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# The Effects of Goal–Landmark Distance on Overshadowing: A Replication in Humans (*Homo sapiens*) of Goodyear and Kamil (2004)

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Goodyear and Kamil (2004) assessed the ability of Clark's nutcrackers to find buried food based on a cross-shaped array of landmarks at different distances from the goal. Their findings suggested that proximal landmarks overshadowed learning about distal landmarks, and this was attenuated when assessing the effect of distal landmarks on learning about proximal landmarks. In this study, we aimed to replicate their findings in human spatial navigation by using a virtual environment. Three groups of participants were trained in an open environment featuring orientation cues, and they had to find a hidden goal with reference to four landmarks that were arranged in the shape of a cross and placed at different distances from the goal. Two of the four landmark distances were common across all three groups to allow a comparison of the extent of overshadowing under comparable conditions. Following training, all participants were tested with each of the four landmarks individually. Consistent with the results in birds, we observed better performance in the groups with more distal landmarks, suggesting that overshadowing was greater in the groups with closer landmarks and thus dependent on the spatial distance between the landmarks and the goal. Landmarks near the goal more effectively overshadowed landmarks far from the goal. A second experiment, in which landmarks and orientation cues were misaligned in order to prevent the use of a straightforward solution to the task, replicated the results. The results are discussed in terms of a modification of Pearce's configural model.

**Keywords:** spatial cognition, overshadowing, competition, proximity, distance

**Supplemental materials:** <https://doi.org/10.1037/com0000362.supp>

In spatial learning, landmarks are defined as conspicuous environmental features that can be processed and retrieved for encoding locations (Waller & Lippa, 2007; Zhou & Mou, 2019). Research across a variety of species such as gerbils (Collett et al., 1986), rats (March et al., 1992), honeybees (Cheng et al., 1987), jays (Bennett, 1993), and pigeons (Spetch, 1995) has shown that landmarks have an uneven behavioral control for goal finding based on their distance to targets. It has also been observed that different species differ in the manner they process metric information (for a review, see Cheng & Spetch, 1998).

For instance, Chamizo and Rodrigo (2004) trained rats in a Morris Water Maze in the presence of landmarks placed at different distances from the hidden platform. In Experiment 2, one group was trained with a landmark 50 cm away from the goal (i.e., Group Near), and its performance was compared to a group trained with the landmark located 110 cm away from the goal (Group Far). They observed that Group Near showed a significantly more accurate searching preference than Group Far during a test in which the goal was removed. In other words, rats were better at locating the goal

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These findings were presented at the Pavlovian Society's annual meeting (2022).

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and investigation, and served in a supporting role for writing—original draft and writing—review and editing. Gonzalo P. Urcelay served as lead for funding acquisition, project administration, and supervision and served in a supporting role for writing—original draft and writing—review and editing.

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the presence of landmarks near to the goal in comparison with landmarks far from the goal. This shows evidence that rats are sensitive to distance manipulations during spatial learning.

Spetch (1995) assessed the effect of a variety of landmarks on the control acquired by a specific landmark. Pigeons as well as students were trained in a spatial search task using a touch screen. They had to search for a hidden goal, with the aid of different 2D graphic visual stimuli as landmarks that were placed at different distances from the goal. Participants (i.e., birds and undergraduates) were trained with a landmark (target landmark hereafter) near the invisible goal location and a second landmark placed far from the goal location. During control conditions, these were the two landmarks presented during training. During overshadowing conditions, a third landmark, closer to the goal location than the target landmark, was also presented during training. At issue was whether this third (closer) landmark would overshadow learning to find the goal in the presence of the target landmark. Spetch found that the control acquired by the target landmark when tested alone was significantly better when it was trained only with the far landmark, relative to when it was trained with the far and closer landmarks in the compound. In other words, in both pigeons and humans, learning about a landmark was overshadowed when trained together with a compound that included a closer landmark. This shows evidence that learning to locate a goal with reference to a landmark depends not only on the absolute distance between them but also on their relative distance with other stimuli present during learning (for a review about distance estimations in pigeons, see Cheng et al., 2006). Overall, there is clear evidence that different species are sensitive to spatial distance. Little is known, however, about how these visual features interact with each other in 3D environments.

Competition between different types of spatial cues (e.g., landmarks and geometric cues) is a phenomenon where dedicated modular processes such as the geometric module hypothesis (Cheng, 1986) and domain-general associative theories (e.g., Mackintosh, 1975; N. Y. Miller & Shettleworth, 2007; R. R. Miller & Matzel, 1988; Pearce & Hall, 1980; Rescorla & Wagner, 1972) have been contrasted. Across humans and other species, competition between features and boundary information has been documented in some reports (e.g., Austen & McGregor, 2014; Herrera et al., 2022) but not in others (Pearce et al., 2001; Redhead & Hamilton, 2007), and hence there is evidence in favor of both families of theories, which has led to numerous debates (e.g., Jeffery, 2010; Pearce, 2009).

Urcelay (2017) reviewed the theoretical implications of the disparate cue competition findings across species and preparations and suggested that cue-interaction phenomena should be understood as a continuum that ranges from cue competition to facilitation, with a diversity of outcomes (including an intermediate point in which competition is not observed). According to Urcelay, the different outcomes may result from the use of different task parameters such as the proximity between predictive signals and an outcome.

Consistent with this notion, Herrera et al. (2022) trained human participants in a kite-shaped virtual arena, requiring them to locate an invisible goal. The control group was trained with only boundary information (i.e., the shape of a kite), whereas the experimental groups were trained in the same environment, but in the presence of an additional source of information, a landmark (i.e., a portion of the wall was painted in a different color). The landmark–goal distance (i.e., proximity) was systematically manipulated, and competition between landmark and boundary information was consistently

observed when the landmark was proximal to the goal (i.e., in the same corner where the goal was located), but not when it was placed distal from the goal (i.e., in the opposite corner). These results suggest that spatial proximity has a critical role in the observation of competition between events in human spatial navigation. However, the distances were constrained to the size of the arena itself (i.e., landmarks were either proximal or distal to the goal location), and thus, Herrera et al. were unable to observe a gradient in the degree of competition based on spatial distance. Establishing that proximity is a determinant of competition in the spatial domain with only two outcomes (competition vs. no competition) leaves open the possibility that different strategies are involved in each outcome. For example, it could be possible that participants used a beacon strategy (walk toward the landmark) for the close landmark but not for the distal landmark, and this is what resulted in overshadowing of geometry learning by the close landmark relative to the distal one. In addition, Cheng et al. (2007), using a Bayesian framework, provided functional explanations on how cues can be combined and become integrated, or not, and hence compete with each other. They argued that depending on how well the cues signal where the goal is, they receive different weights, thus affecting their influence on performance. That is, cues are weighted depending on landmark–goal distances, with subjects relying more heavily on the closer landmarks relative to the more distal ones. In other words, with longer landmark–goal distances, landmarks are weighted less strongly, so less competition is to be expected. Thus, documenting the dependence of overshadowing with multiple levels of proximity may better support the notion that spatial distance results in differential weighting of the landmarks (also see Chamizo & Rodrigo, 2004; Chamizo et al., 2006).

Relevant to this last issue is a study by Goodyear and Kamil (2004), who reported an experiment assessing the effect of spatial distance on cue competition in food-storing Clark's nutcrackers (*Nucifraga columbiana*). Building on the 2D experiments by Spetch (1995), they trained birds to locate buried seeds in the presence of a cross-shaped array of four landmarks (i.e., poles of different patterns and colors) that differed in terms of goal–landmark distances for each group. Birds allocated to Group Close were trained with landmarks placed at 30, 50, 70, and 90 cm from the goal, birds allocated to Group Medium experienced training with landmarks placed at 50, 70, 90, and 110 cm from the goal, and birds allocated to Group Far were trained with landmarks placed at 70, 90, 110, and 130 cm from the goal. Following training, all birds were tested with each individual landmark separately, and their performance (i.e., distance error from the goal) was measured. The critical performance comparison between the three groups was in estimating the goal location in the presence of landmarks at 70 and 90 cm from the goal, which was common across all three groups. Goodyear and Kamil's design allowed for the examination of relative (i.e., within-group comparisons) and absolute (i.e., between-group comparisons) goal–landmark distances on competition. When assessing performance to the closest common landmark (i.e., the landmark at 70 cm), they observed worse performance in Group Close relative to Group Far, suggesting that overshadowing decreased as landmark–goal distances increased, a finding that is consistent with the literature reviewed by Urcelay (2017) suggesting that spatial (and temporal) contiguity (i.e., distance) is a critical determinant of competition.

Unlike the findings by Herrera et al. (2022), the design used by Goodyear and Kamil (2004) revealed the presence of a competition gradient with three different levels. This, however, raises the

question of whether this finding is unique to the spatial abilities of Clark’s nutcrackers or can also be observed in human participants. It is noteworthy that whereas birds experienced the environment from a top-down view, participants did it from a first-person perspective, as they would do in real-life scenarios. Therefore, in order to better understand the dependency of competition on spatial distance (absolute and relative), and the effect that an array of landmarks placed at different distances from the goal have on human navigation, we aimed to replicate as closely as possible the Goodyear and Kamil study in two experiments. In each experiment, three groups of human participants were each trained with four distinct landmarks arranged as a cross with a hidden goal in its center (see Figure 1). Landmarks were placed at different distances from the goal, in Group Close, these were located at 10, 30, 50, and 70 virtual units (VUs) from the goal. For Group Medium, these were located at 30, 50, 70, and 90 VUs, and for Group Far, these were located at 50, 70, 90, and 110 VUs. Note that all groups were trained with landmarks at 50 and 70 VUs and these were the target cues which we were most interested in because behavioral control by these could be subject to competition from the alternative cues that were either closer to the goal in Group Close, or further from the goal in Group Far (in Group Medium, one of the alternative landmarks was closer and was further away). Based on Goodyear and Kamil’s findings, we anticipated that landmarks near the goal would overshadow landmarks far from it, but this effect should decrease as the overall landmark–goal distances increase.

### Experiment 1

#### Method

##### Participants

One hundred and twenty-seven participants (of which 65 identified as female, 60 as male, one as “Other”, and one preferred not to say) with a mean age of 26 years (range 18–50 years) were recruited through Prolific ([www.prolific.co](http://www.prolific.co)) and were given monetary compensation in return. Participants were randomly allocated to Groups Close, Medium, and Far. We aimed to recruit around 40 participants per group in line with our previous studies in humans

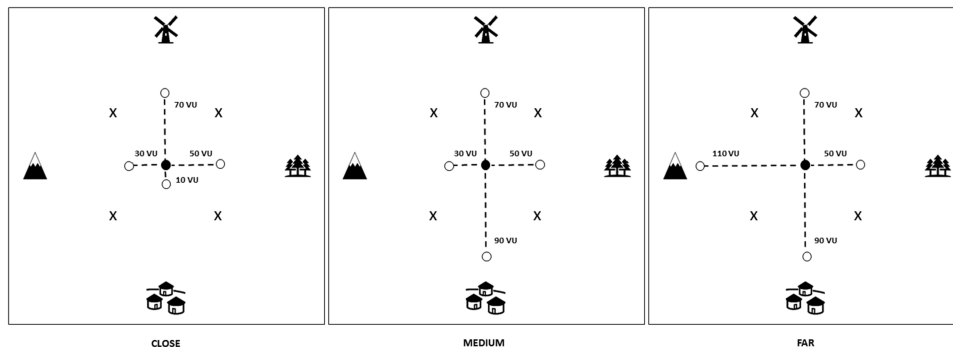
(Herrera et al., 2022). Because this is the first time that this task was used with human participants, we could not calculate a priori power analyses. Ethical approval was obtained from the Psychology Ethics Committee at the University of Nottingham. Informed consent was obtained from each participant in this experiment and in the subsequent one.

##### Apparatus and Materials

All virtual environments were built using Unity game engine (Version 2019.4.0f1 for Windows; Unity Technologies, San Francisco, California, United States,) and deployed as WebGL applications that participants could run in their browsers. The environmental setup was inspired by Goodyear and Kamil (2004) except that our experiments were conducted in an open field environment rather than in an enclosure. In order to allow participants to know where they were heading during test trials and to make the experiment more realistic, orientation cues were incorporated. Participants were tasked to find a buried seed (i.e., the hidden goal) under the guise of being a farmer and needing to provide it with water, which could be located by reference to a landmark array. The environment was viewed from a first-person perspective at a height of 1.6 VUs. The environment was created such that 1 VU was equivalent to 1 m. The arrays differed in terms of the distances between the goal location and the landmarks. The goal was set at the intersection of two virtual axes connecting the landmarks opposite to each other in the array. Each group was trained with a different landmark array: Group Close was trained with the landmarks set at 10, 30, 50, and 70 VUs from the goal; Group Medium had landmarks at 30, 50, 70, and 90 VUs; and Group Far was trained with the landmarks placed at 50, 70, 90, and 110 VUs (see Figure 1). Each of the four unique black and white landmarks featured distinct patterns (horizontal stripes, a chevron pattern, vertical stripes, and a checkerboard pattern). Landmark identity (i.e., the distinct patterns) was randomized between participants, but was kept constant through the experiment for each participant.

Four orientation cues were used. These were a windmill, a village, a snow-capped mountain, and a forest. These four cues formed a cross-shape, and the array of cues was randomly rotated (at 90° intervals) for each participant. The center of the mountain and the forest were located at a distance of approximately 240 VUs from the goal,

**Figure 1**  
*Experimental Design for Each Group in Experiment 1*



*Note.* Black circles represent the goal location, white circles represent distinct landmarks, and the orientation cues (windmill, forest, village, and mountain) can be seen aligned with the landmarks. X represents the four possible starting points for each trial. Goal–landmark distances are expressed in virtual units (VU).

and the windmill and the village were at 210 and 160 VUs, respectively. Importantly, these were aligned with each landmark in such a way that if the participants were located in the center of the array, each orientation cue appeared just behind each landmark (see the layout in Figure 1). The landmark pattern arrangement was counter-balanced across participants. Traveling straight from any of the start points to the goal took approximately 9 s (speed 8 VUs/s).

As with the landmarks, this array rotation remained constant during training and test for each participant. Some irregular mounds behind the orientation cues provided more orientation information. A grass texture was applied to the ground and a clear sky was applied to the skybox. The goal–landmark array kept the same orientation in relation to the orientation cues throughout training and test (see Figure 2 for a picture of the environment and search space).

### Procedure

The experiment had two phases, training and testing. During training, participants experienced 16 trials in the presence of the four landmarks, and they were tasked to locate an invisible goal (i.e., a buried seed). Thus, the four landmarks were key to finding the exact goal location during training. At the beginning of each trial, participants were released facing in a random direction from one of the four corners of an invisible square of  $100 \times 100$  VUs, with the goal in its center. Thus, the four starting points were placed at a distance of 71 VUs from the goal (see Figure 1). They began the trials once from each corner per block in a random order. To navigate, participants used the up arrow key to move forward, the down arrow key to move backward, and the left and right arrow keys to rotate counterclockwise and clockwise, respectively, with a turning speed of  $60^\circ$  per second. Latencies to find the goal were recorded during training. If participants did not find the buried seed within 60 s, a corn plant within a blue light column was presented at the goal location to aid participants in learning the exact goal location. Once they reached the goal, participants could no longer move forward and backward, and a congratulatory message was displayed encouraging them to rotate  $360^\circ$  and attend to their surroundings. After 10 s, the next trial started automatically.

During the test phase, participants experienced a total of four blocks of tests, each block comprised of four single landmark tests with each of the landmarks (i.e., three of the four landmarks were

removed in each test). The order of landmark presentations during blocks was pseudorandomized with the constraint that the different landmarks were presented once within each block (always featured at their original location). Participants were asked to move to the exact goal location and press the “G” key once they thought they had located it (no feedback was provided during testing). Following Goodyear and Kamil (2004), the distance from where the participant thought the goal was located to the true goal location was calculated for each test trial and measured in VUs.

### Statistical Analyses

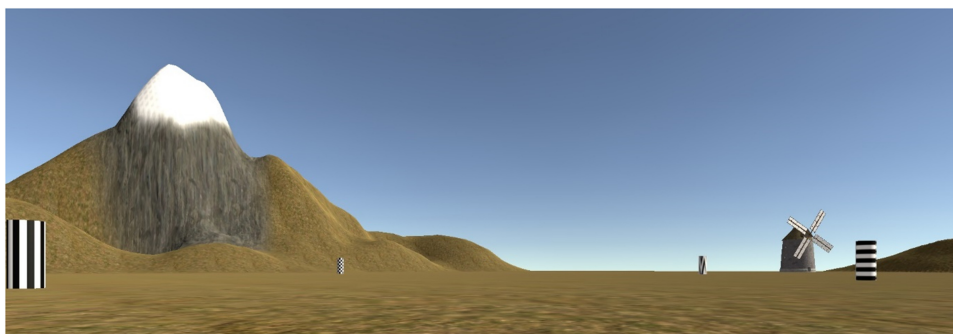
Participants who took more than 60 s to find the goal on Trials 15 and 16 of training were excluded from all analyses as this was taken as an indication that they had not adequately learned the task. For training, a mixed analysis of variance (ANOVA) was used, and for testing, a mixed ANOVA and one-way ANOVAs were used. During the single-landmark tests (i.e., four blocks of four trials, one of the four landmarks present at a time), the distance between where participants signaled the goal was located and its actual location (i.e., distance error) was averaged across the four single-landmark tests. The 50 and 70 VU landmarks (i.e., the two landmarks that all groups had in common) were then averaged for each participant to obtain a better estimate of their performance. Bonferroni post hoc tests were used to further investigate significant omnibus ANOVAs or interactions. All statistical analyses are reported with two-tailed levels of significance and alpha set at .05. In repeated-measures analyses, the Huynh–Feldt correction was used to adjust degrees of freedom when the sphericity assumption was violated.

### Transparency and Openness Statement

We report how we determined our sample size and explained all data exclusions (if any), all manipulations, and all measures in the study. The data reported in this article are available at <https://doi.org/10.17639/nott.7267>. Data were analyzed using IBM SPSS Statistics (Version 27). This study’s design and its analysis were not preregistered. The task was programmed using Unity and the materials are available upon request. Videos of the task can be found at <https://osf.io/djwsy/>.

**Figure 2**

*A Screenshot of the Search Space of Experiment 1, Featuring the Four Landmarks Placed at Different Distances From the Invisible Goal and Two of the Four Orientation Cues, a Mountain, and a Windmill*



*Note.* See the online article for the color version of this figure.



## Results

### Training

Twenty-one participants (13 female and 8 male) failed to reach the learning criterion stated above and were excluded from all analyses. The total sample size analyzed was therefore 106 participants with a mean age of 26 years (range: 18–47 years). Hence, there were 44 participants in Group Close and 31 participants in Group Medium and Group Far.

Figure 3A shows the latencies to find the invisible goal during training for each group across the 16 training trials. The figure indicates that latencies decreased across groups as training progressed, with participants in Group Close finding the goal in the shortest time. A mixed ANOVA with group as a between-subjects factor (Close, Medium, and Far) and trial as within-subjects factor (1–16) was conducted. The ANOVA revealed a significant main effect of Trial,  $F(8.16, 840.47) = 77.40, p < .001, \eta_p^2 = .43$ , 90% confidence interval (CI) [.38, .46], indicating that participants found the goal quicker as training progressed. There was a significant main effect of group,  $F(2, 103) = 3.88, p = .024, \eta_p^2 = .07$ , 90% CI [.01, .14] and a significant Group  $\times$  Trial interaction,  $F(16.32, 840.47) = 1.65, p = .050, \eta_p^2 = .03$ , [.00, .03], suggesting that there were significant differences in performance among groups. A follow-up Bonferroni-corrected post hoc analysis on the main effect of group revealed that Group Close performed better than Group Far ( $p = .028$ ), a result which is consistent with Goodyear and Kamil's (2004) findings. Group Medium did not differ from either Group Close or Far. A one-way ANOVA comparing the performances of the groups in the last training trial revealed that they did not differ from each other,  $F(2, 103) = 1.53, p = .222, \eta_p^2 = .03$ , 90% CI [.00, .09].

### Test

The results of the goal–landmark distance errors per group are depicted in Figure 3B and indicate that participants, irrespective of their group, were more accurate in identifying the goal location with the closer landmarks than with the more distal landmarks. The

differences between landmarks were less pronounced for Group Far, which displayed somewhat similar levels of accuracy across landmarks. A representative sample of the paths that the subjects traversed in search of the goal can be found in the online supplemental materials.

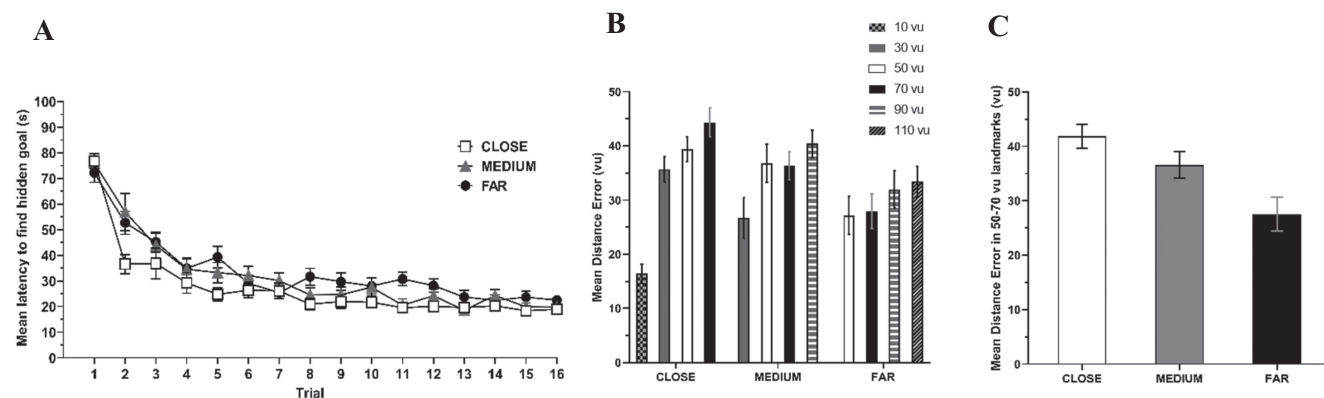
A mixed ANOVA with a between-subjects factor of group (Close, Medium, and Far) and a within-subjects factor of landmark (1–4; 1 = *being the closest to the goal* and 4 = *the furthest*) revealed a significant main effect of landmark,  $F(2.88, 297.10) = 33.50, p < .001, \eta_p^2 = .25$ , 90% CI [.17, .31], no main effect of group,  $F(2, 103) = 1.20, p = .304, \eta_p^2 = .02$ , [.00, .07], but a significant Group  $\times$  Landmark interaction,  $F(5.77, 297.10) = 6.70, p < .001, \eta_p^2 = .12$ , [.05, .16]. As each group was trained with a unique landmark array, we carried out separate analyses for each group. These analyses revealed an effect of landmark in Group Close with a large effect size,  $F(3, 129) = 48.85, p < .001, \eta_p^2 = .53$ , 90% CI [.42, .60], an effect of landmark in Group Medium with a smaller effect size,  $F(2.32, 69.63) = 5.69, p = .003, \eta_p^2 = .16$ , [.03, .27], but no effect of landmark in Group Far in which the effect size was the smallest,  $F(3, 90) = 2.47, p = .067, \eta_p^2 = .08$ , [.00, .15]. These results indicate that the extent to which closer landmarks overshadowed distal landmarks was attenuated in Group Far. These results replicate those reported by Goodyear and Kamil (2004) in Clark's nutcrackers.

As all three groups were trained with the 50 and 70 VU landmarks, we averaged the distance error for these two landmarks for each participant and conducted a one-way ANOVA with group as the independent variable (Close, Medium, and Far). This analysis revealed significant differences between groups  $F(2, 103) = 8.08, p = .001, \eta_p^2 = .14$ , 90% CI [.04, .23]. Bonferroni post hoc analyses revealed that the distance error was significantly higher for Group Close relative to Group Far ( $p < .001$ ; see Figure 3C). Group Medium did not differ from Group Close ( $p = .424$ ) or Group Far ( $p = .064$ ).

## Experiment 2

Although the observations in Experiment 1 are entirely consistent with Goodyear and Kamil's (2004) findings, we cannot completely

**Figure 3**  
Performance During Training and Testing in Experiment 1



*Note.* Panel (A) shows the mean latencies to find the hidden goal for the three groups across the 16 training trials (smaller values indicate better performance). Panel (B) represents the mean distance error per landmark across groups. Panel (C) depicts the averaged distance error estimation for the 50 and 70 VU landmarks for each group. Error bars show  $\pm$  standard error of the mean. VU = virtual units.

rule out that alternative explanations aside from spatial distance manipulations can account for our results. For instance, participants might have simply learned to align a landmark with an orientation (i.e., background) cue and then walk toward it. Hence, it could be possible that participants in Group Close found it easier to align the 10 VU landmark with an orientation cue compared to, say, participants in Group Far, who had to align a 90 VU landmark with an orientation cue, just because the sizes of the landmarks on the screen were different (i.e., the 10 VU landmark is closer to the participant when aligning with an orientation cue, therefore taking up more space on their field of view and allowing a more accurate alignment). This might explain why there was a greater overshadowing effect in Group Close. Therefore, to ensure our spatial distance manipulations were the only factor affecting competition between landmarks, in Experiment 2, we conducted a similar experiment but misaligned the orientation cues relative to the landmarks. If the effect observed in Experiment 1 was due to landmark–goal distances, we anticipated that rotating them  $45^\circ$  from their original position should result in the same qualitative pattern of data, although overall performance may be slightly worse due to the more difficult nature of the task. This replication would also add generality to the findings in Experiment 1.

## Method

### Participants and Materials

One hundred and seventy-five participants (86 identified as male and 89 identified as female) with a mean age of 26 years (range: 19–49 years) were recruited via Prolific and were given financial compensation in return. The materials used for this experiment were the same as in Experiment 1 except that, for technical reasons, the snow-capped mountain was replaced with a similar one (a video example of the training phase can be found in [osf.io/m2uj6](https://osf.io/m2uj6)).

### Procedure

The procedure was the same as in Experiment 1 except the landmarks were misaligned with the orientation cues (rotated  $45^\circ$ ), in such a way that each landmark was always viewed in between two

of the orientation cues when participants walked in a straight line from the center of the array toward the landmarks (see Figure 4).

## Results

### Training

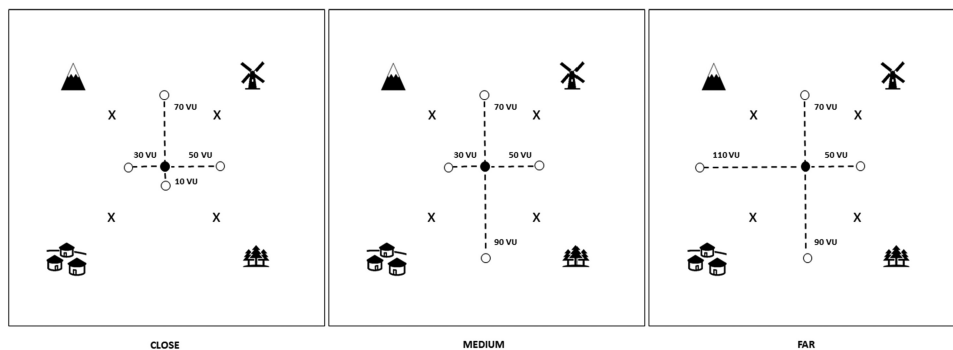
Fifty-three participants (37 female and 16 male) failed to reach the learning criteria and were removed from the data analyses. The total sample size analyzed included 122 participants (of which 52 identified as female and 70 as male) with a mean age of 25 years (range: 18–44 years). Group Close comprised of 42 participants and Group Medium and Group Far had 40 participants each.

Figure 5A depicts the mean latencies to find the goal for each group across the 16 training trials. The data suggest that Group Close performed better than the other groups, but for all groups, latencies became smaller as training progressed. A mixed ANOVA with a between-subjects factor of group (Close, Medium, and Far) and a within-subjects factor of Trial (1–16) revealed a significant main effect of Trial,  $F(10.87, 1,293.80) = 79.83$ ,  $p < .001$ ,  $\eta_p^2 = .40$ , 90% CI [.36, .43], indicating that participants found the goal faster as training progressed. There was also a significant main effect of group,  $F(2, 119) = 18.20$ ,  $p < .001$ ,  $\eta_p^2 = .23$ , 90% CI [.12, .33] and a significant Group  $\times$  Trial interaction,  $F(21.75, 1,293.80) = 1.79$ ,  $p = .014$ ,  $\eta_p^2 = .03$ , [.00, .03]. A post hoc Bonferroni analysis revealed that Group Close performed significantly better than Group Medium and Group Far, ( $p < .001$ ) with no differences between the latter two groups. A one-way ANOVA was conducted to analyze the performances of the groups in the last training trial and it revealed they performed significantly different,  $F(2, 119) = 4.50$ ,  $p = .013$ ,  $\eta_p^2 = .07$ , 90% CI [.01, .14]. A post hoc Bonferroni analysis showed that Group Close performed significantly better than Group Medium ( $p = .017$ ). No other significant differences between groups were found.

### Test

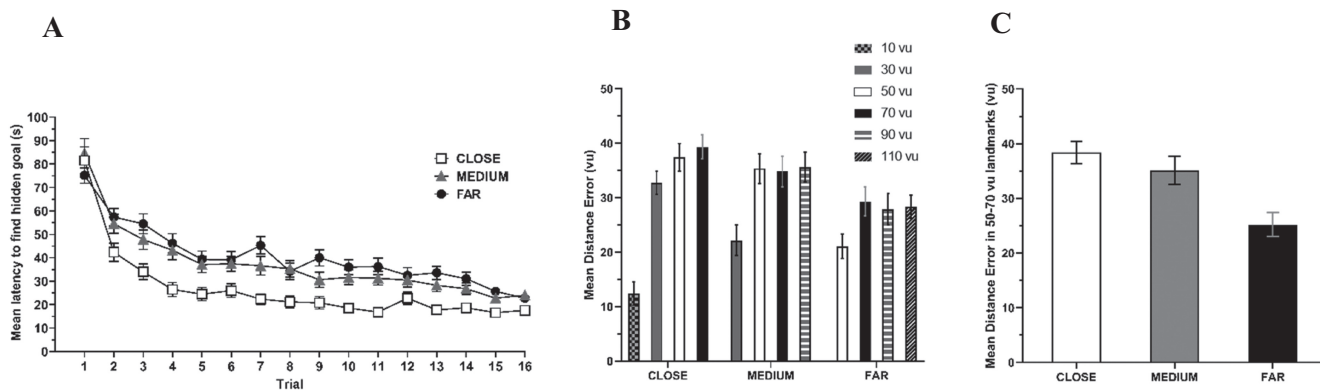
The test results are illustrated in Figure 5B. Overall, there was an increase in the mean distance error within each group as goal–

**Figure 4**  
Experimental Design for Each Group in Experiment 2



*Note.* Black circles represent the goal location, white circles represent distinct landmarks, and the orientation cues (windmill, forest, village, and mountain) were misaligned with the landmarks (rotated  $45^\circ$  from their original position in Experiment 1). X represents the four possible starting points for each trial. Goal–landmark distances are expressed in virtual units (VU).

**Figure 5**  
Performance During Training and Testing in Experiment 2



*Note.* Panel (A) shows the mean latencies to find the hidden goal for the three groups across the 16 training trials (smaller values indicate better performance). Panel (B) presents the mean distance error per landmark across groups. Panel (C) depicts the averaged distance error estimation for the 50 and 70 VU landmarks for each group. Error bars show  $\pm$  standard error of the mean. VU = virtual units.

landmark distance increased, but this effect was smaller in Group Far (see the online supplemental materials for a representation of the paths the participants passed through in search of the goal).

A mixed ANOVA with group as the between-subjects factor (Close, Medium, and Far) and landmark as the within-subjects factor (1–4; 1 = *being the closest to the goal* and 4 = *the furthest*) revealed a significant main effect of landmark,  $F(3, 357) = 66.85$ ,  $p < .001$ ,  $\eta_p^2 = .36$ , 90% CI [.29, .41], no main effect of group,  $F(2, 119) = 1.72$ ,  $p = .183$ ,  $\eta_p^2 = .03$ , [.00, .08], but a significant Group  $\times$  Landmark interaction,  $F(6, 357) = 8.47$ ,  $p < .001$ ,  $\eta_p^2 = .13$ , [.06, .17]. Follow-up analyses in each group revealed there was an effect of landmark in all groups, but the size of the effect decreased as landmarks were more distal from the goal. That is, there was an effect of landmark in Group Close,  $F(3, 123) = 59.18$ ,  $p < .001$ ,  $\eta_p^2 = .59$ , 90% CI [.49, .65]; as well as in Group Medium,  $F(3, 117) = 16.94$ ,  $p < .001$ ,  $\eta_p^2 = .30$ , [.18, .39] and Group Far,  $F(2.65, 103.27) = 5.91$ ,  $p = .001$ ,  $\eta_p^2 = .13$ , [.03, .22], but the effect sizes became smaller as goal–landmark distances increased. Consistent with the results in Experiment 1, the monotonic decrease in the effect size indicates that the overshadowing effect was attenuated by increasing landmark–goal distances.

We averaged the distance error for the 50 and 70 VU landmarks (those that were common across all three groups) for each participant and conducted a one-way ANOVA with group as the between-subjects variable (Close, Medium, and Far). This ANOVA revealed significant differences between groups  $F(2, 119) = 9.15$ ,  $p < .001$ ,  $\eta_p^2 = .13$ , 90% CI [.05, .22]. A follow-up Bonferroni post hoc analysis revealed the error was significantly greater for Group Close compared to Group Far ( $p < .001$ , see Figure 5C), and likewise for Group Medium relative to Group Far ( $p = .008$ ), which overall shows a similar pattern as that observed in Experiment 1. No differences between Groups Close and Medium were observed ( $p = .924$ ).

### General Discussion

Proximity has been suggested to be a critical determinant of competition between events across different species and preparations (Alcalá et al., 2022; Cheng et al., 2007; Herrera et al., 2022;

Urcelay, 2017; Urcelay & Miller, 2009). The present study was designed to assess the effect of different landmark–goal distances in human spatial cognition, following Goodyear and Kamil’s (2004) study in birds, which suggested that landmark–goal distance determines competition between landmarks during navigation. At issue was whether human participants would be sensitive to different landmark distances when entered in competition, as were food-storing birds of the corvid family. In two experiments, we reproduced the experimental design of Goodyear and Kamil but using 3D virtual environments and human participants that were trained from a first-person perspective rather than from a top-down view. The relative landmark–goal distances varied across groups (i.e., Close, Medium, and Far), but two of the landmark distances used were similar in all three groups (i.e., 50 and 70 VU landmarks), which enabled the assessment of absolute distance effects between groups. Consistent with Goodyear and Kamil’s findings in Clark’s nutcrackers, tests of landmarks 50 and 70 VU revealed that participants in Group Far (Experiments 1 and 2) showed a better absolute distance estimation than Group Close and slightly better than Group Medium. These results suggest that overshadowing was greater in Group Close, and therefore dependent on goal–landmark spatial proximity, a finding that is by and large consistent with that reported by Herrera and colleagues (Herrera et al., 2022).

Similarly, participants’ distance error decreased with the 50 and 70 VU landmarks when the relative distance of the remaining landmarks within the array was larger. That is, Group Far was more accurate in locating the goal when these landmarks (50 and 70 VU) were the most proximal ones (i.e., trained in the presence of landmarks at 90 and 110 VUs from the goal). This performance can be compared to that of Groups Close and Medium, for which 50 and 70 VU landmarks were placed either as the farthest or at intermediate distances from the goal, respectively. Overall, this suggests that the closest landmark to the goal is the one that gains the strongest behavioral control at the expense of learning about the other (more distal) landmarks. This also suggests that participants, irrespective of the groups they belonged to (i.e., absolute distance estimation), learned more about the landmark closest to the goal within the array, which mirrors the birds’ study.



In these experiments, we used an experimental design that was based on an experiment by Goodyear and Kamil (2004) conducted in food-storing birds. Despite species and task differences, our results revealed a striking similarity with those collected in Clark's nutcrackers. This is relevant because food-storing birds have been argued to have a specialized system for spatial learning (Papini, 2008). At a neural level, the hippocampus volume relative to telencephalic volume of food-storing passerines is larger than nonstoring (Sherry & Duff, 1996). In spatial working memory tasks, Clark's nutcrackers outperform scrub jays and pigeons (Olson, 1991; also see Balda & Kamil, 1989), suggesting some degree of specialization. Thus, the present results suggest that previous findings in food-storing birds concerning the dependency of overshadowing on landmark distance are a general phenomenon observed not only in food-storing birds but also in humans.

As our study relied upon virtual rather than physical environments, alternative explanations could have driven our findings, in particular in Experiment 1. For example, in Experiment 1, participants may have learned to align a landmark with an orientation cue by learning their size and relative positions on the screen (i.e., similar to taking a mental snapshot). The closest landmark should appear to be the biggest one in their field of view (relative to the orientation cue), providing a more accurate estimation and minimizing the influence of spatial distance manipulations. In other words, it could be possible that participants aligned the landmarks with the more distal-orienting cues and used this information during the test. For this reason, in Experiment 2, the orientation cues were misaligned relative to the landmark array. As a result, it was more difficult for participants to utilize a mental snapshot-like solution for the task, and therefore, participants needed to consider spatial distances and orientation for goal finding. This ensured that the spatial distance manipulations were the most likely factor that determined the critical differences between groups. Relevant to this discussion is the observation that the groups trained with the misaligned cues in Experiment 2 took overall significantly longer during training to locate the goal ( $M = 34.86$  s) compared to the performance of groups in Experiment 1, which were trained with the landmarks aligned ( $M = 30.54$  s). This suggests that in Experiment 2 it was more difficult to locate the goal, likely because participants had to compute both orientation and distances in order to find it, leading us to conclude that this manipulation was successful in preventing people from snapshotting, or in other words, memorizing the sizes and positions of different elements on the screen, and then moving around to match their current and their expected view (Cheng, 2008). However, this should be taken cautiously as it is a cross-experiment comparison. Regardless, the results during the test phase in Experiment 2 are remarkably similar to those in Experiment 1. Thus, we can argue that the distance manipulations affected participants' spatial learning, leading to overshadowing with the closest landmarks to the goal as was observed in food-storing birds (Goodyear & Kamil, 2004; Gould-Beierle & Kamil, 1999) and humans (Herrera et al., 2022). Our results also reveal in human participants that spatial proximity manipulations have "dose-dependent" effects on competition between landmarks.

All in all, our results suggest that the same principles that characterize spatial learning in birds are also observed in humans, where distal or proximal landmarks exert different effects on spatial learning. An account that has been put forward to explain the effect of spatial proximity in a number of species such as pigeons (Cheng & Roberts,

1991), Clark's nutcrackers (Goodyear & Kamil, 2004), and honeybees (Reynolds et al., 2013) is Weber's law (Weber, 1846), which states that variation (or error) increases with distance to the goal. Applying this notion to our results, greater certainty in estimating distances with proximal landmarks may lead to more accurate goal finding, and hence, the closest landmarks acquire most of the behavioral control leading to overshadowing of the more distal landmarks within the array. Contrarily, the amount of overshadowing diminishes as the landmark-goal distances increase, as does so the level of certainty; hence a single (distal) landmark is no longer a good predictor of the goal location, encouraging participants to learn about the other landmarks within the array. This may lead to a better encoding of the configuration of landmarks, resulting in no competition with larger landmark-goal distances. Cheng et al. (2007) have also proposed a Bayesian approach—discussed in the introduction—that uses uncertainty which is proportional to distance to weight different landmarks and also predicts diminishing overshadowing with longer distances to the goal.

Another explanation of these results, which we have simulated using Chung et al.'s simulator (2018) of the Rescorla-Wagner model (Rescorla & Wagner, 1972), is that landmarks at different distances from the goal have different saliences. Assuming different saliences for the four landmarks in the array, the Rescorla-Wagner model can easily accommodate the findings of these three-group experiments, as obviously does a variation of the model that has been proposed to account for some findings in the spatial domain (N. Y. Miller & Shettleworth, 2007). That is, if landmarks at 10, 30, 50, 70, 90, and 110 VUs from the goal are assigned saliences (alphas) of .8, .7, .6, .5, .4, and .3 (respectively), then the model and its variation predict that learning about target landmarks 50 and 70 VUs from the goal will be more impaired by those closer (10 and 30 VUs—more salient than the targets) than from those more distal (90 and 110 VUs—less salient than the targets).

Finally, the results can be accounted for by a modification of Pearce's model (1987) outlined in Herrera et al. (2022), which is based on generalization decrement. Pearce's model assumes that organisms encode the information in their surroundings in a configural unit. However, when they are tested with some of the information present during training, they show a generalization decrement, understood as the decrement in performance that results from the dissimilarity between what was trained and what is tested (Guttman & Kalish, 1956). Thus, the more similar the elements are from training to testing, the less generalization decrement. Importantly, similarity varies in a gradual manner, and we have argued that proximity (spatial and temporal) seems to be a key factor underlying generalization decrement. Hence, when events are close either in space or time with an outcome, small variations in the stimulus arrays have a larger effect on performance (i.e., large generalization decrement), but this effect diminishes as events become more distant. Applied to the present findings, performance with the landmarks 50 and 70 VUs from the goal was impacted more when the removed landmarks were closer to the goal relative to when they were more distal from the goal. In other words, landmarks which are proximal to the goal are likely to overshadow learning about the more distal landmarks (e.g., Close Group), whereas landmarks placed at a certain distance from the goal can enter into a configuration with the other ones in the array (see Herrera et al., 2022, for a formal elaboration of this account). This may be because proximal landmarks are processed as more "unique" than "common" elements, whereas "distal"

landmarks become blended with the entire environment and hence have less of an effect when removed (i.e., the elements are similar). In spatial learning tasks, removal (or alteration of the position) of distal landmarks often has little effect on performance (Gimeno et al., 2021; Prados & Trobalon, 1998), a finding that has led researchers to argue that distal landmarks are better “combined” as part of a cognitive map (also see Hupbach & Nadel, 2005) or holistic configurations (see Cheng et al., 2013, for a discussion of configural processing in the spatial domain).

Whatever the merits of these theoretical speculations, the current results suggest that distance to the goal is a critical variable determining the interaction between landmarks in human spatial navigation. The outcomes of competition designs have been debated, particularly in the spatial domain, where the absence of competition has driven domain-specific theoretical proposals (e.g., geometric module hypothesis; for studies conducted with rodents see Cheng, 1986; Margules & Gallistel, 1988; with children Hermer & Spelke, 1994, 1996) that are at odds with the predictions of domain-general theories of learning (Mackintosh, 1975; N. Y. Miller & Shettleworth, 2007; R. R. Miller & Matzel, 1988; Pearce, 1987; Pearce & Hall, 1980; Rescorla & Wagner, 1972). Although our results do not discriminate between different accounts that can explain the empirical phenomena, they do unambiguously point to a variable that parametrically determines the extent to which landmarks are affected by other landmarks, and hence go some way in identifying reasons for such discrepant findings. Together with temporal proximity manipulations reported in predictive (Herrera et al., 2022) and action–outcome learning (Alcalá et al., 2022) scenarios, the current results suggest that proximal temporal and spatial events are critical for the observation of competition in human learning.

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