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Impact of white noise on spatial navigation of people without visual cues

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The current study examines how multisensory cues-specifically, passive proprioception combined with white noise-affect navigation ability in the absence of visual input. The main goal was to investigate whether adding white noise, as a non-structured auditory stimulus, could enhance spatial learning and navigation in blindfolded sighted participants. Using a novel motion-tracking technology, SensFloor®, participants completed navigation tasks under two conditions: a unisensory condition (passive proprioceptive cues only) and a multisensory condition (proprioception + white noise). We found that participants' navigational accuracy significantly improved under the multisensory condition. While the white noise source (a speaker) was not intended as a spatial landmark, it may have supported spatial orientation by offering a stable auditory reference, possibly through mechanisms like enhanced balance or rudimentary echolocation. These findings underscore the importance of multisensory integration in spatial cognition and have significant implications for assistive technologies aimed at supporting mobility in individuals without vision.

Keywords White noise, Auditory perception, SensFloor, Path integration, Multisensory integration, Navigation of blind

Path integration is a fundamental navigation process that continuously updates position and orientation using body-based cues such as velocity and acceleration[1]. It allows individuals to track movement from a starting point and return by integrating sensory information. While vision provides detailed spatial and motion-related information[2], non-visual cues are essential, particularly for individuals with visual impairments. The auditory system serves as a key compensatory mechanism, aiding spatial orientation and mobility[3].

People without vision adopt distinct navigation strategies compared to sighted individuals, exhibiting reduced sensitivity to perspective changes and inferential navigation[4]. Their gait patterns also differ, characterized by shorter strides and slower movement[5], underscoring the importance of alternative spatial cues like auditory input. Spatial memory plays a central role in navigation by encoding, storing, and retrieving spatial information[6,7], yet its interaction with different sensory modalities remains an open question[4].

Auditory information provides critical spatial cues in the absence of vision. White noise, though often viewed as a non-specific or unstructured auditory stimulus, can serve as a stable auditory reference point. In the context of stochastic resonance, white noise has been shown to enhance sensory signal detection by amplifying weak signals[8]. In navigation, it may support spatial orientation not by acting as a landmark, but by offering a consistent auditory backdrop that aids balance or facilitates rudimentary echolocation. Prior studies have found that white noise can support homing performance[9], improve spatial task performance[10], and even enhance postural control during movement[11].

Moreover, auditory cues contribute significantly to echolocation, where sound waves interact with surfaces and objects to generate echoes that provide spatial information. Both blind and sighted individuals can process these echoes to perceive distances, shapes, and environmental structures[12–14]. This ability enables individuals to navigate effectively, demonstrating that auditory spatial processing is not solely a compensatory mechanism for vision loss but a fundamental aspect of human perception.

Multisensory cues provide critical information for navigation by combining inputs from different sensory modalities to enhance spatial awareness. Research indicates that individuals utilize these cues effectively to improve accuracy and minimize variability in navigation[15]. Compared to single-cue navigation, multisensory cues

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enhance spatial memory and reduce navigation errors[16]. In immersive environments, multisensory information has been shown to improve spatial memory even in individuals with hippocampal lesions, suggesting a compensatory mechanism that engages extrahippocampal regions[17]. Moreover, multimodal training approaches have demonstrated benefits for individuals recovering from visual impairments, emphasizing the importance of combining movement with sensory feedback for effective navigation[18,19].

Technological innovations intended to monitor and improve human mobility provide additional emphasis to the importance of multisensory integration. Many technologies have been introduced to track people's navigation. The seamless integration of technological solutions, such as pressure-sensitive flooring, into surroundings has made them popular for tracking human movement. One such example is large-area passive sensor systems. Prior research[20,21] has shown that these systems are helpful in tracking individuals based on their movement patterns. Other active technologies are available, but their accuracy is usually low, such as mobile phones and infrared badges[22,23]. In order to evaluate the effects of path complexity and audio-proprioceptive signals on path integration without visual input, we used the SensFloor® technology[24] in our study to exactly track participants' real-time departures from specified pathways. The SensFloor® system's advantages include accurate localization, extensive coverage, and the ability to blend into everyday living environments, making it a valuable tool for our research[25,26].

This study explores the role of white noise and its impact on navigation in individuals without vision. Specifically, we examine how participants interpret their environment using unisensory (proprioception-only) and multisensory (proprioception + white noise) cues. Importantly, the auditory stimulus-a speaker emitting white noise-was not intended to function as a spatial beacon or landmark, but rather as an ambient reference to support orientation, balance, or echolocation. To accurately track their movements, we utilize SensFloor®, a pressure-sensitive flooring system that provides real-time motion data[24]. By analyzing navigation performance across different sensory conditions, we aim to assess whether white noise enhances spatial awareness and improves path integration. Additionally, we evaluate the standard deviation for each sensory condition to measure the precision of participants' spatial estimates, reflecting the consistency or variability of their responses. Based on prior research, we hypothesize that multisensory cues, particularly those incorporating white noise, will enhance navigational accuracy.

Methodology

Participants

The present research study involved twenty-two blindfolded sighted individuals (mean age: 42.42 ± 12.46 years, 10 females). All participants were healthy and had no sensory or motor impairment. All participants were Italian and recruited through the Italian Institute of Technology (IIT) database.

All studies were conducted in accordance with the Helsinki Declaration, and each subject provided written informed consent for the research project. The local health service ethics committee (Comitato Etico, ASL 3, Genoa, Italy) approved the trial. The length of the experiment varied according to the participants' abilities, but it usually lasted around half an hour.

Data acquisition

We collected navigational data in a 5.63m $\times$ 6.37m room using SensFloor®, a capacitive sensor system by Future-Shape GmbH[27] (see Fig. 1A). SensFloor® consists of interconnected modules embedded beneath the flooring, each containing a microcontroller linked to eight triangular sensor fields, achieving a spatial resolution of 32 sensor fields per square meter. The system detects human presence by measuring capacitance changes when a foot contacts a sensor field.

Each module features a three-layer structure: an electrically conductive polyester fleece on top, a 3mm conductive middle layer, and aluminum foil at the base. The triangular sensor grid enhances spatial resolution compared to rectangular layouts. Modules are electrically connected via textile stripes, ensuring seamless

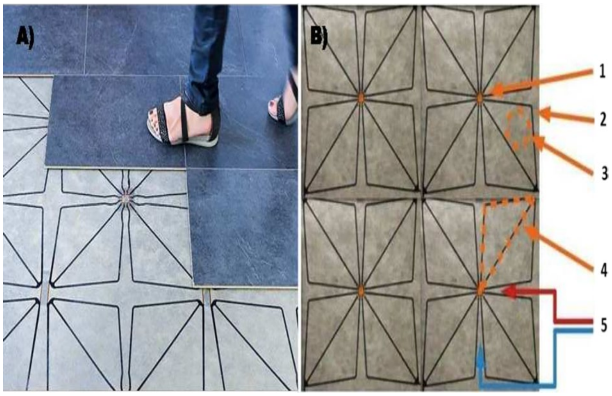

Fig. 1. (**A**) Illustrates the standard SensFloor® system[28], while (**B**) presents its circuitry layout[24]. The numbered components in (**B**) correspond to: (1) electronic module, (2) black base material (polyester fleece), (3) coated conductive polyester fleece, (4) triangle-shaped sensor field, and (5) power supply.

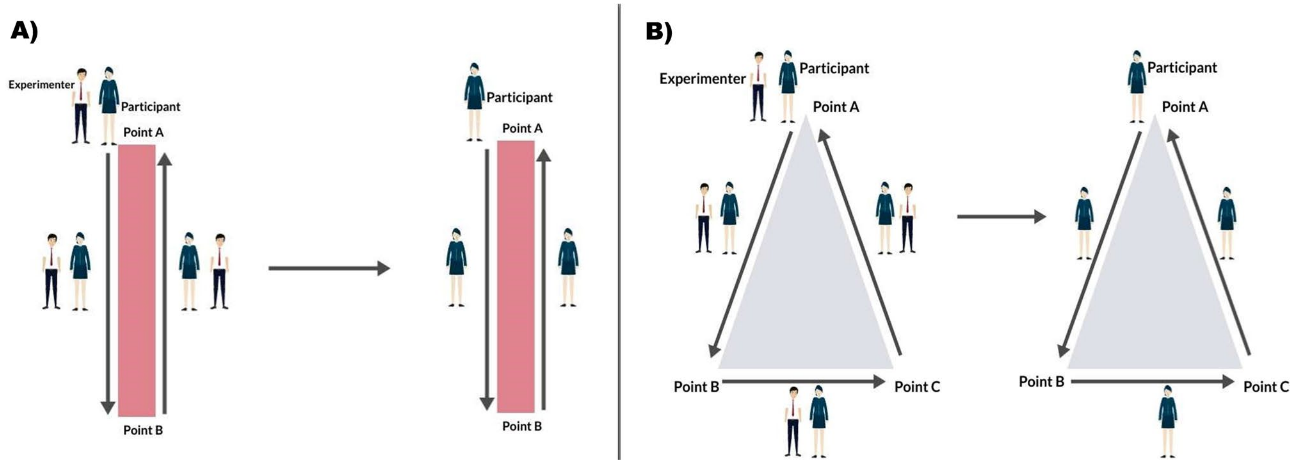

Fig. 2. Graphical representation of the passive proprioceptive condition for the straight path (**A**) and triangular path (**B**). The illustrations depict both phases: first, where the participant was guided by the experimenter, and second, where the participant independently recreated the path without any external cues. The infographics were made using https://www.visme.co/.

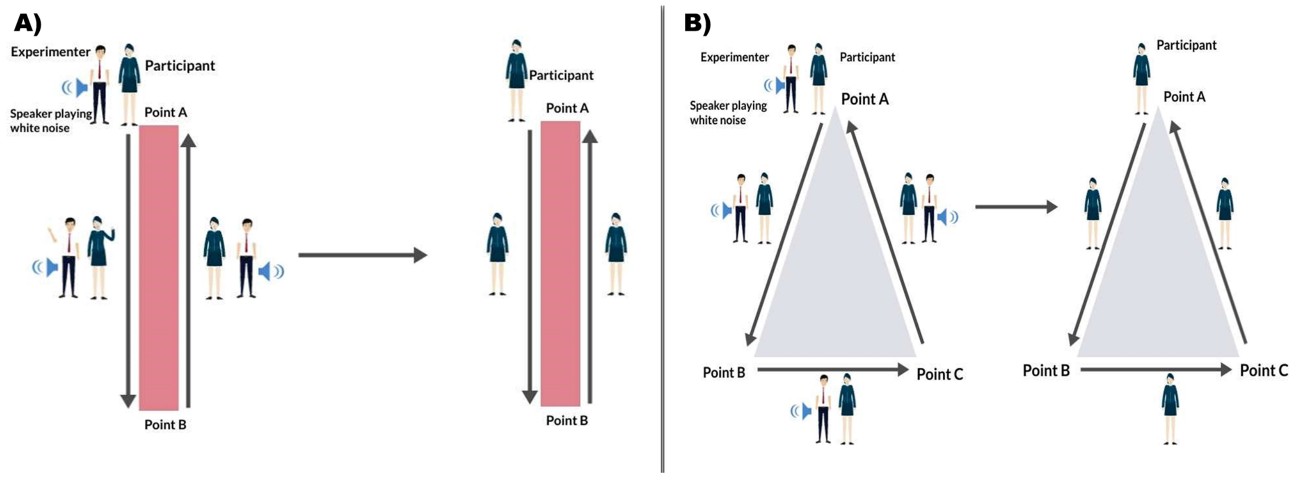

Fig. 3. Graphical representation of the multisensory condition for the straight path (**A**) and triangular path (**B**). The illustrations depict both phases: first, where the participant was guided by the experimenter holding the speaker, and second, where the participant independently recreated the path without any external cues (no guidance or auditory cue was present. The infographics were made using https://www.visme.co/.

integration across the floor (see Fig. 1B). The system operates on a 12V power supply and transmits data event-based at 10 Hz, minimizing redundant data processing by generating messages only when significant capacitance changes occur. The data rate depends on the number of individuals present and their movement patterns rather than the total sensor area.

Experimental setup

Each participant was blindfolded and instructed to follow two paths: the straight path (as a simple task), and the triangular path (as a complex task). Each path could be walked in two distinct conditions: (1) multisensory condition and (1) passive proprioceptive condition. Two points, A and B, were marked on the floor to indicate a straight line. The length of the straight path was 3.51 m, as shown in Fig. 2A and 3A. Three points-A, B, and C-were marked on the floor for the triangular path. The length of the triangular path leg of Point A to Point B, Point B to Point C, and Point C to Point A were 3.87 m, 3.78 m, and 3.13 m, respectively, and the area was 5.46 m^2, as shown in Fig. 2B and 3B.

Each participant completed 12 trials in total (six trials for straight paths (three with Passive proprioceptive, and three with multisensory condition) and six trials for triangular paths (three with Passive proprioceptive and three with multisensory condition). Before performing three trials in any condition, the participant was guided by the experimenter along the whole path to familiarize with it, and then the participant performed three trials on their own. Before starting a new trial, the participant was brought back to the initial point, i.e., point A, by the experimenter. Trials within each condition were conducted consecutively, but the order of paths and conditions was randomized for each participant. For example, if Subject 1 started the experiment by doing three trials of passive proprioceptive condition on a straight path, then Subject 2 started an experiment with three trials of multisensory condition in the triangular path or straight path.

Passive proprioceptive condition

In the passive proprioceptive condition of the straight path, the experimenter held the subject's right elbow while guiding them gently down the straight line from point A to point B and back to point A (Fig. 2). Then, the participant was asked to follow the same path independently by using their memory and mental representation of the path. As soon as the participant started moving from point A, we began to collect data from the SensFloor®, and when the participant turned around and stopped, we stopped recording the data. Figure 2A shows a graphic representation of the passive proprioceptive condition in the straight path.

Regarding the triangular path, the experimenter gently held the participant's right arm at the elbow while guiding them along all three legs of the triangle, from point A to point B, from point B to point C, and finally from point C to point A. After the guidance of the experimenter, the participant was asked to recreate the path on his own, without any sensory cue, beginning at point A and ending at point A. We started collecting data from SensFloor® as soon as the participant moved away from point A. When the participant returned and stopped, reckoning to have reached the initial point again, we stopped recording the data from the SensFloor®. Figure 2B shows the graphic representation of passive proprioceptive condition along a triangular path.

Multisensory condition

During straight path trials of multisensory condition, the researcher held a speaker playing white noise. The intensity of the white noise was 78 dB, and the speaker was about 0.76 m away from the participant's ear. The experimenter guided the participant by supporting their right arm gently at the elbow from point A to point B and back to point A. The participant was then told to travel alone from point A to point B and back without any external cue (no guidance or auditory cue was provided). We stopped collecting data from SensFloor® when the person stopped walking. Figure 3A shows a graphic illustration of multisensory condition along a straight path.

During the triangular path, the experimenter, who was holding the speaker, gently grabs the blindfolded subject's right arm from the elbow and guides him along the three legs of the triangle, from point A to point B, point B to point C, and point C to point A. On the speaker, white noise was continuously playing. The individual was then told to follow the path on his own, beginning at point A and finishing at point A without any external cue (no guidance or auditory cue provided). As soon as the participant left point A and started moving, SensFloor® started collecting data. When they reached back and stopped at any point, SensFloor® stopped collecting data. The graphical representation of multisensory condition in a triangular path can be seen in Fig. 3B.

Data analysis

Our methodology in the current study aimed to measure two variables: (1) mean absolute error (Euclidean distance between the vertices of the reference path and the vertices of the path followed by the subject), (2) point-wise error (mean of absolute Euclidean distance between each point of reference from each point of participants' path). Based on these two measurements, we performed two different kinds of analysis: (1) binomial test to see whether the null hypothesis stands for 50–50 occurrence of true shapes (shapes which were closely related to reference triangular path) and false shapes (shapes which were open or not related to the reference triangular path) in each condition, and (2) correlation between mean absolute error and point-wise error.

During data collection, there were some artifacts from the SensFloor®, even when there was no one walking on it. These artifacts can be seen in Fig. 4. We named such artifacts as phantom errors. Phantom errors were present throughout the data collection. We carried out pre-processing to eliminate phantom errors using MATLAB 2022a. An example of raw and preprocessed representation of trial data of straight and triangular paths can be seen in Fig. 5A, B, respectively.

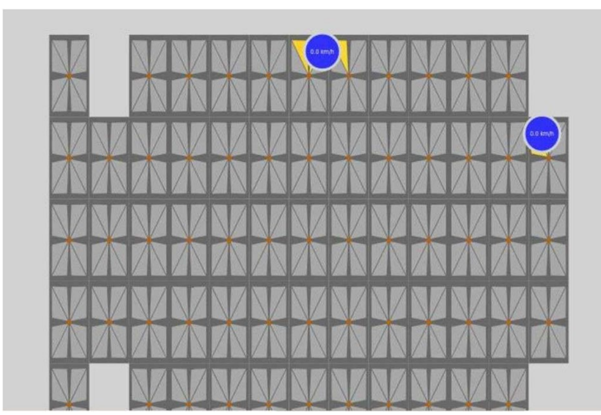

Fig. 4. The picture depicts the Application programming interface (API) of SensFloor®, where we can see the presence of two objects (in blue), even though there was no one standing/walking on it.

Following the preprocessing phase, we were able to get the interested measurements for each subject in each path (straight and triangular) and conditions (passive proprioceptive and multisensory condition). We calculated the mean absolute error (Euclidean distance from reference points) to see how accurately participants reached the desired location. We also calculated the point-wise error (average of absolute Euclidean distance at each point of the participants' path from the corresponding point of the reference path) to see the variability. For the binomial test, we did a qualitative visual analysis of data from each subject's trial in a triangular path of each condition. This analysis was performed by a human rater who assessed whether the shape created by the participant closely resembled the reference triangular path. If a participant made a shape closely related to the reference triangular path, we considered it a true shape, and we gave number 1 as a representation in data. If the participant created an open or very different shape, we considered it as a false shape and gave the number 0 for its representation in data. As each participant performed three trials, if one made two or three true shapes in three trials then we considered that participant's responses as true (i.e., 1). Similarly, if a participant made two or three false shapes in three trials, then we considered the participant's responses as false (i.e., 0). Then, we performed a binomial test on true vs false shape results. The graphical representation of true and false shapes can be seen in Fig. 6A, B, respectively. The binomial test aimed to see a significant difference in participants' creation of paths between conditions. Moreover, we correlated the Euclidian distance at each point of the path and the Euclidean distance at the vertices to see the effect of variability in reaching the goal.

We used the statistical programming language R in RStudio 2023.03.0 to perform all the statistical analyses. Using the perm.t.test function from the RVAideMemoire package[29], we used permutation t-tests on mean

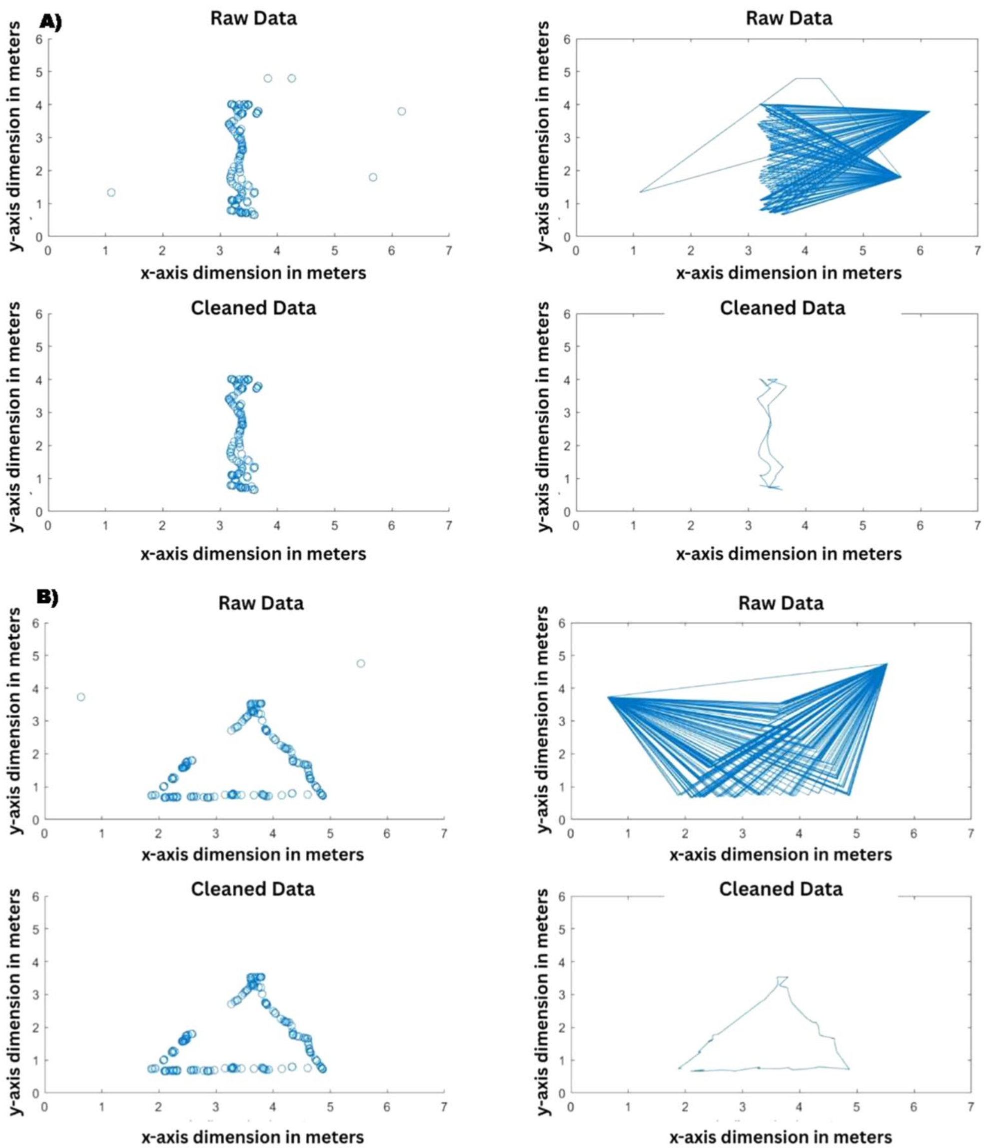

Fig. 5. Graphical representation of data in a straight (**A**) and triangular (**B**) path from SensFloor® before and after pre-processing. The pictures on the left-hand side show the scatter plot of the data. The right-hand side pictures show the consecutiveness of data points with the help of a line plot.

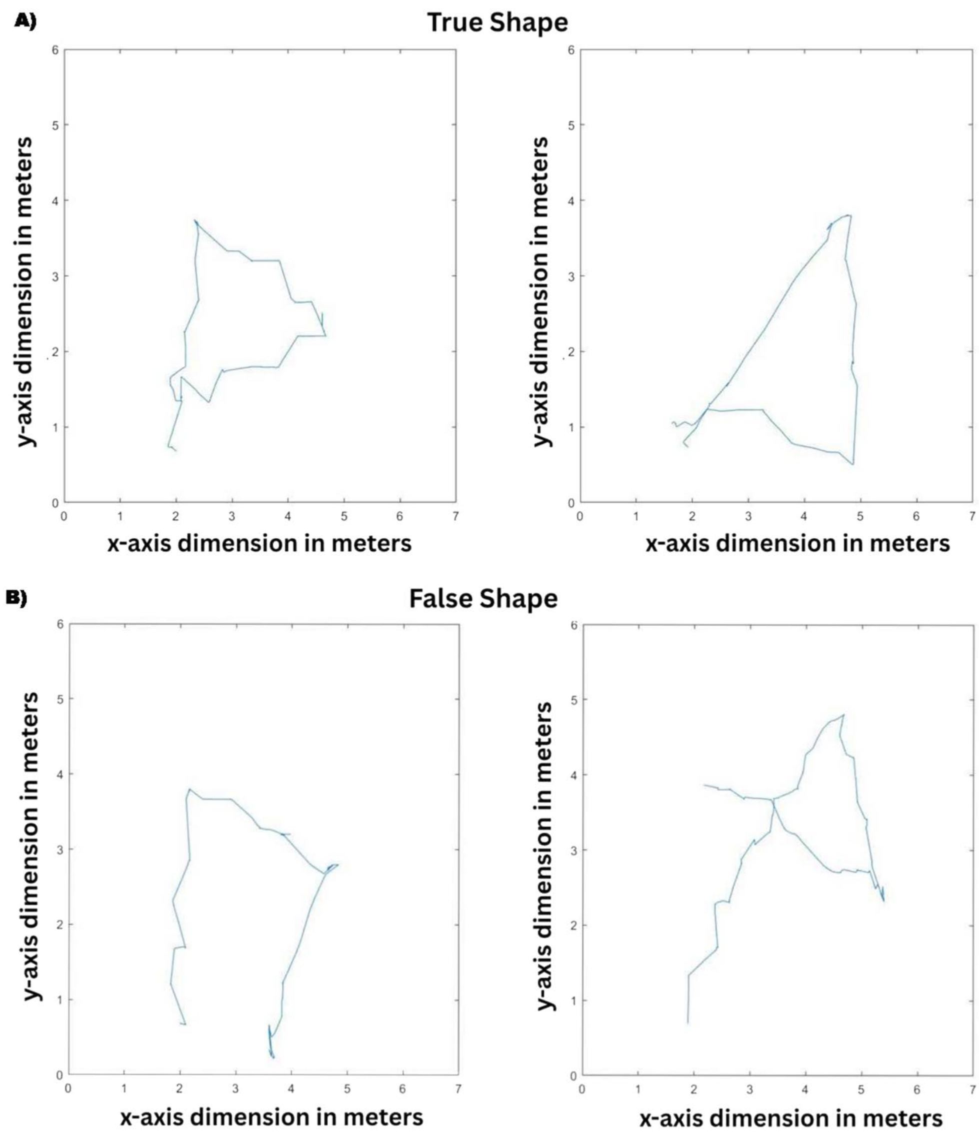

Fig. 6. (**A**) The graphical representation of participants' path we considered true shape. The plot depicts a person creating a three-vertice shape, either tilted or not. We considered it as true shape. (**B**) The graphical representation of the participants' path we considered false shape. The plot represents that a person was creating an open shape or a shape that was very different from the triangular one. We considered it as false shape.

absolute error and mean point-wise error in each sensory condition of each path. We carried out pairwise comparisons with N=10000 permutations to investigate the significant effects of sensory conditions.

Results

In this study, we evaluated the navigational skills of sighted people wearing blindfolds using two types of sensory cues: multisensory and passive proprioceptive cues. Notably, blindfolded participants showed higher absolute error in the passive proprioceptive condition compared to the multisensory condition for both straight (t = 2.3702, p-value = 0.02575 and $|r|$ = 0.429) and triangular path (t = 3.8206, p-value = 0.00025 and $|r|$ = 0.246). We also applied a permutation t-test on the standard deviation for each sensory condition to assess the precision of participants' spatial estimates, which refers to the consistency or variability of their responses, but we found a significant difference neither in the straight path (t = -0.67825, p-value = 0.5234 and $|r|$ = 0.070) nor in the triangular path (t = 1.4643, p-value = 0.1557 and $|r|$ = 0.450). The graphical representation of mean absolute error in straight and triangular paths can be seen in Fig. 7A, B, respectively.

We also performed a point-wise error analysis: the Euclidean distance between each position on the reference path and each position in the participants' trajectory. Results from this analysis were in line with the mean absolute error assessment, suggesting that blindfolded sighted participants performed better in the multisensory condition. In particular, the multisensory condition had a lower point-wise error than the passive proprioceptive

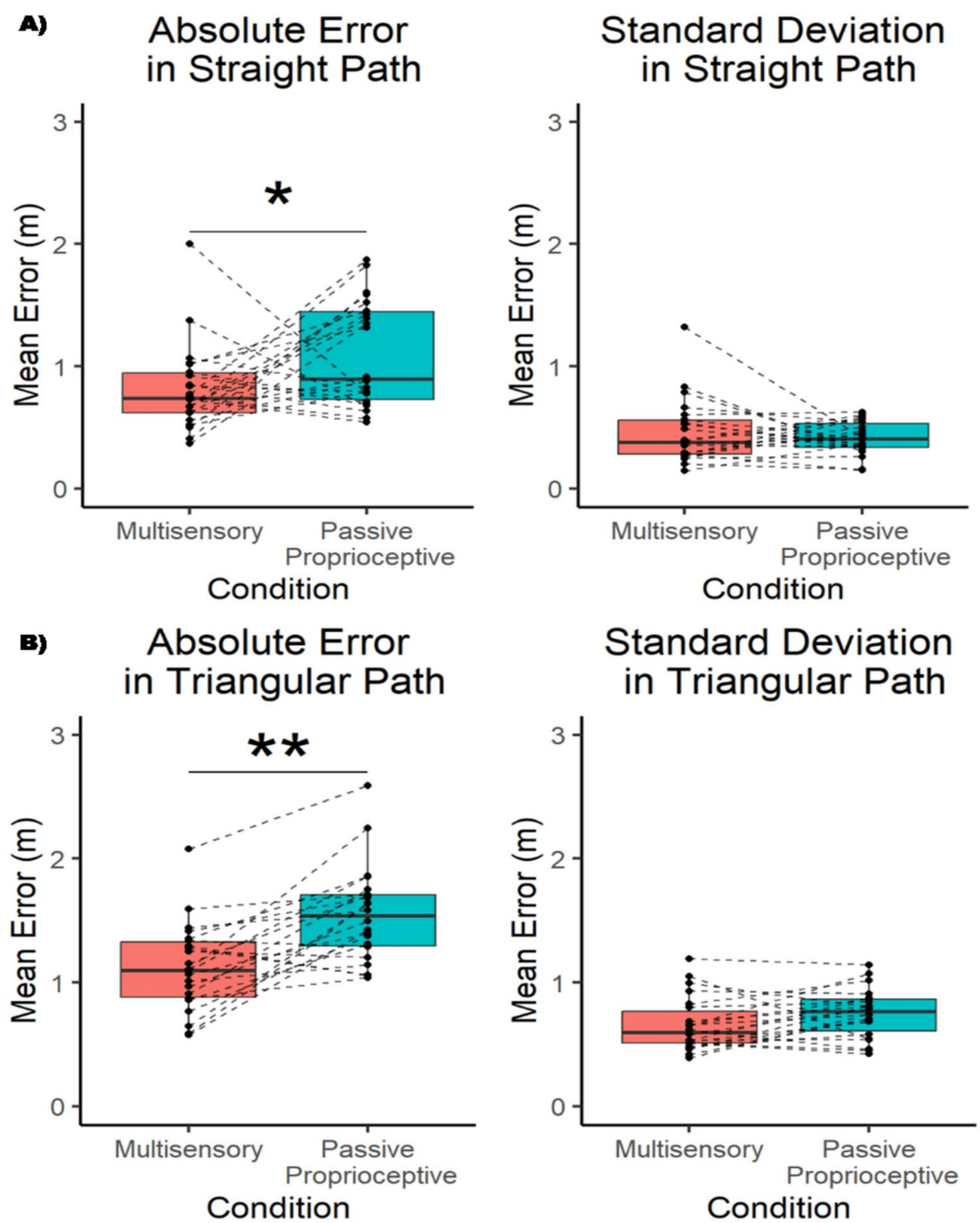

Fig. 7. In Figures **A** and **B**, the left plots show the graphical representation of mean absolute error, and the right plot shows the standard deviation in each sensory condition in a straight path (**A**) and triangular path (**B**). "*" is representing p < 0.05.

condition. These results were further supported by the permutation t-test, which showed a significant difference in the straight path (t-value = 3.3049, p-value = 0.00125, and $|r| = 0.456$) and the triangular path (t-value = 3.0962, p-value = 0.00225, and $|r| = 0.428$). Similar to absolute error, we did a permutation t-test between standard deviations of each sensory condition in each path. In the case of the straight path, we did not find any significant difference (t = 1.635, p-value = 0.1162, and $|r| = 0.377$, while in the case of the triangular path, the standard deviation of each sensory condition was significantly different from each other (t = 2.6486, p-value = 0.012, and $|r| = 0.637$). These findings support the effectiveness of multisensory input in improving blindfold-sighted people's navigational skills. The graphical representation of pointwise error in straight and triangular paths can be seen in Fig. 8A, B, respectively.

A correlation analysis was performed in passive proprioceptive and multisensory conditions to investigate the link between point-wise and mean absolute error. The correlation results for the straight path in the passive proprioceptive condition showed to be significant (t = 5.9436, df = 20, p-value < 0.01), with a correlation coefficient of 0.799, supporting a positive relationship between the two kinds of error. Likewise, with a correlation coefficient of 0.816, the triangular path's correlation result was also significant (t = 6.3214, df = 20, p-value < 0.01). The correlation plots for the straight and triangle paths under passive proprioceptive circumstances are shown in Fig. 9A, C, respectively.

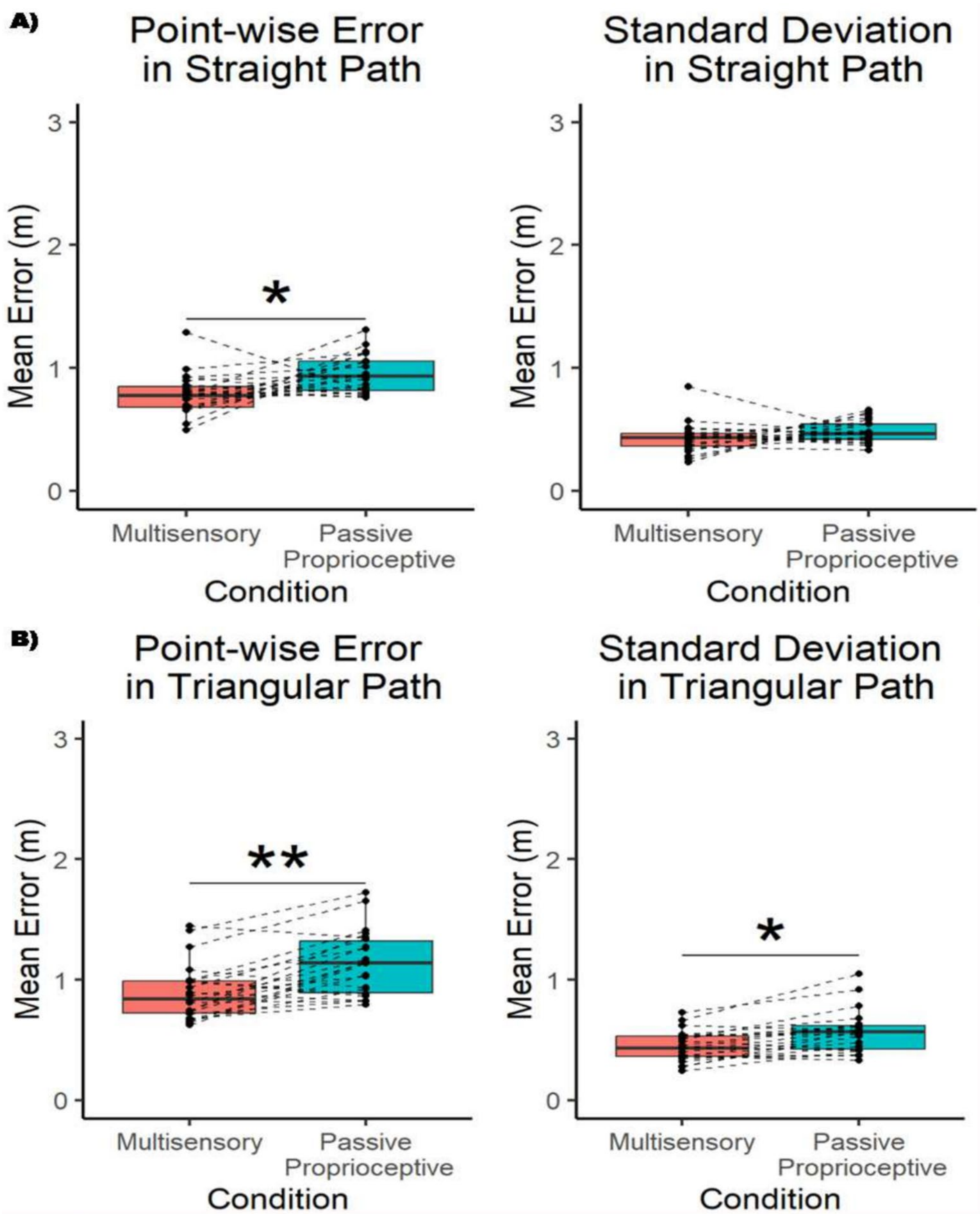

Fig. 8. In Figures **A** and **B**, the left plot shows a graphical representation of point-wise error, and the right plot shows the standard deviation in each sensory condition in straight path (**A**) and triangular path (**B**). "**" and "*" are representing $p < 0.01$ and $p < 0.05$, respectively.

Point-wise error and absolute error for both the straight and triangular pathways under the multisensory condition positively and significantly correlate with each other (with a correlation coefficient of 0.613, $t = 3.478$, $df = 20$, p-value = 0.002373). Likewise, a noteworthy correlation was discovered for the triangular path ($t = 6.4058$, $df = 20$, p-value = 3.003e-06) with a higher correlation coefficient of 0.819. These results imply a connection between the accuracy of reaching the path arrival point and the variability in path traversal. Figure 9B, D, respectively, show the correlation graphs for multisensory situations in the straight and triangular pathways. More variability during navigation leads to a larger error in reaching the end destination, as these graphs show a strong association between point-wise error and absolute error in the triangle path. The correlation in the straight path, on the other hand, shows a more moderate association. This analysis is used as a control measure to evaluate performance in both the general navigation to the destination and the particular walking performance along the path. It sheds light on the relationship between path variability and accuracy in reaching the target destination and offers insightful information about how these error indicators interact in various navigational circumstances.

Finally, we performed a binomial test between true path shape and false path shape to see which sensory condition participants performed better in path interpretation. We considered the data as binary, where 1 represented true shape, and 0 represented false shape. If the sensory condition had no effect on shape-making,

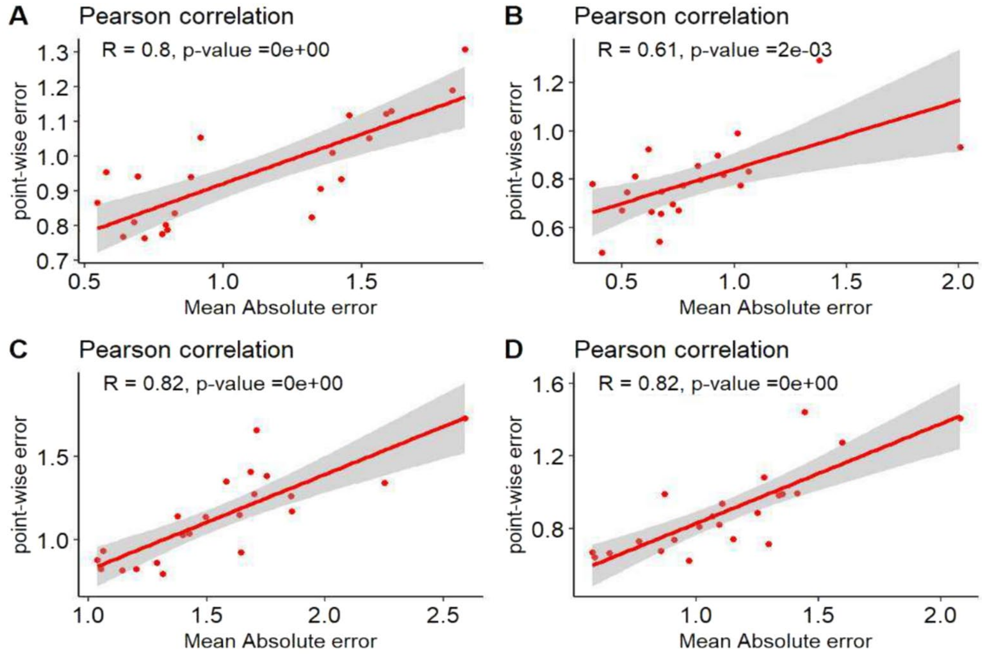

Fig. 9. Correlation between mean absolute error (x-axis) and point-wise error (y-axis) in passive proprioceptive condition in the straight path (**A**), multisensory condition in the straight path (**B**), passive proprioceptive condition in the triangular path (**C**) and multisensory condition in the triangular path (**D**).

then we could expect an equal amount of true shapes and an equal amount of false shapes (50–50%) in each condition. The results depicted that most people made more likely false shapes in the passive proprioceptive condition, while in the multisensory condition, the majority of people made shapes that were closely related to the triangular path, i.e., true shape. The binomial test showed a significant p-value in the passive proprioceptive condition (p-value = 0.0043 and $|r|$ = 0.63), with the true shapes being 18.18% and false shapes being 81.81%. In contrast, in the multisensory condition, the binomial test did not show any significant results (p-value = 0.2863 and $|r|$ = 0. 27), with the true shapes being 63.63% and the false shapes being 36.36%.

Discussion

In this study, we aimed to investigate the effect of multisensory cues on non-visual spatial navigation in healthy individuals. Specifically, our study explored the role of white noise in aiding blindfolded sighted individuals in navigation. Our findings indicate that participants exhibited reduced navigational errors in the audio-proprioceptive (multisensory) condition compared to the passive proprioceptive condition.

Several factors may explain this improvement. First, research has demonstrated that auditory stimuli, particularly when paired with other modalities, enhance spatial task performance[30]. Additionally, compared to silence, auditory stimulation has been shown to improve sensory input processing, thereby enhancing memory function[31]. In our study, white noise in the learning phase likely played a dual role-enhancing the effectiveness of proprioceptive cues while also improving spatial memory, leading to better navigation performance. White noise, in particular, has been shown to play a critical role in cognitive function and memory enhancement[32,33]. According to Bottiroli[10], the effects of white noise on arousal, mood, and enjoyment can significantly impact memory function during cognitive tasks. Furthermore, Daud[31] demonstrated that performing memory tasks in the presence of white noise increases beta activity in the EEG, which is associated with heightened attention and alertness. In our study, the integration of white noise as an auditory cue likely helped participants maintain focus during navigation, facilitating better spatial awareness and reducing errors in route memorization.

Furthermore, multimodal navigation systems have been shown to enhance efficiency, flexibility, and accessibility compared to unimodal systems[34–36]. Sears and Jacko[37] further supported this by suggesting that integrating multiple sensory modalities can improve user comfort. In our study, participants who relied solely on unisensory (passive proprioceptive) cues tended to deviate from the original path when asked to recreate it without sensory input. However, their learning and memory performance significantly improved when exposed to passive audio-proprioceptive (multisensory) input under the supervision of an experimenter using a white noise-emitting speaker. In the multisensory condition, continuous white noise during the familiarization phase likely facilitated spatial understanding through echoes, as echoic information has been shown to provide blindfolded sighted participants with spatial layout awareness[38]. Our findings align with Bakir[39], who demonstrated that multimodal cues in the built environment enhance perceptual tasks for individuals without vision. Similarly, Lahav[40] found that participants in a multisensory environment significantly improved their exploration techniques, methodologies, and processes, further reinforcing the benefits of multisensory cues in spatial navigation.

In our prior work[41], we found that blind participants did not perform well in the condition where audio cues were provided. Numerous causes can account for this disparity relative to the results reported here. The auditory cues in that previous investigation were positioned at the path's vertices. Setti[42] states that blind people may not be able to perceive the whole spatial layout; therefore, they will walk each section of the path independently. As a result, creating an all-encompassing global spatial representation becomes difficult, leading them to divide their path into segments and try to learn each one separately. When they attempted to reconstruct the path from memory, the segmented strategy probably made more mistakes. On the other hand, we used a different methodology in this study, which is similar to Gori's[43], in which the sound source moved with the participant. There was less need to divide the course into sections because participants could keep a consistent understanding of the whole thing thanks to the constant audio feedback. Participants were, hence, less likely to encounter cognitive overload, which decreased the likelihood of mistakes. Furthermore, although in the previous study, participants were guided along only two legs of a triangle and instructed to complete the third leg independently, in this study, they were guided along the entire path before trying to recreate it. This discrepancy shows that full-path guiding and previous training might be essential for enhancing performance. We can, therefore, draw the conclusion that a more fragmented path results in a higher cognitive burden, which raises the risk of errors. Sufficient training and ongoing supervision seem to be necessary to improve blind participants' navigational accuracy.

The results of our study, showing significant improvements in accuracy but not in precision between unisensory and multisensory conditions, align with findings from previous research on cue integration and spatial navigation. Regenbogen[44] demonstrated that multisensory integration enhances accuracy by combining information from multiple sensory modalities, leading to more reliable spatial representations. In our study, the presence of white noise as an auditory cue may have helped participants refine their spatial estimates, reducing systematic errors without necessarily decreasing response variability. This aligns with research[45] suggesting that landmarks serve to correct navigation errors by anchoring spatial representations, thereby improving accuracy without directly affecting the precision of movement execution. Additionally, multisensory inputs are initially processed separately before being integrated at higher-order brain regions responsible for spatial perception and motor planning[44]. Thus, our findings suggest that white noise, when paired with proprioceptive input, improves spatial navigation by reinforcing spatial cues rather than directly affecting the precision of sensory encoding.

A correlation analysis was conducted under passive proprioceptive and multisensory conditions to examine the relationship between point-wise and mean absolute error, aiming to determine whether error accumulation affected target location accuracy. The results showed that increased error along the path corresponded to greater error in reaching the target, highlighting the impact of error accumulation on navigation performance. This analysis underscores how small deviations in path-following accumulate over time, leading to larger errors in target localization and revealing the critical role of error accumulation in spatial memory and path integration. Our findings are consistent with an increasing number of studies highlighting the critical function of multisensory integration in spatial cognition[46]. When information from many sensory modalities is integrated, people can navigate and understand their surroundings more skillfully, especially in situations with few or no visual cues. Various studies have employed different tracking systems to monitor and analyze navigation. For instance, Gori[43] utilized a VICON tracking system to track movement and interpret the effects of multisensory systems.

We used SensFloor® to track participants' movement, allowing us to extract spatial parameters such as absolute error at vertices and errors at each path point. Although SensFloor® has applications in gait analysis and behavior studies[47,48], we primarily utilized it to assess path accuracy in our study.

While our study provides valuable insights into the role of sensory modalities in path integration, it is not without limitations. Notably, we did not include participants with visual impairments or blindness, limiting our findings' generalizability to this population because blind people may have different mechanisms to perceive and interpret the environment and recreating the path using multisensory cues. Furthermore, we did not compare our results to those obtained using other sensory modalities, such as haptic or vibrotactile feedback, which would have provided a more comprehensive understanding of the relative contributions of different sensory modalities to path integration. Future studies that include participants with visual impairments or blindness would be necessary to validate our findings and ensure that they are applicable to a broader range of individuals. Additionally, comparing our results to those obtained using haptic or vibrotactile feedback would provide valuable insights into the specific effects of each sensory modality on path integration.

Conclusion

Our study aimed to understand the effect of an additional white noise on path integration ability. Our designed methodology and results proved that white noise helps the participants memorize and recall the path accurately. Moreover, our findings highlight the significance of the multisensory condition since its enhanced performance among blindfolded participants, particularly while navigating the triangle path. Our research clarifies the benefits of multisensory integration, especially for navigation and spatial learning. Notably, the representation of spatial information was significantly better in the multisensory condition, which included auditory white noise input and proprioception. These results provide important new information about how multisensory approaches might be used to help people with vision impairments navigate more successfully.

Data availability

Data will be available upon reasonable request to the author, Shehzaib Shafique.

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Author contributions
S.S. and W.S. developed the study design, S.S., W.S., and M.G. recruited the participants for the experiment, S.S. collected the data, S.S. analyzed the data, S.S. wrote the manuscript, S.Z., C.C., C.B., G.L.B, M.G., and A.D.B reviewed the manuscript and M.G. and A.D.B. approved the final version of the manuscript.

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Declarations

Competing interests
The authors declare no competing interests.

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