Pedestrians' time-to-collision estimation and road-crossing judgments differ between electric and conventional vehicles

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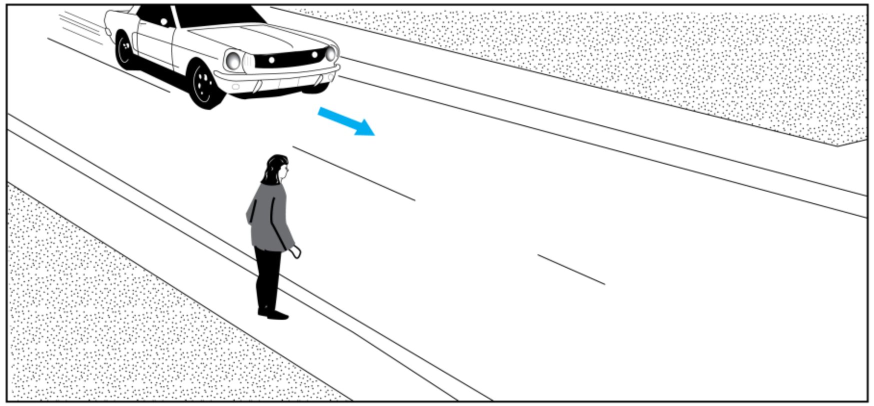
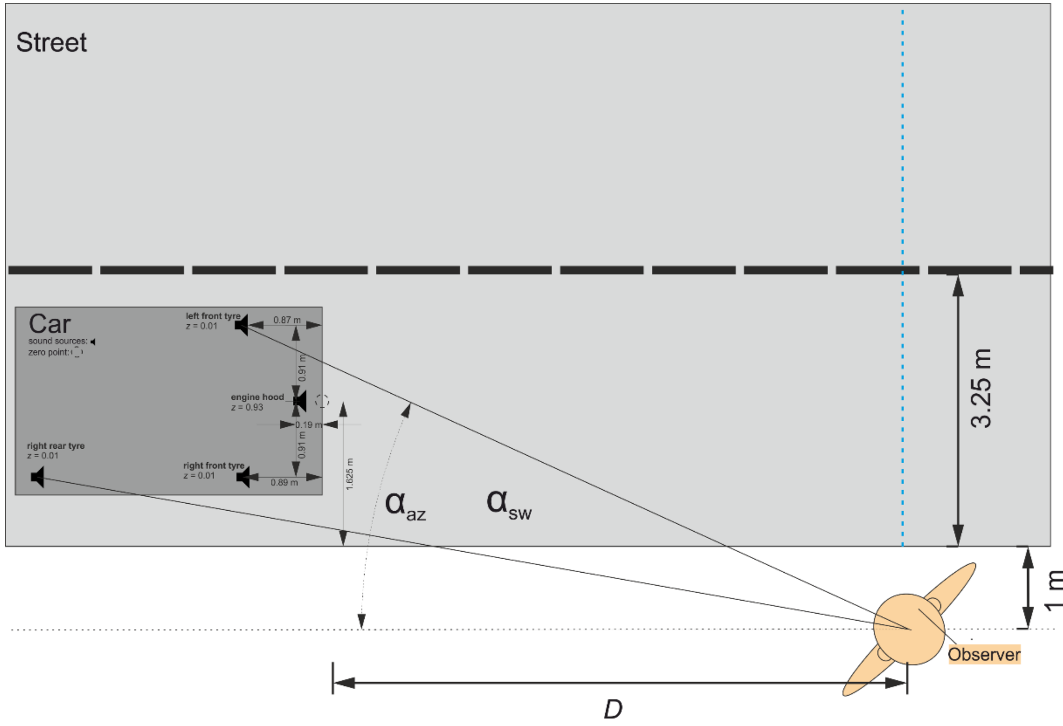
Hearing for safe mobility

- **Avoiding collisions** in a traffic situation:
  - Are there any vehicles near me? – *detection*
  - Is the vehicle on a collision course with me? – *collision detection*

Street-crossing decisions

- *Can I reach the other side before the car arrives?*
  - Estimation of the **time-to-collision (TTC)** required
  - TTC **>** crossing time: 
  - TTC **<** crossing time: 



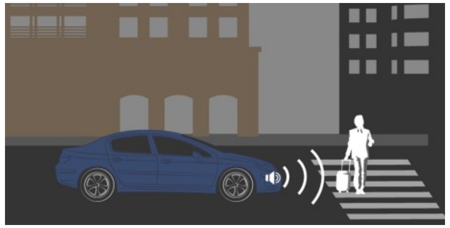


- **Motion-related** acoustic cues to TTC
  - dynamic intensity cues
  - dynamic binaural cues
  - dynamic spectral cues
- **Vehicle-noise** cues
  - tire sound (~ speed)
  - powertrain noise (~ engine rotational speed and load)
  - aerodynamic noise (~ speed)

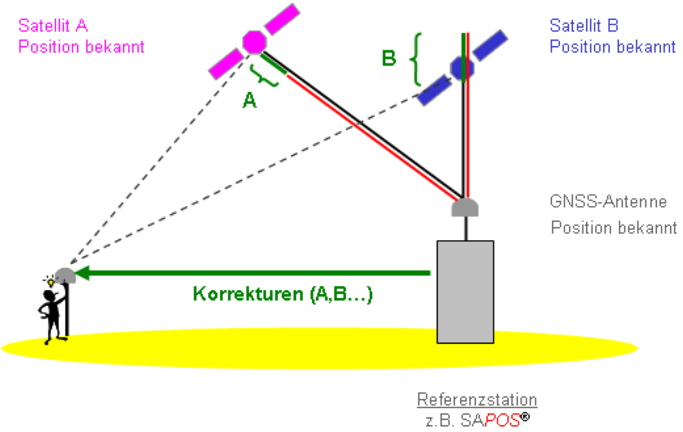
Audiovisual VR simulation of approaching vehicles

- **Source-based** simulation approach
  - **4 microphones** mounted on the chassis
  - Driving profiles: constant speed (10-60 km/h) / constant acceleration
- **ICEV**: Kia Rio

- **EV**: Kia eNiro 2019 (UNECE R138 Acoustic Vehicle Alerting System inactive or active < 28 km/h)



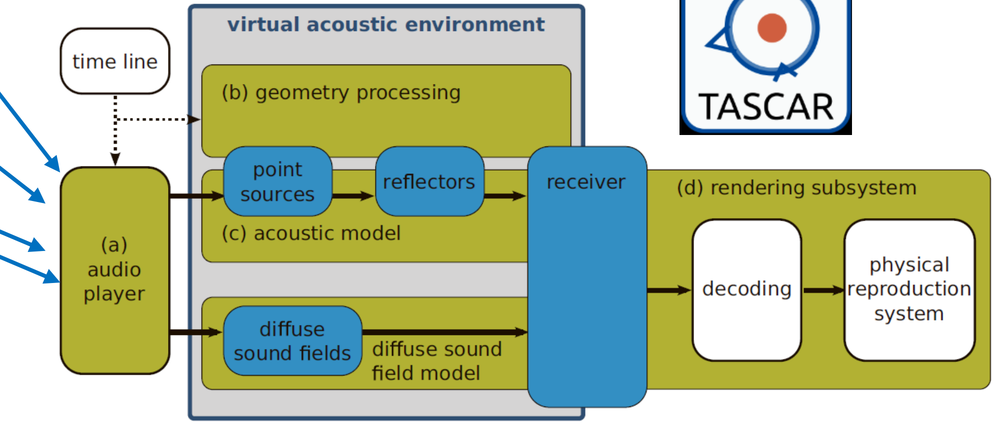
- High-precision **GPS tracking**



Audiovisual VR system

Vehicle recordings

Acoustic simulation



TASCAR

http://tascar.org/

Grimm, Luberadzka, & Hohmann (2019, *Acta Acustica*)

Rendering

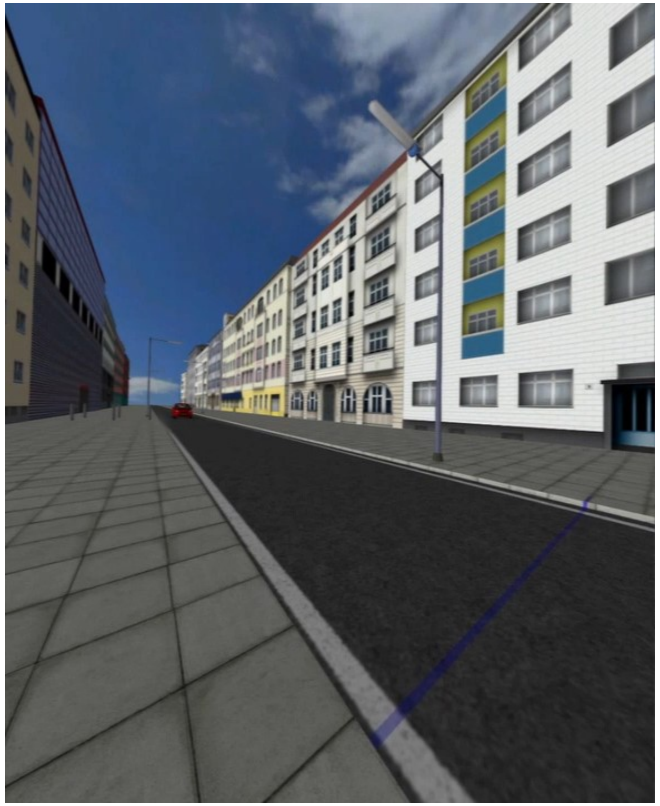
2D Ambisonics & 3D VBAP

Visual VR

- Source signals: *real vehicle sounds*
- *Distance-dependence* of the sound level and sound spectrum
- Dynamic *binaural auditory localization information* (interaural time and level differences)
- *Reflections/absorption* by ground surface / houses -> comb-filter effects etc.
- *Propagation time* (-> Doppler)
- *Stereoscopic presentation* of the visual 3D scene, interactive

Exp. 1: Effects of vehicle loudness on TTC estimation

- Previous studies: *Louder* sound source appears to arrive **earlier** than a *softer* sound source with the same actual TTC (DeLucia, Preddy, & Oberfeld, 2016, *Multisens. Res.*; Keshavarz, DeLucia, Campos, & Oberfeld, 2018, *Att. Percept. & Psychophy.)*
  - BUT: artificial sounds, no spatial rendering



- **Simulated traffic scenario**: Car approaches a pedestrian at a **constant speed** (10, 30, 50 km/h)

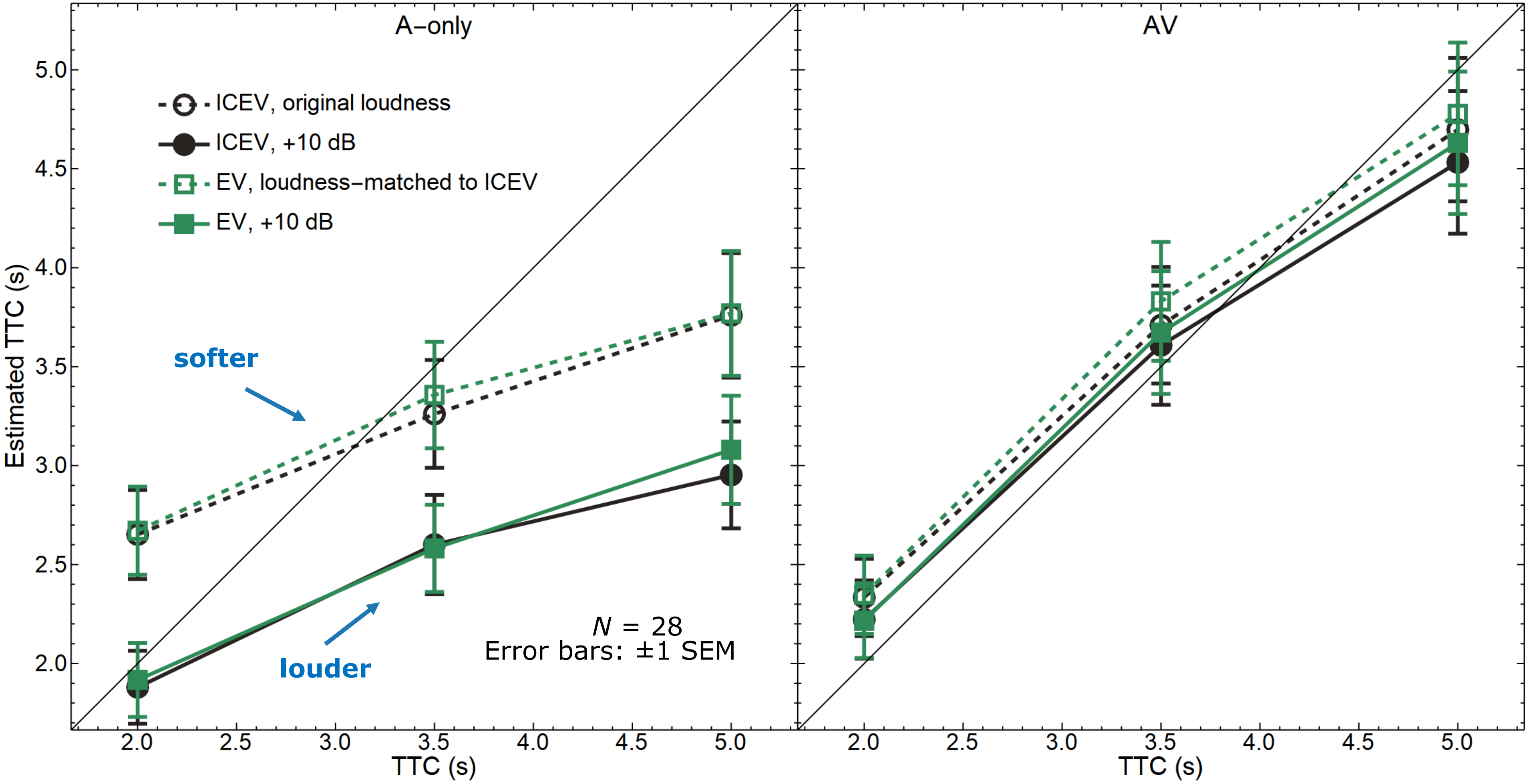
- **TTC estimation** („prediction-motion task"; Schiff & Detwiler, 1979)

- Two **vehicle loudness levels**:
  1. Lower: ICEV (as recorded) and **loudness-matched** EV
  2. Higher: ICEV and loudness-matched EV **+10 dB**

- **Auditory-only** (**A**; car invisible) and **audiovisual** condition (**AV;** car visible)

Oberfeld, Wessels, & Büttner (2022 *Acc. Anal. Prev.*)

Exp. 1: Results



→ **Effect of vehicle loudness confirmed** using realistic acoustic simulations

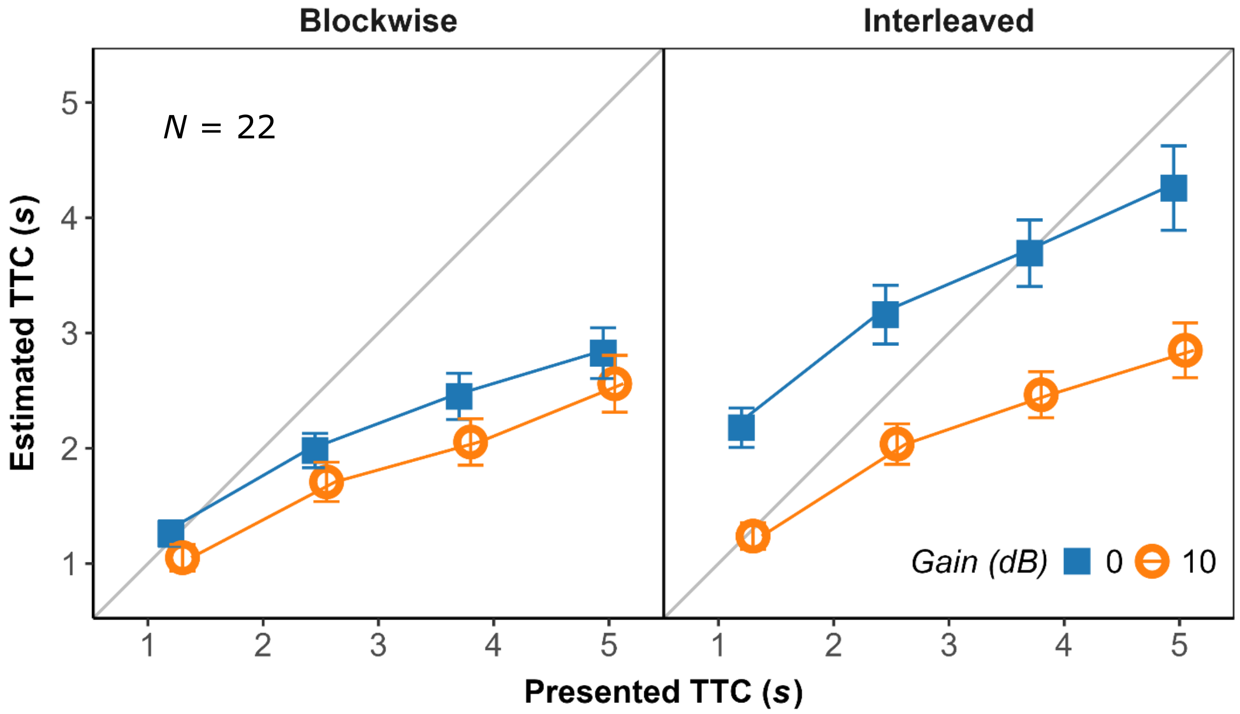
■ **No sign. differences** between EV and ICEV at equal loudness!

- Mean estimated TTC **740 ms shorter** at the **higher loudness level** ($p < .001$, $d_z = 2.06$)
- Mean estimated TTC **136 ms shorter** at the higher loudness level ($p < .001$, $d_z = 0.95$)

Oberfeld, Wessels, & Büttner (2022 Acc. Anal. Prev.)

Exp. 2: Blockwise loudness variation

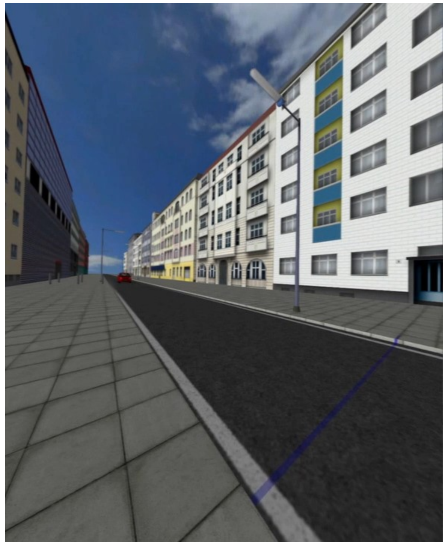
- E.g., block 1 lower loudness level, block 2 higher loudness level, block 3 interleaved
- **A-only**, **ICEV** sound



- Significant effect of vehicle loudness in **both regimes**, but stronger in the interleaved condition

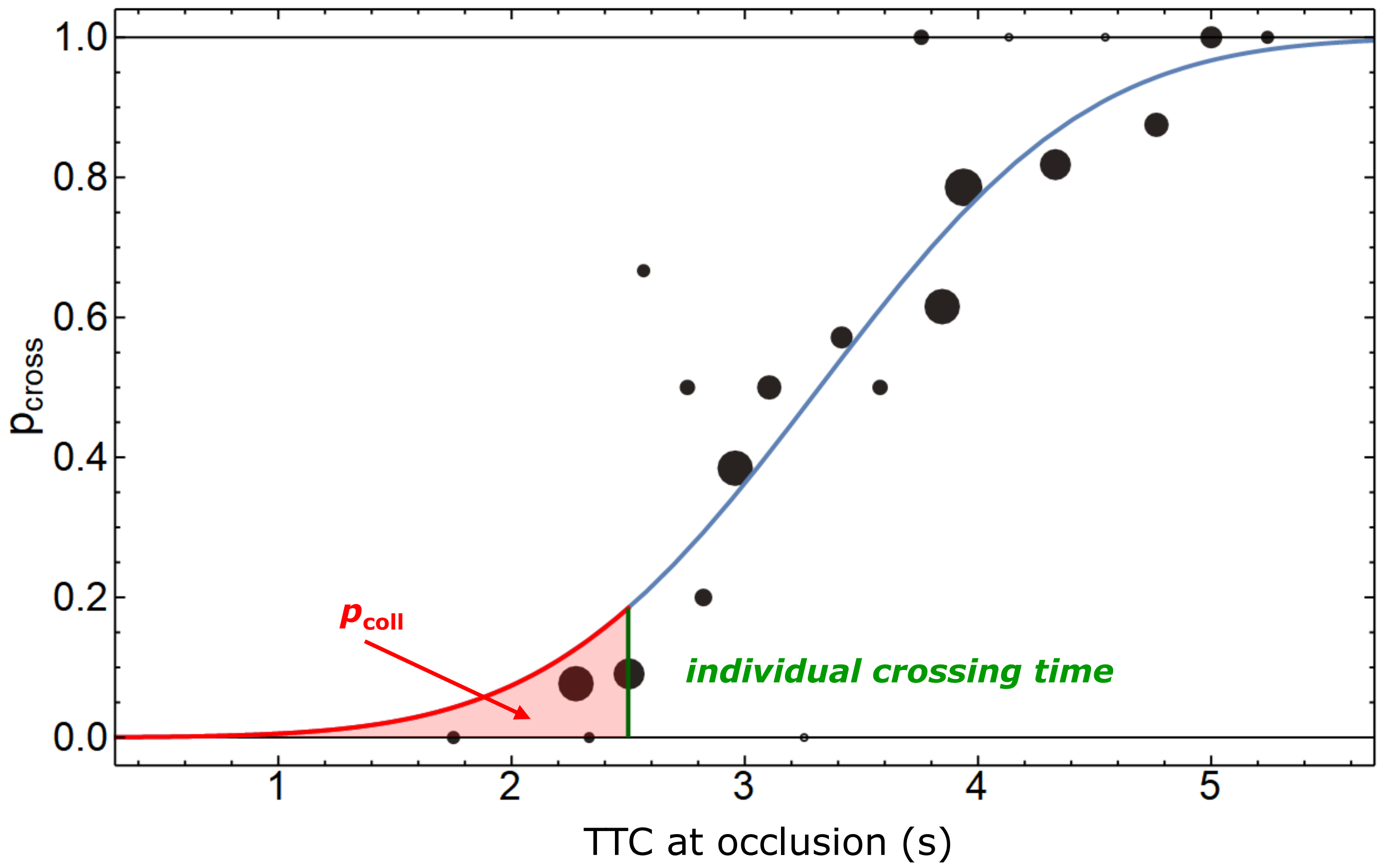
Exp. 3: Effects of vehicle loudness on street-crossing decisions

- **Auditory-only** and **audiovisual** presentation, occlusion paradigm
  - Vehicle approaches for 6 s, then it disappears
  - **Task:** *At the moment of occlusion, could I have crossed the road in my normal walking pace?* -> ***„Yes"/"No"***
  - **TTC at occlusion** varied by an **adaptive procedure ->** measurement of the **psychometric function** relating the probability of a positive street-crossing decision („gap acceptance") to the presented TTC at occlusion



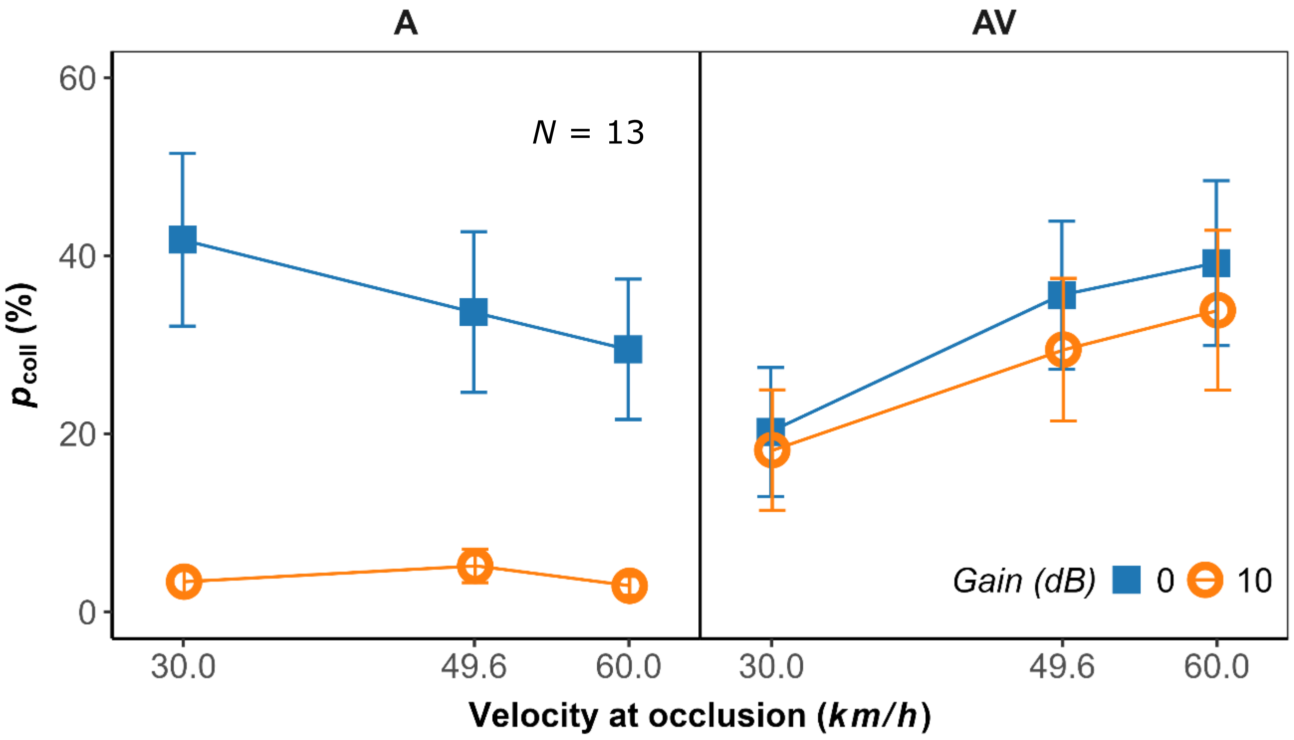
Exp. 3: Collision probability

- If the vehicle does not brake: **collision** if the participant decides to cross when the *TTC at occlusion* is **shorter** than the *crossing time*



- Collision probability p_{coll}: probability of a **positive crossing decision** when the *TTC at occlusion* is **shorter** than the *individual crossing time*

Exp. 3: Results



- Large effect of vehicle loudness in the **A-only** condition -> loudness seems to be a dominant cue
- Significant effect of vehicle loudness also in the **AV** condition -> **riskier** crossing decisions in interaction with quieter vehicles

Oberfeld, Huisman, & Wessels (in preparation)

TTC estimation for accelerating objects

- Visual TTC estimation: **insufficient consideration** of acceleration (e.g., Lee *et al*., 1983, *JEP:HPP*)

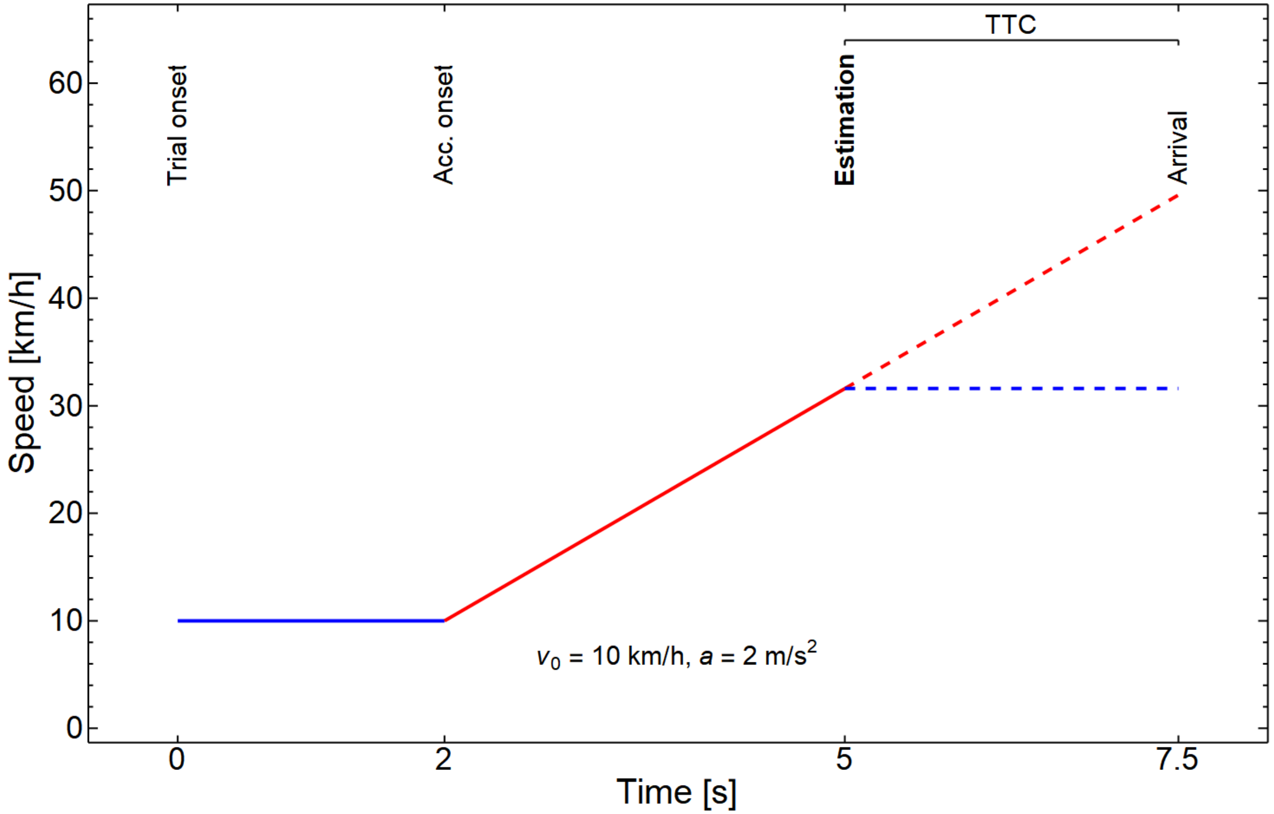
  - Participants should do this:

$$TTC(t) = \frac{-v(t) + \sqrt{2a\,D(t) + v^2(t)}}{a}, a > 0$$

  - But they seem to do that:

$$TTC_1(t) = \frac{\boldsymbol{D(t)}}{\boldsymbol{v(t)}} = TTC(t) + \frac{\boldsymbol{a \cdot TTC^2(t)}}{\boldsymbol{2 \cdot v(t)}}$$

    - *„First-order estimation“*: as if the object maintained the instantaneous velocity shown at the moment of estimation
    - Results in **overestimated** TTC

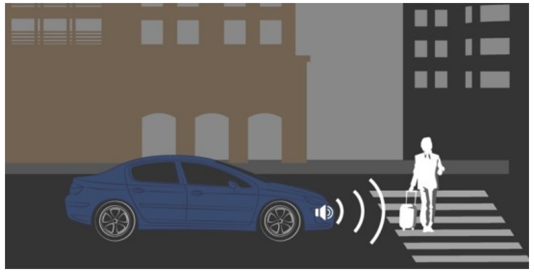


Accelerating vehicles: acoustic acceleration information

- **ICE vehicles** provide salient **acoustic information** about their state of acceleration

- **E-vehicles**: the acoustic signal is **less salient**

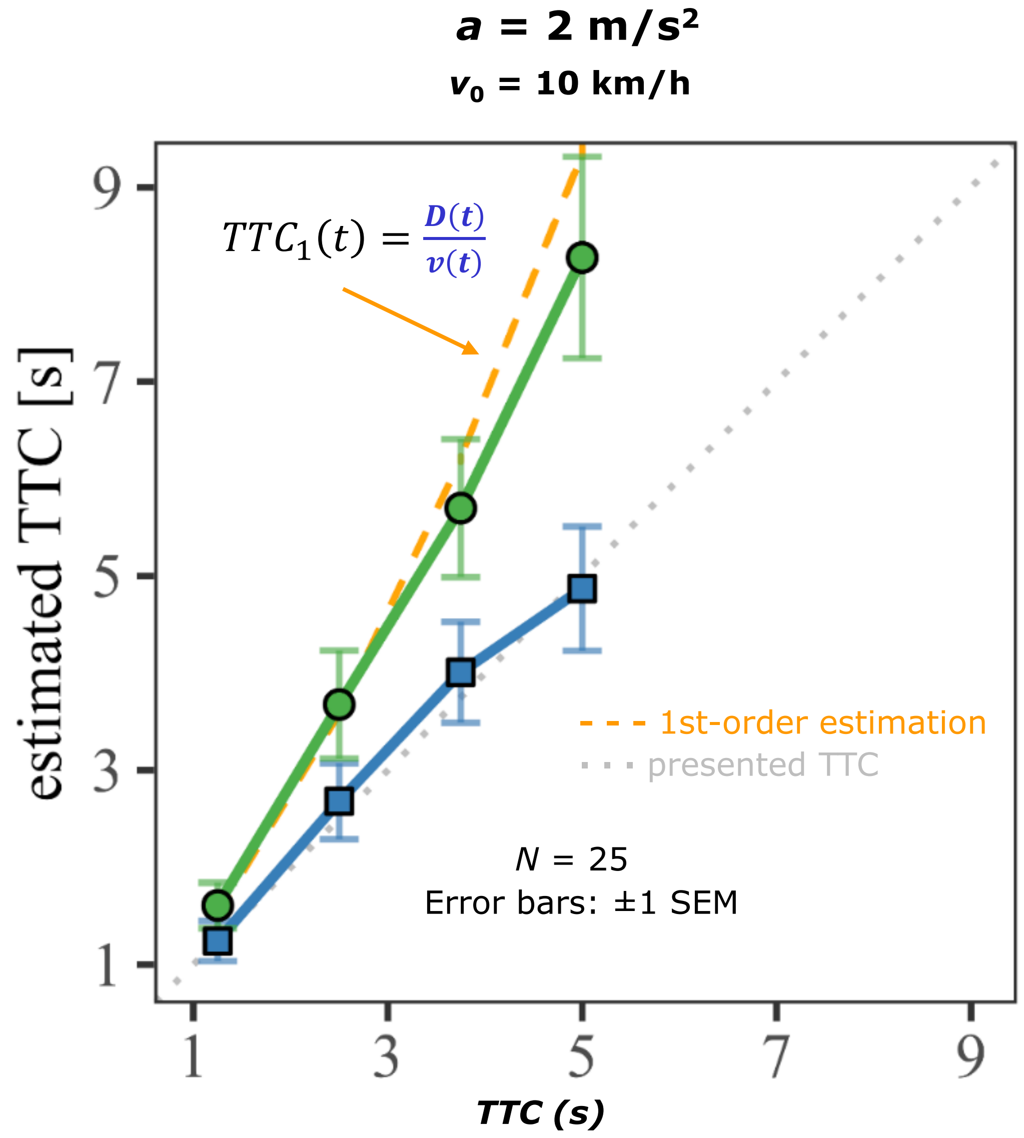
- **E-vehicle with AVAS**: Does this again provide better acoustic acceleration information?



Exp. 4: Visual-only vs. audiovisual TTC estimation for accelerating ICEVs

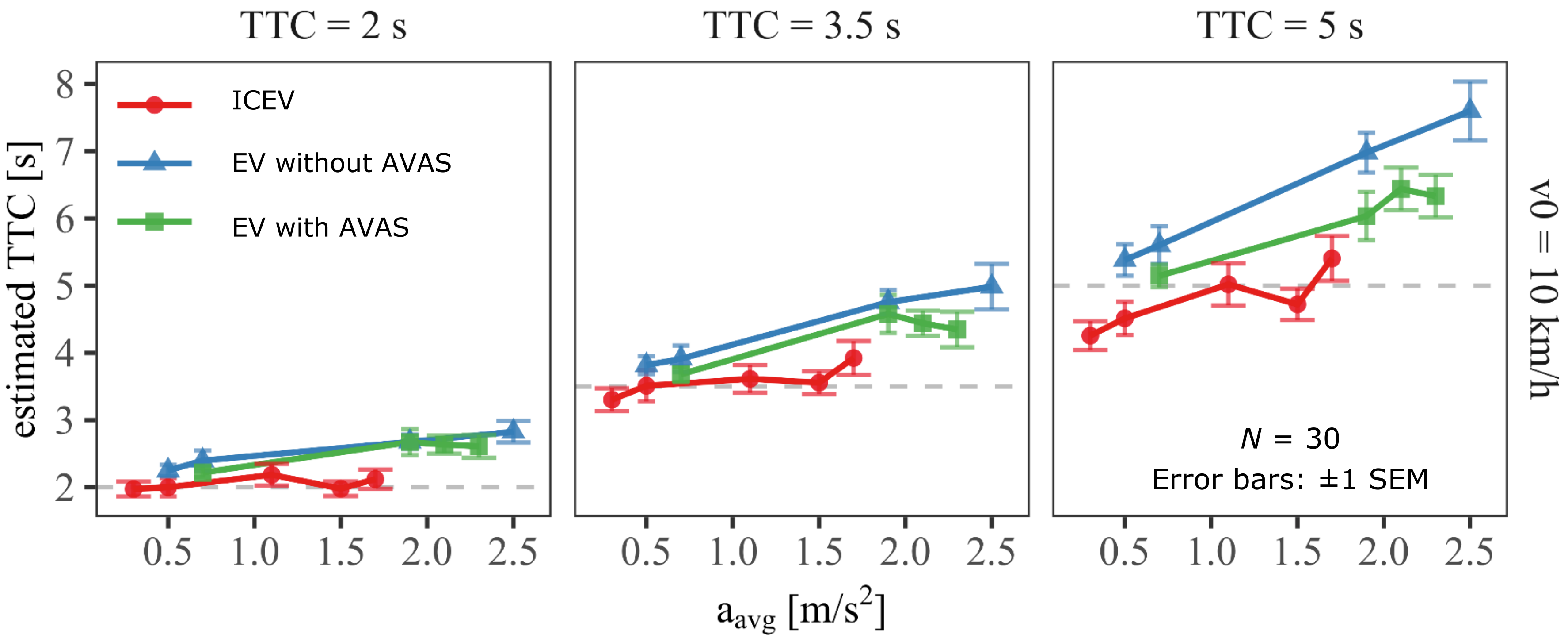
- **V-only**: 1st-order pattern

- **AV**: 1st-order pattern removed/reduced -> **audiovisual benefit**



Wessels, Zähme, & Oberfeld (2022 Curr. Psych.)

Exp. 5: Electric versus conventional vehicles



$$TTC_1(t) = \frac{D(t)}{v(t)} = TTC(t) + \frac{a \cdot TTC^2(t)}{2 \cdot v(t)}$$

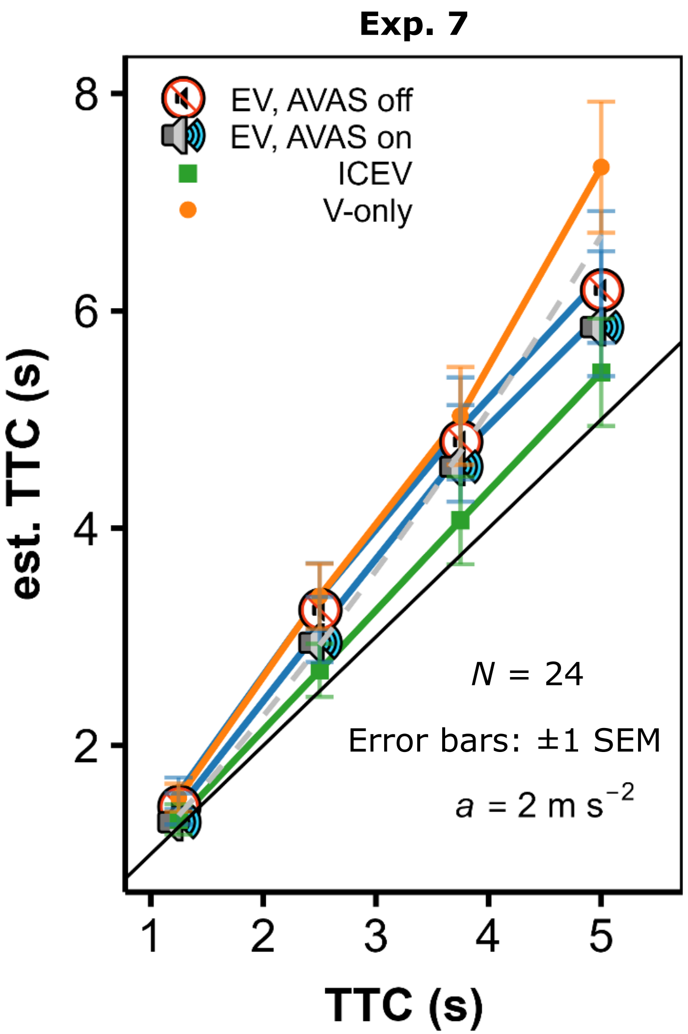
Audiovisual presentation

- **ICEV:** no substantial effect of the acceleration rate on the estimated TTC
- **EV without AVAS** and **EV with AVAS**:
  - As the acceleration rate increases, the TTC is increasingly **overestimated** (*1st-order pattern*)
  - Effect reduced when the AVAS was activated, but judgments still less precise than for the ICEV

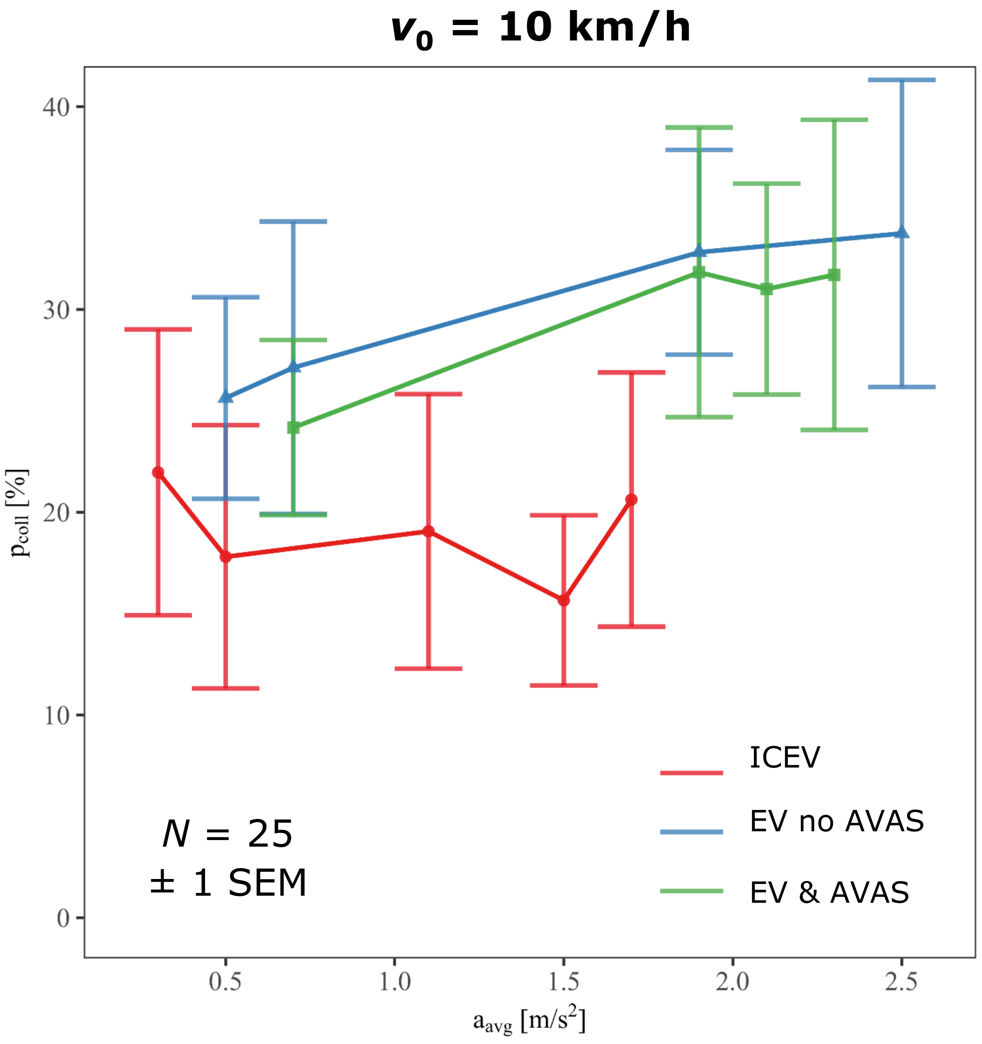
Oberfeld & Wessels (2022, UDV Forschungsbericht 76)
Wessels, Kröling, & Oberfeld (*2022*, *Transport Res. F*)

Exp. 6+7: Confirmation of the reduced audiovisual benefit for EV

- Recorded vehicle source signals as in Exp. 5, but **identical simulated motion** for all vehicles types



Exp. 8: Street-crossing decisions in interaction with accelerating vehicles



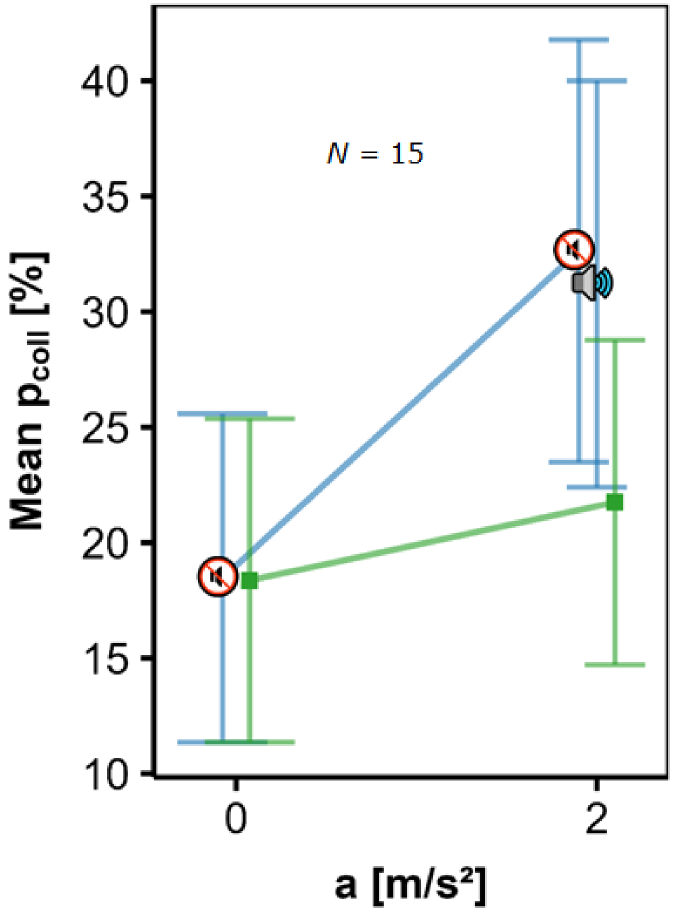
Audiovisual presentation

- **ICEV:** no systematic effect of the acceleration rate on p_{coll}
- **EV without AVAS** and **EV with AVAS**:
  - p_{coll} **higher** than for the ICEV, increasing with the acceleration rate
  - p_{coll} slightly lower with AVAS than without AVAS

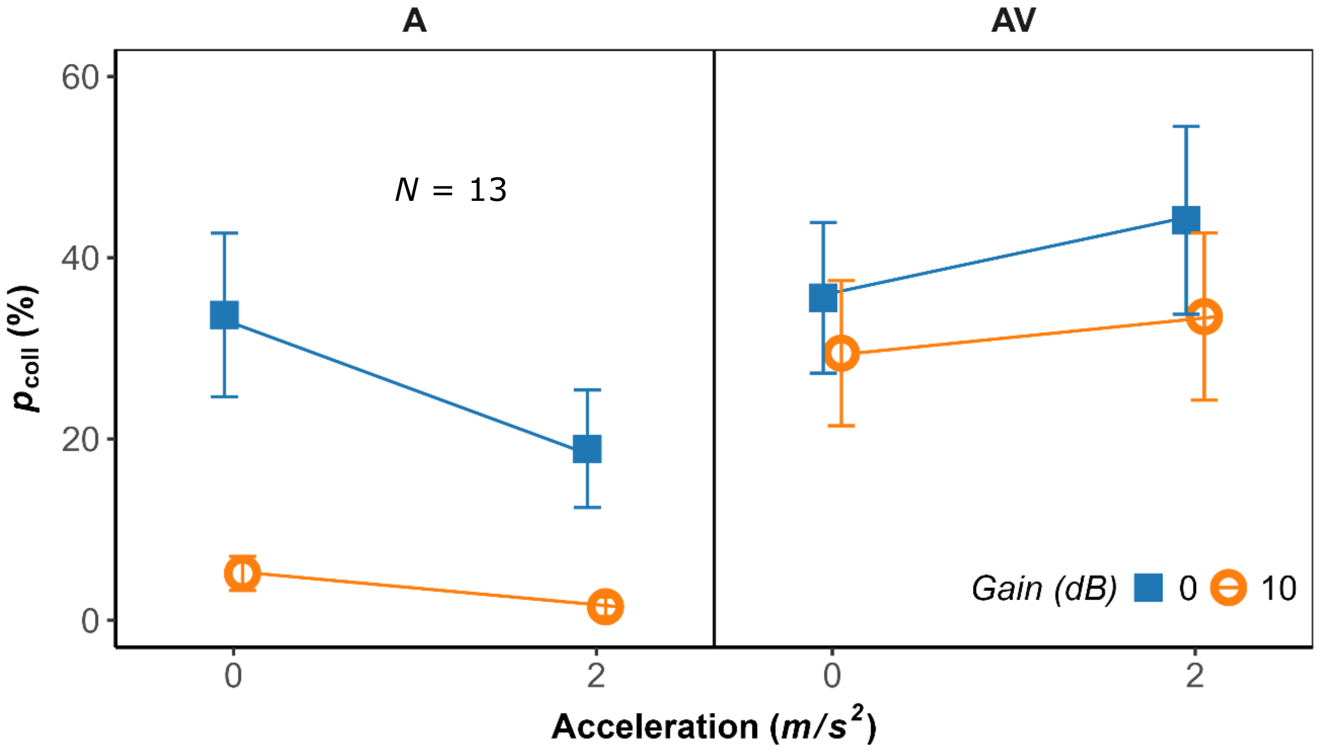
Oberfeld & Wessels (2022, UDV Forschungsbericht 76)
Wessels & Oberfeld (*in preparation*)

Street-crossing decisions (2)

- **Exp. 9: Simulated motion identical for all vehicle types (AV condition)**



- **Exp. 10: A-only versus AV + loudness varied (ICEV)**



Summary & discussion

1. **Longer estimated TTCs** and **riskier** crossing decisions observed for **quieter vehicles**
   - Strong effects in A-only condition, significant but relatively weak when visual information is available

2. Clear **benefit** provided by the **sound of accelerating ICEVs**
   ⇒ Largely accurate TTC estimation and safe street-crossing decisions

3. This benefit is **significantly reduced** for **EVs** with and without AVAS
   - Overestimated TTCs, riskier crossing decisions

The vehicle sound is not only important for detection, but also for street crossing!

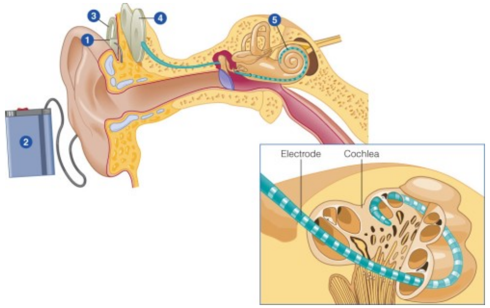
- Limitations:
  - Recordings available for only one ICEV and one EV so far
  - Relatively small set of driving profiles

Perspectives (1)

- What are the **cognitive mechanisms** and **psychoacoustic cues** underlying the benefit provided by the sound of accelerating ICEVs?
  - **Correction mechanism** triggered by the vehicle-noise cues to acceleration, or **direction of attention** to the second-order motion cues?
  - Which acceleration-related vehicle-noise changes are most important (loudness, pitch, roughness)?
- Improvement of **AVAS technologies:** How to enable better judgments of accelerating e-vehicles?
  - Speed-pitch scaling
  - Active speed range
  - Sound changes linked directly to acceleration
- **Training**: Can pedestrians **learn** to use the AVAS sounds better?

Perspectives (2)

- Persons with **impaired hearing** -> To which extent can they use **auditory TTC information**?
  - reduced auditory localization abilities, distorted dynamic cues (hearing aid algorithms)
  - A-only and AV TTC estimation in CI users (with Tobias Weißgerber, Audiology Uni Frankfurt)



- Persons with **impaired vision** (AMD) -> increased importance of auditory information?
  - with Pat DeLucia (PI; Rice Houston), Joe Kearney (Uni Iowa), Robin Baurès (CNRS Toulouse)

Thirsa Huisman

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Unfallforschung der Versicherer GDV

Gefördert durch DFG Deutsche Forschungsgemeinschaft

AUDICTIVE SPP2236

Looking forward to your comments!

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