DDI2022 GOTHENBURG

Valeo

LIÈGE université

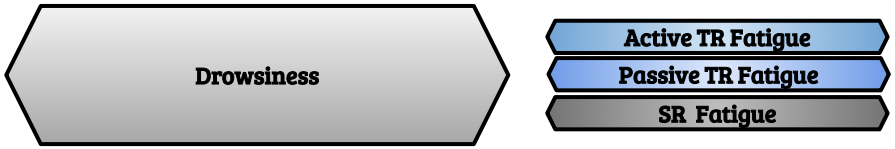
Assessment of the effectiveness of several countermeasures in reducing driver fatigue and associated risks for safety during autonomous driving

Cognitive sciences PhD at Valeo
Dabic (Degrand), Stéphanie
Annemasse - France
CDA/CIC/ISC

DDI 20-10-2022

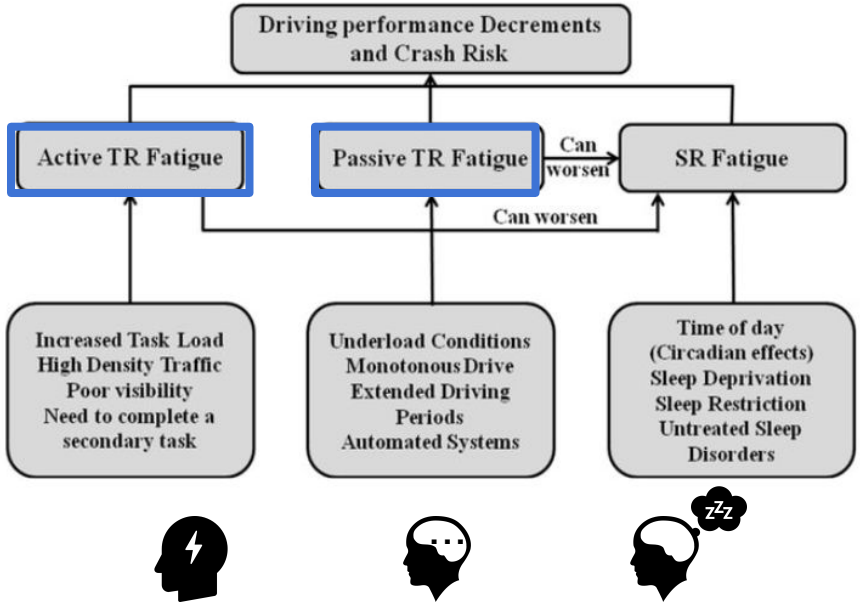
SMART TECHNOLOGY FOR SMARTER MOBILITY

Definitions



Distinction between sleep-related (SR) and task-related (TR) fatigue

A model of fatigue : (May and Baldwin, 2009)



Automation and ADAS could be dangerous for driver : Underload not required

Sources: AAA foundation for traffic safety. december 2019

The use of automation that remove sources of workload from the driver may create issues associated with mental underload.

Indeed, reducing it too much : negative impact driver performance (Nachreiner, 1995; Young and Stanton, 2002)

ACC function could negative impact : lower workload and poorer responses times (1-1.5 s slower) (young and stanton, 2004;2006) due to monotony and fatigue (Passive TR fatigue) (Matthews, 2009)

Table 1
The effectiveness of driver fatigue technologies in detecting or combating TR and SR fatigue.

	TR-active fatigue	TR-passive fatigue	SR fatigue
Detection technologies			
PerCLOS			X
Head-Nod			X
Deadman switch			X
Crash prevention			
Lane departure warning systems	X	X	X
Collision avoidance warning systems	X	X	X
Countermeasures			
Adaptive automation	X	X	
Interactive technology		X	

Take over: critical juncture

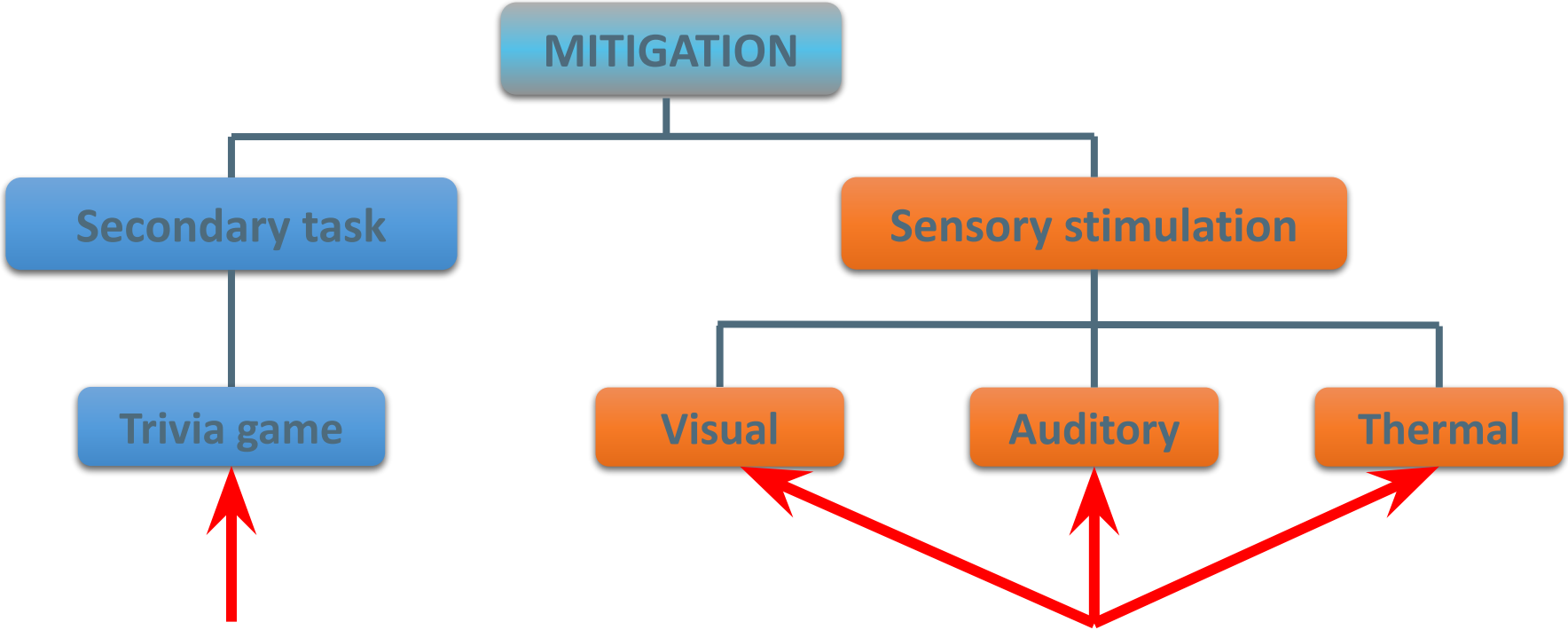
Drastic and rapid increase of workload

Limited amount of resources available for the driver

In conclusion: Increased workload during autonomous driving

1. to diminish PASSIVE fatigue
2. Without causing ACTIVE fatigue

Passive fatigue countermeasures



AIM

Objectives of This Project

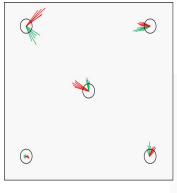
1. Evaluate the BUILDUP of PF during autonomous driving
2. Evaluate the EFFECTIVENESS of the countermeasures to mitigate PF
3. Evaluate the impact of the countermeasure on Take Over and Driving performance after TO.
4. Determine which countermeasure leads to the BEST COMPROMISE between risk-reduction and driver comfort

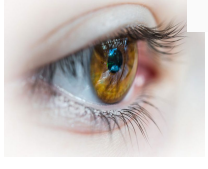
Imbedded system to mitigate PF during partially autonomous driving

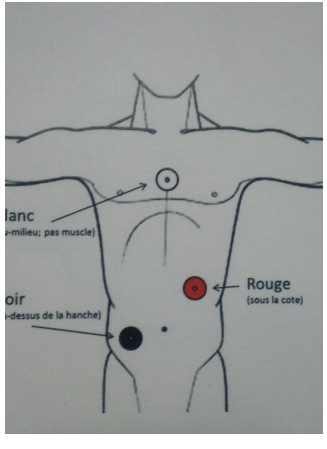
MATERIAL

Simulator

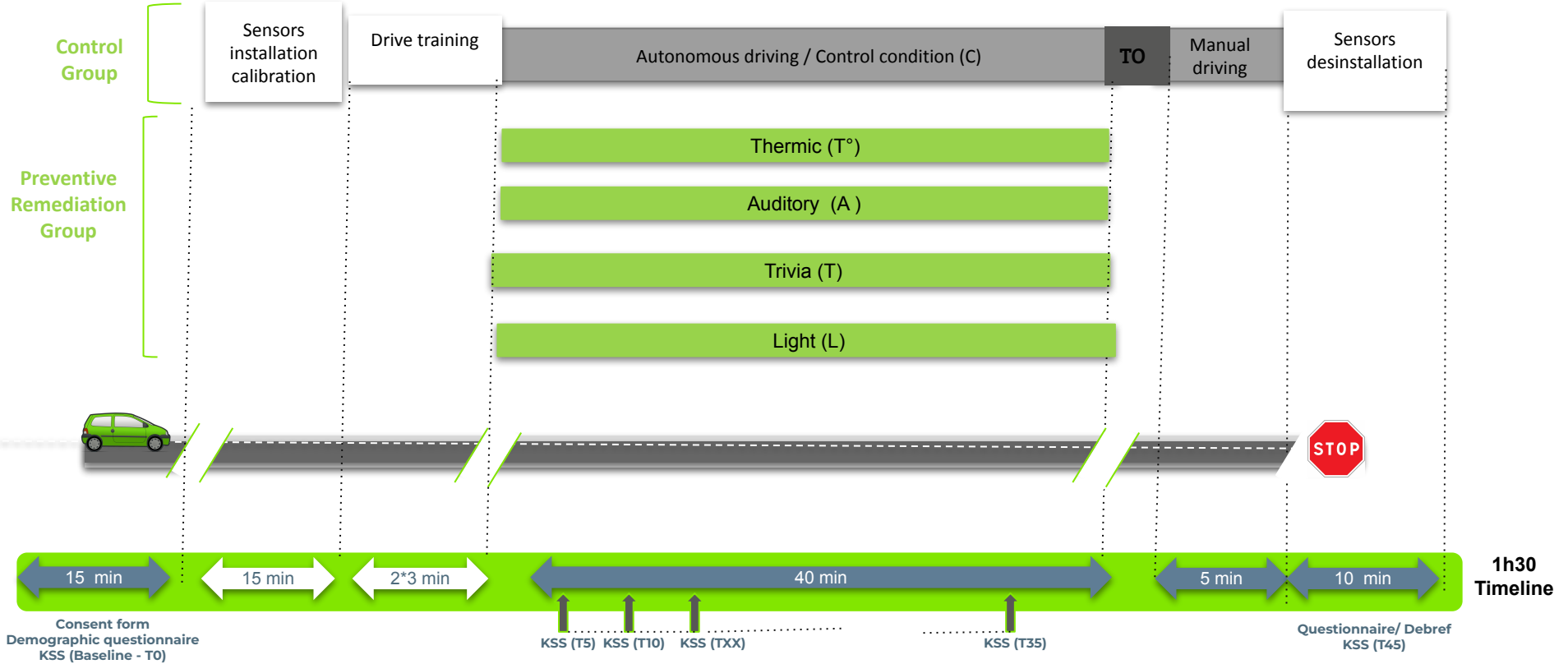
100 participants







Experimental protocol



Experimental protocol : Critical Take Over

Drive in autonomous mode for 40 minutes (See Saxby et al., 2013 for the times duration of the drive simulation)

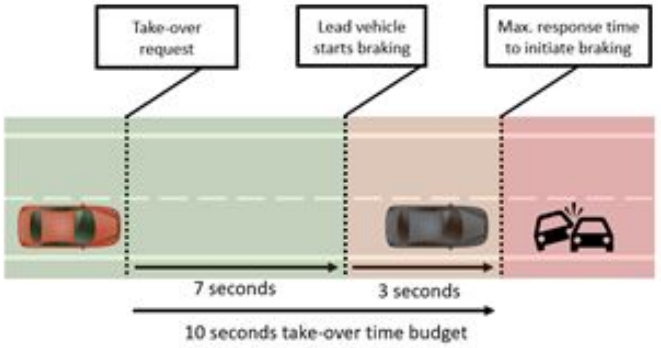
All road are highway-routes with very little traffic

TO request is initiated after 40 minutes of autonomous driving during 10 seconds

An hazardous driving event is triggered 7 seconds after end TO request

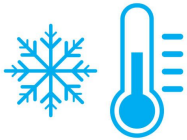
<u>Emergency braking</u> to avoid a collision

=> 5 minutes of manual driving to finish the experiment.



Counter measure

Thermic stimulation condition



- **Using a remotely controlled Air Conditioning device (AC), cold air (18°C) was blown toward the participants.**
- **Cooling will begin 4 minutes before TO request**

  (stimulation duration to have an impact on fatigue, see Schmidt & Bullinger, 2019).
- **Air will be directed towards the face of the driver.**

  (Landström et al., 1999; Schmidt et al., 2017; Schmidt et al., 2018)

Counter measure

Auditory stimulation condition

- **Participants were asked to bring playlists with songs they like during the all automated driving scenario**

  (see Navarro et al., 2019 for the effect of the type of music listen by the driver)

- **Music played at 75 dBA (comfort level)**

  - Optimal volume of music “U-shaped function” (see Turner, 1996; Dalton et al., 2007)

Counter measure

Cognitive stimulation condition (Trivia)

- **Participants will play “Trivia game” during the entire autonomous driving scenario**

  - Multiple choice questions (three or four possible answers)

    - Interactive task are the best to counteract Passive Fatigue (Jarosh et al., 2017; Jarosch, Bellem & Bengler, 2019).

    - Trivia is the Preferred secondary task (Oran-Gilad et al., 2002, 2008).

  - Questions selected from a variety of topics (sport, music, geography, history,…)

Counter measure

Light stimulation condition

- **Original and innovative countermeasure**
- **Promising but still little studied as Passive Fatigue in car countermeasure.**
- **Blue and Red Led light around the car cabin**
  - Increase arousal and alertness
  - Decrease sleepiness

"To conclude, light seems to be a promising way to diminish fatigue but more studies have to be done to construct more solid hypothesis" (Elliot, 2015).

APPROACH

Data collection

- Passive fatigue
  - Self-reported scale (i.e. KSS)
  - Ocular parameters (i.e. percentage of eye closure, pupil diameter)
  - ECG
- Comfort of the countermeasures
  - Self-reported scale
- Driving performance (reaction times to…)
  - Video recordings (i.e. hands on wheel and on pedals)
  - Simulator outcomes (i.e. take-over and braking initiation, driving performances, crash)
  - Gaze-tracking (i.e. attentional focus on speedometer and middle and left-side mirror)

Results: impact of the countermeasures

1. On Passive Fatigue

KSS : **Subjective measure, asked every 5' to the participants**

Pupils diameter : **Objective measure : recorded 120 seconds before TO.**

2. On TAKE OVER performances

a. **Time to take over the steering wheel after the TO Request**

b. **Time to take over the pedals (accelerator or brake)**

c. **First time watching the middle and side rear view mirrors after the TO request**

3. On reactions to the critical event

a. **Presence or absence of collision with the braking vehicle**

b. **The way to avoid the braking vehicle (braking only or braking + change of lane)**

c. **Braking reaction time in reaction to the critical event**

4. Comfort

Subjective scale

Results

1. Impact of countermeasures on passive fatigue

KSS scores

- State of alertness
- 9 point Likert scale
- 1 = extremely awake ; 9 = extremely sleepy and fighting sleep

1	Extrêmement éveillé
2	Très éveillé
3	Eveillé
4	Assez éveillé
5	Ni éveillé, ni somnolent
6	Signes de somnolence
7	Somnolent mais sans difficulté à rester éveillé
8	Somnolent avec difficulté à rester éveillé
9	Très somnolent, luttant contre le sommeil

Results

1. Impact of countermeasures on passive fatigue

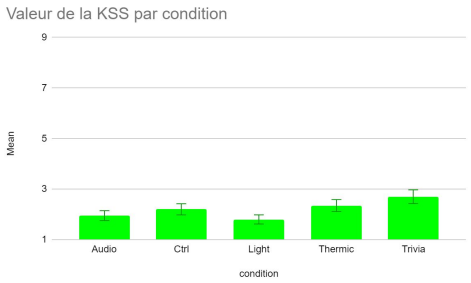
Is the KSS score the same for the five groups before the beginning of the scenario?

ANOVA with the type of countermeasure as Grouping factor and T0' KSS as dependent variable

	Sum of Squares	df	Mean Square	F	p
Countermeasure	9.900	4	2.475	1.865	0.123
Residuals	126.100	95	1.327		

condition	Mean	SD
Audio	1.950	0.826
Ctrl	2.200	1.152
Light	1.800	0.834
Thermic	2.350	1.348
Trivia	2.700	1.455

No significant difference between groups for T0' KSS



Results

1. Impact of countermeasures on passive fatigue

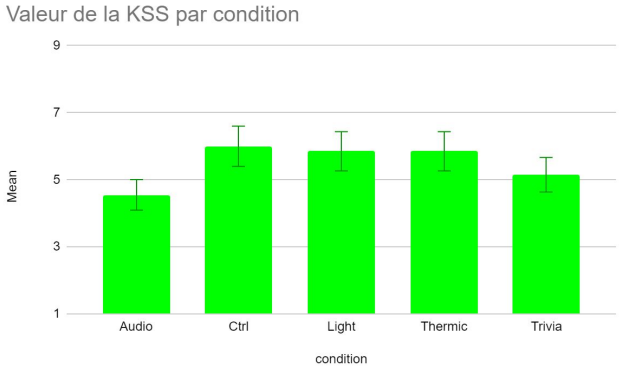
B. Is the KSS score the same for the five groups after 35' of driving scenario?

ANOVA with the type of countermeasure as Grouping factor and T35' KSS as dependent variable

	Sum of Squares	df	Mean Square	F	p	η^2
condition	30.360	4	7.590	2.607	**0.040**	**0.099**
Residuals	276.600	95	2.912			

- **Significant impact of the condition**
- **Post Hoc Tests reveal an almost significant difference between Audio and Control condition (t = 3.26; p = 0,002)**

condition	Mean	SD
Audio	4.550	1.468
Ctrl	**6.000**	**1.338**
Light	5.850	2.110
Thermic	5.850	1.725
Trivia	5.150	1.785



Results

1. Impact of countermeasures on passive fatigue

C. Is the difference between T0' KSS and T35' KSS the same for the conditions?

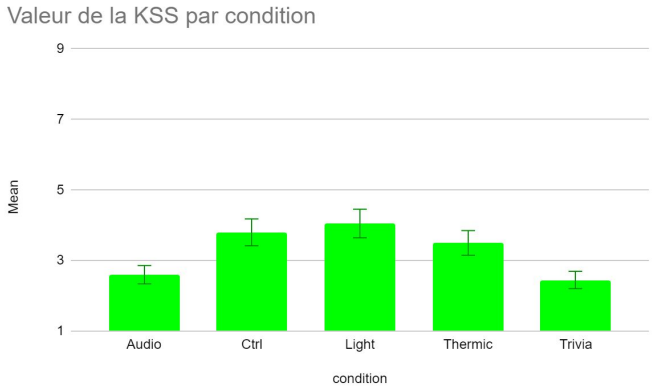
ANOVA with the type of countermeasure as Grouping factor and ΔKSS as dependent variable

	Sum of Squares	df	Mean Square	F	p	η^2
condition	41.260	4	10.315	4.357	**0.003**	**0.155**
Residuals	224.900	95	2.367			

- **Significant impact of the condition**

- Post Hoc Tests revealed a significant difference between
  - Audio and Light ($t = 2,98$; $p = 0,029$)
  - Trivia and - Control ($t = 2,775$; $p = 0,05$)
    - Light ($t = 3,288$; $p = 0,012$)

Condition	Mean	SD
Audio	2.600	1.392
Ctrl	**3.800**	**1.436**
Light	**4.050**	**1.905**
Thermic	3.500	1.469
Trivia	2.450	1.432



Results

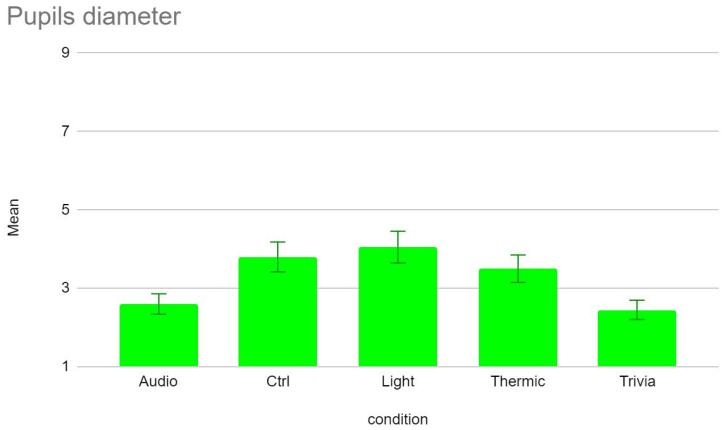
1. Impact of countermeasures on passive fatigue

ANOVA with the type of countermeasure as Grouping factor and pupils diameter as dependent variable

	Sum of Squares	df	Mean Square	F	p	η^2
condition	1.097	4	0.274	1.656	0.167	0.065
Residuals	15.728	95	0.166			

Condition	Mean	SD
audio	3.104	0.347
Ctrl	2.986	0.441
Light	2.885	0.332
T°	3.070	0.490
trivia	3.192	0.403

- **No significant impact of the ‘condition’ on the pupils diameter.**



Results

2. Impact of countermeasures on TAKE OVER PERFORMANCES

Three measurements

a. Time to take over the steering wheel after the TO Request

b. Time to take over the pedals (accelerator or brake)

c. First time watching the middle and side rear view mirrors after the TO request

Valeo

Results

2. Impact of countermeasures on TAKE OVER PERFORMANCES

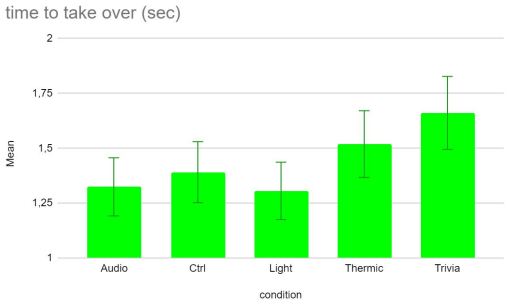
A. Time to take over the steering wheel after the TO Request

ANOVA with the type of countermeasure as Grouping factor and time to reach the steering wheel as dependent variable

	Sum of Squares	df	Mean Square	F	p	η^2
Condition	1.770	4	0.443	3.422	**0.012**	**0.126**
Residuals	12.288	95	0.129			

condition	Mean	SD
Audio	1.324	0.342
Control	1.391	0.286
Light	1.306	0.308
Thermic	1.519	0.396
Trivia	1.661	0.443

- **Significant impact of the condition**
- **Post Hoc tests reveal significant difference between :**
  - Audio and Trivia (t = 2,957; p = 0,031)
  - Light and Trivia (t = 3,116; p = 0,020)



Valeo

Results

2. Impact of countermeasures on TAKE OVER PERFORMANCES

B. Time to take over the Pedals after the TO Request

ANOVA with the type of countermeasure as Grouping factor and time to reach the pedals as dependent variable

	Sum of Squares	df	Mean Square	F	p	η^2
Condition	11.090	4	2.773	1.127	0.349	0.045
Residuals	233.805	95	2.461			

 No significant difference between the groups.

condition	Mean	SD
Audio	3.209	1.629
Ctrl	3.454	1.673
Lumi.re	2.896	1.193
Thermique	2.591	1.425
Trivia	3.445	1.844

Results

2. Impact of countermeasures on TAKE OVER PERFORMANCES

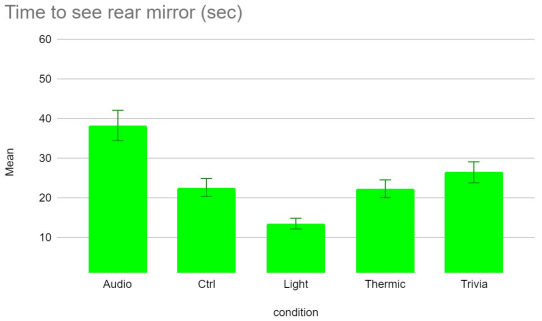
C. First time to watch the rear view mirrors after the TO Request

ANOVA with the type of countermeasure as Grouping factor and first time to watch the left side rear view mirror as dependent variable

	Sum of Squares	df	Mean Square	F	p
Condition	2826.667	4	706.667	2.994	0.030
Residuals	8969.417	38	236.037		

condition	Mean	SD	N
audio	38.327	18.853	7
Ctrl	22.672	18.696	8
Light	13.531	12.662	12
T°	22.355	13.384	7
trivia	26.498	13.927	9

- **Impact of the condition : Light group significantly faster than Audio**
- Many participants did not look at the middle mirror in the 60-second interval after TO
- On average, participants watched it after the critical event



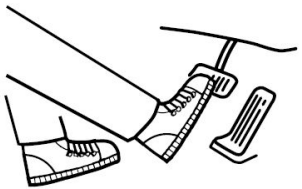
3. Impact of countermeasures on REACTIONS TO THE CRITICAL EVENT

Three measurements

a. Presence or absence of collision with the braking vehicle

b. The way to avoid the braking vehicle (braking only or braking + change of lane)

c. Braking reaction time in reaction to the critical event



Results

3. Impact of countermeasures on reactions to the critical event

	0 = No accident ; 1 = accident		
condition	0	1	Total
Audio	17	3	20
	85 %	15 %	
Control	14	6	20
	70 %	30 %	
Light	16	4	20
	80 %	20 %	
Thermic	17	3	20
	85 %	15 %	
Trivia	17	3	20
	85 %	15 %	

Twice as many accidents for the control group compared to the Audio, Thermic, and Trivia groups

$\chi^2 = 2{,}209$; $p = 0{,}697$

No significant link between the presence or absence of accident and the experimental condition

Results

3. Impact of countermeasures on reactions to the critical event

B. The way to avoid the collision

	Braking = 1 ; Braking + lane change = 2		
condition	1	2	Total
Audio	6	11	17
	35.29 %	64.71 %	
Ctrl	5	9	14
	35.71 %	64.29 %	
Light	7	9	16
	43.75 %	56.25 %	
Thermic	6	11	17
	35.29 %	64.71 %	
Trivia	4	13	17
	23.53 %	76.47 %	
Total	28	53	81
	34.57 %	65.43 %	

$\chi^2 = 1{,}528$; $p = 0{,}822$

No significant link between the way to avoid the accident and the experimental condition

Valeo

Results

3. Impact of countermeasures on reactions to the critical event

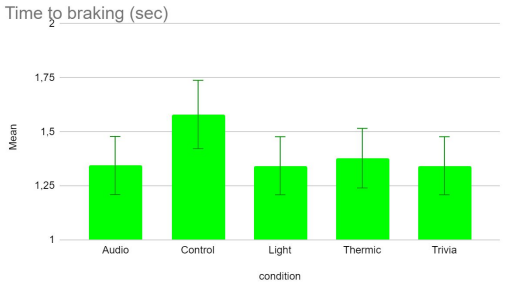
C. Braking reaction time in reaction to the critical event

ANOVA with the type of countermeasure as Grouping factor and braking reaction time as dependent variable

	Sum of Squares	df	Mean Square	F	p	η^2
Condition	0.849	4	0.212	2.399	0.055	0.092
Residuals	8.401	95	0.088			

	Mean	SD
Audio	1.344	0.256
Control	1.580	0.347
Light	1.343	0.264
Thermic	1.378	0.289
Trivia	1.343	0.321

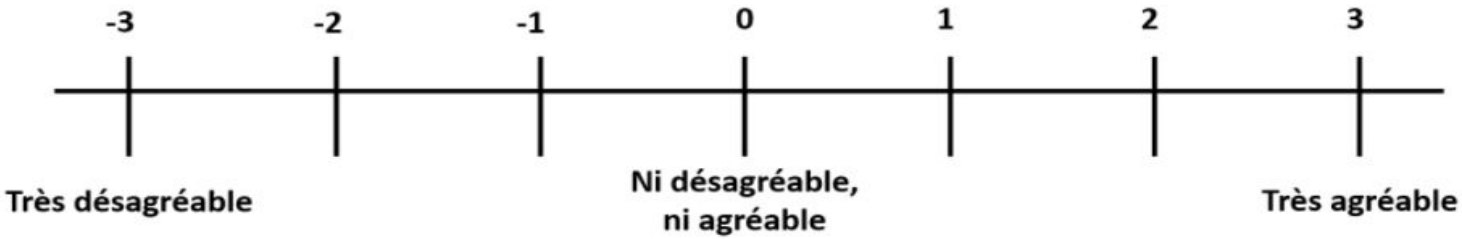
- No significant difference between the groups.



4. Agreeability rating of the countermeasures

- 1 to 7 Likert scale
- 1 = Very unpleasant; 7 = Very pleasant

« Comment jugez-vous l'agréabilité/plaisant de la contre-mesure mise en place pour contrer la fatigue passive ? »



Results

4. Confort : Agreeability rating of the countermeasures

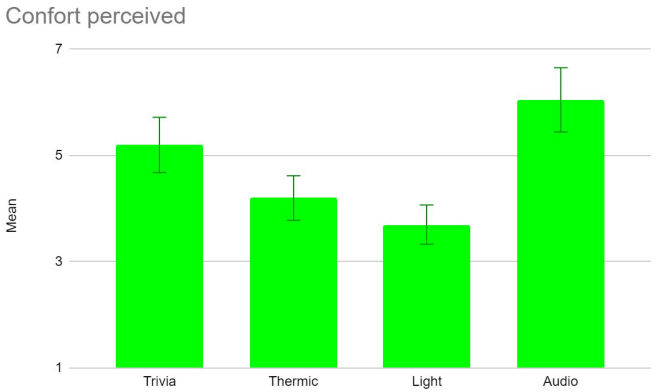
ANOVA with the type of countermeasure as Grouping factor and Agreeability rating as dependent variable

	Sum of Squares	df	Mean Square	F	p	η^2
condition	65.837	3	21.946	14.189	< .001	0.359
Residuals	117.550		76	1.547		

condition	Mean	SD
Audio	6.050	1.356
Light	3.700	0.657
Thermic	4.200	1.704
Trivia	5.200	1.005

Post Hoc Tests revealed significant difference between the groups

- **No significant difference between Thermic and Light (p=0.2284)**
- **Trivia and Audio significant difference : higher than both other(p<0.05)**
- **Audio significant difference between Audio and Trivia (Audio better)(p=0.02964)**



Conclusion

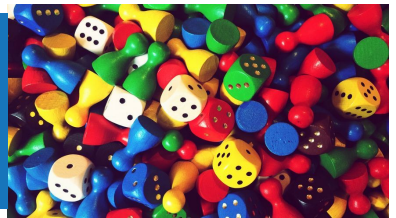
1. **Fatigue :** Audio and Trivia best countermeasures

2. **Take over performance :** little impact of the countermeasures : audio longer for first glance in rear mirror but less time to take over on steering wheel=> OVERconfidence, poor awareness of the situation (?)

3. **Reaction to the critical event :** Participants of the control group seem to have had more difficulties to react properly

4. **Comfort :** Audio and Trivia best linking countermeasures

Trivia : Best compromise between risk-reduction and driver comfort! But could involve immersion problem….



Valeo

Merci de votre attention

Thank for your attention

Valeo

SMART TECHNOLOGY
FOR SMARTER MOBILITY