Spatial Multimodal Alert Cues for Virtual Reality Control Environments in Industry 4.0

Konstantinos Gkagiannis & **Andreas Komninos**

Computer Engineering & Informatics Department

University of Patras

Greece

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Motivation

- To replace complex monitoring & control environments with VR immersive spaces
    - Spherical arrangement of information
    - Dynamic adaptation of arrangements
    - Single – device for multiple control scenarios
    - High mobility of engineers & tele-presence

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Problem space

- Information overload
  - How to locate important information (alerts) quickly and accurately?
  - How to divert user attention without adding visual clutter?

"Ideally, the HMI does not depend on the remote-operator's vigilance at all but **directs attention quickly and effortlessly to relevant stimuli**"

- Kettwich et al. (2021)

Approach

- Use of spatial (3D) audio

- Use of ambient (directonal) lighting

- Combination of both

- Alerts are prioritized
  - High, medium and low priority with different
    modality settings
    - Audio: Buzzer with modulated intermission
    - Light: Colour-coded rotating beacon

Materials

- Unity environment replicating a complex control room

- Extending 360o around user

- User stops "alerts" via hand tracking

- Oculus Rift 2 headset

Experiment

- Pre-experiment:
  - Benchmark tests for reaction time, visual memory and sequence memory
  - Demographic questionnaire
- Main experiment:
  - Within-subject with 3 conditions (Audio, Light, Mixed)
  - 10 alert per session (3x10=30 alerts)
  - Balanced latin-square to avoid learning effects
 - NASA-TLX after each condition

Participants

- 24 recruited to satisfy balancing requirements (9f)
  - Adequate to detect large-size effects (study power $1-\beta = 0.95$)
- Average age 28yrs old ($\sigma=3.724$)
- 9 users of VR, 3 owners
- All within 1σ from sample mean in benchmark tests

Quantitative Results

- Mean reaction time lowest for Audio alerts
  - Statistical significance against both types (p<0.001)*

- Users quicker to react to higher importance alerts under all modalities (p<0.001)**

- No interaction effect (modality x importance)

* Post-hoc Bonferroni corrected t-tests
** 2-way RM ANOVA, main effect importance on reaction time
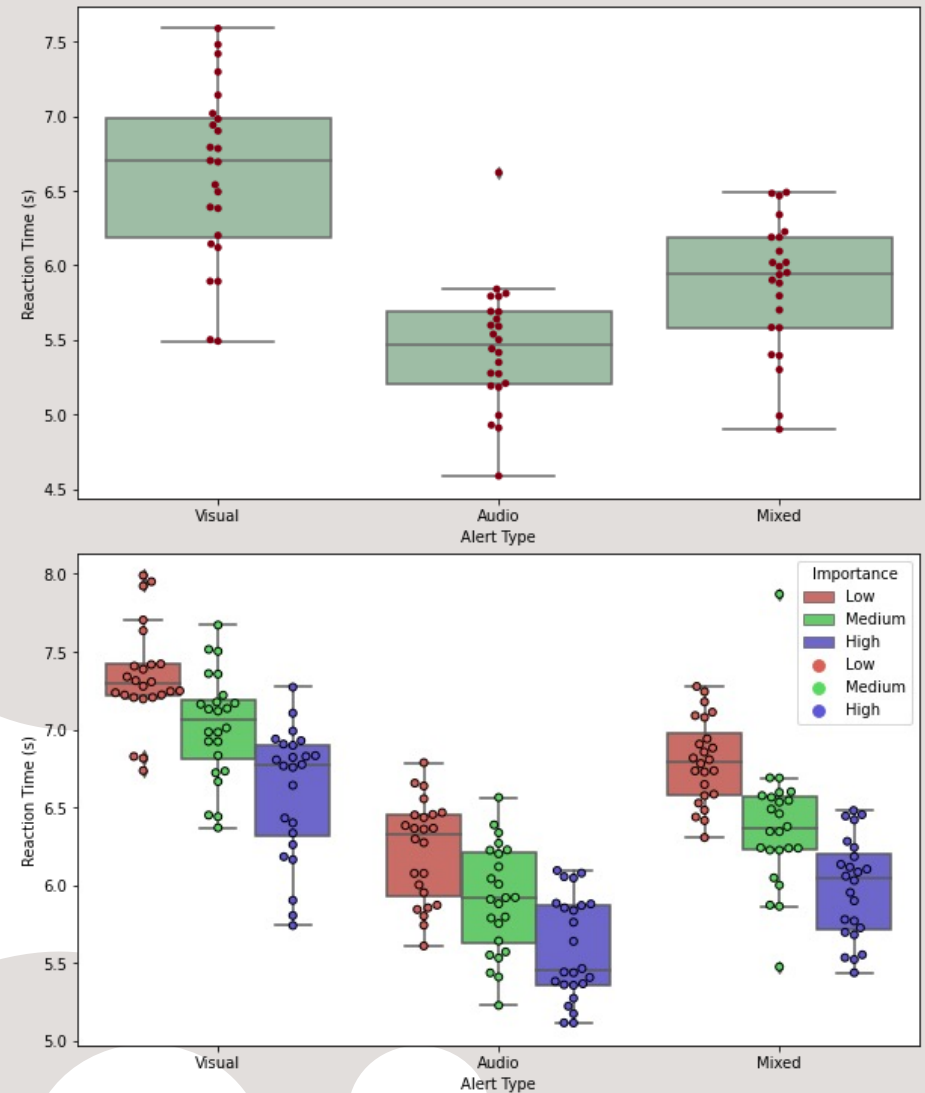
Subjective Results

- Mixed modality is most taxing, without performance advantage

- Localisation was mentally more challenging with Audio cf. Visual (p=0.004)

- Subjective temporal demand higher with Audio (counter to actual data, all cases p<0.01)

- Subjective performance best with Audio, Mixed vs Visual (matches data, p<0.01)

- Frustration low for all conditions, lowest for Visual (p<0.05)

* Post-hoc Bonferroni corrected t-tests

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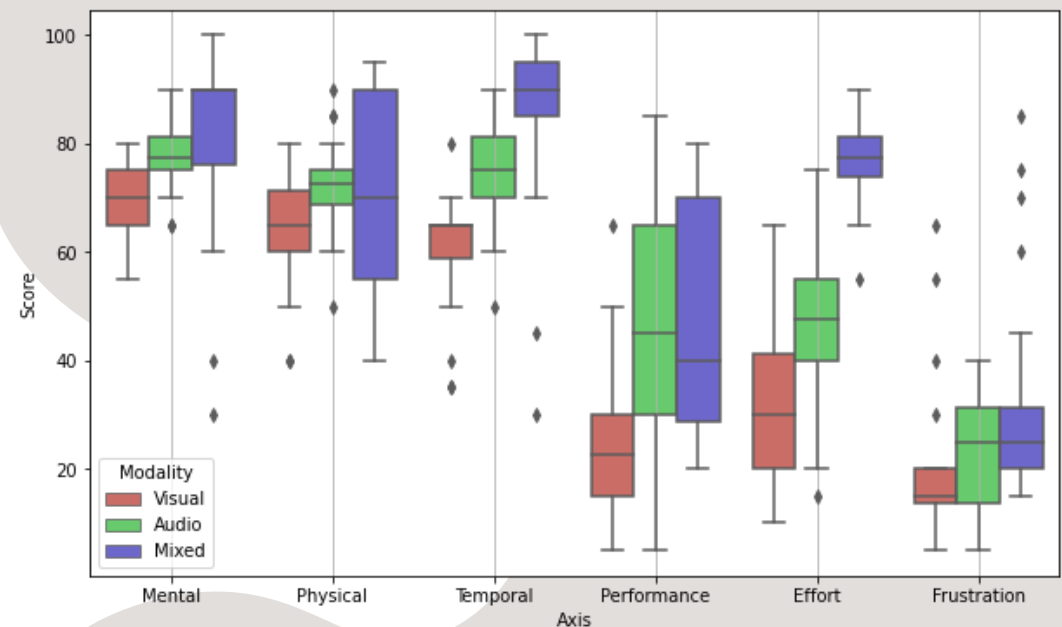
Discussion

- Ambient directional cues are a promising direction
  - 3x faster reaction compared to previous work (Tsigkounis et al. 2021)

- Limitations
  - Artificial environment (no real pressure)
  - Repeated studies needed to show performance curve
  - Single-user scenarios only
    - Should move to collaborative environments
  - Static configuration
    - Alternative environments
    - Dynamic instrument positioning
    - Ability to move around room

Thank you!

- Please read our paper for more details
- Contact me for further questions!
  - akomninos@ceid.upatras.gr