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Mechanisms of peripheral vision in complex decision-making

Beyond Fixation: A Systematic Review of Peripheral Vision Use in Driving

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Institute of Sport Science, University of Bern | Driver Distraction and Inattention Conference 2026

20 October 2026



Driving requires information from several places at once

But you cannot look at everything at once

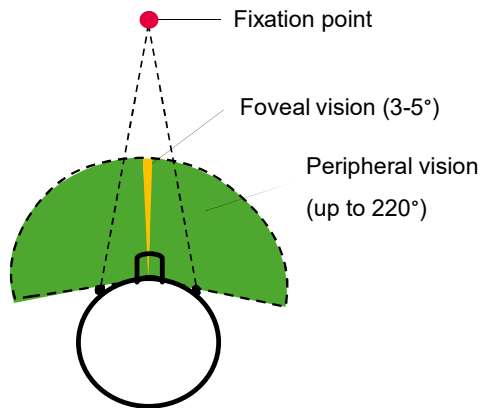
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Introduction

Visual system

- Foveal vision
- Peripheral vision

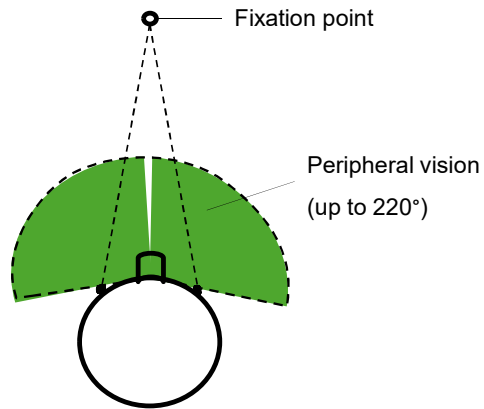
● = Fixation point



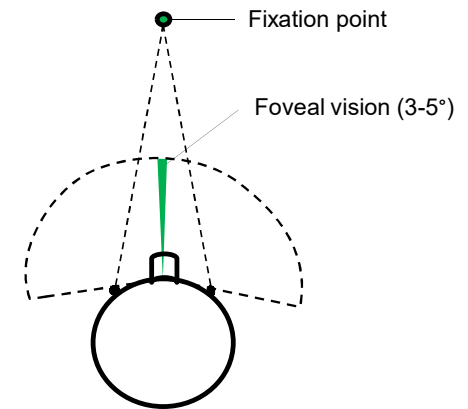
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Introduction

Peripheral information processing



Direct fixation needed



Eccentricity

**Visual
information
degradation**

Time pressure

Predictability

**Cognitive
demand**

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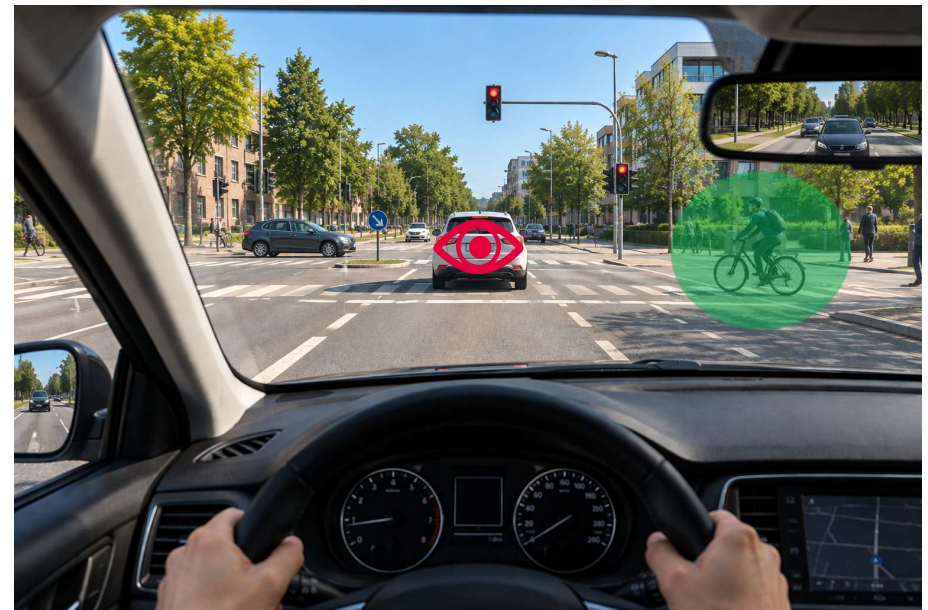
Introduction

Where we look is not necessarily what we process

Looking at something $\neq$ processing it



Not looking directly at something $\neq$ not processing it



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Introduction

Sport Context

Foveal Spot



process foveal information with an optimally adjusted attention field

Visual Pivot



process peripheral information to select the next target for foveal vision

Gaze Anchor



process peripheral information and avoid saccadic costs

Dynamic sport → strategic foveal–peripheral coordination → could similar principles matter in driving?

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Introduction

Daily Life Context

Driving



1

Monitoring

Aviation



2

Presaccadic
preview

Walking



3

Action planning

Introduction

What we already know

- Peripheral vision can be functionally useful
- Gaze and peripheral processing can be coordinated strategically

What is still unclear in driving

- Which factors affect peripheral vision use?
- Under which driving conditions?
- Through which mechanisms?

Research question

Which factors affect peripheral vision use in driving, under which conditions, and through which mechanisms?

Direct driving evidence ↔ theoretical support from vision, attention and sport science

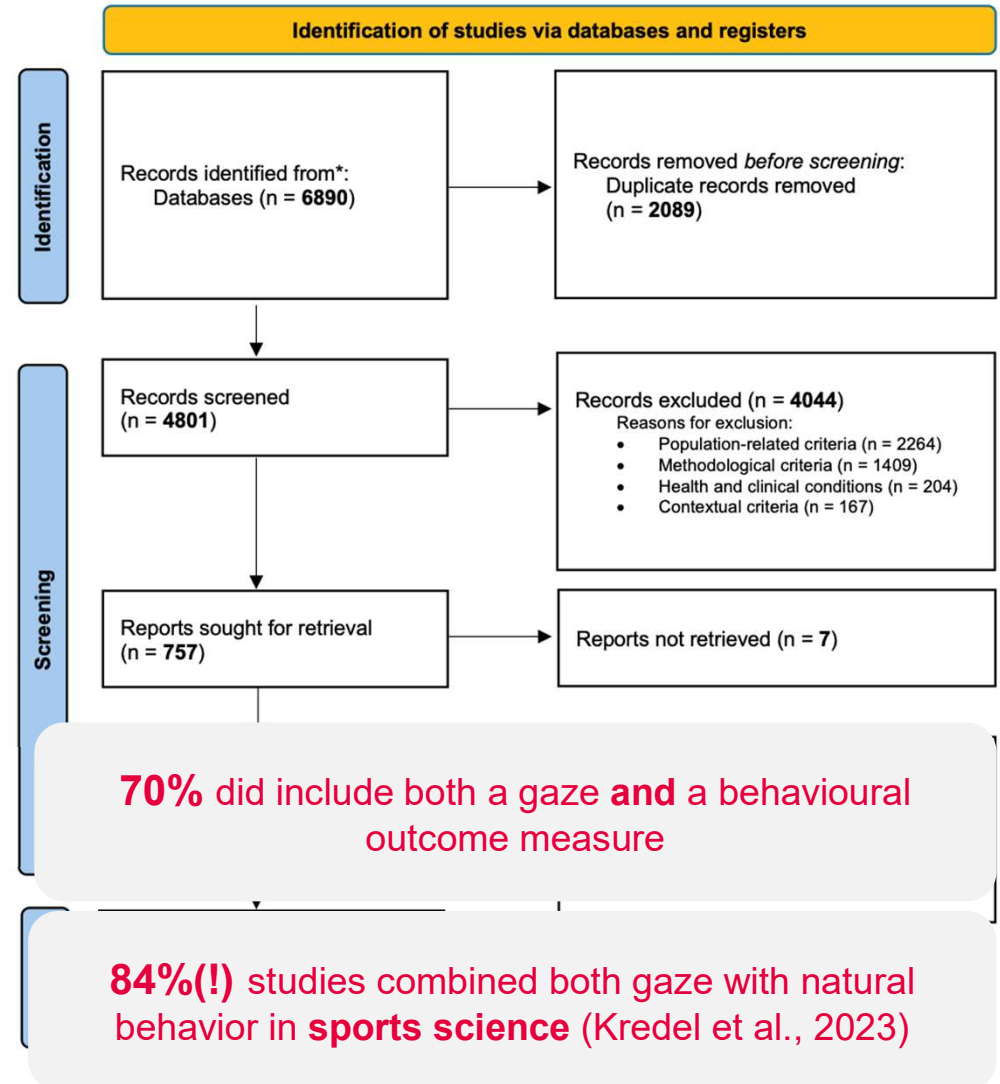
Methods

Search

PubMed · Scopus · Web of Science
April 2025

Key eligibility

- Drivers as target population
- Dynamic driving context
- Objective gaze assessment
- Gaze- and behavioral-related outcome measures



Methods

Data extraction

How was peripheral vision studied?

- Experimental
- Observational

What was the experimental set-up?

- Lab (no driving-related component)
- Lab (one driving-related component)
- Simulator
- Test track
- Real traffic

What did the driver need to do?

- Steering/vehicle control
- Interaction with other road user(s)
- Tracking/monitoring traffic environment
- In-vehicle interaction
- Automation

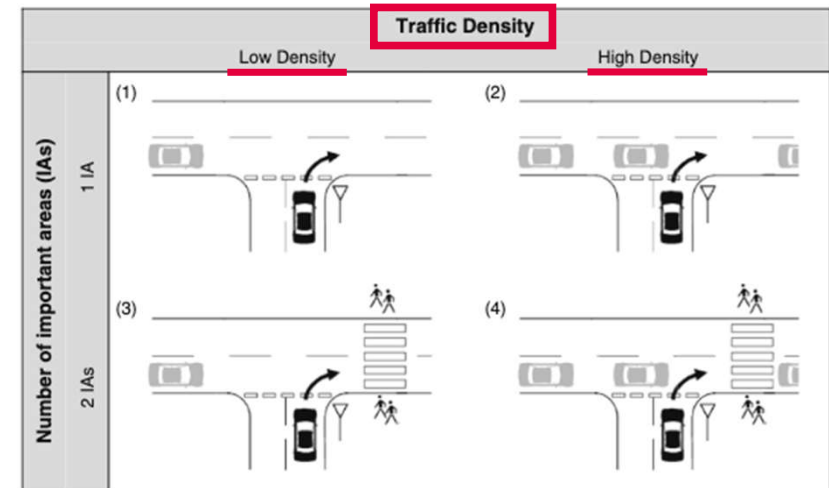
What was manipulated or compared?

- Perceptual constraints
- Cognitive demands
- Combination (e.g., environmental complexity or motor dual-task)
- Other (e.g., expertise or automation)

Methods

Manipulation type (PV Factor)	Category	Manipulation Type	Combination
Perception	Eccentricity	Varying the angular distance of stimuli (e.g., hazard, target, or traffic lights) or the positioning of the car (e.g., lane position)	-
Perception	Field of view limitation	Restricting the available visual field by limiting or occluding parts of the visual scene	-
Perception	Visual information degradation	Reducing quality or clarity of visual information	-
Perception	Moving window or gaze-contingent restriction	Dynamically controlling which regions are visible based on gaze	-
Cognition	Cognitive load (without visual or auditory load)	Working memory, n-back task, (imagery) verbal task	-
Cognition	Visual load	Additional visual information, either through in-vehicle displays or external, non-driving-related stimuli	-
Cognition	Auditory load (conversation)	Passenger conversation, or listening to music	-
Cognition	Predictability (cueing and expectancy)	Driving-relevant cues that enable anticipation of upcoming events or hazards	-
Cognition	Emotional or arousal state (within participant design)	Induced anger, anxiety, stress or fatigue	-
Combination	Environmental complexity	Road types, traffic density, presence of pedestrians or cyclists	Perception and cognition
Combination	Motor dual-task	Secondary motor task	Cognition and motor
Combination	Speed or time pressure	Faster driving or temporal constraints	Perception and cognition
Other	Capabilities (between participant design)	Individual differences in capabilities	-
Other	Experience (driving task)	Driving experience, or familiarity with the route	-
Other	Experience (secondary task)	Experience with the secondary task used in the experiment	-
Other	Automation	Driving automation level or full-automated driving	-

Manipulation of environmental complexity



Methods

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Manipulation of visual load × eccentricity



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Preliminary Results

93.8%

Experimental

121 of 129 studies

58.1%

Simulator

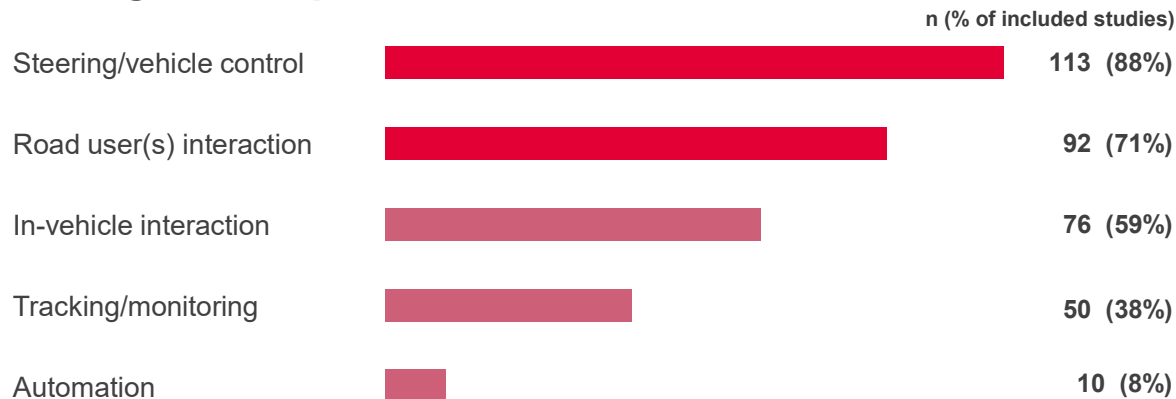
75 studies; real traffic = 34

48.8%

Head-mounted eye tracking

63 studies; remote = 48

Driving tasks represented in the literature

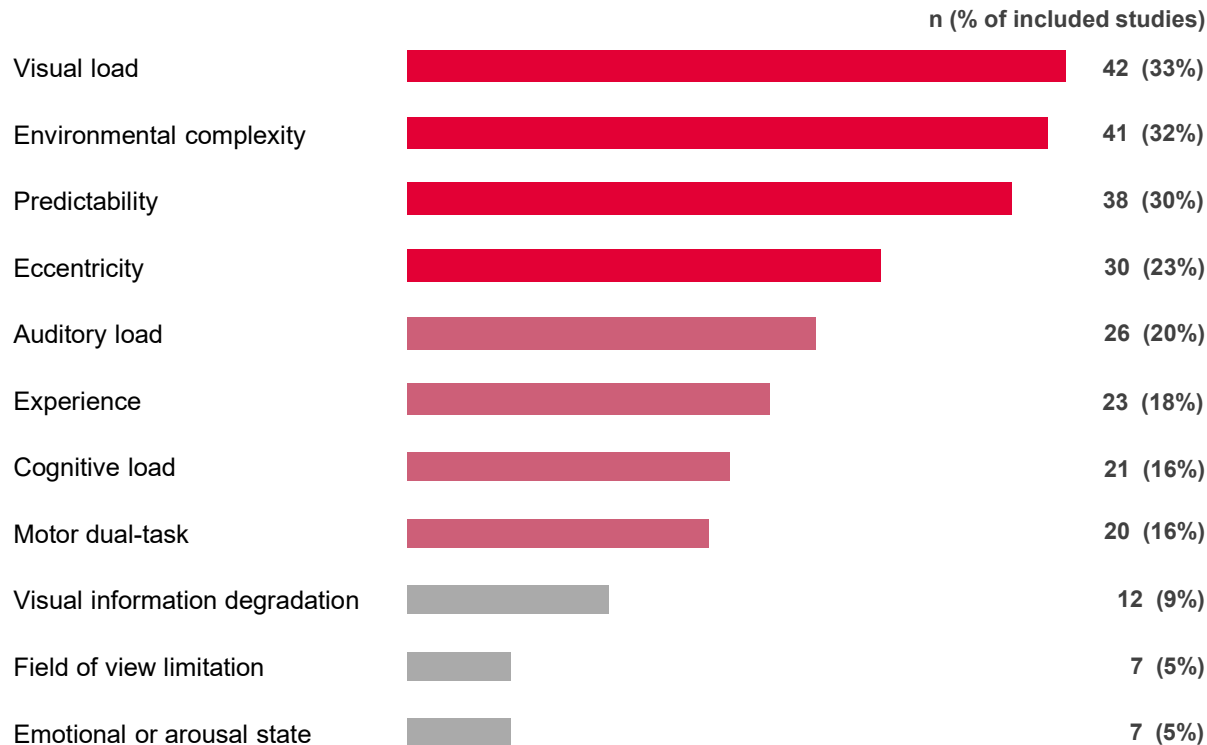


What this means

- Strong experimental control
- Multi-label task coding
- Limited ecological coverage

u^b Preliminary Results

Manipulations represented in the literature



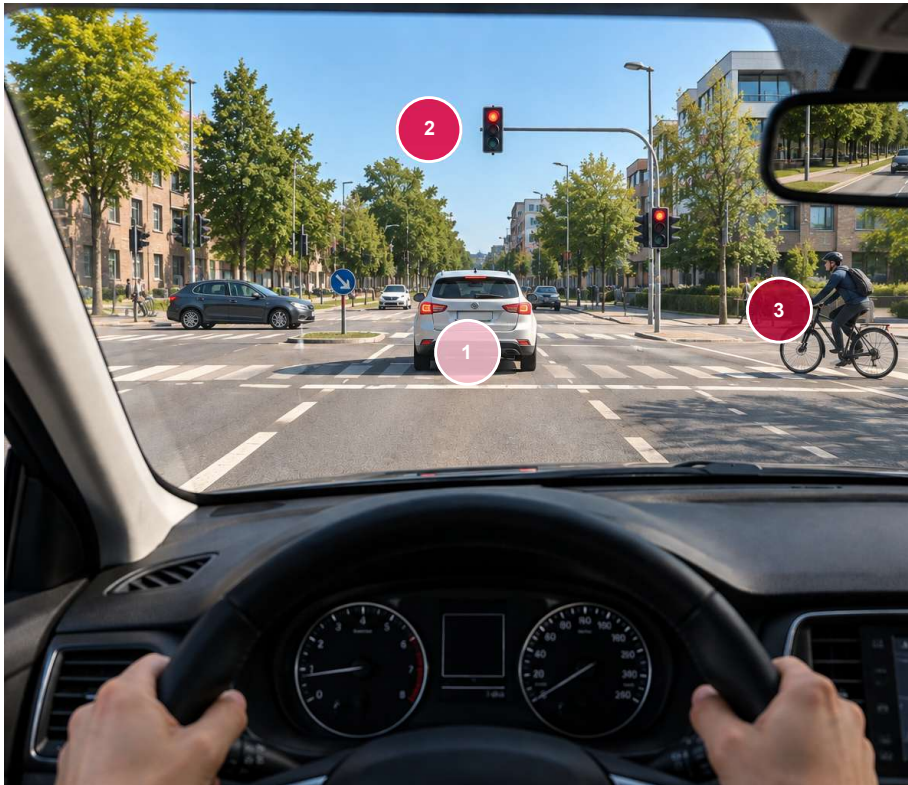
Main descriptive message

The literature is not about one “peripheral vision” paradigm

- Evidence spans perceptual, cognitive and combined factors
- Ecological validity differs between studies and the assigned factors
- Several manipulations co-occur → so certain factors should not be treated as independent

u^b Preliminary Results

Peripheral information can support driving without direct fixation



1

Vehicle control

Peripheral road-edge and optic-flow information may contribute to lane keeping

Kountouriotis et al., 2011

2

Environmental monitoring

Relevant traffic information can be monitored without continuous direct fixation

Doshi & Trivedi, 2012

3

Event-related action

Responses can occur before direct fixation

Huestegge & Böckler, 2016

Preliminary Results

WHERE?

Eccentricity



Information farther from fixation is generally harder to detect or identify

Examples:

Road sign placement (Costa et al., 2019)

HUD placement (Shi et al., 2024)

Pedestrian location (Nair et al., 2024)

WHAT DEMANDS?

Cognitive/visual load



LOW

HIGH

Higher load can reduce peripheral monitoring efficiency

Examples:

Traffic density (Lemonnier, et al., 2020)

Mobile phone usage (Hashash et al., 2019)

Conversations (Desmet et al., 2019)

Presence of billboards (Mollu et al., 2018)

WHO?

Experience/expertise

N

E

Experienced and novice drivers differ in how gaze and attention are distributed

(Lamble et al., 1999; Lazaro et al., 2022)

Discussion

1

Peripheral information is functional

It can support vehicle control, environmental monitoring and event-related behaviour

2

Its use is demand/constraint-dependent

Perceptual constraints, cognitive demands and driver characteristics can influence the use of peripheral vision

3

Gaze $\neq$ information use

DDI research benefits from distinguishing where drivers look, what they can perceive, and what they actually attend to and what they do with this info

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Acknowledgements



Peripheral vision group



Contact

Victor Meulenkamp

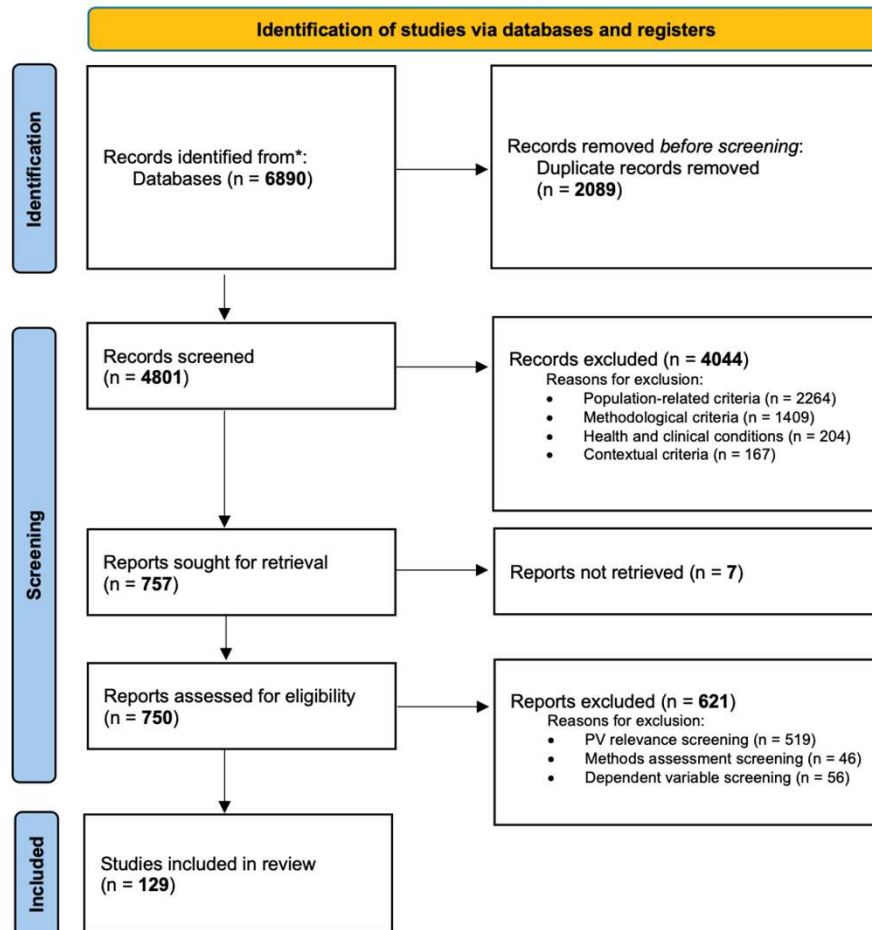
PhD student

victor.meulenkamp@unibe.ch

More info of our research:



Methods



PRISMA Eligibility Screening Numbers

1. Records identified from databases (n = 6890)

- PubMed (n = 574)
- Scopus (n = 2613)
- Web of Science (n = 3703)

Records removed before screening: duplicate records removed (n = 2089)

2. Title/abstract screening (n = 4801)

Reason of exclusion:

- Population-related criteria (n = 2264)
- Methodological criteria (n = 1409)
 - Non-empirical study (n = 391)
 - No objective gaze assessment (n = 737)
 - No dynamic driving context (n = 281)
- Health and clinical conditions (n = 204)
- Contextual criteria (n = 167)

Records excluded (n = 4044)

3. Reports sought for retrieval (n = 757)

Reports not retrieved (n = 7)

4. Full-text screening (n = 750)

Reports assessed for eligibility criteria.

4.1 Peripheral vision relevance screening

Reason of exclusion:

- No peripheral vision-relevant term within discussion section (n = 519)

4.2 Methods assessment screening

Reason of exclusion:

- No objective gaze assessment and dynamic driving context (n = 46)

4.3 Dependent variable screening

Reason of exclusion:

- No gaze-related outcome variable (n = 6)
- No behavioral-related outcome variable (n = 50)

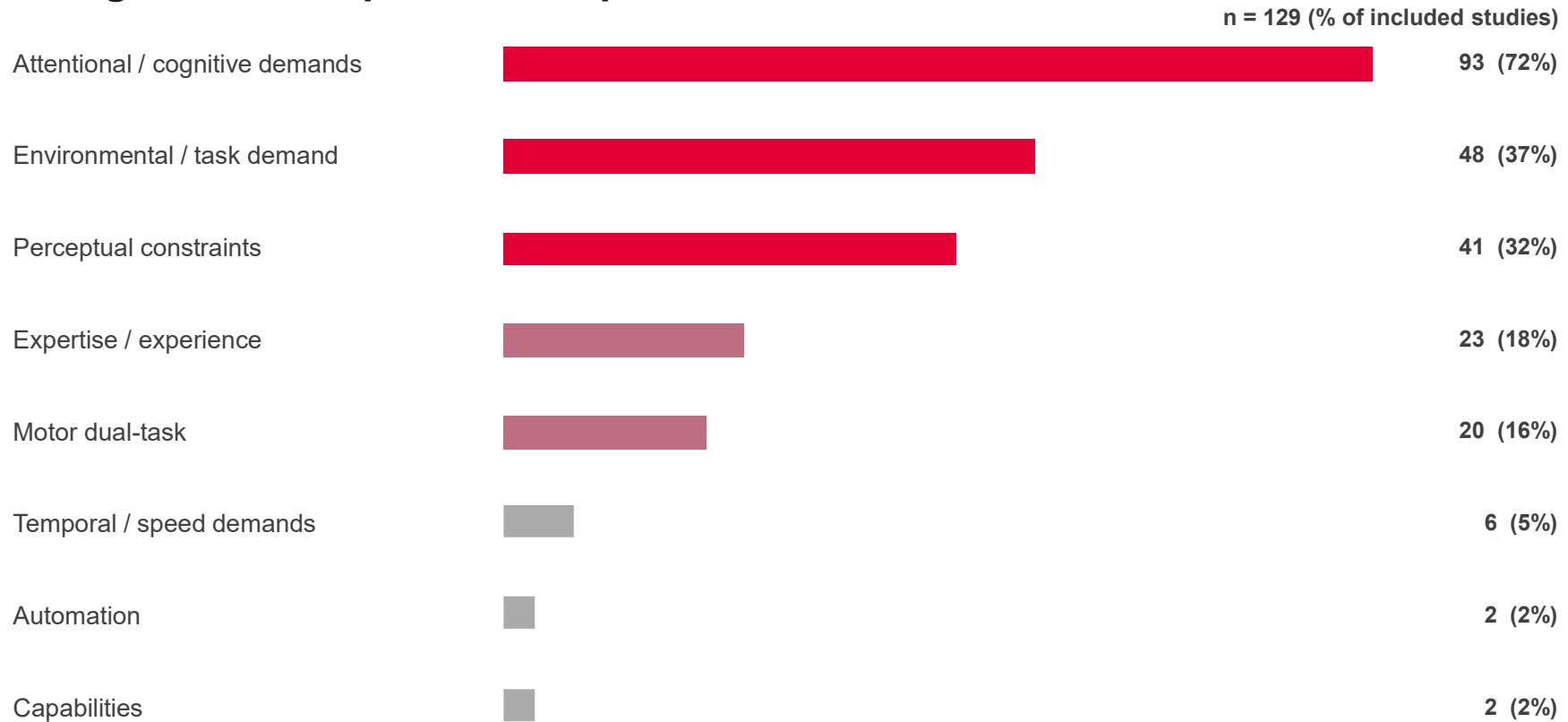
Records excluded (n = 621)

5. Studies included in review (n = 129)

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Preliminary Results

Categorized manipulations represented in the literature



Preliminary Results

Ecologically spread

Specific manipulation type	Total	Simulator	Real traffic
Environmental complexity	41	23	9
Eccentricity	30	16	6
Auditory load	26	16	7
Experience	23	11	6
Cognitive load	21	11	7

Restricted to controlled environments

Specific manipulation type	Total	Simulator	Real traffic
Visual load	42	31	5
Motor dual-task	20	17	1
Visual information degradation	12	9	0
Field of view limitation	7	5	2
Emotional or arousal state	7	6	0
Speed or time pressure	6	5	1

Specific manipulation per experimental set-up

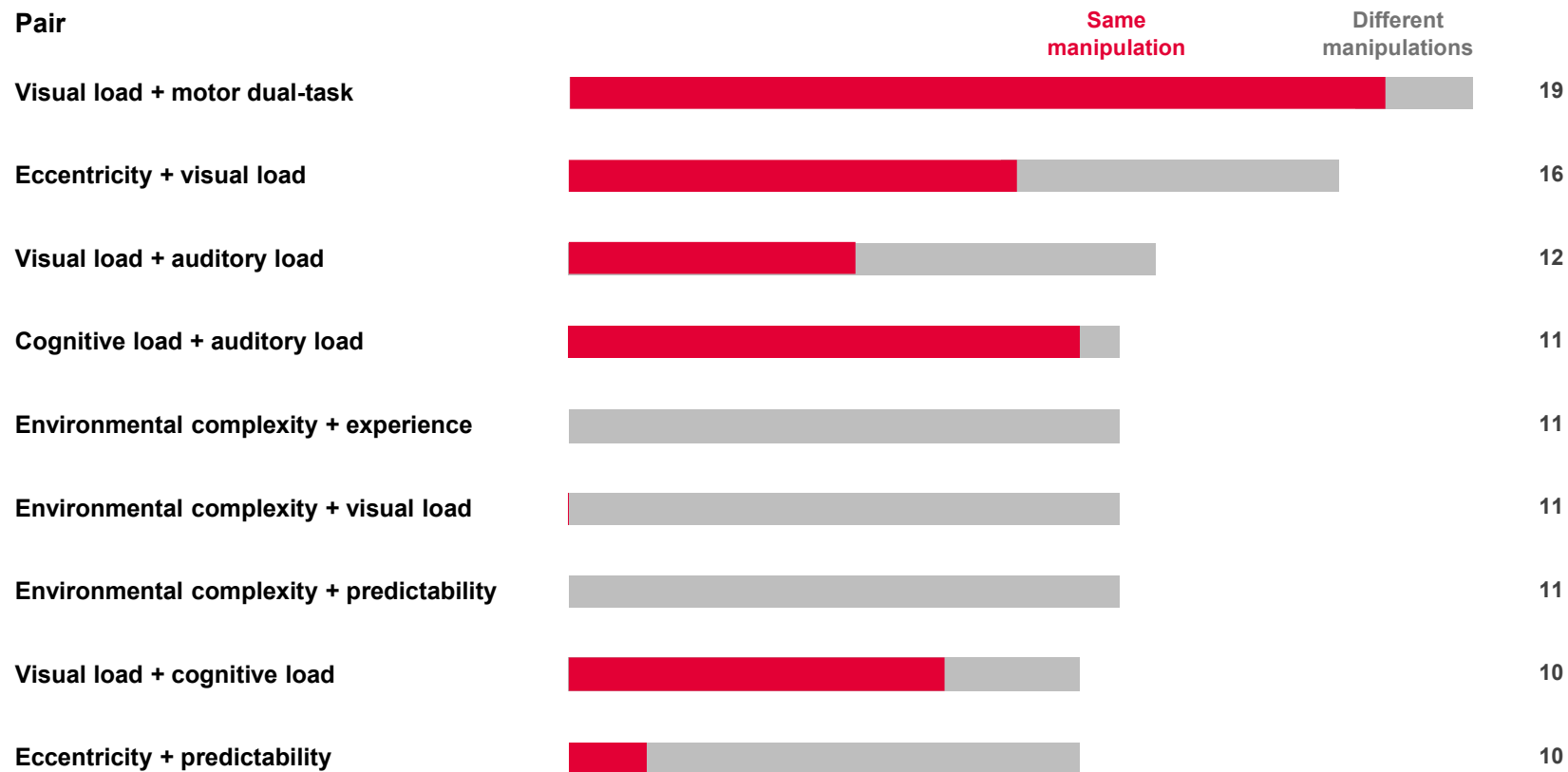


Ecological validation differs strongly between factor domains

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Preliminary Results

Manipulations co-occurrence in the literature



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Discussion

1

Consideration of driving task(s) and condition

2

Interpret gaze in functional context

3

Validate peripheral use behaviourally

Practical implication

This is the methodological relevance of peripheral vision for DDI