Impact of environmental color and instruction on wayfinding in humans

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Research Article

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Abstract

Researchers believe that wayfinding and landmark identification can be enhanced using route instruction and a bird's eye view. It remains an open question whether a bird's eye view or a route instruction would reduce cognitive load in spatial landmark identification. In addition, the effect of environmental colour on human landmark identification during navigation is unclear. The study was conducted with a Virtual environmental (VE) paradigm, and Sixty-six college students (46 males and 20 females) between the ages of 18–35 years volunteered as participants. Participants were randomly assigned to four groups (Instruction- Bird's eye, Instruction- No Bird's eye, No Instruction- Bird's eye, and No Instruction - No Bird's eye). The results of the independent between-group ANOVA yielded a statistically significant effect, $F (3, 56) = 3.75$, $p = 0.01$, $\eta 2 = 0.16$ on coloured environmental conditions. Compared to the B/W condition, coloured environments support landmark identification only in the initial stages of wayfinding. Moreover, the visual trajectory analysis indicates that the number of deviations in the shortest route is less in B/W conditions than in coloured conditions. The study results demonstrated the importance of route instruction on landmark identification under coloured and B/W environments. The results also indicate that the wayfinding time can be reduced by providing clear route instructions in a declarative format.

Introduction

Every day, human beings gather and share information about roadways and landmarks. They collect information about an environment in sequential order, and over time, they condense it to form a mental map or a spatial representation of a place. The travellers use such spatial representation of a place or for their day to day travel (Carroll, 2017; R. P. Darken et al., 1998; R. Darken & Peterson, 2001; Lynch, 1960; O'Keefe et al., 1978; Peters et al., 2010; Roberts et al., 2005; Struiksma & Postma, 2017; E. C. Tolman et al., 1946; Edward C. Tolman, 1948; Wolbers et al., 2004). The spatial representation develops in three different stages: firstly, travellers learn the landmarks around them; secondly, they use them for daily route planning; and finally; as a result, they develop configurational knowledge of their surroundings (Golledge et al., 1985; Montello, 2001; Siegel & White, 1975). Therefore, knowledge of the surroundings or landmarks is the basic building block of the spatial representation models. A landmark could be a natural or artificial object with particular salient features that make them unique and stand out from a group (Caduff & Timpf, 2008). The physical features such as the colour and the size of a landmark could easily catch the attention and help better wayfinding (Wolfe & Horowitz, 2004). This study examines environmental colour's effect on landmark identification. Previous researchers have also extensively studied the visual salience of colour on landmarks (Aziz & Mertsching, 2007; Hidayetoglu et al., 2012; Jansen-Osmann & Wiedenbauer, 2004; Nothegger et al., 2004). Colour is a salient feature that could increase object identification accuracy, supports the encoding process, and reduces reaction time (Aziz & Mertsching, 2007; Carter, 1982). Meerwein, and collobrators (2007, p. p.64) proposed four factors to be consider while use colour in an architectural space or any place with a high level of human involvement. Meerwein and collaborators (2007, p. p.64) highlight the psychological link between people and place, or "Quality of impression." The effects of our environment on our minds are strong and last a long time. The existence of notable and structurally significant landmarks keeps a place in people's minds for a long (Keil et al., 2020). For instance, we easily remember Big Ben in London and the Red Fort in India because of their structural significance and visual salience. Secondly, a user's cognitive appraisal of a particular space makes it active. The quality of a location and users' perceptions of its quality, attract more people and make it more social (Olwig, 1989). Then "conciseness," which is the 3rd component that reflects the clarity or "legibility of a place" (Lynch, 1960). Further, conciseness makes a place more functional. For example, the ambient colour will help to improve object detection accuracy, enhance the encoding process and minimize response time (Aziz & Mertsching, 2007; Carter, 1982). The effective use of visual features in a search area might thereby lower the subject's cognitive strain. Finally, "appropriation" refers to the process of connecting people with a place. For instance, an individual may connect to a place if it meets his or her own needs to identify with it and feel comfortable. An appropriation is a socio-communicative act as well as a personal one. In summary, using colour in a location improves readability, attractiveness, attachment, activity, and sociability; also, when colour is included in the environment, wayfinding cues become more clearly delineated (2007, p. p.64). However, the results of a previous study demonstrated that colour does not affect wayfinding strategies such as choice of angle, and the frequency of choosing a sequence of turns (Jansen-Osmann & Wiedenbauer, 2004), even if it could ease the process of object identification and wayfinding. Hence it is still unclear, how do people do landmark identification during wayfinding in a black and white (B/W) environment? And how do the explicit features (build forms and natural elements) of the environment support wayfinding if the environment is B/W?

Turning now to the use of instructions and bird's eye view in wayfinding. Few studies compared human wayfinding using instructions and bird's eye view in coloured and B/W environments. Bird's eye view, i.e., the presence of a map, positively impacts wayfinding (Wu et al., 2009). In previous studies, researchers tried to determine the information that supports orientation during wayfinding using the mapping technique and verbal instruction. For instance, Schwering and collaborators (2013) investigated the role of verbal instruction and sketch maps on participants' spatial orientation. Drawing maps convey global orientation better than verbal instructions (Schwering et al., 2013). However, most studies mainly used a map (bird's eye view) and route instructions for examining route learning and the route planning paradigms.

Also, studies reported that route instruction assists the planning activities (Denis, 1997; Levelt, 1982). Denis (1997) explained three specific features related to route instructions. It is more convenient to use and store the spatial instructions in a language-like or declarative format. The second most important function is route instructions, which indicate the user's action in space. The final concept by Denis is the structure of route instruction as the third essential feature. The instructions should be explained in a linear and sequential order. In this study, we used the written instructions with the environmental plan, which could aid the planning activities and support the formation of a mental map. The present study examines the effect of colour on landmark identification, mainly in the presence and absence of instructions and bird's-eye view during landmark identification during wayfinding. The study assesses landmark identification time as a measure of the wayfinding of the participants. If it takes someone longer to identify a landmark, it means they have difficulties with wayfinding tasks. The study analyses this factor in both coloured and B/W settings.

Methods

Sixty-six volunteered college students (46 males and 20 females) were distributed into four different groups. Before conducting the study, each participant was screened for colour vision (Ishihara, 1972). The visual acuity was ensured using the Snellen chart test (Snellen, 1873). All the participants were further assessed on their sense of direction questionnaire (Hegarty, 2002) and handedness (Oldfield, 1971). The exclusion criteria were poor colour vision, left-handed individuals, individuals with psychological abnormalities, neuropsychiatric, neurological, and a history of epilepsy. A total of six participants were excluded, three with poor colour vision and one with short vision, and data of two participants who failed to respond in 50% of the trials were also excluded from the analyses. This study included healthy-right-handed participants with lower anxiety scores (Spielberger et al., 1971) and an average sense of direction (Hegarty, 2002). The final sample (N = 60) consisted of 19 females (M = 25.89, SD = 2.99) and 41 males (M = 24.46, SD = 3.64). We then assessed the distance travelled between each target and the behavioural pattern of our participants' route choices. According to previous research, the target-to-target analysis reveals the shortest route travelled by individuals (West & Leskovec, 2012) and the efficacy of landmark-based piloting. This indicator can also offer an accurate depiction of the cognitive load of the activity. If participants take a long time, they expend more cognitive load between targets. The four different conditions in the study were: 1)Instruction-Bird's eye (InstBV condition), where participants will get the aid of both instruction and bird's eye view for wayfinding; 2)Instruction-No Bird's eye (InstNBV condition) participants will get only instruction but no bird's eye view aid for wayfinding; 3) No Instruction-Bird's eye – (NInstBV condition) participants will not get the instruction but they have to rely on bird's eye view for wayfinding; 4) No Instruction-No Bird's eye (NInstNBV condition) there is no instruction or bird's eye view in this condition. Participants were randomly assigned to one of the four conditions so that there were 15 participants in each condition. Participants were given informed consent stating that participation was voluntary and they could refuse to participate at any stage of the experiment without loss or any benefit.

Apparatus

A virtual desktop environment was created using 3D Design Software, Google Sketch Up software (https://www.sketchup.com/), and Unity 2020.1 (Unity Real-Time Development Platform, https://unity3d.com/) for programming purposes. The targeted landmark building models were selected using a pilot study (Sambath et al., 2022) which assessed the acceptance of these models in the Indian context. Participants are required to navigate from one starting point to a particular destination using a computer mouse. Participants got coloured and B/W environments in a pseudo-randomized order. The hardware consists of Dell compatible computer with Windows 10 equipped with 16 GB RAM, an inbuilt Intel® Core (T.M.) i7-9700 Processor at 3.00 GHz graphic card, and an additional 4GB NVIDIA GeForce G.T.X. 1050Ti graphics card with a memory speed of 7 Gigabit per second. Displayed using HP N246v 60.45 CM (23.8) light-emitting diodes (LED) monitor. It was also equipped with a three-button mouse and a standard (QWERTY) computer keyboard. The experimental procedure is shown in (Fig. 1).

Instruction

General instruction was provided to all the participants before the experiment. General instruction stated, "This study analyses an individual's spatial landmark identification ability using a virtual framework containing an environment with four landmark buildings: a school, a temple, a church, and a mosque and paths connecting the start and finishing points. Kindly use the keyboard to navigate through the environment, and when you see a landmark, press the ‘Left shift key’, and the moment you reach the landmark, press the ‘Right–hand shift key’. The study does not contain any elements that hurt the emotion or sentiments of any participants. The collected data will be used only for study purposes. Thank you for your participation! The written route instructions with the environmental plan were given only to groups with instructions (Instruction-Bird's eye and Instruction-No Bird's eye) prior to the study. The iconic representation of each landmark is shown in the plan provided with written instruction. There was no time limitation for the instruction presentation, so participants got enough time to read and understand the instructions clearly (Fig. 2).

The written instruction is like a descriptive summary of the route, and instructional statements prescribe the participants to act in the given trials. (e.g., take the third left after the Mosque", or “Go ahead till you reach the target point"). The structure of the instructions is carefully formatted in sequential linear order and includes all the names of all landmarks in the experimental trials (Denis, 1997).

Virtual environments

A small environment (224.56 m x 224.56 m) was created and used in the experiment, covered with trees, buildings, and open spaces. The camera in the virtual environment (traveller’s eye) was placed at 1.75 m above the floor, corresponding to the average human height (Sharma et al., 2017). The moving speed in the environment was set at a constant walking speed (8km/hr.) throughout the experiment, so we can assume that people pay more attention to their environment, which helps the wayfinding and landmark identification. We provide a bird's-eye view of the environment in two conditions (InstBV condition & NInstBV condition).

The bird's eye view camera was placed 100m above and 90° angle from the centre of the ground so that the participants would get a live camera view of the plan or bird's eye view with an orthogonal vanishing point of the environment (Abbas & Zisserman, 2019). The environment contains four structurally significant landmark buildings (mosque, church, temple, and school). The height of these landmarks is more than 10m, higher than other ordinary buildings. Hence a participant could get a simultaneous view of more than one landmark. The environment layout and spatial configuration of the buildings played an important role in the wayfinding process (Snopková et al., 2022). Greater path width provides a larger visual perceptive hence we gave a 3.4m. width for the street roads in the virtual environment. The environment's layout was C-shaped (a very simple and symmetrical layout), and the ground of the environment was flat without any slopes, hills, or mountains (Fig. 3).

Thus, in each trial, participants had to traverse a 'C' shaped route through the outermost edge of the environment (Fig. 4). The structurally significant landmarks were positioned in each lane of the 'C' shaped route. The targeted landmark one (t1) would appear in the middle of the first lane, the targeted landmark two (t2) and three (t3) in the second lane, and the targeted landmark four (t4) in the middle of the third lane of the 'C' shaped path. The distance between t1 and t2 was equal to that between t3 and t4. The distance between t1 and t2 is almost twice that between t2 and t3. The placement of all four targeted buildings was in random order, and similar to a natural setting, it appeared on the traveller's way. The opening of all the targeted landmark buildings was towards the 'C' shaped route (i.e., towards the perimeter of the environment). At each junction, the participants made a 90∘-turn to face the new direction of travel (Yamamoto & DeGirolamo, 2012). The position of each landmark changes from trial to trial in a pseudo-randomized order. The orientation of the path also randomized, so they had to take either a 'C' route or an 'inverted C' route from the starting point.

Landmark identification task

The landmark identification task involved navigation and wayfinding in a virtual environment. The accuracy of landmark identification is assured by checking participants' responses when seeing and reaching a landmark or destination in each trial.

Trajectory visual analysis

According to previous literature, map-views aid orientation while route instruction provides information about local and global landmarks; therefore, we hypothesized that people follow a bird's eye view to pick a path leading them to reach a nearer landmark or a goal point. For example, it is easy for participants to use a map view rather than memorize a route instruction. Map view gives them the independence to calculate and visualize their position in the environment. Trajectory analysis and visualization of the travelled path have been explored by past researchers, which is an effective way to analyse the wayfinding behaviour of travellers (Cogné et al., 2018; Jeanne Sholl et al., 2000; Peters et al., 2010; Watson & Lashley, 1915). In this experiment, the unity (software) traced each participant's x-y coordinates (position) every 200milliseconds; these data were automatically generated as an output file into a .csv file format. Based on this captured data of every participant in each of the four conditions, we mapped the data points of each condition onto a 2D map of our environment to get a visual trajectory representation (refer to Fig. 7 in the appendix).

Procedure

After participants received a standardized overview of the experimental tasks, they were informed to consent. Then the participants completed the pre-test questionnaires, including a basic demographic questionnaire, handedness inventory (Oldfield, 1971), State-Trait Anxiety Inventory (STAI) (Spielberger et al., 1971), and the Santa Barbara Sense of Direction Scale (SBSOD) (Hegarty, 2002) on a desktop computer using E prime software. Moreover, tests for visual acuity and colour deficiency were also performed as screening criteria. In the experiment section, participants were tested individually, where they were seated on a chair about 70 cm away from our stimulation computer. The experiment was done under controlled conditions. The visual comfort of the participants was satisfied by preventing glare on the computer screen in a partially dark room. After completing the pre-test questionnaire, participants were asked to navigate and familiarize themselves with the virtual-city environment. They got two minutes of free exploration to get accustomed to the visual environment and were assigned keys to the computer keyboard. During the test, phase participants navigate the virtual maze using arrow keys on the computer keyboard. Participants were randomly assigned to any of the four experimental conditions like Instruction- Bird's eye (InstBV condition), Instruction- No Bird's eye (InstNBV condition), No Instruction- Bird's eye (NInstBV condition), and No Instruction-No Bird's eye (NInstNBV condition). Participants allotted to the InstBV condition received instruction and a bird's eye view for landmark identification (Fig. 2). Participants in the InstNBV condition relied on instruction in their landmark identification task, and they won't avail a bird's eye view of the environment. Participants in the NInstBV condition relied on a bird's eye view, and they didn't receive instructions for wayfinding. Participants in the NInstNBV condition didn't receive both instruction and a bird's eye view.

Participants were asked to respond when they "see and reach" a landmark during the wayfinding trial. They press the left-hand and right-hand shift keys when they see and reach a landmark in the virtual environment, respectively. Our software tracks and saves participants' moments and behaviours. The system automatically measured participants' positions in x–y coordinates and heading orientation (yaw). These data were automatically saved into a .csv file. The software also calculated the participation score. Participation scores included coordinates of the path travelled by the participants, total time taken for travel, the time taken to reach one target landmark to other, average time spent to see a landmark, and total distance covered. The average time taken from the start point to the end-point was 4 min in each trial of a controlled condition (an instructed condition with a bird's eye view).

Moreover, at the end of each trial, the system generated and saved a bird's-eye view / aerial view of the environment. Our virtual environment was 224.56 x 224.56 m. We added 10.21 m x 10.21 m square grids and divided the environment into 22 equal squares for trajectory analysis. The whole experiment lasted about 1 hour. The study was split into two equal sections and a 5-minute break. Participants received four randomized trials in the first phase, either colour or B/W (presentation of coloured and B/W trials was also randomized between participants). They were granted a 5-minute activity break after completing the first section. The experimenter asked them to subtract odd numbers from any randomly chosen four-digit odd number; this cognitive shifting could minimize trial learning and enable participants to adapt to a new environment (Moriguchi & Hiraki, 2009).

Results

Table 1. The number of times participants deviates from the "C shape" path

Condition	Colored Environment		Black & White Environment	
	"C "Shape	"Inverted C"	'C "Shape	"Inverted C"
Inst BV	3	1	0	0
N Inst BV	14	12	10	11
Inst N BV	0	3	3	0
N Inst N BV	17	21	15	16

The table indicates the number of times participants deviate from the "C shape" path (out of 32 targets of 8 trials). InstBV = Instruction bird's eye view condition, NInstBV = No Instruction bird's eye view condition, InstNBV = Instruction no bird's eye view condition, NInstNBV = No Instruction no bird's eye view condition.

Table 1 shows the number of deviations from the "C shape" route in each condition. We can see comparatively lesser values in the data of InstBV and InstNBV conditions where people make less deviation. However, the values of NInstNBV and NInst BV conditions are comparatively higher than InstBV and InstNBV. Similarly, the number of route deviations in the colour environmental condition seems to be higher than in B/W conditions.

Time difference between targets

The one-way analysis of variance (ANOVA) was conducted using SPSS 2.0 software (Statistical Package for the Social Sciences) to determine the impact of colour on landmark identification with and without instruction and bird's eye view. The independent between-group ANOVA yielded a statistically significant effect, $F(3,56) = 3.75$, $p = 0.01$, $\eta^2 = 0.16$ on coloured environmental condition but not on black and white conditions, $F(3,56) = 1.87$, $p = 0.144$, $\eta^2 = 0.091$ (Table 1). Moreover, F values for different environmental contexts were calculated. There was a significant difference between and within environmental colour groups concerning landmark identification. Thus, the result demonstrates that the colour of the environment impacts landmark identification accuracy in all four conditions. A post hoc pair wise comparison (The Least Significant Difference (L.S.D.)) was performed to examine the effect of colour in each of the four conditions. Table 2 shows the meantime taken by participants in each environment (Colour and B/W) from starting point (S) to targeted landmark – 1(T1); T1 to landmark-2 (T2), T2 to landmark-3 (T3), and T3 to landmark-4 (T4).

Table 2. The time difference in both coloured and B/W settings.

	Target	N	Mean (S.D.)	*p*	*d*	η2
Color	T1	60	39.92 (6.79)	.028	0.13	0.29
	T2	60	65.22 (8.99)	.051	0.04	0.26
	T3	60	27.85 (5.84)	.769	0.03	0.09
	T4	60	64.81 (10.95)	.016	0.04	0.31
B/W	T1	60	39.17 (4.69)	.062	0.16	0.25
	T2	60	64.79 (11.78)	.215	0.04	0.19
	T3	60	27.67 (4.72)	.355	0.04	0.16
	T4	60	64.30 (14.67)	.377	0.03	0.16

The table shows the time difference in both colored and B/W settings, N = the number of participants, M= Mean, SD.= Standard deviation, d = cohen's d, η2 = eta squared or effect size and statistics for one-way ANOVA of Instruction- Bird's eye (InstBV) condition, Instruction- No Bird's eye (InstNBV) condition, No Instruction- Bird's eye – (NInstBV) condition, No Instruction - No Bird's eye – (NInstNBV) condition.

Time taken from T1 to T2 (M = 65.22, SD = 8.99), and T3 to T4 (M = 64.811, SD = 1.41) were significantly higher compared to time taken by participants from the starting point (S) to T1 (M = 39.92, SD = 6.78). However, there was no statistical significance on time taken to reach T3 from T2 (Table 2). Nevertheless, the result doesn't show any significant effect on B/W condition, even though the results of B/W condition is virtually identical to coloured condition on the time consumed between S to T1 (M = 39.17, SD = 4.69), T1 to T2 (M = 64.79, SD = 11.78), T2 to T3 (M = 27.67, SD = 4.71) and T3 to T4 (M = 64.30, SD = 14.66).

Time difference between targets in coloured conditions

The time consumption for travel in the coloured environment from starting point (S) to T1 is significantly higher in the NInstBV condition (M = 42.52, SD = 10.88) compared to the NInstNBV condition (M = 42.35, SD = 5.13), there were no significant effect on InstNBV condition (M = 38.32, SD = 3.98) and InstBV condition (M = 36.49, SD = 2.12) compared to the other conditions in targeted landmark-1.

Travelling time from T1 to T2 was significantly higher in the NInstNBV condition (M = 69.0720, SD = 12.18) compared to the NInstBV condition (M = 67.29, SD = 9.37), there was no significant effect on InstNBV condition (M = 63.73, SD = 7.10) and InstBV condition (M = 60.79, SD = 3.18) compared to the other conditions (Fig. 5). Time consumed to reach T2 from T3 did not show any significance on any other conditions. Results of the travel time between T3 to T4 was significantly higher in NInstNBV (M = 71.62, SD = 16.72) compared to NInstBV (M = 65.85, SD = 10.04).

Time difference between targets in black and white settings

The time consumption for travel from the starting point (S) to T1 was significantly higher in the NInstBV condition (M = 40.96, SD =. 6.24) and NInstNBV conditions (M = 40.15, SD = 5.35). The test shows no significant effect on InstNBV condition (M = 38.92, SD = 3.26) and InstBV (M = 36.65, SD = 1.80) in targeted landmark – 1 of B/W environment (Fig. 6).

Travelling time between T1 and T2 was numerically higher in the NInstBV condition (M = 68.92, SD = 17.65) than in the NInstNBV condition (M = 66.96, SD = 13.13). InstBV (61.88, SD = 4.28) and InstNBV (61.43, SD = 6.14) showed similar values. Travel time T2 from T3 was numerically visible in NInstBV (M = 29.35, SD = 7.26) compared to NInstNBV (M = 27.98, SD = 4.95). Results showed lesser value on InstNBV (M = 26.80, SD = 2.45) and InstBV (M = 26.57, SD = 2.30) conditions. The travel time between T3 to T4 was numerically higher in NInstBV (M = 69.22, SD = 26.45) compare to NInstNBV (M = 65.50, SD = 10.75), both InstBV (M = 60.60, SD = 3.82), and NInstNBV (M = 61.88, SD = 5.31), showed comparatively small values.

Discussion

Our study addresses whether the environmental colour has any role in landmark identification and which element of wayfinding communication is most effective. More specifically, we were interested in how people identify landmarks with the presence and absence of route instruction and bird's eye view. The study considers the landmark identification time as a measure of wayfinding. Initially, participants were assigned four conditions to calculate the time to reach targets and finish trials. We reported different behavioural markers, including trajectory analysis, for both coloured and B/W settings. Also, the trajectory visualization provides an overview of the number of times a participant deviate from the shortest possible ("C" shape) route. We examined the accuracy for trials with and without route instruction, and it was observed that total travel time was comparatively less in the presence of route instruction. A possible explanation is that instructions help the participants pre-planning the route (Denis, 1997; Levelt, 1982). Hence the instructions create a mental map, which eventually helps spatial orientation (Schwering et al., 2013). The mode and structure of spatial information can accelerate the creation of a mental map of the subjects. The instructions provided in this study were written instructions with the virtual environment's plan. Moreover, it is more convenient to use and store the spatial instructions in a declarative format (Denis, 1997). Therefore, we found that a route instruction reduces the landmark identification time.

On the other hand, our findings are not going along with the belief that a bird's eye view or "view-in-view map" eases wayfinding (Wu et al., 2009). A possible explanation for this is that the bird-eye view could act as a visual distracter on the screen when presented alone or without route instruction conditions. Moreover, a map or a bird's-eye view supports the traveller's overall guidance by providing global orientation, but the route instructions support local orientation (Schwering et al., 2013). Hence, wayfinding performance is enhanced with the combined use of travel aids (Holscher et al., 2007). Thus the results of the current study accord with earlier observations that when participants get both bird's eye view and route instructions, they take less time for landmark identification, indicating less cognitive load when people get clear route information. The finding of this study would also be valuable in giving a clear understanding of the impact of environmental colour on the accuracy of landmark identification. We observed that the coloured environment distracts the participants while they travel from one landmark to another or a destination. We found that accuracy for trials in a B/W setting, i.e., the total number of deviations from the shortest possible ("C" shape) route, was less in the black and white setting than in a coloured environment. It is visible in the result of the NInstNBV condition that the features like colour support only in the initial stage of the attention process (Treisman & Gelade, 1980). Over time, colour or other visual elements can hinder the wayfinding performance. Wayfinding communication has been of primary interest for decades. Our findings advance the existing knowledge that written route instruction with clear visual indication has more privilege than a bird's eye view in reducing landmark identification time.

Limitation

According to previous studies, the semantic plausibility of an object is coded at an early stage of fixation, and the object's saliency affects only the attentional target (Nothegger et al., 2004; Treisman & Gelade, 1980). The current study does not consider the semantics of spatial features but looks at the environment's colour. However, our experimental paradigm is designed so that variables may be easily altered.

Another consideration is the recognition of spatial objects or landmarks (Spelke, 1990). From one perspective, a specific building may appear to be a significant spatial feature, while it will blend in with other objects from another view. In this approach, our model does not account for the emphasis on landmark salience in the study. According to the literature, there are two different landmarks based on their visibility. A local landmark where people experience landmarks visible only from a limited area and only from specific directions (Raubal & Winter, 2002; Schwering et al., 2013). The second type is a global landmark, visible from any/every location in a setting (Lynch, 1960). The salience features and the concepts of the local and global aspects of the landmarks need to be considered in further studies. Another consideration is that the spatial scene must have a level of detail that enables the extraction of low-level data (Nixon & Aguado, 2012). For example, the variance of colour in the visual spectrum, including tint, tone, shades or different hues, saturation, or other environmental features, is a fruitful area for future research. One of the most important limitations is that wayfinding requires different sensory inputs; sometimes, simultaneous usage of sensory modalities is also necessary for spatial orientation (Horberry et al., 2006; C. Wickens, 1981; C. D. Wickens, 2002). The current study focused only on the visual environmental aspects of wayfinding. A further study could consider the impact of other sensory modalities such as auditory, taste, temperature, pressure, and smell on landmark identification. Moreover, it would be fruitful to explore with different groups of participants, particularly those that rely on other sensory input other than vision.

The study was conducted amidst the pandemic situation of COVID 19. We have followed all the COVID protocols, including social distancing. Our participants felt uneasy about co-operating for the physiological measure; therefore, we did not include physiological markers in the study. Hence, we do not know physiological changes when the participants navigated in coloured and B/W settings. Since the study was limited to participants between 18 and 35 years, it is unknown how these wayfinding aids will support other age groups, especially the elderly population. Finally, as we were looking at the visual impact of instruction and bird's eye map on landmark identification, the usage of verbal instructions was not an objective of the current study. So, we do not know the effect of verbal signs on landmark identification.

Conclusions

This paper examines the effect of colour on landmark identification and wayfinding, mainly in the presence and absence of instruction and bird's-eye view during wayfinding. As a quantifiable factor, we use landmark identification time to measure the cognitive load to achieve this goal. Moreover, the study analyses the trajectory of the participants to identify how often participants deviate from a shortcut route in the virtual environment. To examine the efficacy of bird's eye view and route instructions, we assigned the participants to four different conditions: they had to navigate in randomly assigned coloured and B/W environments. The participant's performance in the given conditions shows promising results. People who navigate in conditions with route instructions make fewer deviations from the shortest possible path. Similarly, the number of route deviations seems to be higher in colour environmental conditions compared to B/W conditions. Trajectory data, which captures the positions of moving objects at certain intervals, has long been used to research human behaviour and solve traffic problems (Kong et al., 2018); hence, these results still leave room for improvement. The current study made these analyses in a simple environment. Trajectory analysis could be similarly done to analyse the efficacy of route instruction and environmental colour in more complicated settings similar to real life. The result also shows the efficacy of route instruction in a declarative format (Denis, 1997). It is more convenient to use and store the spatial instructions with a clear indication of environmental features and landmarks, state the user's action, and be well-structured in a linear and sequential order (Denis, 1997). However, the features of the landmarks were not mentioned in the route instructions given in this study. People who did less deviation in a B/W environment also opened a space for further research. Even if we expected better performance in a coloured environment, it is found that colour supports wayfinding only in the initial stages. It might be because after accustoming to the environment, environmental colour may not be required for wayfinding (Treisman & Gelade, 1980), but they use their sequential route memory. Over time, colour or other visual elements might hinder wayfinding performance. We plan to investigate how different sensory modalities (visual, auditory, tactile, taste, temperature, pressure, and smell) act on human wayfinding in complex environmental conditions. The next step in this work will be to incorporate the physiological markers and chances of other modalities in our existing paradigm and try them out in new situations.

Declarations

Ethical approval

The study was conducted following American Psychological Association (A.P.A.) guidelines and approved by the Institute Human Ethics Committee (IHEC), Indian Institute of Technology Roorkee (Protocol No.: BT/IHEC-IITR/2020/7004/12).

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Author contributions

The authors confirm contribution to the paper as follows: Study conception and design: Manish Kumar Asthana (M.K.A) and Sambath RD (S.R.D), Software: Divyanshu Tiwari (D.T.), Data collection: S.R.D; Analysis and interpretation M.K.A, S.R.D; Results section: Deepak Kumar (DK) Draft manuscript preparation: S.R.D; Structuring the manuscript and Deepak Kumar (DK). All authors provided critical feedback and helped shape the research, analysis and manuscript.

Declaration of interest statement

The authors declare that we have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data Availability Statement

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available because it contains information that could compromise the privacy of research participants.

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Figures

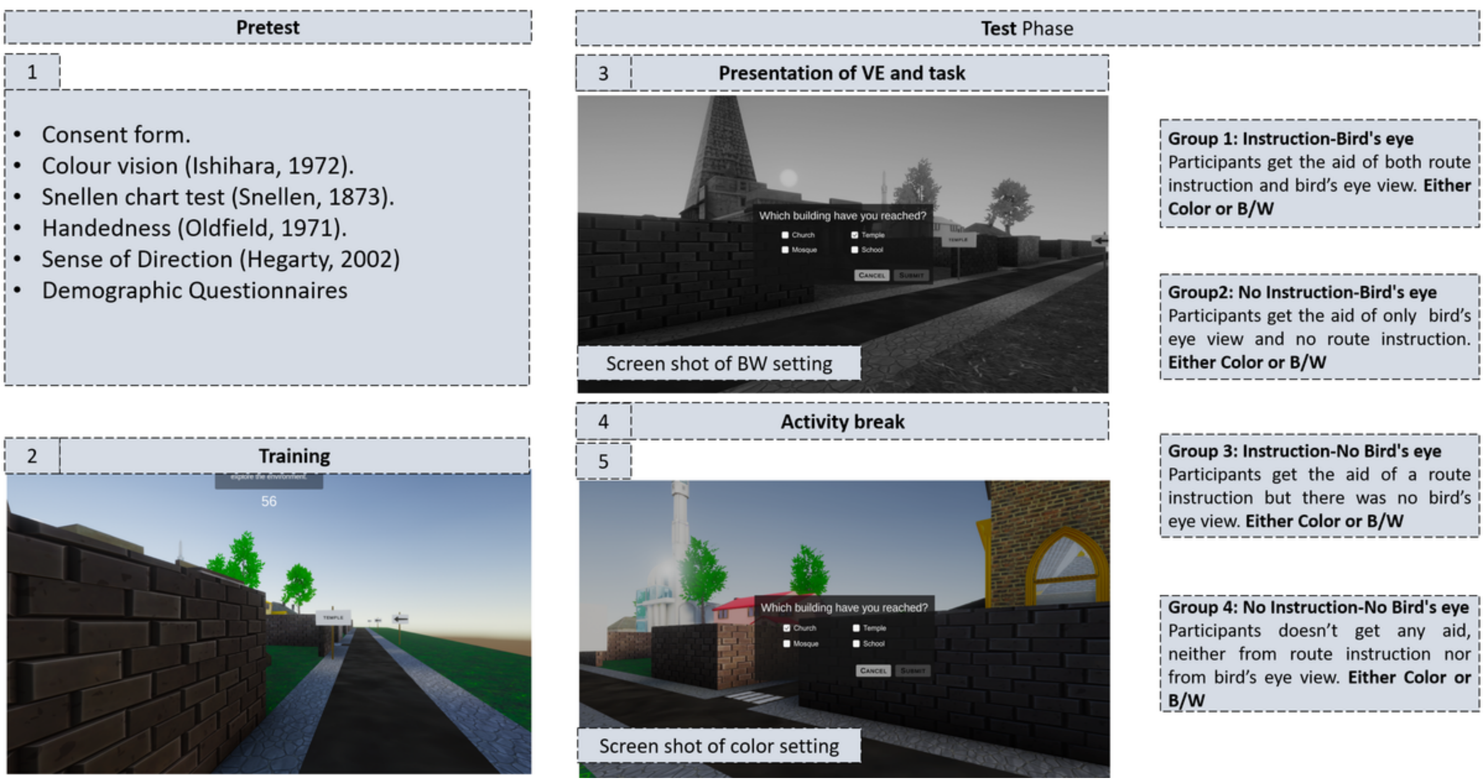

Figure 1

Experimental procedure: Step 1 pre-test; Step 2 training for 120 secs; Step 3 and Step 5 test phase either in colour or in B/W, presentation in a pseudo-randomized order; Step 4 activity break for 5min. Step 3 illustrates the landmark identification protocol used in the study; when a participant reaches a landmark and presses the "right shift key," the pop-up question appears, and participants can answer them (Image created using Inkscape).

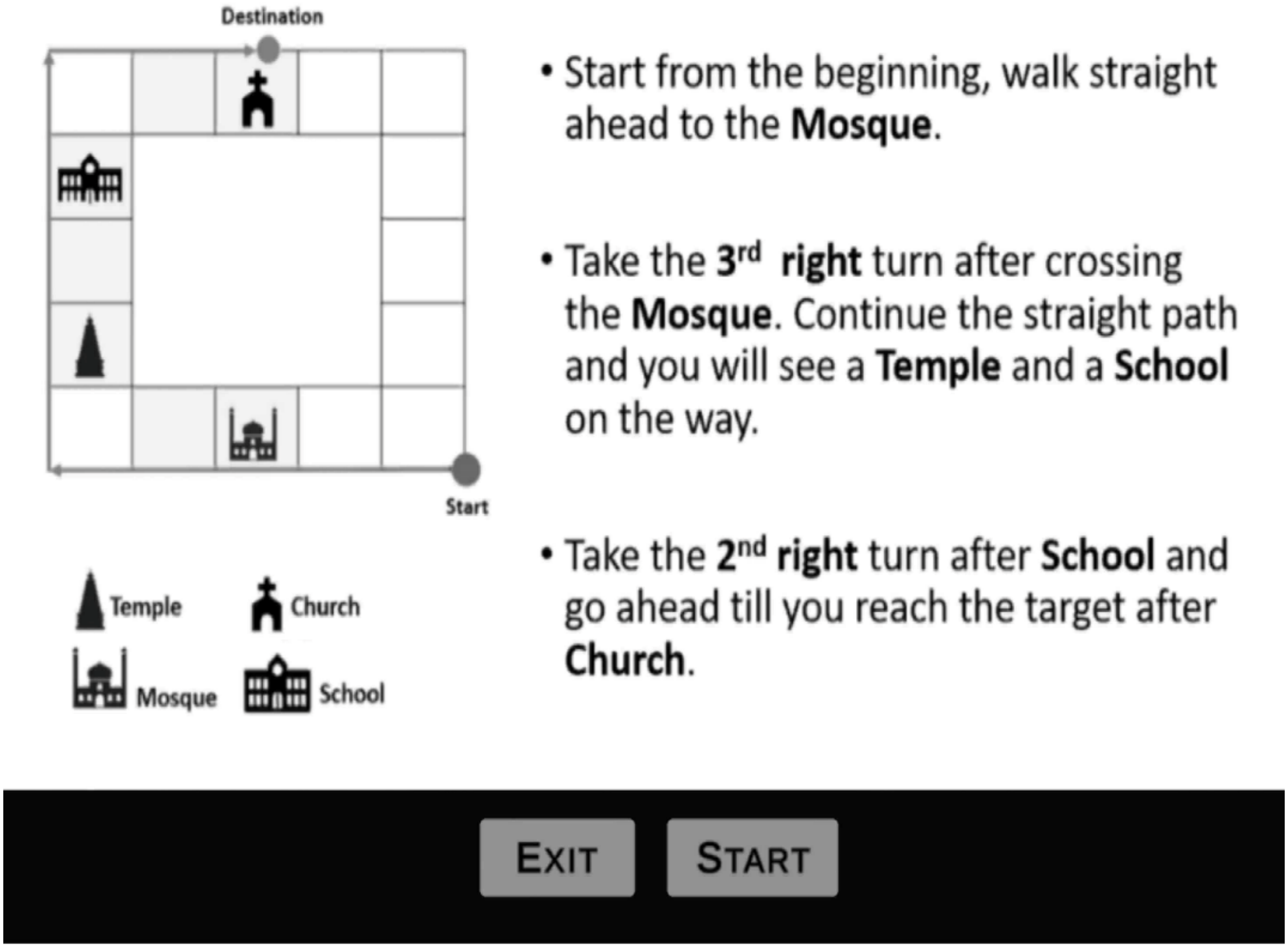

Figure 2

Illustrates a sample route instruction provided for the instructed group (InstNBV and InstBV conditions) ; (Image Composed in Inkscape).

Figure 3

Screenshot of the experimental environment (left) and bird's eye (right).

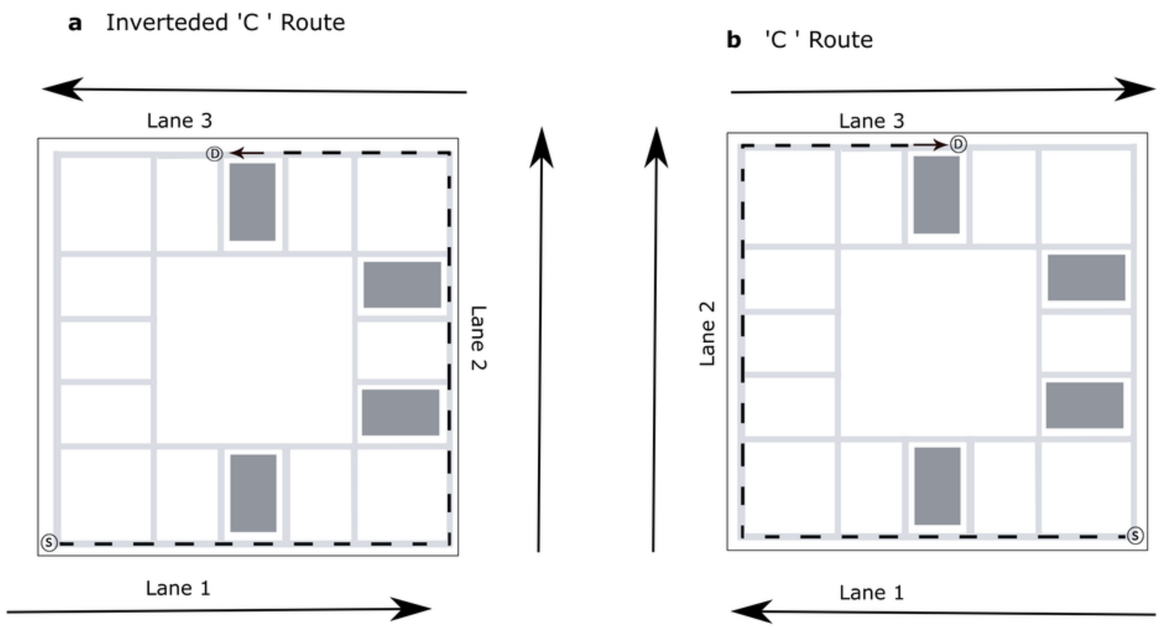

Figure 4

Bird's eye view of the virtual environment, (a) Inverted C route, (b) C-shaped route. The alphabet "S" indicates the start, and "D" indicates the destination point, (Image Composed in Inkscape).

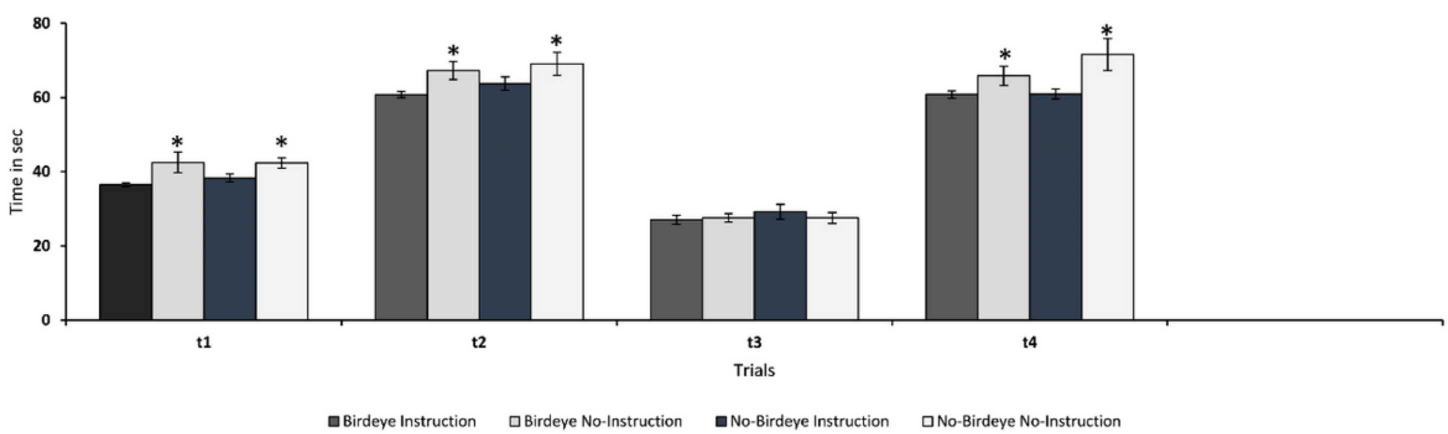

Figure 5

Time difference between targeted landmarks (T1, T2, T3, and T4) of 4 different conditions in coloured. Significant differences are denoted (*$p \leq 0.05$). The plots visualize the time difference between targets in InstBV (Instruction + Bird's eye view) condition (n= 15), NInstBV (No Instruction + Bird's eye view) condition (n= 15), InstNBV (Instruction + No Bird's eye view) condition (n= 15), and NInstNBV (No Instruction + No Bird's eye view) condition (n= 15) in colored and B/W environment.

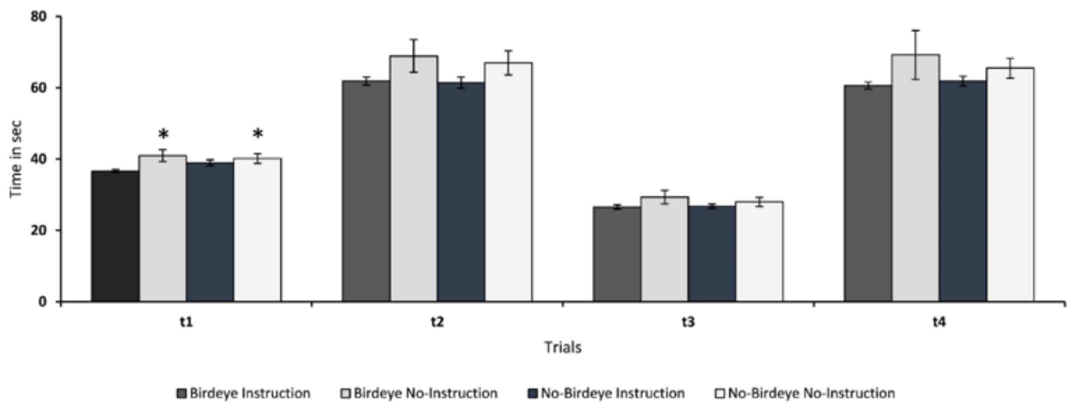

Figure 6

Time difference between targeted landmarks (T1, T2, T3, and T4) of 4 different conditions in B/W environment. Significant differences are denoted (*p ≤ 0.05). The plots visualize the time difference between targets in InstBV (Instruction + Bird's eye view) condition (n= 15), NInstBV (No Instruction + Bird's eye view) condition (n= 15), InstNBV (Instruction + No Bird's eye view) condition (n= 15), and NInstNBV (No Instruction + No Bird's eye view) condition (n= 15) in colored and B/W environment.

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