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# MAP-VERSE: MAP Usability - Validated Empirical Research by Systematic Evaluation

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**Abstract.** This paper introduces **MAP-VERSE** (MAP Usability - Validated Empirical Research by Systematic Evaluation), an open metadata repository designed to address the lack of accessible and consistently reported datasets in map usability research. Currently, researchers face challenges in discovering and reusing relevant data due to the absence of centralized platforms and standardized reporting practices. This hinders reproducibility, comparative analyses, and the development of predictive models for map usability. MAP-VERSE tackles these challenges by establishing core metadata dimensions for describing map usability datasets; defining validity criteria for best practice datasets to ensure methodological rigor and transparency; developing a user-friendly search interface for efficient data discovery; and proposing strategies to encourage standardized metadata reporting. The repository currently features curated metadata for nine existing open-access datasets encompassing various map types, tasks, and methods. Future work includes expanding the repository, implementing automated validation, and promoting standardized reporting practices through templates and guidelines. MAP-VERSE aims to foster open data sharing and collaboration, ultimately advancing our understanding of human-map interaction and improving map design.

**Submission Type.** infrastructure, metadata repository

**BoK Concepts.** [CV6-2] , [CV6-3]

**Keywords.** map usability, metadata repository, user experiments, cartography, user research

## 1 Introduction

Understanding how people interact with maps is essential for improving map design and user experience. With the rise of AI, especially generative AI (Kang et al., 2024; Harrie et al., 2024), accessing and repurposing existing data has become more and more prevalent for training models with well-labelled and objective ground truth data. Reusing data is not only beneficial for scientific research in terms of reproducibility, generalizability, or transferability of previous findings but also is efficient and contributes to environmentally responsible research practices. By reducing the need for repetitive and redundant data collection, we can minimize the consumption of time, energy, and computational resources, ultimately reducing the environmental impact of our work (see 3.3. for detailed $CO_2$ emission calculations).

Methods such as neuroimaging techniques, including electroencephalography (EEG), functional magnetic resonance imaging (fMRI), and physiological signal measurement (e.g., eye tracking, electrodermal activity (EDA), cardiovascular activity, skin temperature) provide valuable insights into the cognitive, attentional, and emotional processes underlying human-computer interactions. These methods are increasingly prevalent in map usability research, enabling a deeper understanding of how map users perceive and interact with cartographic information. Designing user experiments utilizing these methods requires careful planning and execution. These meticulous phases include selecting a balanced and representative group of participants, formulating meaningful tasks and a robust analytical framework to achieve corresponding metrics, dedicating sufficient time to data collection, and controlling confounding parameters such as lighting conditions, screen resolution, and participant fatigue.

There is a vast number of empirical studies published in scientific journals, but the relevant datasets are not always made available. Even when shared, accessing and utilizing them can be challenging due to the absence of centralized platforms, limited awareness of available resources or data repositories for specific purposes, and inconsistent reporting practices. Furthermore, existing repositories, such as MIT/Tübingen's Saliency Benchmark (Kümmerer et al., 2018), predominantly focus on free-viewing tasks with abstract and graphic images (e.g., icons, simplified drawings) or natural images that are often used in fields such as experimental psychology (e.g., Karim et al., 2017), and they feed the development of current saliency models. These datasets are not well-suited for task-driven cognitive assessments and lack the diversity to address cartographic visualizations and their associated geospatial tasks. For example, even fundamental tasks, such as route planning or location selection, are not well-represented in existing datasets in repositories. Map usability datasets are task-specific datasets recorded during map reading and/or geospatial tasks conducted in-lab, online, XR or real-world. It is crucial to make this distinction from the traditional usability datasets because maps are artificial and abstracted representations of the world and possess unique complexities and implicit information. These characteristics distinguish them from the traditional stimuli, such as natural images. This makes it imperative to adapt existing practices to suit the specific requirements of geospatial tasks (Keskin et al., 2023), as the predictive models which have been trained in other type of data are not always working (e.g., saliency models are suitable for natural images; Krassanakis et al., 2013). Therefore, collecting map-relevant tasks and/or stimuli in a repository dedicated to map usability can directly facilitate the objective description of map users' behaviour.

The present work aims to address two main research gaps in the field of map usability research:

**Research Gap 1.** Currently, no single platform offers a comprehensive and searchable repository for open-access datasets collected during user studies involving geospatial tasks. Researchers struggle to discover relevant benchmark data for their purposes like comparative or in-depth analyses. It also jeopardizes the development and validation of predictive models for map usability due to such inaccessible well-labelled training data.

**Research Gap 2.** Existing datasets often lack consistent reporting structures, making it difficult to compare and integrate data from different studies. This inconsistency hinders the validity of the published research and the efforts to build a comprehensive understanding of map usability.

Building upon previous conceptual research (e.g., Keskin et al., 2023), we have implemented practical guidelines for reporting map usability experiments that utilize physiological signal measurements and neuroimaging techniques and created **MAP-VERSE** (MAP Usability - Validated Empirical Research by Systematic Evaluation), an open metadata repository for map usability that allows researchers to query open-access benchmark datasets. We note that this is a volunteer initiative, and the platform, **MAP-VERSE** website (https://map-verse.github.io/Repository/); is under a continuous development.

### 1.1 Research Questions and Goals

Establishing a comprehensive dataset repository for map usability, we aim to address key challenges in data discoverability and reproducibility within the field of map perception and cognition. Our research focuses on four core questions:

**RQ1.** What are the core/essential metadata dimensions for describing map usability datasets?

**RQ2.** What are the validity criteria for open datasets to be recognized as best practice examples, ensuring methodological rigor and transparency?

**RQ3.** How can a user-friendly search interface be designed to enable efficient data discovery based on these metadata dimensions?

**RQ4.** How can we develop strategies to encourage researchers to adopt standardized metadata reporting practices for map usability studies?

Our repository aims to provide researchers with structured access to a wealth of metadata, from neuroimaging (EEG, fMRI), to physiological signal measurement (eye tracking, electrodermal (EDA), cardiovascular activity, etc.) datasets collected during geospatial tasks in-lab, online (i.e., webcam eye tracking), virtual/augmented environments (XR) or real-world. By presenting detailed metadata across key dimensions of experimental design like participant characteristics, stimuli, task, and analysis methods, we strive to facilitate data discovery, reuse, reproducibility, and comparative analysis. Therefore, our metadata repository will address the identified research gaps by:

**Goal 1.** Providing a central repository for researchers to discover open-access datasets collected during a map reading/geospatial task.

**Goal 2.** Promoting best practices for empirical studies through open datasets by showcasing datasets that satisfy the validity criteria we developed.

## 2 Methodology

To establish core metadata dimensions (**RQ1**) and validity criteria for best practice map usability datasets (**RQ2**), we developed a robust metadata schema for reporting map usability studies. This schema, informed by existing repositories and standards across disciplines such as behavioural and psychophysiological research, as well as expert opinions from International Cartographic Association Commission on User Experience, Geovisualization and Location Based Services, encompasses crucial dimensions like participant characteristics, stimuli properties, task parameters, and analysis methods.

### 2.1 Data Selection Criteria & Dimensions

The repository focuses on datasets related to "tasks that include visual processing of geospatial information", including artificial/synthetic maps and spatial environments. The open-access datasets hosted on existing data repositories are identified based on the presence of a "map figure" within the paper, keywords ("map," "map reading"), and and the presence of a DOI for the dataset. To promote accessibility and transparency, we link directly to the datasets shared on platforms such as Zenodo (https://zenodo.org/), Harvard Dataverse https://dataverse.harvard.edu/), and figshare (https://figshare.com/).

To encourage researchers to describe their data effectively, enhancing interoperability and facilitating future data sharing and analysis, we pay attention to reporting quality (e.g., sufficient sample size, full-procedural details, etc.) (**Goal 2**). Through a comprehensive review of existing data repositories and standards for user study data collection across various disciplines (e.g., the MIT/Tuebingen Saliency Benchmark), we have identified six key dimensions critical to map usability studies. These dimensions are: **(1)** Controlled Conditions, **(2)** Well-Defined Tasks and Research Questions, **(3)** Well-Defined Metrics, **(4)** Explicitly Specified Stimulus Properties, **(5)** Well-Defined Participant Characteristics, and **(6)** Ethical Considerations (see Appendix A for more detail).

**Dimension 1: Controlled Conditions.** This dimension explains the controlled conditions for collecting experimental data. It includes things like the experiment medium or display, performance evaluations, system specifications, user interaction methods, recording **devices**, and managing extra variables. Some conditions have only one option, e.g., the medium, while others can have multiple options e.g., recording devices.

**Dimension 2: Well-Defined Tasks and Research Questions.** This dimension focuses on clearly defining tasks and research questions to ensure experiments can be reproduced and compared. It covers key aspects like the experiment procedure, environment, task details (free viewing or task-specific), task type, related documents, task design, and duration.

**Dimension 3: Well-Defined Metrics**. This dimension primarily defines the metrics used for data extraction and analysis in experiments. It includes a range of measurement categories, such as behavioural metrics, eye movement metrics, EEG metrics, fMRI metrics, and other physiological signals such as electrodermal activity (EDA). Additionally, qualitative user feedback not only triangulates findings from quantitative analyses but also adds depth to understanding user experiences, preferences, and interpretations.

**Dimension 4: Explicitly Specified Stimulus Properties.** This dimension primarily defines the stimulus properties from which experimental datasets are derived. It encompasses several critical aspects, including the dimension/reality of the stimuli, the format/environment in which the stimuli are presented, their specific descriptive details, any manipulations applied during the experiment, and the ownership information of the stimulus materials. By detailing these properties, this dimension ensures transparency and reproducibility in experimental design.

**Dimension 5: Well-Defined Participant Characteristics.** This dimension primarily defines the participant characteristics from which the experimental data are derived. It includes key aspects such as sample size, individual characteristics, and special considerations. Clarifying these attributes is crucial for understanding the specificity of the dataset, as well as the target population addressed by the research questions.

**Dimension 6: Ethical Considerations.** The final dimension pertains to the ethical considerations associated with the experimental data. It involves getting approval from ethics committees and having an ethical statement during data collection. This protects participants' rights and privacy and shows that the data was collected responsibly, especially when dealing with sensitive data or vulnerable groups.

Other additional considerations are as follows:

**Data Security & User Privacy.** We prioritize data security and user privacy by ensuring our platform's alignment with data protection regulations such as GDPR. We do not store or publish any kind of personal data.

**Design and Development.** To facilitate discoverability, we implemented a searchable interface based on developed metadata dimensions, allowing researchers to find datasets relevant to their research questions (**Goal 1**). We also strived to design a user-friendly web-based platform to ensure that our repository is accessible, user-friendly, and compatible with various web browsers. We used GitHub Pages to host our platform because it is a free, reliable, and widely used service for deploying static websites. By using GitHub Pages, we ensured compatibility across devices and browsers, minimal maintenance overhead, and a simple deployment process. In specific, we created the repository as a static HTML/CSS/JavaScript website generated by Hugo (https://gohugo.io/), a flexible static site generator, and regularly update it by changes to the GitHub repository. This workflow ensures that our metadata repository remains current, secure, and easily accessible to researchers.

## 3 Results

Based on the data selection criteria and dimensions, we showcase nine datasets in our repository (https://map-verse.github.io/Repository/) including all necessary details and links to facilitate the data access (Table 1). Addressing **RQ3**, we tried to design the interface in a systematic and user-friendly way allowing for exploring datasets in their study context. For example, the full abstract, related papers, links and figures describing the datasets are presented as well (Figure 1).

### 3.1 The functionality of the platform

**Function 1: Archiving and Searching with Taxonomies for Keywords.** Our repository uses Hugo's built-in taxonomies to organize and display **metadata keywords** as **tags**. This taxonomy system enables automatic categorization and cross-referencing of content, providing an efficient way to search and browse related resources. Keywords used in the metadata schema are assigned as tags, and Hugo dynamically generates tag-specific pages that group all related entries. Users can explore resources associated with specific tags directly by navigating to the tags section, enabling an interactive and structured exploration of our repository (Figure 2). This functionality not only simplifies content organization but also facilitates targeted searches for researchers interested in specific topics or categories. Figure 3 is a word cloud of the prominent topics emerging in the existing datasets we showcase on the website.

**Function 2: Google Search Integration.** To enhance user experience and enable seamless navigation, we integrated a built-in Google Custom Search Engine (CSE) into our platform. This feature allows users to perform full-text searches across all subpages within our websites. The integration was achieved by configuring Google CSE with our website's domain, ensuring that all indexed pages are searchable directly from our platform. This approach not only enhances discoverability of specific metadata and resources but also provides users with a familiar and intuitive search interface. By embedding the custom search icon on the homepage, users can locate desired information quickly, improving accessibility and usability.

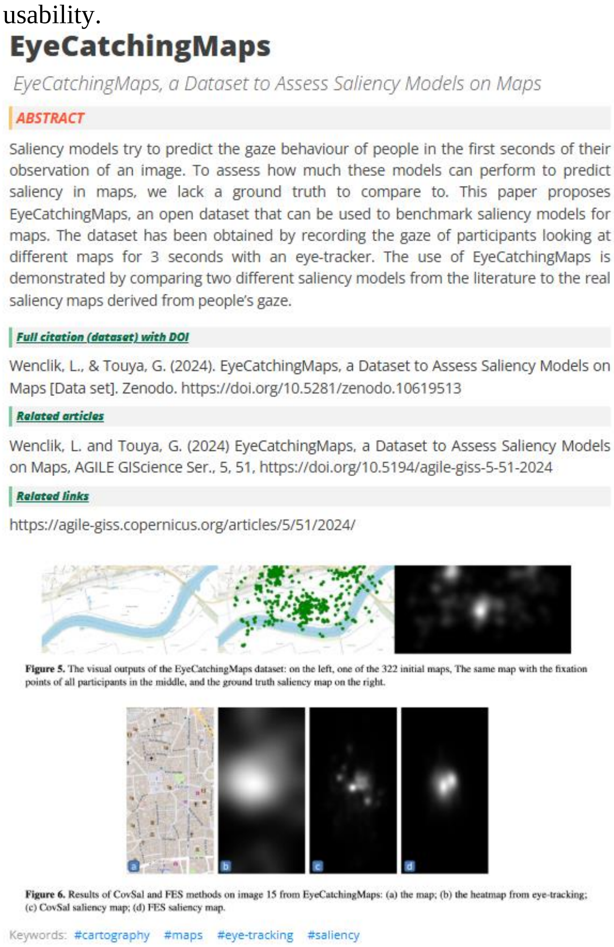


Figure 1. How a dataset looks like in MAP-VERSE.

**Function 3: A Dedicated Page for "Useful Tools for Datasets"**

To support researchers in map usability studies, we created a dedicated page titled "Useful Tools for Datasets". This page summarised a list of external websites, resources, and tools that are relevant to empirical research in map usability studies. It includes links to open-access datasets, geospatial analysis software, and other online utilities that can aid in conducting and analysing research. By providing a centralized collection of resources, this page serves as a valuable reference for the community, promoting collaboration and streamlining research workflows.

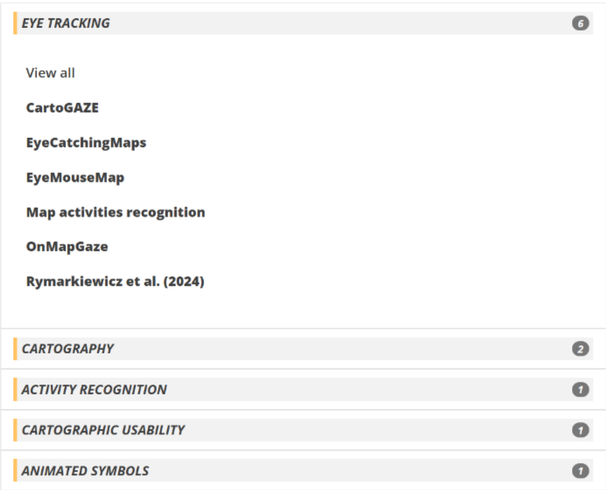


**Figure 2.** Keywords section from the website


**Figure 3**. Word cloud from the author keywords of the datasets

### 3.2 Data and Software Availability

The developed Open Educational Resources, including the data and code used in the provided examples and exercises, are published under a permissive **MIT License** and available at https://github.com/MAP-VERSE

### 3.3. Environmental Impact

Our rough estimation, using an average emission factor of 0.244 kg $CO_2$/kWh for EU (EEA, 2024), indicates that hosting a metadata repository on GitHub results in an estimated $CO_2$ emission of about ~5 kWh, corresponding to 1.22 kg $CO_2$ per year, thanks to the shared, efficient, and often renewable-powered infrastructure of Github. On the other hand, conducting an eye tracking experiment, for instance, lasting 30 minutes per participant over a 7-day lab occupancy, which would consume around 36.15 kWh, would emit approximately 8.8 kg of $CO_2$. This comparison clearly demonstrates that the GitHub-hosted repository is far more environmentally efficient in terms of electricity consumption and associated emissions and the overall footprint.

## 4 Discussion and future work

The first release of the repository serves as an initial base for further expansion and development. Future enhancements could include the implementation of a more sophisticated search engine, enabling dataset exploration based on specific criteria such as researchers' names, research areas, or types of cartographic stimuli. Furthermore, visualizing links between studies - such as reuse of published datasets or follow-up studies - for instance, EyeCatchingMaps (Wenclik & Touya, 2024) makes use of CARTOGAZE (Keskin, 2023) - could provide valuable insights for users.

The task of adding relevant datasets to **MAP-VERSE** could be performed by automated methods such as web scraping, e.g., detecting the presence of map figures in publications, as this could streamline the selection data discovery process and enhance efficiency. Additionally, to ensure metadata consistency and accuracy, the addition of an automated validation function on the website is planned for future work. The current datasets listed in the platform may not represent the diversity of the cartographic products used in map reading experiments so far. For example, the studies using thematic maps, dashboards, or mobile maps would a valuable addition to our repository.

Although it remains unanswered in this paper, **RQ4** highlights that the standardization of metadata reporting is crucial due to the varying reporting habits among researchers. We are aware that the transition towards standardized metadata reporting may face resistance from researchers who have established their own reporting practices, potentially hindering participation. To encourage adherence to reporting standards, we plan to implement functionalities for researchers to upload metadata descriptions and link to their open access datasets. In this context, intuitive templates and guidelines could simplify the process of filling in metadata and ensure alignment with the reporting dimensions outlined in this paper. Looking toward a long-term vision, this standardized metadata reporting form could be utilized during the submission of empirical research papers in journals.

**Table 1.** The datasets included in MAP-VERSE.

| Name of the dataset / Author & year | Link to the dataset | Sample size (N) | Keywords/tags |
|---|---|---|---|
| MDHScomplexity<br>Tzelepis et al. (2020) | Zenodo,<br>https://zenodo.org/records/14680770 | 15 | multidirectional hill-shading<br>visual complexity<br>eye movement analysis<br>expert judgment process |
| CartoGAZE<br>Keskin (2023) | Harvard Dataverse,<br>https://doi.org/10.7910/DVN/ONIAZI | 38 | eye tracking<br>AOI<br>spatial memory<br>memorability<br>cartographic usability<br>task difficulty<br>expertise<br>eye tracking dataset<br>navigational maps |
| GeoEYE<br>He (2021) | figshare,<br>https://doi.org/10.6084/m9.figshare.14684214.v4 | 110 | eye movement dataset<br>geospatial image<br>cartography<br>GIS<br>visual saliency detection |
| Horbiński (2024) | Harvard Dataverse,<br>https://doi.org/10.7910/DVN/DZUFJ1 | 58 | eye tracking<br>mobile maps<br>daily smartphone usage<br>spatial contexts<br>locating symbols<br>mobile navigation |
| Map activity recognition<br>Qin et al. (2023) | figshare,<br>https://doi.org/10.6084/m9.figshare.23805027.v2 | 50 | eye tracking<br>map activities<br>activity recognition<br>electroencephalography<br>map adaptation |
| Fixations & Saccades metadata<br>Cybulski (2023) | Harvard Dataverse,<br>https://doi.org/10.7910/DVN/YHYXLI | 103 | animated symbols<br>preattentive processing<br>pictorial symbols<br>motion distribution<br>cartographic design |
| EyeCatchingMaps<br>Wenclik, & Touya (2024) | Zenodo,<br>https://doi.org/10.5281/zenodo.10619513 | 44 | cartography<br>maps<br>eye-tracking<br>saliency |
| OnMapGaze<br>Liaskos & Krassanakis (2024) | Zenodo,<br>https://doi.org/10.5281/zenodo.11520659 | 30 | eye tracking<br>gaze dataset<br>graph-based metric<br>visual perception differences<br>statistical grayscale heatmaps<br>cartographic backgrounds<br>online map services |
| EyeMouseMap<br>Vlachou et al. (2024) | Zenodo,<br>https://doi.org/10.5281/zenodo.13929730 | 30 | eye tracking<br>mouse tracking<br>comparison metrics<br>lab-based and online user studies |

Evaluation of the repository and its functionalities will be key to ensuring its effectiveness. Usability testing with researchers (i.e., a questionnaire to the scientific community to both advertise the platform and improve its functionality) is planned to assess the platform's user experience, search functionalities, and metadata schema after a working period of the platform (e.g., six months or a year). Feedback gathered during this process will inform iterative refinements to address shortcomings and improve the overall platform.

## 5 Concluding remarks

In the present study, we introduce an open metadata repository that primarily aims to collect existing scientific datasets publicly available to the scientific community and related to experimental studies on map usability, perception, and cognition. Our repository website can serve as an initial foundation for promoting open data discovery and standardization, while it can substantially support collaboration among researchers worldwide. It can contribute to the comprehensive understanding of how people perceive, cognitively process, and interact with maps. At the same time, the existing datasets could be used to develop new data analysis and modelling techniques and/or methods that either describe or model map user behaviour, aiming to enhance and improve the map design process. The first release of the website includes experimental gaze, cursor activity, and EEG data collected in recent studies in the fields of cartography and geographic information science.

The experimental visual stimuli utilized in the current datasets in **MAP-VERSE** contain different types of maps, including typical cartographic backgrounds (e.g., citymaps) used in online map services, such as Google Maps and OpenStreetMap (OSM), or more specific cartographic products used in map design and composition (e.g., hill shading visualizations). In addition, our website also hosts scientific open-source software tools that are suitable for the analysis, visualization, and modelling of experimental data.

### Acknowledgements

The authors would like to express their sincere gratitude to the members of the **International Cartographic Association (ICA)** Commission on User Experience, Geovisualization, Cognitive Visualization, and Location Based Services for the insightful discussions on metadata access issues, as they were instrumental in shaping the ideas and research presented in this paper.

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## Appendix

A. Data Selection Criteria & Dimensions (see 2.1.)

| CONTROLLED CONDITIONS | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Medium/display (*choose one) | | | | Performance for data collection and system specification (*report all) | | | Input modality (the means by which a user interacts with a computer or other electronic device) (*report all) | | | | | | | Recording devices (*choose one or more) | | | | | | | Extraneous variables (*report all) | | | |
| smartphone | tablet | laptop/desktop | other medium (specify) | data quality | claimed error of the recording system/device | calibration accuracy of the recording system/device | keyboard | mouse | touchscreen | joystick | simulator (wheel, ...) | voice recognition | gaze control | remote/screen-based eye trackers | webcam/smartphone cam eye trackers | standalone EEG recording modules | VR, AR | fMRI | EDA sensors | Multiple device combinations (please specify) | lighting conditions | noise (removal of artificial components) | shielded room | software / developed own method/programming |

| WELL-DEFINED TASKS & RESEARCH QUESTIONS | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Full procedural details of the experiment (*provide a link) | | | Environment (*choose one) | | | Free viewing vs. Task-specific (*choose one) | | Task type (*choose one or more) (report what authors report) | Task related documents (*choose one or more based on availability) | | | Task design | | Task duration |
| relevant peer-reviewed research paper | relevant conference presentation, blog post, link to a webpage, etc. | flowchart | Screen-based in lab | VR/simulation in lab | real world (field tests) | Free viewing | Task-specific | navigation, direction and distance perception, spatial reasoning, spatial memory, visual world paradigm, free-viewing, etc. | Orientation of the participant | Task instructions | Trial task(s) | Randomized block design | Event-related design | within-subjects / between-subjects / mixed design |

| WELL DEFINED METRICS | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Behavioral metrics | | | Eye movement metrics | | | | | | EEG metrics | | | | | fMRI metrics | | Other | | | Qualitative User Feedback | | | | |
| response time | response accuracy | others | fixation-related | saccade-related | scanpaths | heatmaps | AOI-specific | others | time-domain | frequency-domain | time-frequency domain | hemispheric differences | others | BOLD signal changes | functional connectivity | Electrodermal Activity (EDA) | cardiovascular activity (heart rate variable (HRV)) | skin temperature (ST) | pre-test questionnaire | post-test questionnaire | sketch maps | think aloud | structured / verbal interviews |

| WELL DEFINED STIMULUS PROPERTIES | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Dimension/ Reality (*choose one) | | | Environment (*choose one) | | | Descriptive details | | | Manipulations | | Ownership information | | | | |
| 2D | 3D | XR (AR, VR, MR) | static | dynamic | interactive | size | position | format | visual | task-related | data source | authorship | existing stimuli | new stimuli | the number of stimuli |

| WELL DEFINED PARTICIPANT CHARACTERISTICS | | | | | | | | | | | ETHICS | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Sample size | | | Individual characteristics | | | | | Special Concerns | | | Permission from ethics committees (*choose one) | | Ethical statement (*choose the ones that apply) | | |
| <30 | >30 | large datasets | age | gender | education | spatial abilities (grouped based on cognitive test, e.g., NASA TLX) | curiosity about the experiment nad/or eqipment | color blindness | other disabilities | other concerns (e.g., driving license, visual acuity) | yes | no / no mention | what ethical standards the study adheres | informed consent | anonymization of collected personal data |