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# Interaction of orientation cues within a nested virtual environment

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A R T I C L E I N F O

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A B S T R A C T

Three experiments examined whether three factors (view of external targets, colored wall cues, previous exploration of room) facilitate orientation within a virtual building and whether the interaction between the first two factors align with predictions from associative learning. Participants were teleported into a virtual room and asked to face in the direction of an external occluded target using all, none, or a combination of these factors. Experiment 1 (n = 62) showed all 3 factors individually improved orientation. Experiment 2 (n = 28) illustrated that the interaction between external targets and colored wall cues was similar to an associative learning phenomenon, where more salient cues inhibit learning about less salient cues (called overshadowing). Previous research suggests salience of spatial cues can be moderated by familiarity with the cues. In both Experiment 1 and 2, participants were familiar with the external targets but not the colored wall cues. Experiment 3 (n = 92) manipulated familiarity with the external targets and found that when participants were not familiar with the external targets, they became overshadowed by colored wall cues. The results are a novel demonstration that spatial cues within a nested environment interact in a way predicted by associative learning.

Finding your way around a building can be extremely difficult (Jamshidi & Pati, 2021). The typical layout of a building, being divided into enclosed areas or rooms that are not visible from all positions, adds to the difficulty in navigation. Such buildings can be described as having a nested environment. Navigation and maintaining orientation within such nested environments have been the focus of extensive research (Devlin, 2014; Madson & Goodwin, 2021; Wan et al., 2021). For a review see Ghamari and Sharifi (2021). Effective orientation within nested environments is a considerable challenge, as people struggle to track changes within both their local and external environment (Wang & Brockmole, 2003a; 2003b). The aim of the current paper is to examine whether three factors aid orientation within a nested environment, and whether they interact in a way that might be predicted by associative learning models.

Previous research has demonstrated that associative learning models can predict how associations are formed between spatial cues and how spatial cues interact (Chamizo, et al., 1985, 2003; Redhead & Chan, 2017; Redhead, Roberts, Good, & Pearce, 1997). One prediction is overshadowing of one cue over another less salient cue. Overshadowing is an established phenomenon within standard conditioning procedures (e.g., Kamin, 1969; Pavlov, 1927). For example, if a light–tone compound stimulus signals the delivery of food, both the tone and the light become associated with food. How strongly each cue is associated with the food is partly dependent on the relative saliences of the cues. If the tone is more salient than the light, the association between the light and food would be relatively weak. The standard associative account for this phenomenon is cue competition (see, e.g., Rescorla & Wagner, 1972). The two cues compete for a finite amount of associative strength, and thus, the more associative strength that the salient tone acquires, the less the light can acquire.

Overshadowing has been demonstrated in the spatial domain in humans (e.g., Alexander et al., 2009; Chamizo et al., 2003; Deery & Commins, 2023; Redhead & Hamilton, 2007, 2009). In a computer-generated version of the Morris water maze task, Redhead and Hamilton (2007) asked human participants to find the location of a platform that had a conspicuous visual cue (a beacon) placed directly above it. The location of the platform could also be defined in relation to other visual cues (referred to as landmarks) placed on the walls of the pool. During a test trial in which the beacon was removed, leaving only the landmarks to guide navigation, participants spent no more time in the platform area than would be expected by chance, suggesting that the beacon effectively overshadowed the presumably less salient landmark cues. Such competition between the cues involved in the control of navigation has led several authors (e.g., Chamizo, 2003; Miller &

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Shettleworth, 2007; Pearce, 2009) to suggest that spatial learning follows the same rules as those described by associative-learning models. The current paper will extend the research by looking at whether spatial learning within a nested environment also follows these rules. The current studies provide a novel demonstration of how spatial cues interact within a nested environment. This interaction will be tested to ascertain whether the more salient cues overshadow less salient ones in a manner predicted by associative learning models. Experiment 3 further demonstrates, for the first time, that manipulating familiarity with the cues can affect which set of spatial cues become overshadowed.

In the present studies, participants were placed into a room in a virtual building and asked to face in the direction of an occluded External Target. In the initial study, three orientation factors were chosen, which have been shown to enhance orientation presented in isolation but the interaction between the cues when presented together has not been tested. The first orientation factor was a view of one of the External Targets that form a stable spatial array outside of the building (See Fig. 1a).

By learning the spatial relationship between, for example, the Physics Building and the Car Park, if allowed a view of the Physics Building, a person should know in which direction the Car Park should be. Evidence suggests that participants are able to maintain orientation within a building by using an external frame of reference created by targets external to the building (Jiang, Allison, & Duchowski, 2021; Meilinger et al., 2014). It has been shown that people struggle to maintain orientation in rooms which have no views of these External Targets (Allison & Redhead, 2017; Carlson et al., 2010). The second factor was experience of navigating to the room within the nested environment. During acquisition trials, participants were only allowed access to certain rooms. Navigating between distinct areas has been shown to improve orientation in other studies (Lei, Mou, & Zhang, 2020; Mou & Wang, 2015). Mou and Wang demonstrated that when participants were asked to point to an object in another room pointing accuracy was far better when they had been allowed to walk between the rooms. The third factor was the presence of internal cues that could be used to indicate the cardinal directions within the nested environment and the position of the External Targets. Allison et al. (2017) demonstrated the use of colored wall cues could enhance spatial orientation within a virtual building when they had a consistent spatial association with an array of spatial targets. For example, all south facing walls had a green band across the width of the wall (See Fig. 1b for lay out of colored Wall Cues). By learning the association between the green colored Wall Cue and the Car Park, a person would face the green wall cue to face in the direction of the Car Park. Wang et al. (2021) have shown that visible internal cues which have become associated with the non-visible External Targets have allowed participants to maintain orientation. It should be acknowledged that this list of factors that control spatial navigation are not exhaustive. For example, Hayward et al. (2003) illustrated that geometric cues provided by the shape of a test arena could allow animals to learn the position of a hidden goal.

The further reason for choosing these specific factors is that while the External Targets and colored Wall Cues are both visual cues within the testing room, the third factor of experience of having previously visited the room during acquisition, might be considered different in nature. Myers et al. (2001) and Redhead (2007) have demonstrated different interactions between stimuli depending on the modality of the stimuli. The current study will extend our knowledge of how spatial cues from the same or different modalities.

Given previous evidence of overshadowing in the spatial domain (Redhead et al., 2013), it might be expected that the three factors would interact in the way predicted by associative learning models. However, previous demonstrations of overshadowing have been observed in environments such as a watermaze, where all aspects of the environment can be viewed from one point. This type of environment has been described by Montello (1993) as "vista space". The nested environment used in the current study could be described as an "environmental space", as the spatial relations between all cues could only be viewed from several different points within the environment (Montello, 1993). As such, this work presents a novel test of whether cues in a nested environment interact in a way predicted by associative models. The first aim of the paper is to examine the effectiveness of these cues in controlling navigation. The second aim of the paper is to test whether, when presented together, the cues interact in a manner described by existing associative learning models. Experiment 1 tested orientation in the

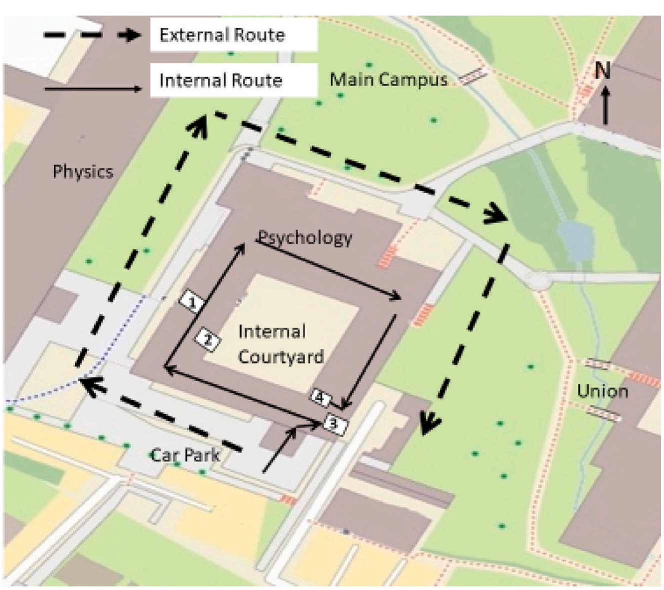


**Fig. 1a.** Layout of Psychology Building for Group Control in Experiment 1, including surrounding External Targets, and routes taken during acquisition trials.

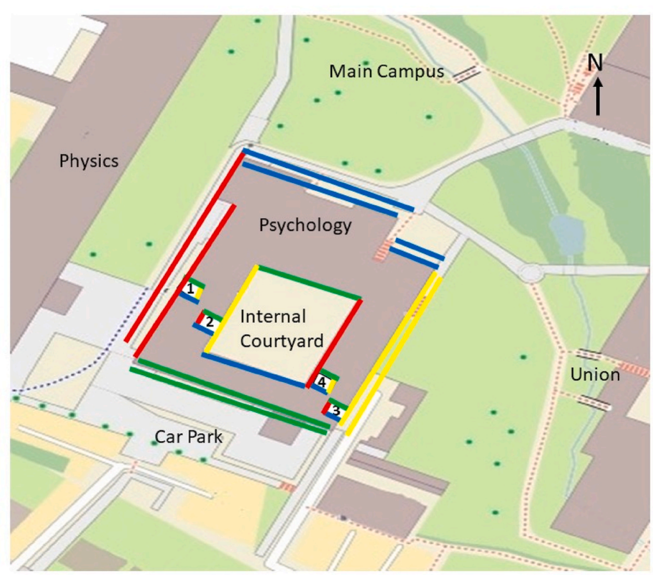


**Fig. 1b.** Layout of colored Wall Cues in Psychology Building for Group Wall Cue in Experiment 1. For this group all internal south facing walls and the external wall facing the Car Park were green; all internal north facing walls and the wall facing the Main Campus was blue; all internal west facing walls and the wall facing the Physics Building was red; all internal east facing walls and the wall facing the Union Building was yellow. For both Fig. 1a and b; the External Facing Unvisited Room is labelled 1; the Internal Facing Unvisited Room is labelled as 2; the External Facing Visited Room is labelled as 3; the Internal Facing Visited Room is labelled as 4.

presence or absence of the three factors (view of External Target, experience of visiting room, colored Wall Cues). This was done to explore whether they improved orientation within a nested environment and how they interacted with each other.

Experiment 2 examined the interaction between two of the factors, the most effective (view of External Target) and least effective (colored Wall Cues), to examine if the former cue came to overshadow the latter, in a manner predicted by associative learning models. Orientation was measured in trials where cues were presented both together, and separately. Associative learning models would predict the salient cue would overshadow the less salient cue. A final test trial presented the External Targets and internal colored Wall Cues in conflict so that they indicated different directions for the occluded External Targets. Associative learning models would predict that participants would predominantly use the more salient factor to control orientation.

Experiment 3 tested whether reducing the salience of the External Targets would mean that they would be overshadowed by the colored Wall Cues. The salience of the External Targets was manipulated by changing familiarity with them. Several studies have shown that familiarity with cues affects participants' performance in spatial tasks (Davis & Therrien, 2012; Ligonnière et al., 2021). For example, people living with dementia rated the salience of a landmark as partly due to meaningfulness, which included subjective factors of personal and emotional significance that linked the landmarks to participants' pasts (Seetharaman et al., 2021). In Experiments 1 and 2, all participants were University of Southampton students and thus familiar with the External Targets but not with the internal colored Wall Cues which were added to the computer model of the Psychology Building. Experiment 3 included participants who were not University of Southampton students and thus not familiar with the External Targets on the campus. By manipulating cue familiarity, and hence salience, the aim of Experiment 3 was to test if overshadowing was due to relative salience of the cues, as would be predicted by associative learning models.

All three experiments were approved by the University of Southampton's Ethics Committee.

## 1. Experiment 1

In Experiment 1, participants were allowed to explore the environment and asked to orient toward an occluded External Target in the presence of the factors either individually or in combination. We expected that each factor would benefit orientation. How effectively each factor enhanced orientation could be used to predict which cue would be overshadowed when presented in compound. If overshadowing occurred between the factors we would expect participants to perform poorly when the less salient cues were presented in isolation compared to when they were presented simultaneously with a more salient cue.

## 2. Method

### 2.1. Design

We conducted a 2 (room type: external-facing/internal-facing) x 2 (experience: visited/unvisited) x 2 (condition: Wall Cues/no Wall Cues) mixed Analysis of Variance (ANOVA) with absolute orientation error as dependant variable. The main effects of room type, experience and condition tested the effect of the three factors. Participants were randomly allocated between the two Wall Cue conditions.

### 2.2. Participants

Participants were 62 psychology undergraduate students from the University of Southampton who completed the study in partial fulfilment of a research participation scheme. Participants were recruited via the use of a departmental recruiting system. Group Control consisted of 8 male and 23 female participants. The mean age was 19.7 years and the range was between 18 and 32 years. Group Wall Cues consisted of 6 male and 25 female participants. The mean age was 20.1 years and ranged between 18 and 25. All participants had normal or corrected normal vision and were familiar with the University of Southampton campus and Psychology Building. They were not familiar with the virtual model of the Psychology Building.

We based the sample size on an a priori power analysis. Our effect-size estimate was informed by an experiment testing spatial orientation in a similar manner (Allison et al., 2017, Experiment 3). We predicated our power analysis on the between x within factor interaction effect ($f = 0.07$). Achieving 80 % power to detect an effect of this magnitude requires 27 participants, given $\alpha = 0.05$ (G*Power 3.1; Faul, Erdfelder, Lang, & Buchner, 2007). We met this recruitment target.

### 2.3. Materials and apparatus

The study took place in a windowless research cubicle in the Psychology Building, University of Southampton. The cubicle measured 2.4 m in length by 1.3 m wide, with a height of 2 m. The cubical contained a single desktop computer. The computer used a standard Windows 7 operating system, with keyboard and mouse, placed on a 1.3 m wide desk in the centre of the rear wall. The computer was connected to three identical 15-inch LCD monitors. The monitors were placed horizontally so that the displayed image was shown continuously across all three screens.

A virtual model of the Psychology Building, University of Southampton, and its surroundings was created and developed within the School of Psychology in University of Southampton, using 3DSMax 2012. The environment presented on the computer was entirely virtual, there were no physical elements to the environment. The programme placed the participants within the environment, and offered a first person perspective. The model enabled participants to explore both the surrounding area, and the third floor of the Psychology Building (Please see Fig. 1a for routes taken around the building and a layout of the third floor of the building and External Targets). In total there were four floors in the Psychology Building. The model only allowed full access to level 3. Participants entered the building on the ground floor, which was on level two of the building, and accessed level three via the stairs. They could not go down to the basement, level one, or to level four via the stairs, and could not explore level two beyond the entrance and atrium containing the stairs.

Participants were able to explore the outside of the Psychology Building to a relative distance of 20 m from all four sides of the Psychology Building. The Psychology Building was surrounded by labelled External Targets (Car Park, Physics Building, Main Campus and Union Building) at a distance of 50 m from the psychology building. All External Targets extended beyond the full length of the four external walls of the Psychology Building (100 m). Level 3 of the Psychology Building contained two sets of rooms, internal facing rooms which contained windows onto the internal courtyard, and external facing rooms with windows onto the External Targets surrounding the Psychology Building. The rooms were separated by an internal corridor which went around the complete Psychology Building. The doors to the rooms could either be open, allowing access during the initial acquisition stage (visited room) or closed denying access (unvisited room). All rooms used in Orientation trials were 3 m $\times$ 4 m in size, had two windows on one wall, and a red square (0.5 $m^2$) in the centre of floor. For Group Wall Cues, the internal walls had a 0.1 m width colored cue at a height of 1.9 m along the length of the walls. For south facing walls the cue was green, for north facing walls the cues were blue, for west facing walls the cues were red, and for east facing walls the Wall Cues were yellow (See Fig. 2a for image of internal facing room). For this group the external walls had a 1 m colored cue at a height of 25 m along the length of the wall (See Fig. 2b for image of the external wall by the Car Park). The color and dimensions of the cues used were the same as those used in Allison et al. (2017), which were found to enhance spatial orientation in

**Fig. 2a.** View from the Internal Facing Room through South facing window onto internal courtyard for Group Wall Cue in Experiment 1.

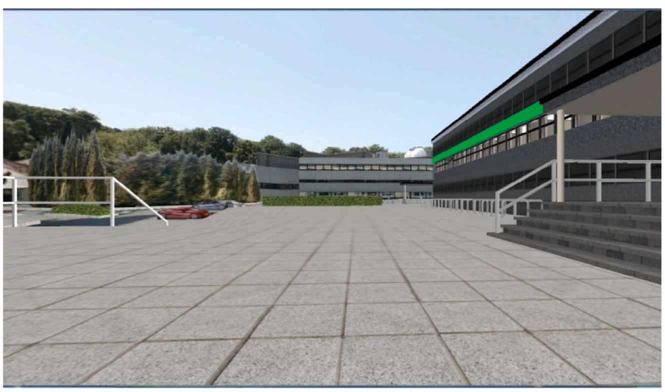

**Fig. 2b.** View of the South side of the building facing the Car Park for Group Wall Cue in Experiment 1.

a passive presentation. The colors chosen allowed the cues to be highly visible against the beige walls of the Psychology Building on which they were placed.

It should be noted that the colors on the external walls did not correspond to the cardinal directions. For example, the external wall opposite the Car Park was green, even though the direction faced while facing the wall was north. These colored cues were added to the external walls following a pilot study which showed them to promote the association between the External Target, and the colored Wall Cues. Thus, when looking out on the Car Park the internal Wall Cue would be green. When standing facing the building in the Car Park, the external wall would also have a green Wall Cue. For Group Control the model did not contain any colored Wall Cues. Participants controlled their movement using the "FORWARD" "LEFT" and "RIGHT" arrow keys, but could not look up or down, or interact with items within the environment. Participants were unable to use the "BACK" arrow key in order to better simulate real life movement.

### *2.4. Procedure*

Participants were led into the research cubicle, and asked to complete the consent sheet, and given the task instructions. The spatial task comprised of two sets of trials: acquisition and orientation test trials. Participants completed two acquisition trials to familiarize themselves with the environmental layout. For the first acquisition trial, participants were required to explore the outside campus environment, allowing participants to see, but not enter, surrounding buildings, including the Physics Building and the Union Building and features such as the Car Park and main campus area. Participants were provided with written instructions regarding a route to take within the environment (See supplementary materials).

This route ensured that participants saw and identified all visible landmarks in the surrounding area and did not become trapped or lost. As movement was controlled by the participants, they were free to divert from the suggested route if they wished to explore further. Once participants had explored the surrounding environment, they were instructed to make their way back to the starting location and to indicate to the experimenter that they were happy to proceed to the second acquisition trial.

For the second acquisition trial, participants were required to enter the virtual building and to explore the third floor of the model. Participants were again provided with written instructions that guided them along a route which ensured that they had visited key locations within the building and looked out of key windows. The windows either allowed them to see one of the four External Targets surrounding the Psychology Building, or a view of the internal courtyard within the Psychology Building (See supplementary materials).

Neither acquisition trial was timed, participants were free to explore the environment for as long as they wished. During the acquisition stage, participants were told to explore the environment and familiarize themselves with its features but were not told that they would be tested on their ability to orient themselves with respect to the External Targets, the rooms they had previously visited or internal colored Wall Cues.

In a series of orientation test trials, participants were teleported into one of four different room types: External Unvisited (EU), Internal Unvisited (IU), External Visited (EV), or Internal Visited (IV). In each room, participants were asked to face toward a non-visible external target. For example, they may be teleported to a room that they had visited before which had a view of the Union Building (an EV room) and asked to face in the direction of the Physics Building. This procedure was similar to that used in Friedman et al. (2020). The order in which rooms were presented was counterbalanced across the participants. In all rooms, participants were asked to move to a red mat placed in the centre of the room and, using the arrow keys on the keyboard, turn to face the central point of one of the non-visible, but previously seen, External Targets: Car Park, Physics Building, Main Campus, and Union Building. Participants were not able to leave the room during the orientation trial. The orientation trial was not timed, and participants were free to take as long as they wished before pressing the TAB key to progress to the next trial. The final heading was recorded for each orientation trial, and the absolute orientation error calculated. Absolute orientation error was the absolute difference between the participant's angle of orientation and that of the correct angle of orientation to the centre of the External Target. For example, if the correct angle of orientation was 180° and the participant's orientation was 185° or 175° then the absolute orientation error would be 5°.

## 3. Results

Mean absolute orientation error for Group Control and Group Wall Cues are presented in Fig. 3. To examine the data in more detail, a 3-way mixed design ANOVA was used to explore the effect of room type (Internal-facing/External-facing), experience (Visited/Unvisited) and condition (Control/Wall Cues) on participants' absolute orientation error scores. There was a significant main effect of room type, $F(1, 60) = 34.39$, $p < 0.001$, $\eta_p^2 = 0.364$, 90 % CI = [0.228, 0.512]. The absolute orientation error was greater within the internal facing rooms than the external facing rooms. The main effect of experience was also significant, $F(1, 60) = 9.16$, $p = 0.004$, $\eta_p^2 = 0.132$, 90 % CI = [0.027, 0.264]. The absolute orientation error was greater within the rooms that had not been visited during the acquisition trials compared to in those that had. The effect of condition was also significant, $F(1, 60) = 4.06$, $p = 0.048$, $\eta_p^2 = 0.063$, 90 % CI = [0.000, 0.179]. Group Wall Cue had a lower

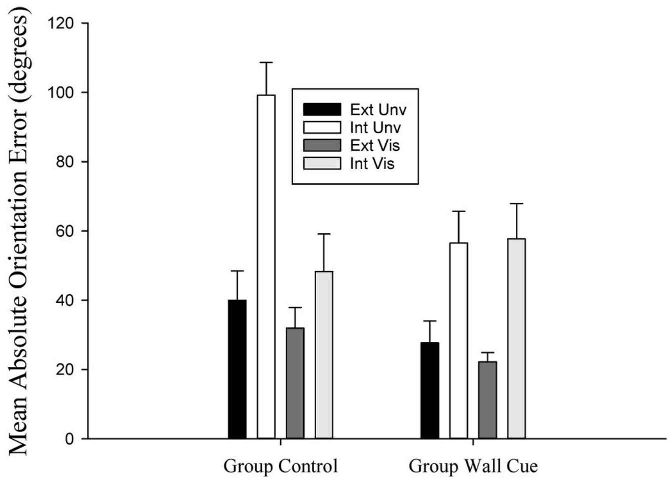


**Fig. 3.** Mean absolute orientation error for Group Control and Group Wall Cue in Experiment 1. Error bars represent the estimated standard error of the mean.

absolute orientation error than Group Control. The three significant main effects suggest all three factors (view of External Targets, experience of visiting room and presence of Wall Cues) significantly enhanced the participants' ability to orient within the building. Though the fact that the main effect of cardinal colored Wall Cues did not reach significance at the $p = 0.01$ level, and the effect size was smaller than the other two factors, might suggest that this factor was the least effective at enhancing orientation, and thus least salient.

A significant 2-way interaction was found between experience and condition, $F(1, 60) = 6.86$, $p = 0.011$, $\eta_p^2 = 0.103$, 90 % CI = [0.013, 0.230]. A significant 3-way interaction was found between Room Type, Experience and Condition, $F(1, 60) = 5.65$, $p = 00.021$, $\eta_p^2 = 0.086$, 90 % CI = [0.007, 0.209]. There were no other significant interactions between the factors.

To further examine the 3-way interaction a series of post hoc Bonferroni corrected pair wise comparisons were performed. These revealed that performance in rooms both previously visited and with a view of an External Target (32°) was not significantly different from rooms that had only the External Target (40°), $p = 00.333$, or only visited (48°), $p = 00.147$. However, in rooms with both External Targets and colored Wall Cues performance was significantly better (27.6°) than in rooms with only colored Wall Cues (56°), $p = 00.013$. This suggested a view of an External Target overshadowed the Colored Wall Cues.

The finding that a view of an External Target facilitated orientation supports the results of Meilinger et al. (2014). The finding that experience of visiting a room within the building prior to testing enhances orientation supports those found by Mou and Wang (2015). The facilitation caused by the presence of the colored Wall Cues supports those of Wang et al. (2021). This is the first time that the facilitating effects of all three factors have been shown when the factors were presented together. The analysis of the 3-way interaction suggests that while there was evidence that the External Target overshadowed the colored Wall Cues which were from the same modality, there was no sign of overshadowing of the enhancement due to the experience of visiting a room previously. This supports the results of Redhead (2007), that combining two stimuli from a similar modality can result in a different interaction than between two stimuli from different modalities. Given overshadowing was only found when the two sets of visual cues were presented, Experiment 2 will focus on the interaction between the colored Wall Cues and the view of the External Targets.

## 4. Experiment 2

Experiment 1 demonstrated that the view of External Targets overshadowed the colored Wall Cues. Experiment 2 will further examine this interaction, comparing performance on trials which contain the cues individually or in combination in a within group design. If associative learning models can be used to predict the interaction of spatial cues in a nested environment, we would expect that learning the spatial relationship between the External Targets would overshadow learning about the spatial relationship between the colored Wall Cues and the External Targets. It would be expected that performance on trials with just the colored Wall Cues would be poor compared to trials containing a view of an External Target, and compound trials containing both cue types. This was shown to be the case in Experiment 1, however, it is not clear what influence on orientation the colored Wall Cues have during the compound trials. To assess this participants were given a Contrast Trial to see which cue type the participants use when both are present. In the Contrast Trial, the arrangement of the colored Wall Cues suggest that the occluded target was to the right, whereas the position of the visible External Target suggest that the occluded target was to the left. To achieve this contrast in indicated directions by the cues, the spatial arrangement of the colored Wall Cues in the room during the Contrast trial was different from during acquisition. For example, during acquisition trials the cue on a north facing was blue. However, during the Contrast Trial, the cue on a north facing wall was a green. If participants used the External Targets alone to orientate they would turn to the left and face the correct direction and thus have an orientation error of close to 0°. If they used the colored Wall Cues alone they would turn to the right and face the opposite direction and have an orientation error of approximately 180°. In Experiment 2, participants completed the same acquisition trials as in Experiment 1. Participants saw both External Targets and colored Wall Cues within the model. During orientation test trials, participants were teleported to four different rooms that they had not previously visited during acquisition: 1) a room view of an External Target only (ET trial); 2) a room with colored Wall Cues only (WC trial); 3) both External Target and colored Wall Cues, (ET + WC trial); 4) both External Target and colored Wall Cues indicating contrasting positions for the occluded External Target (Contrast trial). We expected that the best performance would be displayed in the ET + WC trial, as this would be the most similar trial to the majority of rooms presented during acquisition. If the External Targets overshadowed learning about colored Wall Cues, then we would expect performance in the ET trials to be similar to the ET + WC trials, but poor in the WC trials. Finally, the degree to which the External Targets overshadowed the Wall Cues would govern performance in the Contrast trials. If overshadowing completely stopped learning about the colored Wall Cues, then the rearranged colored Wall Cues would have no influence on orientation and performance should be similar to ET + WC trials. If overshadowing was incomplete, then the rearranged colored Wall Cues would lead participants to face in the opposite direction to that indicated by the External Targets.

## 5. Method

### 5.1. Design

This study used a one-way 4 (Room type) repeated measures ANOVA. The room types varied by the cues available: a room with a view of the External Targets and containing the colored Wall Cues (ET + WC); colored Wall Cues only (WC); External Targets only (ET); External Targets and colored Wall Cues where the spatial relationship between two sets of cues was reversed to that established during training (Contrast). Post hoc planned comparisons were carried out, comparing the ET + WC trials with the other three room types. The order of trial presentation was counterbalanced so that for half of the participants the ET trial came before the WC trial and for others this order was reversed. This was to ensure presenting one set of cues first in isolation did not have an impact on the set of cues presented second. The dependent variable recorded was the absolute orientation error.

### 5.2. Participants

We recruited 28 undergraduate psychology students from the University of Southampton. Participants were randomly assigned between Group Counterbalance 1 (CB1) and Group Counterbalance 2 (CB2). Group CB1 contained 4 male, and 10 female participants and Group CB2 contained 3 male, and 11 female participants. The mean age was 19.8 years and ranged between 18 and 23. All participants had experience of the real Psychology Building, and university campus, but did not have experience of the model, nor had they taken part in the previous experiment. All participants had normal or corrected normal vision. We based the sample size on an apriori power analysis. Our effect-size estimate was informed by an experiment testing the effect of room position and familiarity on spatial orientation within the room (Allison & Redhead, 2017, Experiment 2). The sample size for that experiment was used in the apriori power analysis for the current experiment because both studies assessed spatial orientation with the same measure. We conservatively predicated our power analysis on the smaller of these two effects ($f = 0.68$). Achieving 80 % power to detect an effect of this magnitude requires 20 participants, given $\alpha = 0.05$ (G*Power 3.1; Faul et al., 2007). We met this recruitment target. This was smaller than the recruitment target for Experiment 1 as the design here was a repeated measures, as opposed to a mixed design.

### 5.3. Apparatus

Details were the same as Experiments 1.

### 5.4. Procedure

The acquisition trials were the same as Experiment 1.

Orientation trials took place in rooms that had not previously been visited during the acquisition trials. In Trial 1, participants were teleported into with a view of one External Target and the colored Wall Cues were present, and in the same spatial arrangement as during acquisition (ET + WC). In Trial 2, participants were teleported to a room with a view of the Physics Building, however, no additional colored Wall Cues were provided (External Targets only, ET). In Trial 3, participants were teleported to a windowless room with no view of an External Target, the colored Wall Cues were present (colored Wall Cues only, WC). In Trial 4, participants were teleported to an external-facing room containing a window overlooking the Union Building. Colored Wall Cues were present but in a different spatial arrangement to acquisition. The colored Wall Cue on the north facing wall was green, on the south wall it was blue, east facing wall red and west facing wall yellow (Contrast). The order of the individual cue trials (ET and WC trials) were counterbalanced across participants. For half of the participants the order of trials was 1–4 (Counterbalance 1), and for the rest the order of trials was 1, 3, 2 and 4 (Counterbalance 2). This was done to equate the impact of unreinforced orientation test trials on the two individual cue trials.

## 6. Results

Fig. 4 presents the mean absolute orientation error for the four different room types. The performance varied across the four trial types. The mean absolute orientation error occurring in the trials was as follows:

Trial ET + WC ($M = 12°$; $SD = 32.43$)

Trial ET ($M = 21°$; $SD = 26.25$)

Trial WC ($M = 68°$; $SD = 63.77$)

Trial Contrast ($M = 52°$; $SD = 61.01$)

A 4 Trial (ET + WC/ET/WC/Contrast) repeated measures design ANOVA was used to analyze the data. Mauchly's test showed that the assumption of sphericity had been violated, $\chi2(5) = 20.51, p < 0.001$, as such the degrees of freedom were modified using the Greenhouse-Geisser estimates of sphericity, ($\varepsilon = 0.69$). There was a main effect of Trial, $F(3, 52.19) = 8.31, p < 0.001, \eta_p^2 = 0.24$, 90 % CI = [0.127, 0.439], indicating that there was a difference in participants' ability to orient across the four trials. To examine where the difference between trials lay, a series of post hoc planned Bonferroni corrected pairwise comparisons was performed, comparing the absolute orientation error in the ET + WC trial and the other three trials. The absolute orientation error in ET + WC trials (12°) was significantly smaller than in both WC trials (68°) and Contrast trials (52°), $p < 0.001$. There were no significant differences between the ET + WC and ET trials.

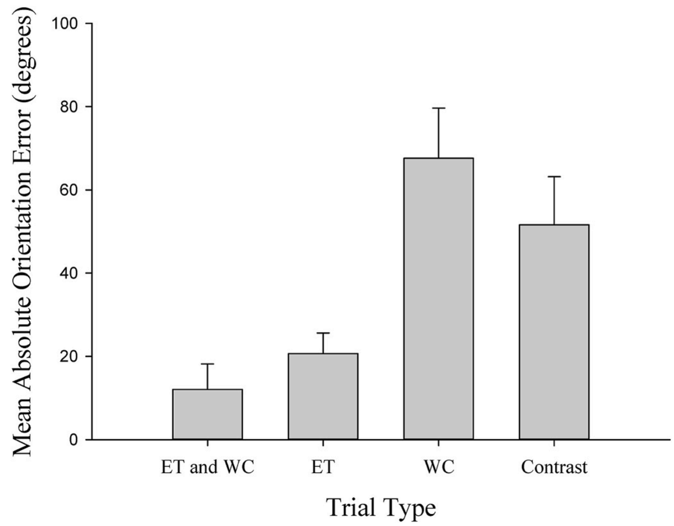


**Fig. 4.** Participants mean absolute orientation error for each of the four conditions in Experiment 2: trials containing views of both External Targets and colored Wall Cues (ET + WC trials); trials containing views of only External Targets (ET trials); trials containing views of only colored Wall Cues (WC trials); trials where the spatial relationship between the two sets of cues was different to during acquisition trials (Contrast trials). Error bars represent the estimated standard error of the mean.

Fig. 5 illustrates the distribution frequency of the absolute orientation for the contrast condition. The distribution of absolute orientation error frequencies was compared to an expected distribution and tested via a chi-squared analysis. The distribution was found to significantly differ from the expected distribution, $\chi^2(1, N = 28) = 41.43, p < 0.001$, $\varphi = 1.22$. The largest frequency of participants is clustered around the

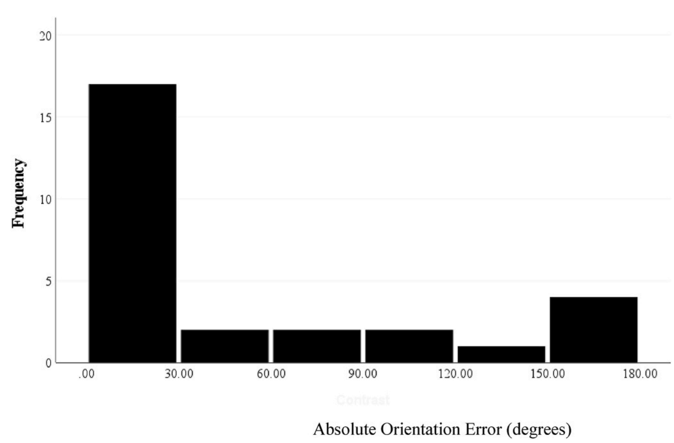


**Fig. 5.** Histogram illustrating the distribution of absolute orientation errors in the Contrast trial in Experiment 2.

0° bin. This suggests that most of the participants (17/28) were using the External Target as the orienting cue. The next largest cluster (4/28) is around the 180° bin suggesting that these four participants used the colored Wall Cues.

The results of Experiment 2 support those of Experiment 1, further suggesting the External Targets were used more to direct orientation. There was no difference between ET + WC trials and ET trials. There was, however, a significant difference between the ET + WC trials and WC trials. This is evidence of overshadowing by the more salient External Targets over the less salient colored Wall Cues. The results of the Contrast trials also suggest that in compound trials participants largely use the External Targets to decide which way to face. In the Contrast test trial, the great majority of participants chose to face in the direction indicated by the External Target (17/28) compared to the direction indicated by the colored Wall Cues (4/28).

It is possible that the poor performance in the WC trials is not due to overshadowing by the relatively more salient External Targets stopping participants being able to learn about the colored Wall Cues. An alternative possibility is that the poor control of orientation by the colored Wall Cues is merely due to the very low salience of the Wall Cues, in which case they might never gain full control of orientation, even in the absence of a salient competing cue. Experiment 3 will test this, possibility by maintaining the salience of the colored Wall Cues, but manipulating the salience of the External Targets.

## 7. Experiment 3

Caduff and Timpf (2008) proposed that the salience of a landmark depends on three factors: visual salience, such as size, contrast, luminance, and color; structural salience, due to its position within the environment, such as its proximity to a decision point within a maze; and cognitive salience, such as the familiarity or personal significance of the object to the participant. Several studies have shown the facilitating effect of familiarity on spatial tasks (Davis & Therrien, 2012; Ligonnière et al., 2021). In Experiments 1 and 2, the campus and the layout of the External Targets around the Psychology Building were assumed to be familiar to the participants as they had attended classes in the real building. The colored Wall Cues, however, were only a feature in the computer-generated model of the Psychology Building, and as such, would have been unfamiliar to the participants. Experiment 3 manipulated participants' familiarity with the External Targets in two ways. Participants in one experimental group were psychology undergraduates at the University of Southampton and so assumed to be familiar with the External Targets around the building in the computer model. However, rather than being able to see the campus landmarks such as the Physics Building through the windows, they were only able to see novel targets such as a guitar on the horizon. For a second group, data was collected from participants who had never visited the campus and thus all cues would be novel. They were exposed to the same model as participants in Experiment 1 Group Wall Cue. These experimental groups were compared to a third control group. The participants in this control group were undergraduate Psychology students at the University of Southampton and were exposed to the same model as used in Experiment 1 Group Wall Cue. To ensure participants in the unfamiliar groups were indeed not familiar with any aspect of the model, familiarity was explicitly measured as part of a self-report questionnaire. They were asked after completing the task whether they recognised the building in the model as the Psychology Building in the University of Southampton. Finally, participants were also asked whether they had used the External Targets or colored Wall Cues to keep orientated within the building.

The goal of Experiment 3 was to manipulate the salience of External Targets to clarify if the spatial cues interact in a way predicted by associative learning via overshadowing. If the previous poor performance in rooms with only Wall Cues was simply due to the low salience of the Wall Cues then there would be no improvement in performance in these rooms when the salience of the External Targets are reduced. If, however, the poor performance is due to the relatively salient External Targets overshadowing learning about the Wall Cues, as would be predicted by associative learning models, then reducing the salience of the External Targets should reduce overshadowing of the coloured Wall Cues and enhance performance in rooms where these are the only cues.

## 8. Method

### 8.1. Design

This study used a 3 (Room type; within) x 3 (Familiarity; between) mixed factorial design. The room types varied by the cues available; both External Targets and colored Wall Cues (ET + WC); colored Wall Cues only (WC); External Targets only (ET). There were 3 levels of familiarity; participants presented with a detailed virtual environment based on a real world environment they were familiar with, participants presented with a detailed environment based on a real world environment they were not familiar with, and participants presented with a basic environment containing external and internal cues they were not familiar with. The dependent variable recorded was the absolute orientation error. Planned pairwise comparisons compared the three trial types in the three groups.

### 8.2. Participants

Participants were divided into three groups: Group Familiar Detail ($n$ = 30, Age Mean = 21.5, Age Range = 18–24); Group Unfamiliar No Detail ($n$ = 31, Age Mean = 20.9, Age Range = 18–24); Group Unfamiliar Detail ($n$ = 31, Age Mean = 26.5, Range = 18–59). Participants in Group Familiar Detail and Group Unfamiliar No Detail were undergraduate Psychology students from the University of Southampton who completed the study in exchange for credit towards a research participation scheme. Group Unfamiliar Detail were elicited via an online participant recruitment platform, (Prolific), for a remuneration of £2. They were excluded if they reported that they had previously taken part in an experiment using the Psychology Building model or had visited the real University of Southampton campus.

We based the sample size on an apriori power analysis. Given we used a similar mixed design analysis as in Experiment 1, our effect-size estimate calculation was the same as that used in Experiment 1. We predicated our power analysis on the between x within factor interaction effect ($f$ = 0.07). Achieving 80 % power to detect an effect of this magnitude requires 27 participants, given $\alpha = 0.05$ (G*Power 3.1; Faul et al., 2007). We met this recruitment target.

Due to technical difficulties 5 participants from Group Familiar Detail and 2 participants from each of groups Unfamiliar Detail and Unfamiliar No Detail did not complete the three questions asked after the orientation test. These participants were excluded from the analysis of these questions.

### 8.3. Apparatus

The model was presented on a site which was accessed on each participant's computer via either a link from the School of Psychology, participant research credit site or the Prolific site. For groups Familiar Detail, and Unfamiliar Detail, the model was the same as that used in Experiment 1, and 2, but the colored Wall Cues were restricted to rooms that had a view of the External Targets (See Fig. 6).

For Group Unfamiliar No Detail, the model had the same dimensions as the original model with the same size rooms and corridors. There were, however, no internal cues such as doors, and the walls and floors were a different color from the real-world Psychology Building. There were no External Targets relating to those of the real world University of Southampton campus (See Fig. 7).

The External Target to the south of the building was a picture of the

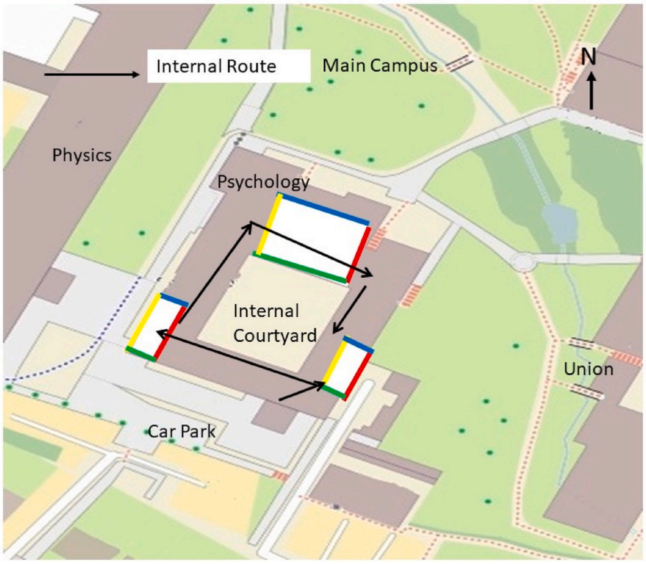


**Fig. 6.** Lay out of colored Wall Cues and routes taken through Psychology Building during acquisition trials by all three groups in Experiment 3. Lay out of External Targets for groups Familiar Detail and Unfamiliar Detail only.

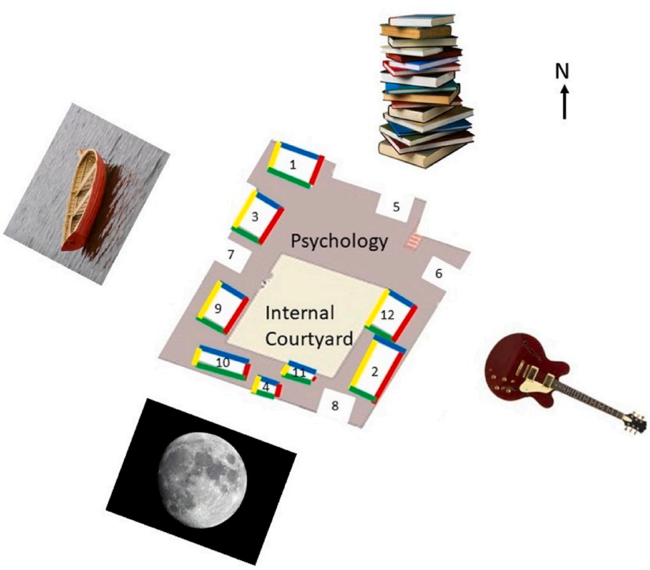


**Fig. 7.** Lay out of colored Wall Cues and position of Orientation test rooms for all three groups in Experiment 3. Trials in rooms labelled 1–4 contained views of both External Targets and colored Wall Cues (ET + WC trials). Trials in rooms 5–8 contained views of only External Targets (ET trials) and trials in rooms 9–12 contained views of only colored Wall Cues (WC trials). Lay out of External Targets for Group Unfamiliar No Detail only.

moon; to the north of the building it was a pile of books; to the west of the building it was a rowing boat; to the east it was a guitar. All External Targets were placed at the centre of the respective side of the building. The relative dimensions of the External Targets were 300 m wide x 200 m high. They were placed at a distance of 100 m from the building, and with the lower edge of the target at a height of 200 m from the base of the building. They could be seen from all of the windows of the building that the target was facing. To equate the exposure of the colored Wall Cues and the External Targets during acquisition, the colored Wall Cues were limited to rooms which had a view of at least one of the External Targets, meaning that both the Wall Cues and the External Targets were always presented together during acquisition.

### 8.4. Procedure

Unlike the previous two experiments, in Experiment 3 we did not allow participants in any of the groups to explore the area surrounding the building. This was because there were no other external features in the Group Unfamiliar No Detail model, other than the four External Targets on the horizon in the cardinal directions. We therefore limited access to level 3 of the building for all groups.

Participants were instructed to follow a path inside the building, the same as that taken in Experiments 1 and 2 (Please see Fig. 6 for the layout of colored Wall Cues and route taken by participants). Orientation trials took place in rooms that had not previously been visited during the acquisition trials. Participants were teleported into each room and requested to face an occluded External Target. There were 4 trials where both an External Target and colored Wall Cues were available and appeared as they had during the acquisition phase (ET + WC). There were 4 trials where only an External Target was visible (ET). There were 4 trials where only the colored Wall Cues were present (WC) (Please see Fig. 7 for position of Orientation trial rooms and cues). The order of these trials were randomly assigned so that no trial type was repeated in two consecutive trials.

Following the orientation trials, participants were asked to rate the accuracy of the following statements on a scale of 1 *(I disagree with the statement strongly)* to 6 *(I agree with the statement strongly)*:

I recognised the building in the study as the University of Southampton Psychology Building
I used the colored Wall Cues to orientate myself in the test trials
I used the External Targets to orientate myself in the test trials

## 9. Results

Fig. 8 presents the mean absolute orientation error for the three different room types in the three conditions. The performance varied across the rooms in a different manner for the three conditions. Group Familiar Detail had the highest absolute orientation error in the rooms where there were only colored Wall Cues. Both groups Unfamiliar Detail, and Unfamiliar No Detail had the highest absolute orientation error in the rooms where only the External Targets were available.

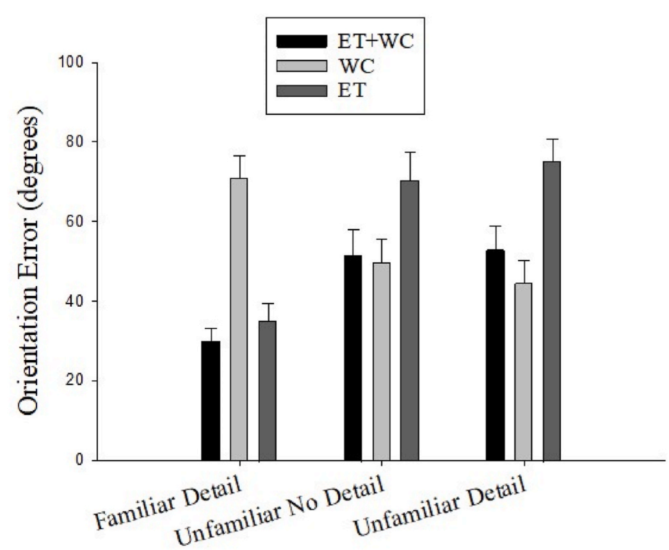


**Fig. 8.** Mean absolute orientation error in Experiment 3 during test trials containing views of both External Targets and colored Wall Cues (ET + WC trials), trials containing views of only external targets (ET trials) and trials containing views of only colored wall cues (WC trials) for Group Familiar Detail, Group Unfamiliar Detail and Group Unfamiliar No Detail. Error bars represent the estimated standard error of the mean.

A 3 Trial (ET + WC/ET/WC) X 3 (Condition) mixed design ANOVA was used to analyze the data. Absolute orientation error was the dependent measure. There was a main effect of Trial, $F(2, 178) = 6.87$, $p = 0.001$, $\eta_p^2 = 0.07$, 90 % CI = [0.018, 0.133] indicating that there was a difference in participants' ability to orient across the three trials. There was a significant Trial × Condition interaction $F(4, 178) = 12.92$, $p < 0.001$, $\eta_p^2 = 0.23$, 90 % CI = [0.127, 0.295]. The use of simple main effects (Keppel, 1973) revealed that there was a significant effect of trial type in all three conditions (Group Familiar, $F(2, 88) = 17.18$, $p < 0.001$, $\eta_p^2 = 0.28$, 90 % CI = [0.146, 0.386]; Group Unfamiliar No Detail, $F(2, 88) = 4.69$, $p = 0.012$, $\eta_p^2 = 0.10$, 90 % CI = [0.013, 0.189]; Group Unfamiliar Detail, $F(2, 88) = 8.67$, $p < 0.001$, $\eta_p^2 = 0.17$, 90 % CI = [0.053, 0.268]). In a series of planned post hoc Bonferroni corrected pairwise comparisons of the three trials in each of the three groups, it was found that for Group Familiar the absolute orientation error was greater in the WC trials (71°) than in both the ET + WC (30°) and ET (35°) trials, $p < 0.001$. For Group Unfamiliar No Detail the absolute orientation error was greater in the ET (70°) trials than in both the ET + WC (52°) and WC (50°) trials, $p = 0.025$. The same was true for Group Unfamiliar Detail, the absolute orientation error was greater in the ET (75°) trials than in both the ET + WC (52°) and WC (45°) trials, $p = 0.006$.

In a series of correlations across all participants in the three conditions it was found that the rating of agreement to the statement "I used the colored Wall Cues to orientate myself" was significantly negatively correlated to the absolute orientation error in the WC trials, $r(79) = -0.37$, $p < 0.001$, 90 % CI = [-0.518, −0.193]. This meant that lower absolute orientation errors were associated with higher ratings for use of the colored Wall Cues. Similarly, the agreement with the statement "I used the External Targets to orientate myself" was significantly negatively correlated to the absolute orientation error in the ET trials, $r(79) = -0.26$, $p = 0.046$, 90 % CI = [-0.395, −0.040].

Finally a one-way between groups ANOVA with ratings of the statement "I recognised the building in the study was the University of Southampton, Psychology Building" as the dependent variable produced a significant effect of condition, $F(2, 79) = 74.91$, $p < 0.001$, $\eta_p^2 = 0.66$, 90 % CI = [0.543, 0.719]. Post hoc Bonferroni corrected pairwise comparisons revealed that participants in Group Familiar Detail rated that they agreed with the statement ($M = 5.68$, $SD = 0.69$) more strongly than both Group Unfamiliar No Detail ($M = 2.67$, $SD = 1.92$), and Group Unfamiliar Detail ($M = 1.44$, $SD = 0.69$), $p < 0.001$. Group Unfamiliar No Detail rated their agreement with the statement more strongly than Group Unfamiliar Detail, $p = 0.002$.

The results of Experiment 3 suggest that the poor performance in the rooms with only colored Wall Cues, seen in Experiment 1 and 2, was not simply due to the low salience of this cue type. If this was the case, then decreasing the salience of the External Targets should have made no difference to the performance in the WC trials. However, in groups Unfamiliar No Detail, and Unfamiliar Detail, the performance in the rooms with only the colored Wall Cues was as good as in ET + WC trials and better than in the ET trials. These results suggest that the poor performance in Group Familiar Detail in the WC trials, and in the equivalent groups in Experiments 1 and 2, was due to an interaction between the salient External Targets and the colored Wall Cues. This interaction would be predicted by associative learning models via a process of overshadowing and is a novel finding within a nested environment.

## 10. General discussion

This series of studies examined what type of cues could facilitate orientation within a virtual nested environment, and whether the interaction between the cues could be predicted by associative learning models. Experiment 1 illustrated that a view of a single External Target allowed participants to maintain their orientation to the other parts of the occluded external environment. Orientation in the internal rooms was also aided by allowing the participants the opportunity to have visited the room during acquisition. Finally, colored Wall Cues, which had a fixed spatial relationship with the External Targets, also improved orientation. Performance in rooms with just the colored Wall Cues was worse than performance in rooms with just a view of an External Target or both External Target and colored wall cues. This result suggests that External Target, was more salient than the colored Wall Cues and overshadowed the Wall Cues when presented together.

Experiment 2 similarly found that performance in rooms which contained just the colored Wall Cues (WC trials) was worse than in rooms allowing a view of an External Target (both ET and ET + WC trials). Experiment 2 further investigated the extent to which each cue, External Targets or colored Wall Cues controlled orientation within a compound trial containing both cue types. It did this by presenting Contrast trials, where the cue types were presented together but in a formation that indicated different directions for the occluded target. Results suggested that participants primarily used the External Targets within the contrast trials. The majority of participants faced in the direction indicated by the External Target. Overall, results suggest that orientation was controlled by the view of the External Targets.

Associative learning models, such as Rescorla and Wagner's (1972) model, would predict the dominance of a more salient cue via a phenomenon called overshadowing. In this case it would appear that the External Targets were more salient and so participants learn the spatial relationship between the External Targets more quickly rather than the relationship between the External Targets and the less salient, simultaneously presented, colored Wall Cues. When the colored Wall Cues are presented by themselves, they have less control over orientation. It has to be acknowledged that the presentation of cues in Experiments 1 and 2 was not the same as in typical demonstrations of overshadowing. For example, in Redhead and Hamilton (2007) the two sets of competing cues were always presented together during training. In Experiment 1, and 2 of the current paper, during acquisition trials, the colored Wall Cues were sometimes presented in rooms where there was no view of an External Target. Despite this difference, the results in Experiments 1, and 2 are consistent with previous demonstrations of overshadowing in the spatial domain (Chamizo et al., 1985, 2003; Redhead et al., 1997; Redhead & Hamilton, 2007, 2009). In addition, in Experiment 3, the Wall Cues were only ever presented in rooms where there was a view of an External Target, and the results of Group Familiar Detail found overshadowing of the colored Wall Cues by the view of the External Target.

It was possible that the results of Experiments 1 and 2 were not due to overshadowing caused by the interaction between the External Targets and the colored Wall Cues, but simply the low salience of the colored Wall Cues. If the latter was the case, then reducing the salience of the External Targets should make no difference to the ability of the colored Wall Cues to control orientation. Experiment 3 manipulated the salience of the External Targets by either using an unfamiliar array of External Targets, or using participants that were unfamiliar with the University of Southampton campus. Caduff and Timpf (2008) have suggested one feature which increases the salience of a landmark is familiarity with that landmark. Participants that were familiar with the External Targets, had smaller absolute orientation errors in the rooms with only an External Target present, suggesting that the External Targets overshadowed the colored Wall Cues as in Experiments 1 and 2. However, participants that were unfamiliar with the External Targets, had smaller absolute errors in the rooms with only the colored Wall Cues, suggesting the colored Wall Cues had overshadowed the unfamiliar and thus now relatively less salient External Targets. This set of results could not occur if the colored Wall Cues were simply too low in salience for participants to ever form an association with the colored Wall Cues and the External Targets array. The interaction between the cues could only be predicted by the associative process of overshadowing.

Previous demonstrations of overshadowing have occurred in environments that Montello (1993) described as vista space, where all of the cues used to navigate to a goal could be viewed from any position within the environment. This is not true for the nested environment used in the current series of experiments where cues are obscured in what Montello described as an environmental space. It could be argued that this type of nested environment is much more akin to our everyday environments within buildings and cities. The current results, therefore, are a novel demonstration of overshadowing in a nested environment and show how associative learning models can predict the way in which cues interact in spatial learning.

### *10.1. Limitations and future directions*

Within traditional real-world environments, spatial updating acts to ensure that individuals retain knowledge of their local environment, do not collide with near objects as they move and enables the tracking of distant targets. Evidence suggests that vestibular and idiothetic information are central in enabling accurate spatial updating processes to occur (Lackner & DiZio, 2005). Vestibular and other body movement cues are not, however, available when examining digital spaces; consequently, tracking object locations within such spaces is potentially a greater challenge than within the real world. Indeed, Witmer et al. (1996) demonstrated that the acquisition of survey knowledge and orientation accuracy is reduced within digital compared to real world environments. Further, previous research (Du et al., 2021; Lei et al., 2020; Mou & Wang, 2015) on cross-boundary navigation within a nested environment such as the ones used in the current experiments has shown the facilitating effect of idiothetic cues on spatial updating. It must also be acknowledged that by teleporting participants into rooms in the test trials of the current studies we were removing even more cues such as optic flow. The results of Experiment 1 indicated that participants that had been allowed to visit the rooms before testing performed better than in unvisited rooms. Presumably this was due to exploration allowing the participants to understand where the room was in relation to the External Targets. It is imperative to test the findings of the present study in a real environment, where teleportation would not be possible.

Experiments 2 demonstrated that the External Targets overshadowed the internal colored Wall Cues. It was assumed that this was due to the familiarity participants had with the External Targets compared to the colored Wall Cues, leading the External Targets to be more salient. This assumption was supported by the findings of Experiment 3, where the familiarity with the External Targets was reduced and the External Targets were no longer found to overshadow the Wall Cues. However, whereas the familiarity with the External Targets and Psychology Building was explicitly measured in Experiment 3, this was not the case in Experiment 2. Therefore, in order to confirm that familiarity played a role in the overshadowing of the internal cues, it would be advantageous to repeat Experiment 2 with an explicit measure of familiarity with the Psychology Building and University of Southampton campus.

A possible alternative explanation for the findings in Experiment 2, that performance in WC trials was worse than in ET + WC trials, might be that the colored Wall Cues could control orientation but only in the presence of the External Targets. Such potentiation of a weak spatial stimulus when in combination with a more salient stimulus has been demonstrated by Pearce et al. (2006). To test this suggestion, it would be necessary to compare the results with participants that had not been exposed to the External Targets and colored Wall Cues in combination. However, given the distribution of participant responses in the Contrast trial presented in Experiment 2, where 17 out of 28 participants face in the direction indicated by the External Target, and only 4 out of 28 face in the direction indicated by the colored Wall Cues, such potentiation does not seem likely.

Experiments 2 and 3 focus on the interaction between the two sets of visual cues, External Targets and colored Wall Cues. However, the finding in Experiment 1 that there was no difference between compound and individual trials involving previous experience and External Targets, is intriguing and deserves further investigation. It must be acknowledged that the mean absolute orientation error in the test trials containing only individual cue types was numerically worse than in the compound trial (External Targets = 40°, Rooms previously visited = 48°, compound trials = 32°). It might be that this was a Type II error and with a larger sample the difference between both single cue type trials may prove significantly different from the compound trial. This would be predicted by associate learning models if the cues were of equal salience. In which case neither cue would acquire full associative strength during the compound trial.

It must be acknowledged that the diversity within the samples used in Experiment 1 and 2, and groups Familiar Detail and Unfamiliar No Detail, was fairly constrained with more females than males of university age. It is reassuring that the more equal gender divide in Group Unfamiliar Detail provide similar results to Group Unfamiliar No Detail. However, given the evidence of sex (Nazareth et al., 2019) and age (Kirasic, 2000; Leon et al., 2015) differences within human navigation skills, it would be prudent to repeat the studies with a more diverse sample.

The results add to the literature on wayfinding in buildings such as care homes (O'Malley et al., 2017) and health care facilities (Devlin, 2014). Particularly the results that illustrate that a view of an External Target can facilitate orientation. This result adds to the growing literature on the importance of building design in facilitating navigation and orientation within buildings (Carlson et al., 2010, Jiang et al., 2021). The results of Experiment 3 in the present paper, illustrates the facilitating effect of colored Wall Cues on orientation in an unfamiliar environment. The Wall Cues would be thus of particular help for new residents moving into a care home. Thus, the results add to the literature of signage within buildings (Guo & He, 2022).

### *10.2. Conclusion*

Overall, the results confirm previous findings (Wang & Brockmole, 2003a) that it is difficult to maintain orientation within in a building. Providing a view of an external landmark or internal colored wall cues or the opportunity to visit a room will allow a participant to maintain orientation. The current study provided novel demonstrations of how two of these factors interact. This interaction has been shown to be governed by associative learning models and it is a novel demonstration of the associative phenomenon of overshadowing in a nested environment. Finally, Experiment 3 supports research showing familiarity with a landmark can enhance its salience (Davis & Therrien, 2012). It demonstrates for the first time that manipulating familiarity can affect how well spatial cues can be used in a nested environment.

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**Ethics statement**

All three experiments reported in the paper were approved by the University of Southampton's Ethics Committee.

**Disclosure of interest**

The authors report no conflict of interest.

**CRediT authorship contribution statement**

**Craig Allison:** Writing – original draft. **Antony P. Wood:** Software. **Edward S. Redhead:** Writing – review & editing, Conceptualization.

## Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jenvp.2024.102259.

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