



Proximity to an edge affects search strategy in adults and children

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ABSTRACT

When searching for a hidden goal, search patterns are often defined according to one of two main search strategies: an absolute strategy, which usually involves searching at a fixed learned distance and direction from a particular reference point, or a relational strategy, which involves searching at a point that maintains the relationship between two or more other points. Past research has shown that humans tend to prefer a relational strategy whereas most non-humans prefer an absolute strategy. However, recent research (Hartley et al., 2004) used a simulated 3D environment to demonstrate that proximity to a boundary affects strategy. In particular, when searching close to an edge, human participants were more likely to use an absolute strategy whereas when searching at a central location, participants were more likely to use a relational strategy. The current studies extend the findings of Hartley et al. Experiment 1 showed that adult humans use different strategies based on the goal's proximity to the edge of a search space, and that strategies differed between males and females. Experiment 2 suggested that children also use different strategies based on the goal's proximity to a boundary, and that some goal locations may be harder to learn than others. Taken together, our results show that search strategies are flexible and context-specific.

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The ability to remember places one has been is an important aspect of everyday life, and as such, researchers have spent considerable time examining strategies that can be used to remember and return to previously visited locations. There are several different ways in which organisms can navigate effectively, including path integration, beaconing, use of celestial cues and landmark-based navigation or *piloting* (Gallistel, 1990). When piloting, organisms must be able to learn and remember both distance and directional information from one or more landmarks. If multiple landmarks are available, an organism can either encode the location of the goal as a specific distance and direction from a single landmark or in terms of the goal's spatial relationship with two or more landmarks. Search pattern based on the former is often referred to as an absolute strategy whereas the latter is referred to as a relational strategy.

Spetch et al. (1996) used a comparative approach to examine whether pigeons and adult humans use absolute or relational strategies when searching for a hidden goal. Both pigeons and humans were trained to search for a goal in the center of a square array of landmarks. On pivotal test trials, the landmark array was

expanded either horizontally, to create a rectangular shape, or diagonally, creating a larger square. On both types of expansions, humans continued to search in the center of the array, suggesting use of a relational strategy. In contrast, pigeons searched at locations that matched the learned distance and direction from individual landmarks, suggesting use of an absolute strategy. This pattern of results was consistent across open field, table-top and computer tasks for humans, and across open field and touchscreen tasks for pigeons (Spetch et al., 1996, 1997). Other non-human animals, such as Clark's nutcrackers (Kelly et al., 2008), gerbils (Collett et al., 1986), flying bats (Winter et al., 2005) and nonhuman primates (MacDonald et al., 2004; Poti et al., 2005, 2010; Sutton et al., 2000) have also been shown to use non-relational strategies when searching within landmark arrays.

The use of absolute strategies by non-human animals seems to reflect a preference rather than a limitation of ability. For example, both pigeons (Jones et al., 2002; Spetch et al., 2003) and Clark's nutcrackers (Kamil and Jones, 1997, 2000) will use the spatial relationship between landmarks to find a goal if they are trained with multiple exemplars. Additionally, pigeons (Gray et al., 2004) and chicks (Tommasi et al., 1997; Tommasi and Vallortigara, 2000) will sometimes use relational strategies when searching for the center of an enclosed arena. Orientation cues, or an animal's ability to maintain a stable directional frame of reference, may play a role in strategy preference or selection. Gray and Spetch (2006) trained pigeons to search in the center of either a square array of landmarks

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or a set of short walls that did not block external cues. On expansion trials, both groups of pigeons searched according to an absolute distance strategy, indicating that strategy preference is not dependent on cue type (i.e. landmarks or continuous surfaces). In another study, [Sturz and Katz \(2009\)](#) found that disoriented pigeons used a relational strategy to find the middle of a two landmark array. That is, when trained in the absence of orienting cues, pigeons continued to search in the middle of the array on expansion trials rather than at the absolute learned distance. Overall, these results suggest that, although non-human animals may prefer to use an absolute strategy, they are capable of learning and using relational strategies in some contexts.

Studies of preferences for relational or absolute strategies in children have yielded mixed results. [MacDonald et al. \(2004\)](#) examined children's (age 5–9 years) search strategies when searching for the center of a square array of landmarks. In one study, participants (children and adults) were presented with a table-top grid of discrete locations that consisted of cups filled with oats; a candy hidden in one of the cups served as the goal. The landmarks formed a square around the goal location and were diagonally adjacent to it. On expansion trials, adults searched at the center location of the array. On the other hand, children tended to choose locations that were directly adjacent to the landmarks, indicating that they used the landmarks as beacons. In a follow-up experiment with children aged 3–5 years, MacDonald et al. used a continuous search space (a tray filled with confetti) and landmarks that were further from the goal. However, this proved to be a difficult task for the children to learn. Approximately half of the children were able to learn the task, and of those, only a few searched according to a relational strategy on expansion tasks.

In contrast, [Uttal et al. \(2006\)](#) found that children (age 4–5 years) readily used spatial relationships in larger scale open-field task. In their study, children were required to search for a toy between two landmarks that were 6 m apart in a field. On expansion trials, children continued to search in the middle of the two landmarks. Additionally, when tested with only one landmark, children searched at the learned distance and direction from the available landmark. In this case, children seem to have learned the location of the goal according to both absolute and relational strategies, but preferred the relational strategy on expansion tests.

[Spetch and Parent \(2006\)](#) found age and sex differences in how easily children were able to acquire a similar, but much smaller-scale, task. Children (age 3–5 years) were asked to look for a sticker hidden between two landmarks spaced approximately 15 cm apart. As in the [MacDonald et al. \(2004\)](#) study, this seemed to be a difficult task for the children to learn; only 37% of the children acquired the task within 20 training trials. Older children (i.e. the five year olds), especially the boys, tended to acquire the task more easily than younger children, especially girls. On the expansion test, most children chose the middle location; however, a few children still chose a location based on an absolute strategy.

Despite these many studies examining the use of a 'center' or 'middle' relation, few studies have looked at other goal-landmark relationships or, more specifically, how search strategies may change based on the goal location. In particular, although studies have shown that animals are capable of using other spatial relationships, such as 'quarter-way' or triangular shapes ([Kamil and Jones, 2000](#); [Spetch et al., 2003](#)), there is little research examining how an individual's search strategy may change according to different spatial relations. One study that addressed this question was conducted by [Hartley et al. \(2004\)](#). They used a video-game-like virtual environment to study how adults remember different locations in a working memory task. Participants explored a virtual environment of a square or rectangular open arena, with distal visual cues for orientation. Participants were required to locate a cue item within the arena; after finding the item, they were briefly removed from the

arena. They were then returned to a test arena, which, on some trials, was expanded or contracted along one or both axes. Participants were asked to place a marker object where they had found the (now absent) cue item. On expansion trials, participants tend to place the marker according to an absolute strategy when the goal location was near the boundary of the virtual arena. If the cue item had been closer to the center of the arena, however, participants were more likely to use a relational strategy. Their results support the idea that preference for absolute or relational strategies can vary according to context.

The goal of the current studies was to extend the findings of [Hartley et al. \(2004\)](#) in four main ways. First, we sought to determine whether similar strategies are used on a smaller scale and with simpler two-dimensional (2D) stimuli. We were particularly interested in whether the use of an absolute strategy for goals close to an edge would hold within a non-immersive 2D environment. In real or immersive virtual spaces the edge of the environment is a physical boundary that prohibits movement beyond the border and distance to the edge can potentially be judged on the basis of motor movement (e.g., actual or virtual steps away from the edge). By contrast, our experiments used a simple non-immersive 2D arena in which the edge of the space was denoted by a graphic stimulus on the computer screen. There is evidence from research on landmark-based search in both pigeons and humans that search strategies often generalize across real and 2D environments ([Spetch et al., 1997, 1992](#)). Therefore, despite the potentially important differences in scale and immersion between our spatial arena and the one used by Hartley et al., we predicted that their results would replicate with our simpler, non-immersive stimuli.

Second, we specifically included tests in which the goal was in the exact center of the square. At the center location, we expect to see strong relational encoding based on past research by [Spetch et al. \(1996, 1997\)](#) and based on the recent study by [Hartley et al. \(2004\)](#). Although Hartley et al. did not include a location that was at the exact center, the model they favored in interpreting their results (the Boundary Proximity Model) predicts that responding should peak at the relational (center) location on expansion tests. According to this model, the goal location is represented in terms of proximity to each of the four walls, with closer walls being weighted more heavily. At the center location all walls should be weighted equally. On expansion tests, none of the locations match the learned proximity so responding is thought to occur at locations that best match the overall pattern based on the weighted contributions of all walls. At edge locations, the fixed distance from the nearest wall(s) are given the most weight, so responding will be skewed toward the absolute distance from the near wall(s) on expansion tests. At intermediate locations, responding should peak between the absolute and relational locations on expansion tests, and at the center responding should fall at the relational location.

An interesting question that [Hartley et al. \(2004\)](#) did not directly address, is how the spread of searching is affected by proximity to the edge. Although their model clearly suggests that people will show relational responding on expansion tests in which the goal was at the center, we are less clear about the predictions of their model regarding the spread, or spatial variability of responding as a function of the proximity of the goal to the wall. One simple prediction derives from Weber's law, which has been found to apply to distance estimation in honeybees ([Cheng et al., 1999](#)), pigeons ([Cheng, 1992](#)) and humans ([Durgin et al., 2009](#)): namely that variability would increase as a function of distance. Hence the spread should be smallest at the edge and largest at the center. The same prediction might also fall from the boundary vector cell model of hippocampal place cell firing (e.g., [Barry et al., 2006](#)), given that cells with preferred distance and direction to near boundaries have sharper tuning than cells which respond to boundaries farther away. On the other hand, if the center is somehow special, in that it

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