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A Theory-Informed Roadmap Towards Multimodal Ocular-based Attention Metrics for Conversational VR

Agnes Widera, Torsten W. Kuhlen, Andrea Bönsch
Visual Computing Institute, RWTH Aachen University

Background

- VR provides tightly controlled, repeatable environments for cognitive research
- Attention is the allocation and maintenance of cognitive resources toward task-relevant stimuli; it can be directed to visual, auditory, or internal information and varies over time
- Attention measurement is central to understanding learning, memory, and task performance, especially in conversational VR where recall is the key outcome
- Traditional measurement methods (e.g., EEG, behavioral tasks) restrict experimental scenarios and compromise ecological validity due to the discomfort additional sensors cause
- Reliable visual attention metrics from eye-tracker data are already established(e.g., **[Bhanushi et al., 2022]**)
- Modern consumer-grade HMDs feature integrated, non-invasive eye-trackers, which offer a compelling alternative

Research Gap and Contributions

Research Gap:

- In conversations, social conventions keep the user's gaze on the partner, making gaze alone a weak proxy for attention; existing approaches also often ignore mind-wandering and fatigue
- No ocular-based attention metric currently exists for conversational VR
- Objective: Evaluate whether a multimodal ocular signature (gaze + blink + pupil) can serve as a basis for reliable attention measure in VR-based dialogues

Contributions:

- A taxonomy linking ocular signals to attentional dimensions
- A three-stage research roadmap to achieve reliable real-time attention measurement in conversational VR

Ocular-based Attention Taxonomy

We define **attention** as the allocation and maintenance of cognitive resources toward task-relevant stimuli

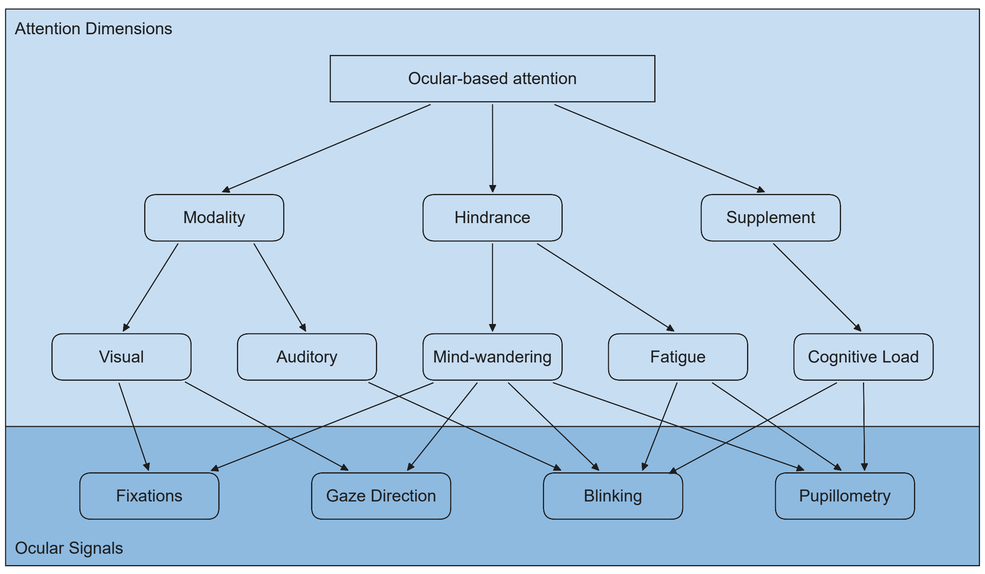

Fig. 1: Taxonomy for ocular-based attention measurement

Grouped Attention Dimensions:

- **Modalities:** *Visual* and *Auditory* - selective prioritization of given information
- **Hindrances:** *Mind-wandering* (task unrelated thoughts) and *fatigue* (both mental and physical)
- **Supplement:** *Cognitive load* - not a direct indicator, but higher cognitive load increases ikelihood of listening effort

Ocular Signals:

- **Fixations and gaze direction:** Indicative of visual attention and mind-wandering - sustained fixations in general indicate active processing, low fixation count indicates mind-wandering
- **Blinking:** Indicative of auditory attention (blinking pattern) **[Holtze, et al., 2023],** mind-wandering and fatigue (more frequent blinks), as well as cognitive load (less frequent blinks) **[Coupal et al., 2025]**
- **Pupillometry:** Indicative of mind-wandering and fatigue (smaller dilation), as well as cognitive load (higher dilation) **[Sirois and Brisson, 2014]**

Research Roadmap

Three key steps toward adaptive systems that react to the user's attentional state in real time:

(1) Robust Pupillometry: Uncontrolled luminance variations confound pupil dilation - correction methods exist **[Eckert et al., 2022]**, but require extensive calibration and need to be more generalizable

(2) Signal Disambiguation: Attentional dimensions produce overlapping signals - disambiguation is needed, and requires mixing raw signals with contextual cues, to separate, i.e., fatigue-driven blinks from processing-related ones

(3) Composite Attention Score: Given (1) and (2), we propose a composite attention score derived from both ocular signals and contextual cues - it should reflect attentional changes in real time and be generalizable across users - this is non-trivial and requires extensive validation

Literature

Bhanushali et al., 2022

Attention Score: Objective Measure of Attentiveness in Immersive Omnidirectional Videos. *In IEEE Int. Conf. Artif. Intell. Virtual Real.* doi:10.1109/AIVR56993.2022.00033

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Pupillary Light Reflex Correctionfor Robust Pupillometry in Virtual Reality. *CM Comput. Graph. Interact. Tech.* doi:10.1145/3530798

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Eye-blink Patterns Reflect Attention to Continuous Speech. *Adv. Cogn. Psychol.* doi:10.5709/acp-0387-6

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Pupillometry. *WIREs Cogn. Sci.* doi:10.1002/wcs.1323

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Visual Computing Institute
Virtual Reality & Immersive Visualization
Prof. Dr. Torsten W. Kuhlen

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