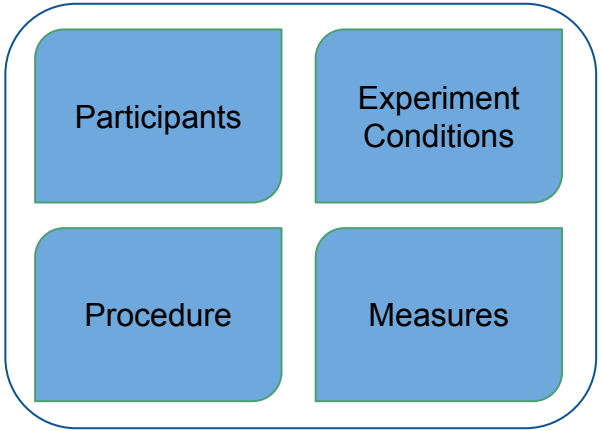


PROVEN: Social Presence, in shaping user's social response to computers

THEIR PREDICTION: Social presence as a mediating role in determining user perceptions of unmanned driving systems.

H3 (a/b): Effects of (a) appearance and (b) autonomy on user perception of an unmanned driving system will be mediated by feelings of social presence.

Method



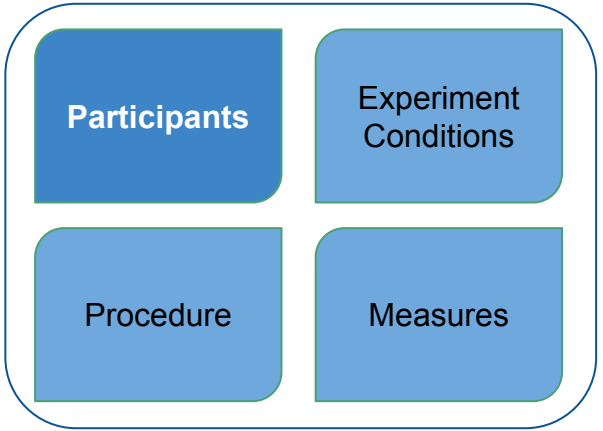
A 2 x 2 factorial between-subjects experiment with 4 conditions representing 2 types of **appearance** (human-like vs. gadget-like), and 2 levels of **autonomy** (high vs. low).

Participants were randomly assigned to one of the four conditions.

Observed an artificial agent's driving performance and style.

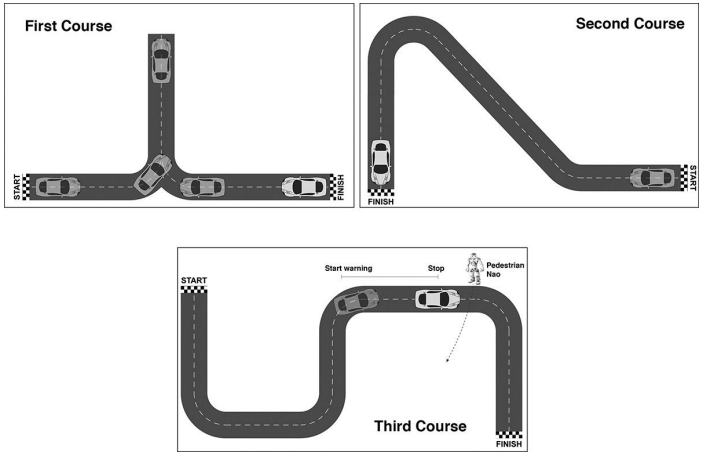
Filled paper-pencil questionnaire that assessed their perceived levels of intelligence, safety, cognitive, and affective trust, and social presence.

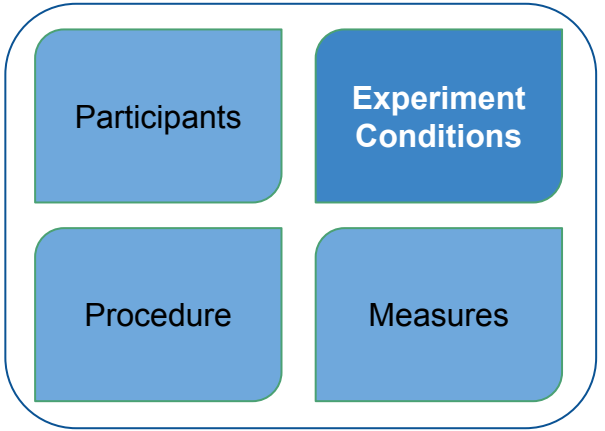
Method



- 89 undergraduate and graduate students at a private university in Seoul, Korea
- 44 Men, 45 Women
- Age range between 19 to 29 years (M = 23.65, SD = 2.21)

Method





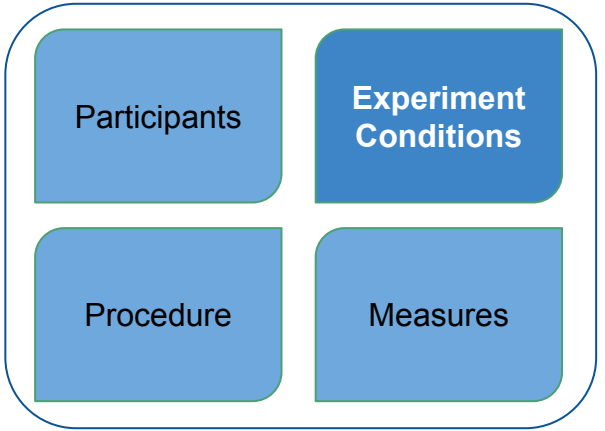
Controlled lab environment resembling actual driving context (!?)

3 Predetermined driving courses (Lines of 4 x 8 m on the ground)

A remote-controlled car for children as a stimulus autonomous vehicle

- 120 x 60 cm
- Top speed of 6 km/hr

Method



Artificial Driving Agent

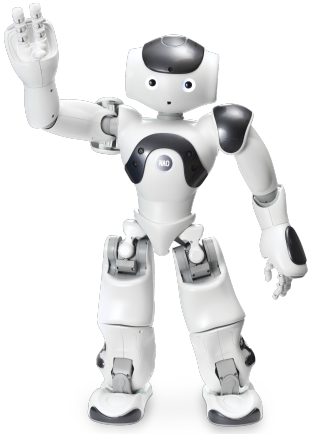
- Human-Like Condition: NAO
  Humanoid robot was placed in the driver's seat
- Gadget-like Condition
  iPhone 5s was mounted on the car's dashboard

Autonomy

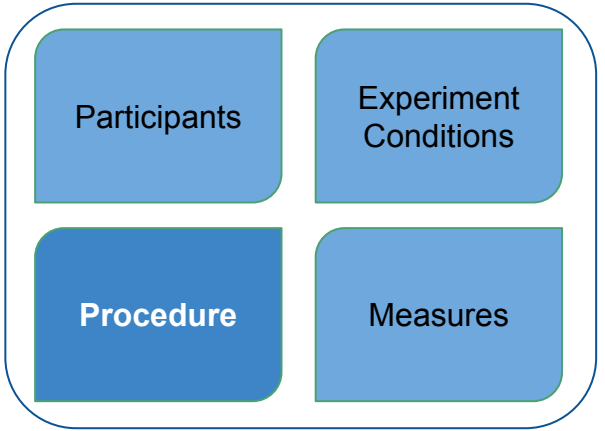
- Low: Asking participants to start or stop the car
- High: The agent was programmed to stopped or started the car

Communication tool between participants and agents

- Through a software application on an iPad
- Feedback to the agent given through the software



Method

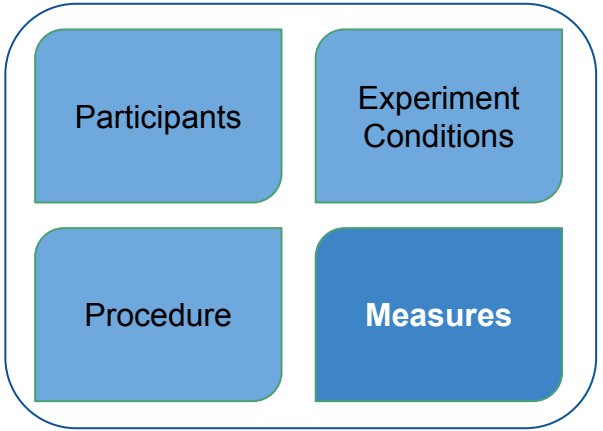


Low autonomy: start button was displayed in participant's iPad

High autonomy: the agent told participants that it's starting the car without the participant's intervention (!)

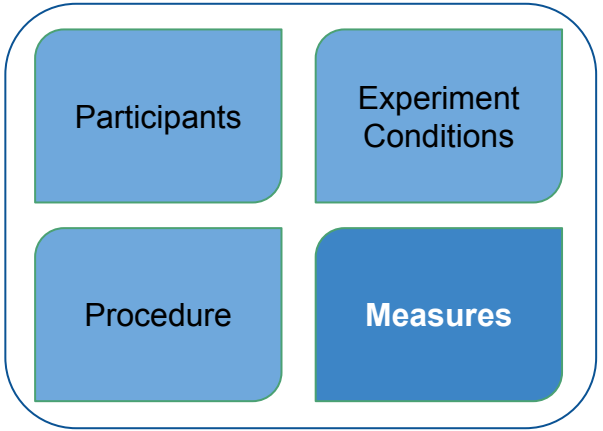
Emergency situation: A hidden pedestrian NAO suddenly appears and tries to cross the road and the driving agent sends a warning message(?)

Method



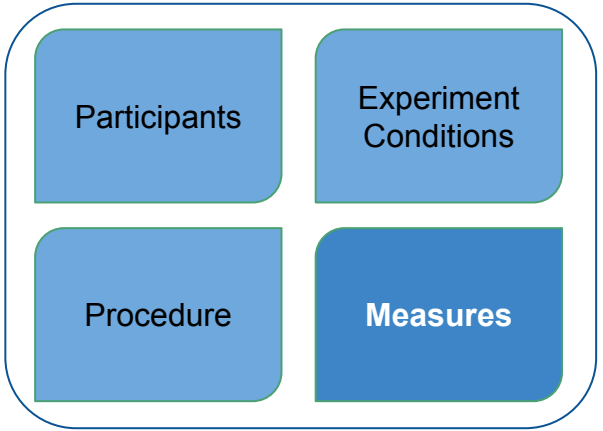
- Questionnaire items adopted from validated prior research (!?)
- Cronbach's alpha for all measured variables between 0.77 and 0.86 ➜ acceptable, good internal consistency and reliability of the questionnaire items
- 7-point Likert scale

Method



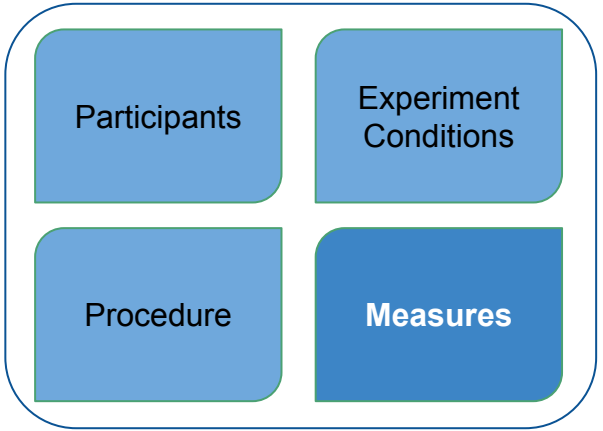
- **Perceived Intelligence**
  - Competent
  - Knowledgeable
  - Intelligent
  - Sensible
- **Safety**
  - Dangerous
  - Hazardous
  - Risky
  - Unsafe
  - Scary
  - (Affective state estimation of participants' feelings → Perceived safety)

Method



- **Perceived level of cognitive trust**
  - Credible
  - Reliable
  - Accurate
  - Useful
  - (Influenced by an analytic, rational assessment of information)
- **Perceived level of affective trust**
  - Likable
  - Enjoyable
  - Positive
  - (Representing likable feelings)

Method



- **Social Presence (co-existence, reacting to participants)**
  - How much did you feel you were interacting with an intelligent being?
  - How much did you feel as if you were accompanied by an intelligent being?
  - How much did you feel involved with it?
  - How much did you feel as if it was responding to you?
  - How much did you feel as if you and the driving agent were communicating to each other?

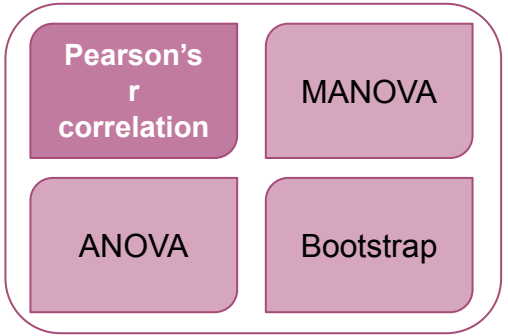
Results - Manipulation Assumption Check

Independent Sample T-Test conducted to validate that the humanlike appearance and high autonomy indeed served as anthropomorphic cues:

- NAO robot (M = 4.48, SD = 0.92)
- Smartphone (M = 4.03, SD = 1.04)
  - **NAO more anthropomorphic than Smartphone**
  - $t(87) = 2.14$, $p < 0.05$
- High Autonomy (M = 4.69, SD = 0.94)
- Low Autonomy (M=3.82, SD = 0.88)
  - **High Autonomy more anthropomorphic than low autonomy**
  - $t(87) = 4.50$, $p < 0.001$

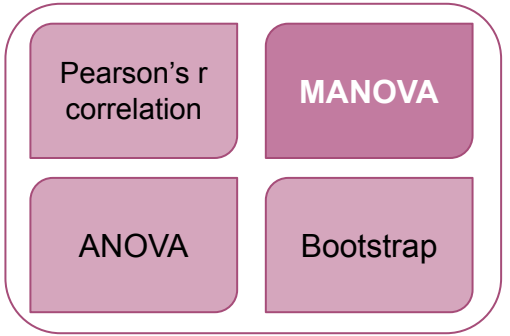
Normal Distribution / Absence of notable outliers

Results - Hypothesis Testing



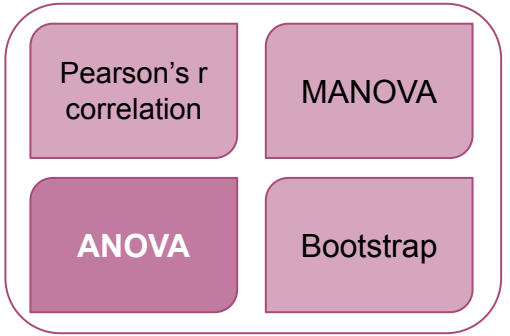
- **Pearson's r correlation analyses**
  - Relationship between **social presence** and the measured variables
  - Social presence positively correlated with
    - Perceived intelligence ($r = 0.41$, $p < 0.01$)
    - Safety ($r = 0.35$, $p<0.01$)
    - Cognitive trust ($r = 0.42$, $p<0.01$)
    - Affective trust ($r=0.25$, $p<0.05$)

Results - Hypothesis Testing



- **2 x 2 multivariate analysis of variance (MANOVA)**
  - **Appearance** $F(5,81) = 6.07$, $p < 0.001$, $\eta^2 = 0.27$
  - **Autonomy** $F(5,81) = 6.11$, $p < 0.001$, $\eta^2 = 0.27$
  - On all measured variables

Results - Hypothesis Testing



- **Analysis of variance (ANOVA)**
  effects of independent variables

	Mean (*SE*)					
	Appearance			Autonomy		
Measured Variables	**Humanlike**	**Gadgetlike**	**F**	**High**	**Low**	**F**
Social presence	4.42(.13)	3.86(.13)	10.83**	4.35(.13)	3.94(.13)	5.83*
Intelligence	4.94(.16)	4.45(.16)	5.53*	5.23(.16)	4.16(.16)	23.90**
Safety	4.66(.17)	3.96(.16)	9.49**	4.55(.17)	4.06(.16)	4.88*
Cognitive trust	4.54(.13)	4.45(.13)	0.40	4.85(.13)	4.15(.13)	14.92**
Affective trust	4.77(.12)	4.14(.11)	15.44**	4.70(.12)	4.21(.11)	9.74*

*$p < .05$. **$p < .01$.

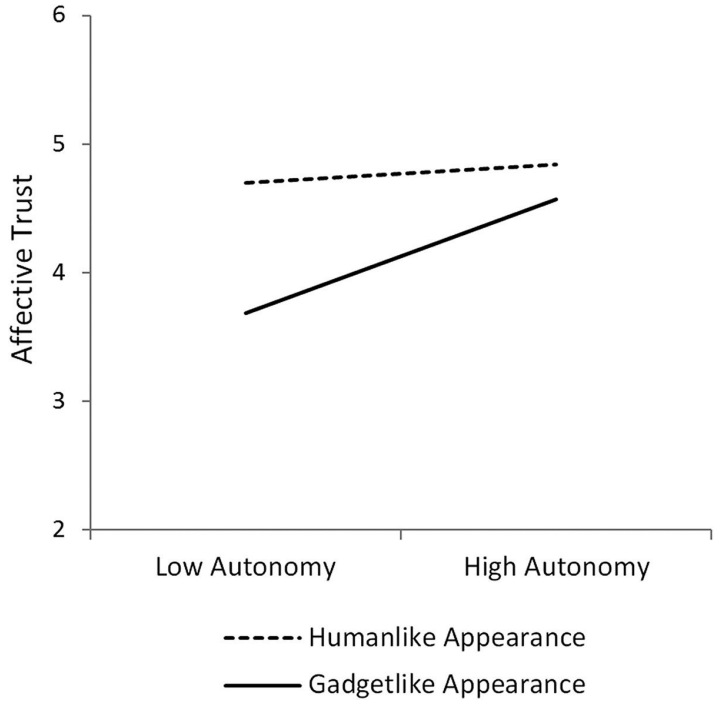
Results - Hypothesis Testing

Pearson's r correlation

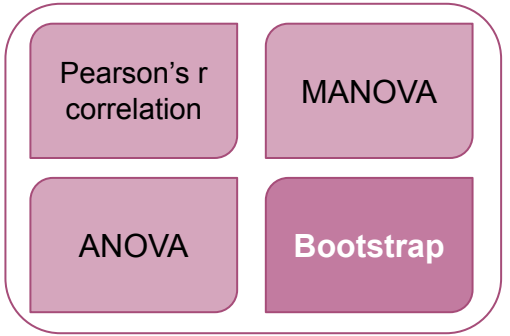
MANOVA

ANOVA

Bootstrap



Results - Hypothesis Testing



- **Bootstrapping procedure for indirect effects**
  - 10,000 bootstrap samples at 95% bias-corrected CIs
  - Whether anthropomorphism has mediating effects on other measured variables

				Confidence Interval	
Independent Variable	**Mediating Variable**	**Dependent Variable**	***B***	**Lower**	**Upper**
H3a Appearance	Social presence	Intelligence	.29	.10	.59
		Safety	.21	.07	.45
		Cognitive trust	.26	.10	.49
H3b Autonomy	Social presence	Intelligence	.18	.03	.40
		Safety	.17	.03	.38
		Cognitive trust	.15	.02	.32
		Affective trust	.08	.01	.24

Discussion

- **Appearance**
  - More effective in affective (not cognitive trust)
  - More structural, easily recognizable compared to autonomy
  - Credibility judgement processed **heuristically (peripheral, immediate)**
- **Autonomy**
  - Significantly effects both affective and cognitive trust
  - Internal quality, requires conscious observation, longer interaction
  - Triggering the **systematic (rational, analytic)**
  - **Autonomy's stronger effect on cognitive trust rather than affective trust**
  - Trust is a multidimensional concept (affective + cognitive), Dual mode processing

Discussion

- **Practical Implications for Designers**
  - Additive, combinatory effects of both appearance and autonomy are restricted
  - Application of the autonomy cue alone may be more practically ideal when one must be chosen over another
- **Social Presence**
  - Confirmation of the role of social presence as an influential mediator in shaping perceptions of unmanned driving systems
  - The extent to which users perceive the driving agent as intelligent, safe, and trustworthy is largely determined by the feelings of social presence experienced during their interaction.

Discussion - Limitations

Experiment Environment

- Ecological validity
- Observe only, not physical involvement
- Unlikely that a humanoid robot would drive a car without a human operator!

Sample of participants

- Young, may not have sufficient driving experience (Different standards and values)
- 3% among more than 20 million registered cars in Korea owned by drivers younger than 30

Potential moderating effects of influential variables associated with driving experience

- Vehicle speed
- Number of passengers
- Car manufacturer’s reputation
- Gender (!?)

Summary

P1	Explored whether applying layers of anthropomorphic cues to artificial driving agent **promotes positive evaluations and perceptions** of an unmanned driving system.
P2	Positive effects of **human-like appearance** and **autonomy**, effective in eliciting positive perceptions of the agent, evoking feelings of **social presence** → **increase in Perceived Intelligence and Safety, and Trust**.
P3	Feasibility of psychologically increasing the safety and trustworthiness of autonomous vehicles Ideas for designers

Discussion Points/Questions

Q1	Very Unrealistic Experiment Design and Setup
Q2	Decision on measuring factors
Q3	Lack of important information (plots, histograms, questionnaire)

Discussion Points/Questions

Q4	Use of Pearson's R Correlation which is a measure of strength of linear associations between two variables
Q5	Emphasis on proving trivial facts
Q6	Order of the contents

Thank you for your attention!

Questions?