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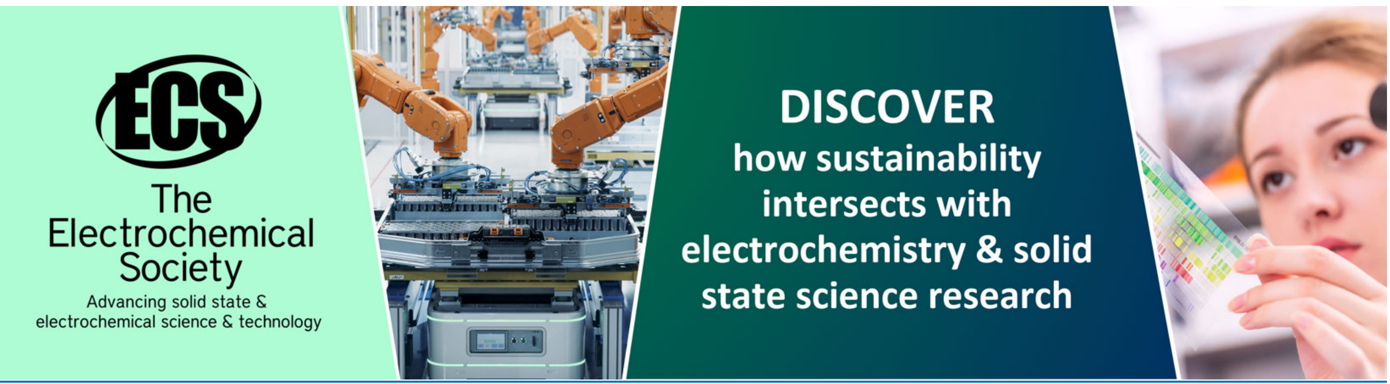

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A review study of space perception and navigation of people with low vision: is simulated low vision a reliable methodology?

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Abstract: The inclusion of visually impaired participants in research protocols concerning their perception of space and navigation is essential for the reliability of the results, given the strategies developed by the people concerned in everyday life. However, the diversity of visual impairments, the scarcity of participants and possible safety issues due to obstacles in the physical space induce limitations and prompt researchers to look into alternative methodologies. Simulated low vision is seen as an option. This method involves sighted participants wearing goggles with customized filters or watching processed images in virtual environments. The objective of this study is to investigate the reliability of simulated low vision as a research method to describe the space perception and navigation of people with visual impairment. We conducted a literature review and identified 36 quantitative studies on low vision spatial performance involving multiple user groups. Simulated low vision proved effective in small-scale spatial ability evaluation, such as object detection and distance estimation, but remained challenging regarding large-scale capacity, such as navigation with mobility requirement. Advances in virtual environments suggest that they are a good alternative to goggles and screen displays because of their precision in mimicking ocular problems in simulation settings. Finally, the use of head-mounted-display (HMD) by people with real low vision could open up the possibility of greater testing in safer and controlled conditions, but requires confirmation of the validity of the protocols.

1. Background

Visual perception is important for human interaction with the world, providing crucial information on spatial interaction, distance estimation, and obstacle recognition, enabling effective wayfinding and orientation. Yet, the transition from merely sensing the environment to perceiving it and then successfully navigating through it becomes an even more critical concern when considering individuals with visual impairments. “Low vision” (LV) means having impaired vision that cannot be corrected by any glasses [1]. According to a meta-analysis of population-based datasets, 216.6 million, roughly 2.8% of world population had moderate to severe visual impairment [2] and 60% of them are aged 65 and over. From social level, only 16% of people with visual impairment at working age are employed [3]. The barrier they faced when moving around, navigating in city and building, getting to and from where they work, are major impediments that isolate this group from the rest of the society. As a response, people with LV typically develop strategies to alleviate their struggles and enhance their overall interaction with spaces. Research pertaining to space perception and cognition proved the importance of visual information (albeit damaged and deficient) in navigation and mobility and endeavored to tap into the barriers that exist in the built environment, in particular the complexity and inaccessibility of the environment from the perspective of people with LV.

1.1. Challenges
The challenges inherent in research on space perception and cognition of people with visual impairment stem from three primary sources:

- **Control over studied variables**: As orientation and mobility assume a critical role in navigation and wayfinding, it frequently introduces a dynamic observation point against a certain route, necessitating constant visual updating [4–6]. Various modes of interaction between an individual and the environment (e.g. active and passive exploration) can introduce uncertainty and stochastic components into the final output.
- **Difficulty in recruiting subjects**: the relative scarcity of the people with LV as well as the diversity of types and severity of visual impairments has led to a smaller and/or non-homogeneous sample, which limits the type of analyses and statistical effects targeted [7]
- **Safety concerns**: Peli [8] also highlighted concerns pertaining to the safety of subjects resulting, for example, from the danger of not seeing the obstacles in experimental context when including people with LV in experimental procedures.

As a result, "simulated LV", defined as an artificial alteration of one's visual perception to mimic the visual barriers faced by individuals with LV, has helped to advance scientific knowledge in the field of visual impairment. There are two classical ways to simulate LV:

- by using specialized filters or lenses to reproduce optical distortions. Fully-sighted people will therefore wear filters in the form of blindfolds and glasses to mimic LV sight
- by post-processing images (or videos) and then presenting them to a sighted subject using a computer screen or head-mounted display (HMD).

Using these technologies, many studies resort to simulating visual impairments by involving sighted individuals (details in Table 1), allowing for the expansion of sample size and precision in controlling impairment severity. However, previous practices have also highlighted an adaptation effect in the visually impaired population, demonstrating enhanced spatial perception and cognition through their long experience of interacting with spaces with limited visual ability. The presence of similar effects in the sighted population who suddenly have their vision diminished via a simulation technology is not guaranteed, and the same experimental method can yield different results depending on the specific objectives of the study (for example, obstacle detection tasks are different from navigation tasks). Moreover, the necessity for a dynamic observational perspective also introduces another methodological challenge to LV simulation since neither goggles nor post-processing method can replicate a full field of vision (FOV) covered by the human eye itself, which includes binocular overlap of up to 200 degrees ($\pm$100 to the temporal side), not counting the additive effect of eye movement [9]. The FOV deficiency arising from traditional flat glasses and 2D images presents an opportunity for compensation through the emerging technology of VR glasses or curved screen, which provide an expanded field of view. With the introduction of VR technology, the reliability of easily manipulated virtual environments (VE) used in LV research in determining real-world validity are another contentious topic [10]. The function of VE is particularly pronounced when investigating the influence of environmental design on the visually impaired. The virtual presentation of the environments with post-processing resolved the problems associated with the variables of the physical experiments and strengthened safety measures. However, these experimental protocols do not involve visually impaired persons, which still raise ethical questions [11].

1.2. Study objective
Our objective is to identify and compare existing tools used in assessing the spatial perception of individuals with visual impairment. In particular, we are interested in the reliability of simulated LV.

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Figure 1 to 4 depict some existing methods for simulating LV. With this review study, we aim to improve the accuracy, reliability and suitability of future research methods used in the field of LV in architecture.

Figure 1. Typical vision-degrading goggles with blind (left) and blurred foil (right) [31]

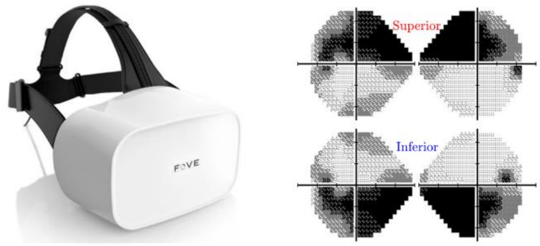

Figure 2. VR headset with integrated eye tracking and the perimetric data used to simulate vision filed loss (VFL) [21]

Figure 3. Simulated visual impairment produced from original photo (left) with blurring and contrast reduction (right) [50]

Figure 4. Example of live-screen presented in VR with superior VFL (left) and inferior VFL (right) 21]

2. Methodology

We conducted a literature review on the existing tools and methods used to study the spatial perception of individuals with visual impairment looking at both the methods applicable to LV research, and their reliability for different types of tasks. The preliminary round of screening is based on keyword searches in repositories including Web of Science, Google Scholar, PubMed and SAGE Journals. We looked at the following key words: "visually impaired", "low vision", "field loss of vision", "acuity loss", "visibility", "cataract", "glaucoma", "macular degeneration", "retinitis pigmentosa", "navigation", "wayfinding", "spatial representation", "spatial cognition", etc. Studies concerned with the introduction or validation of technological aids (e.g. apps, intelligent tools) were excluded. We pre-selected papers based on the above keywords with further screening in:

1. Type of publication: papers were written in a peer-reviewed journal, a peer-reviewed conference paper, a Ph.D. thesis, or as a book edited by an established publisher
2. Language: papers were available in English (written or translated) for accurate interpretation.
3. Objective: papers involved human participants and spatial tasks, exclusive of object recognition, reading or typing; or focused on the impact of different environmental factors on the spatial perception, navigation and cognition from LV subjects or on differences between LV and full sighted group
4. Experimental methodology: papers were based on quantitative research method, which involved using numerical data and statistical analysis to draw structured conclusions.

3. Review outcomes and analysis

In total, thirty-six studies published between 1987 - 2023 were judged eligible and were therefore included in this review. Table 1 provides an overview of the paper found, documenting the participants' type of vision (real LV vs. simulated LV vs. fully sighted), the experimental setting (on-site vs. virtual environment), as well as the type of measurements used.

Prior research has explored how different types of visual impairment impact environmental perception through cross-modal and internal comparison setups. Cross-modal comparisons involve comparing sighted individuals with LV groups, including simulated and real LV participants. Internal comparisons focus on visually impaired individuals, considering differences in impairment types and severity (e.g. acuity loss (AL), peripheral vision loss (PFL) with various severity). In this scenario, simulated LV participants are more frequently included to enhance control over variables of visual condition. Most studies incorporating real LV subjects tend to discuss subgroup performance as a whole without delving into within-group categorizations, despite the fact that there are differences existing between subgroups (AL and PFL) [7,12,13]. The adaptation effect, denoting the phenomenon whereby individuals with sustained vision impairment (blind subjects) exhibit heightened perceptual and cognitive abilities in contrast to those with short-term blinded vision [14], stands as a main experimental limitation of artificially induced alterations in vision, which is less addressed in common vision research. Among the reviewed literature, only a handful of articles encompassed both simulated and real LV subjects, aiming to discern disparities between these two groups. In all reviewed papers, this adaptation effect was only mentioned in comparisons of subjects with AL.

Hegarty et al. [15] proposes a differentiation between "small scale" and "large scale" spatial abilities, putting emphasis on the difference between observing an object in space (smaller than the human body) and perceiving the space (in which the human body is surrounded). This implies a possible categorization for the first six target tasks discussed in this review: *small scale spatial tasks* pertain to mentally transforming representations of small shapes or objects, such as blocks, which aligns with dimension estimation and obstacle detection measurement in the context of this paper, while *large scale spatial tasks* entail more intricate tasks, such as mobility, wayfinding and navigation. The discrepancy between space scale was also indicated in an empirical study involving blind individuals, where congenitally blind participants encountered greater difficulty in spatial tasks within a large-scale space than a small-scale space [16]. Figure 5 describes frequency distribution of sample and method types for six different types of tasks: spatial representation (SP), target finding (TF), object detection (OD), gazing behavior (GB), wayfinding and mobility (W&M), navigation and wayfinding (N&W). Among the thirty-six studies, twenty researches incorporated individuals with simulated LV as participants. Eleven opted for virtual environment (screen display or Immersive Virtual Environment (IVE)). The following sections, intended to respond to the reliability of the method, will be organized according to the type of spatial task in relation to the scale considered.

Figure 5. Frequency distribution of selected studies in term of displayed environment and participants type for different spatial tasks (Note: Some studies were double counted due to multiple research objectives.)

Table 1. Summary of 36 studies

Author, date	Participant			Environment			LV Simulating method		Objective measurement							Subjective measurement
	Real LV	Simulated LV	Sighted	On-site	VE (screen)	VE (HMD)	Goggle	Image processing	wayfinding& navigation	Map sketching	Target searching	Dimention estimation	Obstacle detection	Walking task	Gazing and fixation	Psychological questionnaire
Andrew Freedman (2019)	×	$\times_a$	×	×			×		×					×	×	
Aspinall. P. et al. (2014)	×		×		$\times_p$				×							
Barhorst-Cates et al. (2016)		$\times_p$		×			×		×							
Barhorst-Cates (2017)		$\times_a$		×			×		×							
Barhorst-Cates (2019)		$\times_p$		×			×		×							
Barton, R. (2014)		$\times_p$				$\times_s$		×	×							
Black, A.,et al. (1997)	×		×	×									×	×		
Blades, M.(2002)	×		×	×					×	×				×		
Carpenter. B. (2018)		$\times_a$		×	$\times_s$			×					×			
Chow-Wing-Bom, H. (2020)		$\times_p$				$\times_s$		×			×					
Fortenbaugh, F. C. (2007)		$\times_p$				$\times_s$		×				×			×	
Fortenbaugh, F. C., Hicks, J. C., & Turano, K. A. (2008)	$\times_p$			×		$\times_s$						×			×	
Iwata, M., & Kitamoto, H. (2019).	×		×	×										×		×
Jones. P etal (2020)		$\times_p$		×		$\times_s$		×			×				×	
Kalia et al. (2008)	×		×	×	$\times_{s,p}$			×	×	×						
Katemake. P. (2019)	×	$\times_{a,p}$		×			×						×	×		
Kuyk, T. et al. (1996)	×			×									×	×		
Leat, S. J., & Lovie-Kitchin, J. E. (2008)	$\times_{a,p}$			×									×	×		
Legge, G. et al. (2016)	×		×	×								×				
Legge, Gordon E (2010)		$\times_a$		×			×						×			
Liu, S etc. (2021)	×	$\times_a$			$\times_s$			×					×			
Matsuda, Y et al (2019)	$\times_{a,p}$		×	×										×	×	×
Matsuda, Yuji, et al. (2019)	×		×	×										×	×	
Matsuda. Y et al. (2021)	×		×	×										×	×	
Ozlem Beli, (2010)	×			×						×						
Passini, R., Proulx, G., & Rainville, C. (1990)	×		×	×					×							
Peli D. (1987)		$\times_{a,p}$		×			×						×	×		
Rand et al, (2015)	×	$\times_a$		×			×		×							×
Rand. (2019)		$\times_a$		×			×					×				
Rousek, J. B., & Hallbeck, M. S. (2011)		$\times_{a,p}$	×	×			×							×		×
S.E. Hassan et al. (2007)		$\times_p$				$\times_s$		×					×	×		
Sippel, K, et al. (2014)	×		×	×							×					
Tarampi MR, Creem-Regehr SH, & Thompson WB (2010)		$\times_a$	×	×			×					×				
Thompson, Williams B. Shakespeare (2022)	×	$\times_a$			$\times_s$			×					×			
Yamamoto, N., & Philbeck, J. W. (2013)		$\times_p$		×			×					×			×	
Zou, X., & Zhou, Y. (2023).	×			×										×		×

*×a: Real low vision participant with acuity loss only; ×p: real low vision participant with peripheral field loss only
*×s: Virtual environment generated with simulated model ×p: Virtual environment generated by photorealistic picture/video

3.1. Small-scale spatial task: spatial representation and object perception.

Spatial representation refers to the mental or cognitive mapping of physical space [17,18]. It involves the ability to mentally perceive and manipulate the relationships between objects, distance, orientation and self-locations within an environment. Small scale spatial representation allows individuals to create and maintain an internal model of their surroundings, usually confined with a settled space, within which they can conduct subsequent tasks, including obstacle avoidance, distance estimation, object searching, etc. On aggregate, 20 of the 36 papers investigated the issues mentioned above. A common thread across the execution and evaluation of these spatial tasks is that the observed environment remains confined to a small-scale setting (single room or corridor), often restricted to a field of view of 180 to 360 degrees (could involve head movement) and within eye-catching distance, yet devoid of strenuous body-movement or rotation requirement. A relatively high reliability of simulated LV was seen in studies pertaining to such small-scale representation tasks. Legge, Gage, et al., [19] involved simulated LVs (both AL and PFL) via goggles as subjects and reached a conclusion that there was no evident difference between the spatial estimation accuracy of visually impaired individuals and sighted in judging room dimensions, except in cases of severely reduced visual acuity. This finding was further validated in her subsequent study, which included real LV subjects [20]. In several simulated LV studies [21–23], a common finding indicated that individuals with PFL required more time to find target objects compared to sighted individuals with increased eye and head movements as a compensate strategy. Notably, this result aligns with the findings of [24], which involved real PFL, reinforcing the consistency between simulated and real-world PFL cases. Post-processing has been applied more often in obstacle avoidance and discrimination studies, and it has been verified to be with high reliability through direct comparison to real LV. In its initial stages, image processing software employed fundamental techniques such as Gaussian blurring, texture overlays, and tonal adjustments to simulate various eye conditions, serving as a simplified tool for training in accessible design [25]. Designing Visually Accessible Spaces (DeVAS) is another newly-developed tool developed to better access AL perspectives and predict potential hazards in the architectural space [26]. From a photometrically accurate rendering, it uses a parametric post-processing method based on post-editing, combining edge recognition technology and a regional blur effect to calculate an alternative image representing what a person with LV would see. A corresponding predictive value, hazard visibility score, is then calculated from the degree of edge-line continuity to predict the hazard index of the scene for the LV group. In a subsequent validation study that included both simulated LV and real LV subjects, it was confirmed that DeVAS has a good reliability, particularly concerning obstacle discrimination. Liu et al. [27] also utilized both simulated LV, this time with goggles (loaded with diffusive films to accurately reduce acuity to 1.2 logMAR and 1.62 logMAR), and real LV participants to verify the hazard visibility score. The experiment demonstrated the reliability of post-processed images in predicting obstacle detection ability in individuals with visual impairments. For a common target, another system, CatARact [28] applied an intricate pipeline effect successively following acuity and contrast reduction, color shift, etc. to simulate cataracts and has been undergoing validation with real cataract patients.

3.2. Large scale spatial task: mobility, wayfinding and navigation.

Montello [29] proposed mobility as another important layer of differentiation between small-scale and large-scale spatial tasks: whether or not a place can be visually understood from a place without the necessity of movement. In contrast to tasks in static and controlled settings, tasks related to walking, wayfinding, and map-sketching are categorized as large-scale spatial abilities. These activities involve switching viewpoints and require the skill to navigate through extensive environments, such as buildings or outdoor landscapes.

Mobility, referring to the ability to move freely in a space, is a comprehensive capability that builds on the ability to avoid obstacles, and underlying support for navigational behavior. On aggregate, 14 out of 36 papers investigate mobility-related issues. Most of the experiments are conducted on-site and incorporated real LVs as subjects. Black et al. [12] and Leat and Lovie-Kitchin [7] verified that PFL can significantly slow walking speed, whereas AL impaired self-locomotion perception. Matsuda et al. [13] and Kuyk, T. [30] derived the similar conclusion with both AL and PFL patients. For an on-site experiment that included simulated AL and simulated PFL participants, Tarampi [31] indicated spatial updating remains accurate during locomotion under conditions of significantly degraded AL and contrast, albeit with heightened variability compared to non-degraded viewing. Peli [32] showed that neither visual impairment had a clear effect on walking speed unless the impairment was extremely severe. Although the researchers in the latest experiment explain that this result may have been influenced by the exclusion of important hazards in their experimental set-up, the disparity between the results prompts caution about the results obtained when using simulated LV in mobility-related studies. Freeman [33] also tested walking ability incorporating simulated LV with blurred foil. Conversely, he found that the severity of AL affected walking speed, attributing it to longer gaze times and increased pauses during walking. This behavioral change aligns with the adaptive tendencies observed in real LVs during hospital wayfinding, as summarized in Rousek and Hallbeck's [34] experiments. In several studies that both include simulated LV and real LV, Bochsler et al. [35,36] have confirmed that AL alone could lead to an adaptation effect in terms of locomotion. Katemake et al. [37] displayed a consistent output with this claim, showing that chronically visually impaired subjects exhibit better obstacle avoidance performance and higher speed of movement. Fortenbaugh, Hicks and Turano [38] could not detected a similar adaptation effect comparing simulated PFL and real PFL subjects. One possible reason for this is that PFL can be partly compensated for by eye movements with greater amplitude compared to AL, suggesting that the impact of visual impairment on adaptation and related perceptual processes may differ depending on the type and level of visual impairment.

The navigation task appears to be a more comprehensive task including a multi-processing of perception, updating and cognition, and requires the integration of object motion, information, and experience. The results exhibit a diverse bias in studies using different simulation methods. Rand's [39] study, which involved simulated LV, revealed that AL led to increased errors in navigation and biases in orientation, with these effects becoming more pronounced as the severity of the impairment increased. In Barhost's two experiments pertaining to spatial navigation, which adopted the same methodology with simulated PFL [4,40] in two different environments, it was observed that, compared to a simple navigation route in which only a severe PFL would have a negative effect in orientation and map-sketching performance, individuals showed more pronounced effects in navigating through an environment with higher complexity or richer information. Barton, Valtchanov and Ellard [41] derived a similar conclusion via a study in VE with simulated PFL. In a recent navigating and map-sketching experiment, Zou and Zhou [42] incorporated real LV (regardless of type of impairment) who walked and depicted various routes through a hospital. The success of the task was largely influenced by the environmental elements in the route and the patients' individual strategies. Given the constraints imposed by the experimental setup and environmental intricacies, confirming if only simulated low visual acuity leads to bias through cross-modal comparisons remains challenging. In a different experiment involving real LV within on-site environments [43], it was demonstrated that subjective learning efficiency biases originating from distinct environmental tasks (e.g. subjects are informed with a map-sketching or distance estimation task before experiment) also impact navigation performance. Involving both populations in the same environment and protocol for direct comparisons is the only way to understand whether simulation is a reliable method. While navigational efficiency and success may not directly reflect simulated reliability, the observed commonality in behavior exhibited by both simulated LV and real LV subjects warrants further discussion.

Overall, the difference in information load and cognitive processes between "small scale" and "large scale" spatial tasks, as identified by Hegarty et al. [15], was aligned with the findings in this review: various forms of simulation demonstrated high reliability when applied in small scale spatial tasks, while larger scale spatial tasks exhibited more controversy and bias in the results. Gaze behavior is central to both types of tasks, and calls for a more specific examination.

3.3. Gazing behavior
Gazing behavior, including eye movement, fixation, saccades and blinks, is a concomitant activity of environmental observation that helps researchers to understand perceptual and cognitive processes non-invasively. On aggregate, eight out of the 36 papers looked at gazing behavior. Matsuda et al. [13] studied the gazing behavior of a real LV group during street navigation, which revealed that participants with PFL exhibited wider angles in eye-fixation targets compared to participants without visual impairment, while the most significant deviation for participants with AL was a significantly shorter distance and longer duration to their preferred eye fixation targets. The part related to PFL is consistent with several studies, which simulated PFL respectively via blind mask [44] and mixed reality technology with an eye tracking system [21]. Freedman et al. [33] examined gaze behavior during navigation in people with AL, comparing both simulated LV and real LV, and consistently found that gaze patterns were essentially the same between the two groups. Aspinall [45] investigated gaze behavior among individuals with AL using a photorealistic environment displayed on a projected screen and revealed a correlation between differences in pupil diameter and fixation counts, and the participants' visual acuity. Almost all of the gazing behavior studies mentioned above make the point that the subjects generally spent more time looking towards the ground and boundary (between the floor and the wall) in either simulated or real LV perspective. Without compromising the accuracy of the results, applying simulated LV provides the opportunity to conduct separate analysis between a single type of impairment (PFL and AL), which otherwise can be a challenging case in the real LV study.

Despite its efficiency in working procedure, however, the two types of simulation protocol share a common drawback of eye-movement tracking, as most of the occlusion of the visual field or loss of precision is not distributed uniformly across the retina, instead commonly displayed as a region of opacity which remains invariant on the retina [46]. Jones et al. [21] offers a novel way of integrating eye tracking and real-time image processing in AR to enable floating blurring for simulated PFL, indicating that mixed reality could be a potential form of LV research. Although the loss of this trait does not affect some of the objective measurement, the impact on other items, like mobility or navigation in space, is still unknown. There is also a lacking of monocular visual acuity consideration. Amblyopia research has consistently demonstrated that some form of suppression occurs when there is asymmetric visual input. Specifically, individuals tend to ignore the visual input from the worse eye, leading to binocular visual performance equal to the monocular performance of the better eye [47]. Barhorst-Cates, Rand and Creem-Regehr [4,40], conducted subsequent experiments that turned to monocular masks to weaken the side effects of binocular stereo fusion. However, there is also the alternative argument, which suggests that the eye with worse condition still has an impact on people's gazing behavior and spatial performance [22]. Generally, simulated LV and real LV exhibited comparable gaze behavior in various spatial tasks, indicating a certain level of reliability in terms of their influence in spatial observing strategy.

4. Conclusion and discussion: VE in future LV research
This paper provides an evaluation of the feasibility and reliability of various existing simulation tools applied to LV research. While simulated LV showed promising results for studies of small-scale spatial capabilities, such as obstacle detection and distance estimation, large-scale spatial capabilities, such as mobility-related studies, proved simulation LV less reliable. In term of small-scale spatial ability research, goggles and post-processing serve as useful tools for AL simulation; VE/VR integrated with AL or PFL simulations demonstrate substitutability, with HMD setups offering superior immersion compared to screen displays. Particularly, simulations with eye-tracking systems have proven to be more effective than static blur filters and offer promising prospects for enhanced spatial ability testing.

The usage of VE offer greater control in experimental environments, which is a key asset in research. The adaptability of simulated LV or real LV to simulated environments can be considered for effective strategies pertaining to exploring how environmental factors impact spatial performance. VR technology has advanced from VE to Immersive VE (IVE), enabling larger FOV and additional data collection through equipment like eye tracking. This facilitates understanding spatial patterns in the LV group.

Mixed reality technology further integrates simulated LV with the environment, allowing precise control of intrinsic (visual condition) and extrinsic (environmental factors) variables in LV research [21]. Correspondingly, the overlay function of digital information in AR can also be well adapted to LV simulation, integrating with the real environment while addressing the lack of eye tracking in normal goggle simulations [28,48].

Throughout the review of 36 studies, 28 included a physical environment in the experimental setting, with eleven studies utilizing VE or IVE, either as the primary or partial methodology. Among them, there are only four studies involving both real and virtual environments (e.g., photo or rendering), which demonstrated acceptable validity of VE or IVE as experimental settings pertaining to various research objects, including obstacle avoidance [49], dimension estimation, gaze behavior [38], and target finding in space [21]. However, spatial knowledge acquisition in a large-scale task, such as navigation, has been found to be different compared to in real-world environments [50]. This finding was aligned with previous research involving sighted participants, which indicate that there exists bias between orientation and navigation in desktop VE and direct experience in physical environment [51]. Two potential reasons may account for this:

- The disparity in scale between VE and reality. Media-displayed environment may distort the perception of architectural elements, particularly in confined screens. This distortion could significantly affect visually impaired individuals with partial visual field loss, though the potential mitigation through iso-scale simulation in HMDs remains unverified.
- Lack of locomotion in VE. Walking in real environments allows individuals to automatically update their position through physical movement, which is normally lacking in VE [15]. Empirical experiments involving sighted participants suggested that VR manipulated with whole-body rotation and joysticks is sufficient for the navigation task [52] but that outcome remained debated [53–55].

Except for the display media, the image style of VE seems to have additional influence. In terms of small-scale task, such as obstacle detection, Carpenter [49] verified that photorealistic VE and rendering VE can theoretically achieve the same efficacy. For complex environments, Kalia, Legge and Giudice [50] proposed that the presentation and sparsity of information in VE are key factors affecting navigation performance of the simulated LV group. This created the need for corresponding requirements in environment simulations, where high-fidelity and low-fidelity simulations can impact the output. Another potential factor influencing the experimental results is the presence of bias related to the participants' video game experience or their familiarity with VR technology. Experienced users demonstrated better navigation performance than inexperienced among the simulated LV group [50]. The adaptation effect to the VR necessitates the inclusion of more reasonable trial designs or larger sample sizes in VR experiments to mitigate this bias.

Finally, none of the studies fully replicated and verified the navigation scenario in VR for people with LV, despite this approach being considered having a certain predictive value in research involving sighted groups [56–58]. It remains to be seen whether the use of HMD for people with LV is a suitable scientific approach, in other words, whether people with LV identify the same obstacles and have a similar perception of their surrounding in both virtual and physical realities. This would be particularly interesting for large-scale capacity studies (such as navigation) as it would enable more flexible and safer experimental protocols, while guaranteeing the inclusion of visually impaired people in experimental protocols. Lastly, the question of the sound environment in addition to visualization in VR/VE would also be particularly relevant, given the great importance of auditory cues for the spatial perception of visually impaired people [59–61].

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