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Educational Experiments in 360º Environments with Cognitive Neuroscience Tools: A Bibliometric and Methodological Perspective

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Abstract:

Purpose: *The purpose of this paper is to provide both a bibliometric and methodological overview of research combining 360-degree images and videos with cognitive neuroscience tools. The article also aims to propose a practical framework for designing and implementing experiments conducted in desktop-based virtual environments (DT VR), offering an alternative to traditional head-mounted display (HMD) VR systems.*

Design/Methodology/Approach: *The study consists of two complementary components. First, a bibliometric exploration of existing literature was conducted across major academic databases using keywords related to 360-degree media, virtual reality, eye tracking, EEG and GSR methods. Second, the paper presents a methodological model for developing experiments using game-engine-based environments, detailing technical aspects such as mapping 360º textures, camera placement, transition logic between virtual spheres, data acquisition for eye tracking, and the use of AI-driven object detection to support data annotation. The methodological part focuses specifically on DT VR research setups.*

Findings: *The bibliometric review confirms that the use of 360-degree images and videos in cognitive neuroscience research is growing rapidly and is being applied across several domains, including perception, spatial orientation, emotional analysis and education. The methodological analysis demonstrates that DT VR can serve as a viable and less intrusive alternative to HMD VR, particularly when integrating measurement devices such as EEG and GSR. Furthermore, the study outlines how gaze data from a 2D eye tracker can be accurately transferred into a 3D spherical environment, and highlights the potential of AI-based object detection to streamline annotation processes.*

Practical Implications: *The proposed methodological framework provides researchers with clear guidelines for constructing, managing and analysing experiments based on 360-degree content. The paper may support scholars planning to integrate VR-like experimental conditions without the need for HMD equipment, reducing participant discomfort and lowering technical barriers. The guidelines are also relevant for educational and behavioural research using immersive but non-ambulatory virtual environments.*

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Originality/Value: *This article uniquely combines a bibliometric analysis with a comprehensive methodological workflow for DT VR studies employing 360-degree media and cognitive neuroscience tools. The dual perspective fills a gap in the existing literature, which largely focuses on fully immersive VR setups and offers limited methodological detail for screen-based environments. The paper contributes practical, replicable guidelines that can enhance the design and execution of future experimental research.*

Keywords: *360-degree images, 360-degree video, eye tracking, VR, desktop VR, EEG, GSR, cognitive neuroscience, object detection, virtual environments.*

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1. Introduction

The purpose of this article is to analyse current research trends involving 360-degree images and videos used together with cognitive neuroscience methods, and to present a methodological approach for implementing such experiments in desktop virtual environments, including the integration of eye tracking, EEG and AI-based object detection.

Cognitive neuroscience provides a wide range of tools for measurement and analysis. Through the use of cognitive neuroscience methods such as EEG, eye tracking, GSR, and VR, it is possible to access and attempt to understand unconscious processes involved in information processing (Słupińska *et al.,* 2021).

These methods are frequently employed in experimental designs in which various variables are introduced, and the behavior of participants is systematically observed. According to the definition of an experiment, "it is a type of study in which one manipulates certain variables and observes their effects on other variables" (Michael, 1967). As noted by Sułek, an experiment is "a repetitive procedure involving a change, planned by the researcher, of certain factors in the situation under study, while controlling other factors, undertaken in order to obtain, by means of observation, an answer to the question of the effects of that change" (Sułek, 1979).

The implementation of experiments in virtual environments has gained popularity in recent years, as VR offers a more efficient and controllable setting for investigating various phenomena. The VR environment provides a useful platform for creating controlled experimental conditions in which human behavior can be observed. From the perspective of cognitive neuroscience, this facilitates the analysis of processes such as perception, motor control, learning, memory, and emotional responses.

However, to evaluate the extent to which the integration of VR technology with experimental methods enables reliable management of information and knowledge, a thorough consideration of methodological aspects is required (Słupińska *et al.,* 2021).

360-degree photos and videos make it possible to simulate real-world environments within controlled VR settings, enabling the application of other research techniques, including cognitive neuroscience methods, without the need for traditional fieldwork.

Research using 360-degree images or video is particularly well suited to VR environments utilizing HMDs (head-mounted displays) and various sensors (e.g., EEG, GSR). This approach enhances immersion and reduces biases that may arise from traditional survey-based methods. It has also been successfully applied across a variety of research domains (Aksoy *et al.,* 2021).

Nevertheless, similar approaches can also be implemented using a standard computer monitor (DT VR), along with cognitive neuroscience methods, rather than relying solely on HMD VR (Aksoy *et al.,* 2021).

Numerous publications have examined the differences between the use of HMD VR and DT VR. It has been shown that DT VR can lead to greater efficiency and reduced discomfort compared to immersive HMD-based environments, although the latter tends to enhance perceived control and immersion (Srivastava *et al.,* 2019). Moreover, it is often unnecessary to employ HMD VR when, for instance, increasing the exposure time in DT VR can positively influence the perception of 360-degree materials (Sui *et al.,* 2020). While HMDs offer a more complete immersive experience, DT VR systems are also effective in studying immersion and individual tendencies toward immersive engagement (Oh *et al.,* 2025). In educational contexts, the use of DT VR produces comparable results to HMD VR in terms of memory retention and the acquisition of theoretical knowledge (Queiroz *et al.,* 2022) *(Guo et al.,* 2024).

These findings suggest, among other things, that the use of HMDs may negatively affect participants, prompting consideration of whether it might be more appropriate to conduct such research using a standard computer monitor. This approach may reduce participant discomfort and, in some cases, facilitate the use of certain devices such as EEG and GSR.

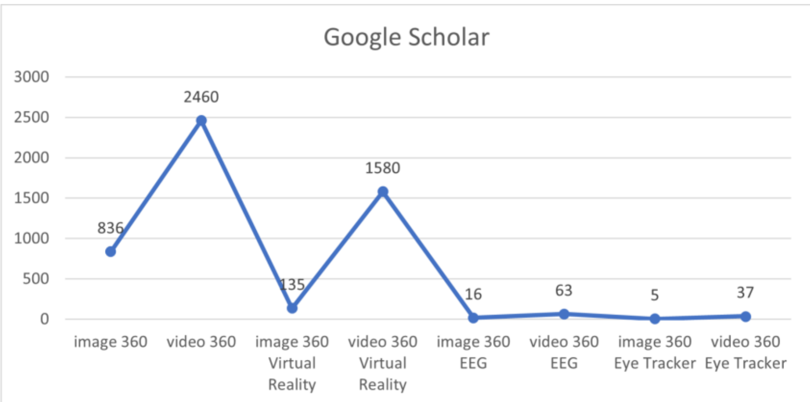
Although this article focuses on research involving 360-degree images and videos, many of the methodological issues discussed also apply to studies conducted within 3D virtual environments provided they are displayed on a monitor screen rather than using HMD VR.

This article offers an original contribution by integrating a bibliometric perspective with a detailed methodological framework for conducting 360-degree image and video experiments using cognitive neuroscience tools in desktop-based environments. While previous studies have predominantly focused on fully immersive VR implementations, this work highlights the methodological challenges and opportunities specific to screen-based testing, including gaze mapping in 3D spherical space and the integration of EEG, GSR, and AI-driven object detection. The combined approach presented here provides researchers with both a systematic overview of the current state of knowledge and a practical guideline for designing and implementing such experiments. This dual perspective fills an important gap in the existing literature, where methodological clarity for desktop-based 360° studies remains limited.

2. Results of Bibliometric Studies

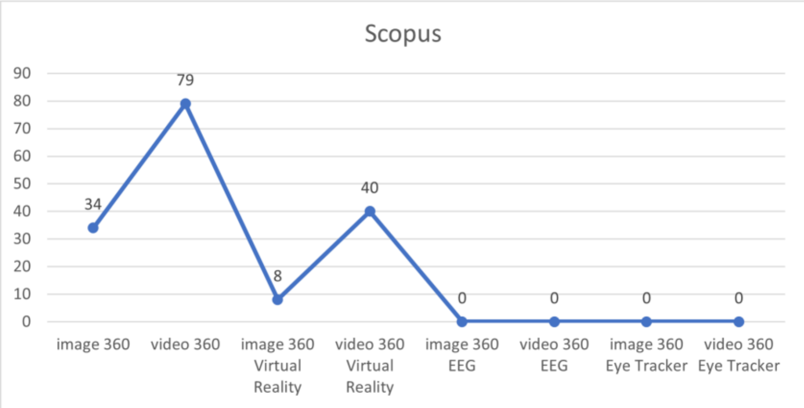
The analysis employed a range of keywords used to identify relevant and interesting content. The primary objective was to gather information related to combinations of 360-degree images, 360-degree video, virtual reality, EEG, and eye tracking, although the review also included sources that did not incorporate all of these terms. At the deepest level of analysis, attention was given to identifying the areas in which the topic was addressed and assessing the extent to which the content described the study's methodology. The final literature search was conducted on 23.07.2025. The results are presented in Figures 1-3.

Figure 1. *Analysis of publications in Google Scholar*



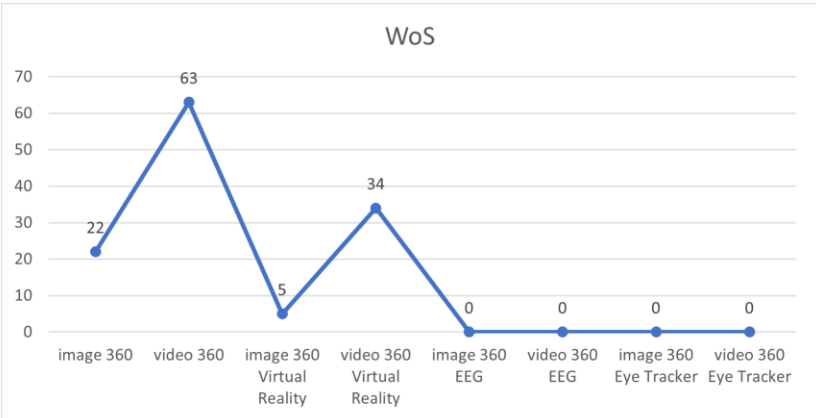
Source: *Own research.*

Figure 2. *Analysis of publications in Scopus*



Source: *Own research.*

Figure 3. *Analysis of publications in WoS*



Source: *Own research.*

The subject of 360-degree images and video is extensively discussed in the scientific literature and demonstrates a wide range of applications. On the one hand, 360-degree imagery is used to represent real-world environments; on the other, it serves as a tool for spatial orientation and cognitive research. It also lends itself to various studies of human behavior and perception.

A brief overview of the relevant literature is presented below.

The article by Adhanom *et al.* (2023) provides a comprehensive overview of eye-tracking applications in VR environments, including those based on 360-degree imagery. It discusses eye-tracking techniques in head-mounted displays (HMDs) and their application in areas such as attention analysis, user interaction, and foveated rendering. The publication also offers a classification of eye movement types and highlights their relevance in immersive visual contexts.

Among other applications, 360-degree imagery is used to assess an individual's spatial orientation within virtual environments, as well as their perception of surroundings and navigation within omni-directional images. Since visual attention plays a crucial role in such settings, research often focuses on tracking both head and eye movements to better understand how users perceive and interact with 360-degree environments (Harada and Ohyama, 2022) (David *et al.,* 2018). In robotics, multiple cameras capturing static 360-degree images are employed to determine depth and direction of robot movement in both real and simulated environments ("MODE," 2022).

An innovative application of 360-degree recordings for estimating the gaze direction of all individuals in a given image or video was proposed by researchers from the Massachusetts Institute of Technology and the Toyota Research Institute (Kellnhofer *et al.,* 2019). This study addressed the challenge of an expanded visual field in which viewers are free to "wander with their eyes." When watching a 360-degree image or video, users may not necessarily follow the narrative intended by the content creator. Consequently, the authors analyze directing techniques designed to guide the viewer's gaze and focus attention on specific elements within the scene.

Another noteworthy example is presented in the article (Zulkiewicz *et al.,* 2020), which uses 360-degree video in an online experiment aimed at eliciting empathy and enhancing understanding of the lived experiences of migraine patients. This study also serves as an example of using 360-degree video in educational contexts.

3. Research Methodology

3.1 Preparation of the Research Environment

A game engine can be used to implement research involving 360-degree photos and videos. To enable the participant to view this type of imagery, a 360-degree image should be mapped onto a sphere within the game engine (e.g., Unity). The camera, representing the participant, must be positioned at the center of the sphere. In this way, the subject is able to observe the surrounding environment, i.e., the texture applied to the interior of the sphere.

The participant can navigate within the sphere to zoom in on specific elements using keyboard input only. If the image is presented in a VR environment, zooming should be controlled solely through the VR controllers. The subject should remain seated in a rotating chair, without the ability to move freely. Care must be taken to prevent the participant from crossing the sphere's boundaries, which would result in the display of the external environment beyond the sphere.

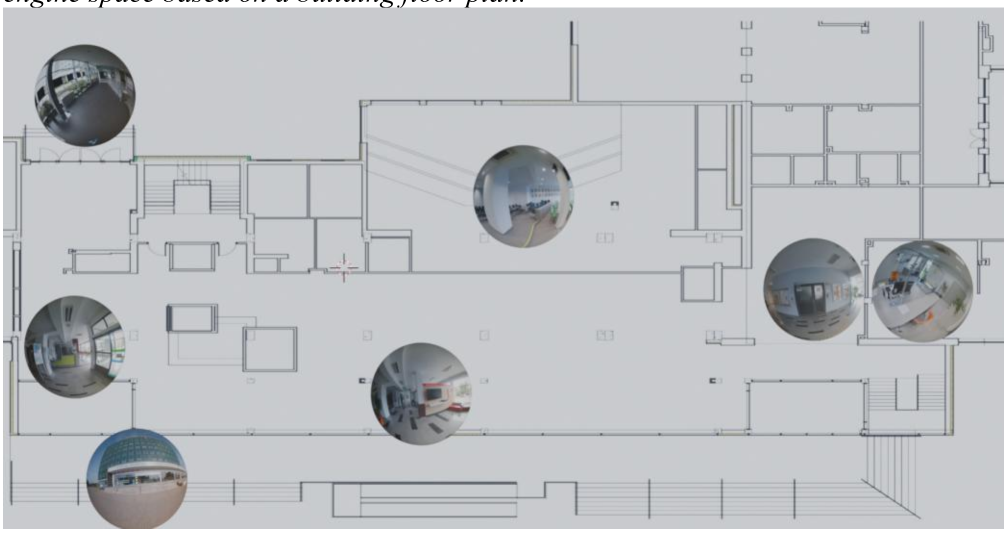
Transitioning to other images is accomplished by moving the camera to different spheres, each of which has a distinct 360-degree image or video texture applied. Figure 1 presents an example of how such spheres can be distributed across a floor plan of a building. One of these spheres serves as the starting point, which is why the camera is placed there and oriented in the direction the participant is expected to face at the beginning of the test. For the sake of clarity, the term sphere, onto which the 360-degree image or video is mapped, will be used throughout the remainder of this section.

If it is necessary to calm the participant e.g., when EEG is being used a suitable texture, such as a black image, can be applied to the starting sphere. The same principle applies to other situations. For example, if a message must be shown to the participant, a dedicated texture containing the relevant text should be created and mapped to the sphere. It is important to remember that the subject remains inside the sphere in order for the texture to be viewed correctly.

To transition to the next image or video, the camera is moved to the center of a different sphere. At this point, the mechanics of inter-sphere movement should be considered. Several solutions can be applied depending on the study's design. One approach involves placing directional points inside each sphere that indicate a link to the next sphere. Each such point serves as a pointer to a specific destination.

Additionally, other events or stimuli can be triggered depending on the sphere being presented. In the study presented here, a separate audio recording was used, which was triggered after a five-second delay once the participant had entered the sphere.

Figure 4. *Example of the placement of successive 360-degree images in game engine space based on a building floor plan.*



Source: *Own research.*

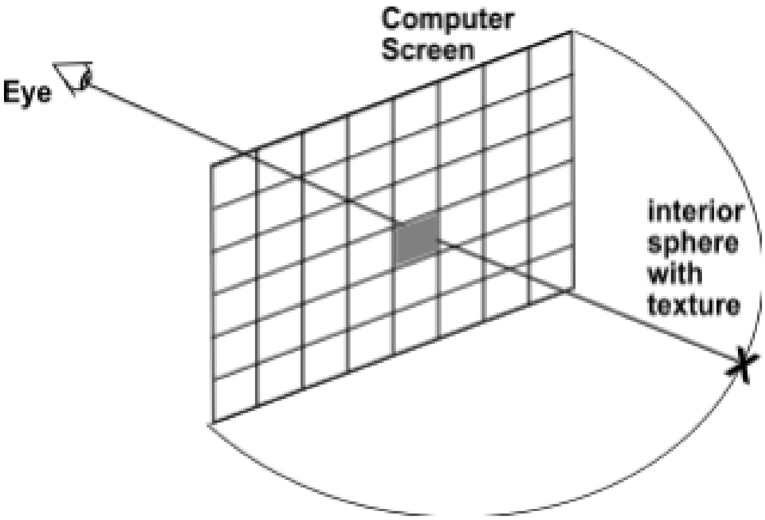
It is also essential to apply colliders or similar detection mechanisms to all interactive objects or events from which data is to be collected. In the case of 360-degree imagery or video, the sphere itself must be equipped with a collider to enable interaction detection.

3.2 Preparation of the Research Environment

A key challenge in studies using a 2D monitor with an eye tracker typically mounted at the bottom of the screen is that gaze data are recorded in 2D screen coordinates (x, y). When using 360-degree images, however, the research focus shifts toward identifying where the subject was looking within the 3D spatial context of the spherical environment.

In the approach presented here, the experiment is prepared similarly to a VR implementation. The difference lies in the use of an eye tracker that is not integrated into VR goggles; thus, the direction of the camera's gaze in the virtual environment must be recorded separately.

Figure 5. *Determining the point on the sphere at which the participant is looking.*



Source: *Own research.*

After the test is completed, two types of data are available (Figure 5):

- x, y coordinates from the eye tracker, indicating where the participant was looking on the 2D monitor screen;
- X, Y, Z coordinates of the camera in 3D space within the game engine, located in the local coordinate system of the sphere;
- The quaternion of the camera, which defines its orientation in 3D space.

These data must be combined in order to determine where the participant was looking. This is done by casting a ray from the 2D screen gaze point through the camera's direction vector into the 3D virtual space of the sphere. To determine the intersection point on the spherical texture, a collider must be applied to the sphere during test preparation. The intersection of the ray with the collider indicates the specific location on the texture where the participant's gaze was directed.

This data processing procedure should be repeated for the entire test and for all participants. If the number of objects of interest is relatively small, it is also possible to apply colliders to specific regions of the texture (i.e., objects) to determine and classify the exact moments when participants fixated on them.

3.3 Preparation of the Research Environment

The use of artificial intelligence can significantly reduce the workload of researchers. Each object of interest must be properly annotated by defining its boundaries on the texture. This task can be performed manually, but it is labor-intensive. AI-based approaches greatly streamline and accelerate this process.

Object detection using AI methods has found applications in various fields, including:

- Construction (Liu *et al.,* 2022; Lung and Wang, 2023)
- Industry (Li *et al.,* 2022; Wang *et al.,* 2021; Yi *et al.,* 2021)
- Medicine (Weikert *et al.,* 2020; Huang *et al.,* 2025; Inoue *et al.,* 2022; He *et al.,* 2025)
- Other domains (Senada Bushati, 2025; Etienne *et al.,* 2021; Bargoti and Underwood, 2017; Department of Computer Science, Jaypee Institute of Information Technology, Noida, India *et al.,* 2024; Guo and Xie, 2021; Kumar *et al.,* 2025).

Until recently, object detection was based primarily on convolutional neural networks. Today, new approaches are used in real-time object detection due to their performance advantages. For example, in Wang *et al.* (2022), the authors evaluated the YOLOv7 detector, which outperformed all other known detectors in terms of both speed and accuracy. It exceeded the speed of convolutional detectors by 509%.

The YOLO family of detectors continues to evolve. In Jia *et al.* (2024), the performance of YOLOv8 is analyzed, with a focus on optimization. In another study (Tian *et al.,* 2024), deep learning-based object detection in smart cities is discussed. The authors conclude that the Dynamic Head (DyHead) detector outperforms other solutions.

As illustrated, AI-based object detection continues to advance rapidly and is already capable of effectively handling automatic recognition tasks. Therefore, these techniques can also be applied to the detection of objects in 360-degree images and video.

4. Conclusions, Proposals, Recommendations

360-degree images and video allow researchers to recreate representations of real-world environments in virtual reality (VR) without the need for complex 3D modeling. When such an approach is sufficient for the research objectives, it significantly simplifies the preparation of the study particularly when implemented using head-mounted displays (HMDs). The use of virtual reality itself provides broad possibilities for manipulating the environment and collecting a wide variety of data.

However, this paper highlights a critical issue: replicating the same virtual environment on a standard monitor screen does not always yield data that are equivalent to those collected using HMDs.

For instance, an eye tracker integrated into a VR headset records gaze data in relation to a 3D immersive space, whereas a screen-based eye tracker measures gaze in a 2D coordinate system. These differences may affect how the data are interpreted and what conclusions can be drawn.

Nevertheless, conducting the study in front of a standard computer monitor presents several clear advantages:

- No physical discomfort or motion sickness commonly associated with HMD-based VR environments
- Faster and more straightforward implementation of the experimental setup
- Fewer technical challenges when integrating additional devices, especially EEG or GSR sensors.

On the other hand, the key advantage of a fully immersive VR environment is that it provides a stronger sense of presence and realism for the participant an aspect that can enhance engagement and improve the ecological validity of certain types of studies.

In conclusion, both approaches HMD-based VR and desktop-based VR (DT VR) offer unique benefits and limitations. The choice between them should be guided by the research question, the methodological constraints of the study, and the types of data to be collected.

As demonstrated throughout this article, even studies relying on 360-degree imagery can be effectively adapted for screen-based testing environments, provided that appropriate tools and interpretation frameworks are applied.

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