Reorienting in Virtual Environments: Examining the Influence of the Number of Discrete Features on the Encoding of Geometry by Humans

By

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Abstract

Orientation – the process by which animals determine their position in an environment – can be accomplished by using the visually distinct properties of objects or surfaces, known as features (i.e., colour or pattern) or the relationship among objects and surfaces, known as geometry (i.e., wall length or angular information). Although features have been shown to facilitate the encoding of geometry, little is known as to whether restricting one's viewpoint to include fewer features will still facilitate the encoding of geometry. During this experiment, men and women were trained to search near either an acute or an obtuse corner of a virtual parallelogram-shaped room that contained either three or four discrete and distinctive features. Participants were subsequently tested for their encoding of wall length and angles when the cues were presented in isolation, together, or in conflict. Results showed that the number of features present during training did not influence the encoding of geometry. However, the discrete and distinctive properties of the features overshadowed the encoding of angles by women as well as by participants who were trained with the obtuse corner. Although some groups of participants did not encode angular information when this was the only available geometric cue, all groups weighed angles more heavily than wall length when the cues provided conflicting information. This result suggests that one type of geometric cue (i.e., wall length) can facilitate the encoding of another (i.e., angles).

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Chapter 1: Reorienting in Virtual Environments: Examining the Influence of the Number of Discrete Features on the Encoding of Geometry by Humans

Prior to navigating to a specific location, an individual must first determine his or her position in the environment and establish a sense of heading, an ability known as orientation (Gallistel, 1990). Orientation can be accomplished by relying on environmental cues or internal cues to serve as reference frames that specify directional information (for reviews see Cheng & Newcombe, 2005; Tommasi, Chiandetti, Pecchia, Sovrano & Vallortigara, 2012). When visual cues are sparse, many species of insects, birds and mammals use path integration to internally keep track of their position relative to their home location (Collett & Collett, 2000; Etienne & Jeffrey, 2004; Muller & Wehner, 1988). When required to navigate substantial distances, animals are able to derive compass directions from numerous sources such as the sun’s position relative to the horizon, the Earth’s magnetic field, or positional information from star constellations in the night sky (Meyer, 1964; Sauer, 1961; Wiltschko & Balda, 1989; Wilzeck et al., 2010). In many cases, animals rely on objects within the environment as landmarks to specify a goal location. The visually distinct properties of these objects, such as the colour, pattern or texture, are referred to as featural cues (Cheng & Newcombe, 2005). Within the last 25 years, another type of visual cue known as geometry has received a considerable amount of attention (Cheng, 2008; for a review see Cheng, Huttenlocher & Newcombe, 2013). Geometric cues specify shape information, and can be described as the distance, direction or angular information between objects or surfaces (Cheng, 2005; Cheng & Newcombe, 2005).

The idea that animals use geometric cues to orient originated with the pioneering work of Cheng (1986). Cheng found that rats were able to use the shape of an enclosed space to orient despite the presence of conspicuous featural cues. During a reference memory task, disoriented rats were trained to search for food that was consistently hidden near one corner of a rectangular enclosure. Featural cues were provided by four panels with distinct visual, tactile and olfactory properties; one distinct panel was situated in each corner of the enclosure (see Figure 1A). Geometric cues were provided by the length of the walls of the enclosure combined with directional or sense information (i.e., long wall to the left of a short wall). After a considerable amount of training, the rats were able to use the featural cues to locate the correct corner. Nevertheless, the rats made a number of rotational errors by searching in the corner that was diagonally opposite to the correct corner. Although these two corners were featurally distinct from each other, they were identical according to geometry (see Figure 1B). Thus the rotational errors made by the rats showed that despite the availability of distinctive featural cues, the rats relied on the geometric properties of the enclosure to reorient.

Since Cheng's findings, numerous studies have investigated the ability of animals to orient using features and geometry. Researchers have adopted the experimental approach originally formulated by Cheng (1986) since the use of an enclosed arena allows for precise control over cue availability. The shape of the enclosure as well as the featural cues within it can be manipulated in numerous ways to study the use of these cues for orientation (Cheng & Newcombe, 2005). In using this paradigm to study orientation, a disoriented individual is initially trained to locate a target that is hidden near one corner of an enclosed rectangular-shaped environment. Geometric cues are provided by the shape of the enclosure and featural cues are provided by distinctly coloured objects or panels that are positioned in the corners of the enclosure. Once the goal position has been accurately identified, the individual is again disoriented and is subsequently reintroduced into the environment after certain aspects of the cues have been manipulated. For instance, removing all of the featural cues during testing can verify whether the individual can use the geometry or the shape of the enclosure alone to reorient. Removing only a few of the featural cues during testing can confirm whether the individual has encoded the remaining features and can use these features to reorient. The displacement of features by positioning them in conflict with geometry can show whether the individual weighs featural cues or geometric cues more heavily during reorientation. Using the orientation paradigm, research has shown that all animal species studied thus far are capable of using featural cues as well as the geometry of a space to determine position in an environment (rats: Cheng, 1986; humans: Hermer & Spelke, 1996; rhesus monkeys: Gouteux, Thinus-Blanc & Vauclair, 2001; pigeons: Kelly, Spetch & Heth, 1998; domestic chicks: Vallortigara, Zanforlin & Pasti, 1990; fish: Sovrano, Bisazza & Vallortigara, 2002, 2003; bumble bees: Sovrano, Rigosi & Vallortigara, 2012; ants: Wystrach & Beugnon, 2009).

Featural Cues

Featural cues can be instrumental to orientation based upon their location, stability as well as their physical appearance (for a review, see Chan, Baumann, Belgrove & Mattingly, 2012; Miller & Carlson, 2011). The visually distinct properties of discrete objects or surfaces (herein referred to as “discrete features” and “surface features”, respectively) can serve as informative cues for an orienting animal (Bodily et al., 2012;

Cheng & Newcombe, 2005; Lew, 2011). Featural cues not only serve to aid navigation, but may also draw attention to other cues that are also present in the environment. The results of a number of studies have supported the idea that featural cues can facilitate the encoding of geometry (Graham, Good, McGregor & Pearce, 2006; Horne & Pearce, 2011; Kelly, 2010; Pearce, Graham, Good, Jones & McGregor, 2006). For instance, Graham et al. (2006) found that rats were more accurate at encoding the geometry of a kite-shaped space when they were initially trained with features as opposed to when they were trained with only geometry. In addition, Kelly (2010) found that Clark's nutcrackers encoded the geometry of a rectangular-shaped array of objects when the array consisted of distinct objects but not when the array consisted of identical objects. In addition to the aforementioned studies, other studies have also supported the idea that features facilitate the encoding of geometry (Horne & Pearce, 2011; Pearce, Graham, Good, Jones & McGregor, 2006). Nonetheless, this idea has only been examined when all of the featural cues within an environment can be seen at a time. For example, in most orientation studies, subjects gain experience with the environment either while performing a navigation task or while observing the environment from a static, elevated viewpoint. These types of experiences allow individuals to view all of the featural cues that are available in the environment. However, in real-world settings it is rare for an animal to see all of the features that are present in an environment prior to orienting, as one's viewpoint may be obstructed by large objects that may be present in the space. To thoroughly understand how orientation occurs in natural environments, it is important to investigate whether geometry can still be encoded when an individual has a partial viewpoint of the environment that limits the number of featural cues that can be seen at a time.

Recently, research has shown that features may facilitate the encoding of geometry from arrays when subjects have a partial viewpoint of the environment (Pecchia, Gagliardo & Vallortigara, 2011; Pecchia & Vallortigara, 2010). Pecchia and Vallortigara (2010) trained chicks to search for food within a rectangular-shaped array of either four identical or four distinctly coloured features made from cardboard pipes. Each of the pipes had four openings where the chicks could insert their head to search for a food reward, thus the chicks only had a partial viewpoint of the environment when rewarded. The opening of the pipes were manipulated so that half of the chicks always accessed food from the same opening of the correct pipe(s) and thus had a stable viewpoint of the environment when rewarded, whereas the other chicks accessed food from different openings of the correct pipe(s) and thus had a variable viewpoint of the environment when rewarded. Results showed that when chicks had a stable viewpoint of the environment, they were able to learn the geometry of the array. However, when their viewpoint varied, the presence of featural cues facilitated learning the geometry of the array. In a subsequent experiment, pigeons were tested using a similar task (Pecchia et al., 2011). When features were unavailable, the pigeons had difficulty learning geometry regardless of their viewpoint during reinforcement. Nonetheless, the pigeons were able to learn the geometry of the array when distinct features were present. Taken together, it appears that when the birds had a partial viewpoint of the environment, the presence of features facilitated the encoding of geometry. It should be noted that during both studies, partial viewpoints were only imposed during reinforcement, in that the birds could still navigate the full environment and view all of the featural cues prior to being rewarded. Consequently, it is unclear whether restricting an individual's viewpoint to include fewer features during the entire experience with the training environment will still facilitate the encoding of geometry.

When the entirety of an environment cannot be seen simultaneously, studies have shown that humans combine information about features that have been observed from different viewpoints, as long as there is some degree of overlap between the viewpoints (Friedman, Waller, Thrash, Greenauer & Hodgson, 2011; Wong & Hayward, 2005). View combination has been observed by training participants with two images of a scene that overlap to some extent, and subsequently testing for recognition with interpolated images (images shown from viewpoints that are in between the training images) and extrapolated images (images shown from viewpoints that are outside of the training images). It is hypothesized that if featural cues from the training scenes have been integrated, then interpolated images should be recognized faster and with greater accuracy than extrapolated images. Many studies have shown that humans recognize interpolated images as quickly as trained images, and are more accurate at recognizing these images than extrapolated images (Castelhano, Pollatsek & Rayner, 2009; Friedman et al., 2011; Friedman, Vuong & Spetch, 2010; Friedman & Waller, 2008; Wong & Hayward, 2005). These findings suggest that humans seamlessly combine information about features that have been learned from multiple viewpoints of a scene. However, view combination has only been examined with featural cues and has not been examined with geometric information. As a result, it is not known whether combining information about features that have been learned from multiple partial viewpoints will influence the encoding of geometric cues. The current study investigated this idea by training participants to orient when their viewpoint was restricted to either three (partial set) or four (full set) discrete features within a parallelogram-shaped environment that contained distinctive wall length and angular cues. Subsequent testing using only the geometric properties of the environment allowed us to examine whether the number of features available during training influenced the encoding of geometric cues.

Geometric Cues

Despite the availability of features, animals incidentally learn geometric cues from the shape of the environment (Cheng, 1986; Gouteux et al., 2001; Hermer & Spelke, 1994, 1996; Kelly et al., 1998; Sovrano et al., 2002, 2003; Sovrano et al., 2012; Vallortigara et al., 1990; Wystrach & Beugnon, 2009). The ability to encode the shape of an environment has been observed with very young animals (chicks: Vallortigara et al., 1990; children aged 17-24 months: Learmonth, Newcombe & Huttenlocher, 2001) as well as with animals that have been reared in environments void of informative geometric cues (fish reared in circular environments: Brown, Spetch & Hurd, 2007; chicks reared in circular or C-shaped environments: Chiandetti & Vallortigara, 2008). It appears that the encoding of geometry is quite robust in that it occurs with little experience or training. Much of the work that has examined the use of geometry has taken place in enclosed rectangular-shaped spaces since the length of the walls combined with sense information (i.e., long wall to the left of a short wall) serve as informative cues by which subjects can orient. Nonetheless, using a rectangular arena to study orientation only accounts for the use of global geometric cues as defined by wall length information and does not account for local geometric cues as defined by angular information.

More recently, research has examined whether animals are capable of using the angular amplitude provided by the corners of a space to orient. To date, several animal species have shown an ability to encode and use angles to orient (humans: Hupbach & Nadel, 2005; Lubyk, Dupuis, Gutierrez & Spetch, 2012; Reichert & Kelly, 2012; domestic chicks: Tommasi & Polli, 2004; pigeons: Lubyk & Spetch, 2012; rats: Pearce, Good, Jones & McGregor, 2004; Kosaki, Austen & McGregor, 2013; Clark's nutcrackers: Kelly & Reichert, 2013). Tommasi and Polli (2004) were the first to examine whether animals could use the angular information provided by the corners of an enclosure to orient. Disoriented chicks were trained to search for food that was hidden in either a 60º or a 120º corner of a featureless parallelogram-shaped enclosure that contained two types of geometric cues – wall length and angular amplitude. The chicks were found to have encoded wall length and angular information when tested in a rectangular-shaped enclosure (only wall length cues were available as all angles were 90º) or a rhombic-shaped enclosure (only angular cues were available as all walls were of equal length), respectively. When the chicks were tested in a mirror image parallelogram-shaped enclosure, a transformation that placed wall length in conflict with angles, the chicks trained with the 60º corner searched in corners with the correct angles, whereas the chicks trained with the 120º corner searched in corners with the correct wall length. The authors proposed that the perceptual salience of acute-angled corners resulted in the chicks trained to the 60º corner to weigh these corners more heavily than wall length cues. Since obtuse-angled corners were less salient, the chicks trained to go to the 120º corner weighed wall length cues more heavily than angular cues.

Recently, a study by Kosaki, Austen and McGregor (2013) reported that rats weighed acute angles more heavily than obtuse angles during a place finding task. During this study, rats were trained to locate an escape platform that was situated in one corner of a rhombic-shaped water maze. A featural cue was located directly above the platform, allowing the rats to use this cue as a beacon to locate the platform. During half of the training trials, the platform was located in an acute corner (60º), and during the remaining trials the platform was located in an obtuse corner (120º); the order of trial presentation was pseudo-randomized. After experiencing a specific number of trials, the rats were tested in the same environment without the beacon or the platform to examine whether the rats preferred the acute or the obtuse corners of the pool. Results indicated that the rats clearly preferred the acute corners as they spent a significant amount of time in these corners compared to the obtuse corners. These findings suggest that the rats found the acute corners to be more salient orientation cues than the obtuse corners.

Although findings with humans also suggest that smaller angles are more salient than larger angles, this is dependent on the training provided to participants. For instance, Reichert and Kelly (2011) trained participants with a rectangular-shaped array consisting of four L-shaped panels; diagonally opposite panels projected either a 50º or a 75º angle. Participants were trained to find a target that was located near either a 50º or a 75º panel. When required to orient using the angular cues alone (i.e., the array was square-shaped) participants trained with the 50º angle were able to orient accurately, whereas those trained with the larger 75º angles were unable to orient. Contrary to these findings, Lubyk et al., (2013) found that humans were equally accurate at orienting with an array of L-shaped angular cues, regardless of whether participants were trained with smaller

(60°) or larger (120°) angles. During this study, the positive corners contained identical featural cues (i.e., a blue strip of paint), leading to the possibility that these features could have facilitated the encoding of the obtuse-angled corners. Another explanation is that the training angles in Lubyk et al. were separated by greater amplitude, and thus made the angles easier to discriminate from each other.

Lubyk, Dupuis, Gutierrez & Spetch (2012) also found that humans could accurately orient using both acute and obtuse angles in enclosed featureless environments. During this study participants were trained to search in either the 60º or 120º corners of an enclosed featureless parallelogram-shaped virtual environment that contained wall length and angular cues. When tested for encoding of angles in a rhombic-shaped virtual environment, participants were accurate at choosing the corners with the correct angular information regardless of whether they were trained with a 60º or a 120º corner. In contrast to this study, when trained with a featureless array of angles (i.e., no walls present), Reichert and Kelly (2011) found that participants were able to encode smaller (50º) but not larger (75º) angles. Taken together, these findings suggest that the presence of wall length cues may facilitate the encoding of angles.

In addition to this, Lubyk et al. (2013) found that when trained in an enclosed rhombic-shaped virtual environment (all walls of equal length) that contained features, participants were accurate at selecting the corners with the correct angles, regardless of whether they were trained with a 60º or a 120º corner. Here, the wall length, but also possibly the presence of featural cues, may have facilitated the encoding of angles. It should be noted that the features used in the Lubyk et al. experiment were only located in the two geometrically correct corners of the environment and were also identical to each other. As a result, participants may have only encoded these correct corners and may not have attended to the corners of the environment that did not contain features (the incorrect corners). Hence, it is unclear whether the presence of featural cues in this experiment facilitated the encoding of angles. To investigate whether distinctive features facilitate the encoding of angles, the present study trained participants with a parallelogram-shaped environment that contained distinct features in each of the corners. Subsequent testing using an environment that presented only angular information allowed us to determine whether the presence of distinct features during training influenced the encoding of angles.

Gender Differences in Encoding Features and Geometry

When features and geometry are both available in an environment, men and women have been shown to attend to these cues differently, but this is contingent upon the environment and the type of cues that are used during training. Sandstrom, Kaufman and Huettel (1998) found that men are capable of orienting with either features or geometry, whereas women show a greater reliance on features in comparison to geometry. Using a virtual water maze task, men and women were trained to locate a hidden target within an octagonal-shaped pool using features (four distinct landmarks situated outside the pool) and geometry (trapezoidal-shaped room). When tested using the features alone, men and women were equally accurate at reorienting, but when tested using geometry alone, men were significantly faster at locating the hidden target in comparison to women. When the features were placed in random locations and were not predictive of the target, men were able to use the geometry of the environment to locate the hidden target, whereas the performance of women was severely affected. In addition to this study, others have shown that featural cues tend to be especially salient for women (Kelly & Bischof, 2005; Lubyk et al., 2013; Andersen, Dahmani, Konishi & Bohbot, 2012). Women have also been shown to excel at object location memory tasks, thus it is not surprising that they adopt feature-based strategies to orient and navigate (Silverman, Choi & Peters, 2007; Silverman & Eals, 1992; Voyer, Postma, Brake & Imperato-McGinley, 2007).

Although numerous studies have reported that women rely on feature-based strategies to orient, this reliance is dependent upon the type of featural cues that are presented during training (i.e., discrete features or surface features). When trained without featural cues in a parallelogram-shaped environment, women and men were equally accurate at encoding wall length and angles (Lubyk, Dupuis, Gutierrez & Spetch, 2012). However, Kelly and Bischof (2005) found gender differences when discrete featural cues were present during training. Using static images of a virtual environment, men and women were trained to search in one corner of the environment using features (four objects with distinct colour and shape located in each corner) and geometry (rectangular-shaped room). When featural cues were removed from the environment during testing, men but not women were found to have encoded geometry as defined by wall length information. Thus, the presence of discrete features during training overshadowed the encoding of wall length for women but not for men. In a subsequent experiment, Kelly and Bischof (2008) again trained participants with static images of a rectangular-shaped virtual environment, but featural cues were now integrated with the surfaces of the environment (four distinctly coloured walls). When tested without featural cues, both men and women were found to encode wall length information with equivalent accuracy, showing that surface features did not overshadow the encoding of wall length for women as was the case with discrete features.

The overshadowing of geometry by discrete features has mostly been observed when women are tested in rectangular environments – thus, it is not known whether it is wall length information specifically or whether it is geometry in general (wall length and angular information) that is overshadowed by the presence of discrete features. The present study investigated this question by training men and women to orient in an environment that contained wall length as well as distinctive angular and featural cues. Subsequent testing with angles alone allowed us to examine whether the presence of discrete features during training also influenced the encoding of angles by women.

The present study examined the orientation ability of men and women with regard to three main issues. First, it is unclear whether having a partial viewpoint of the environment (i.e., viewing a limited number of features) will influence the encoding of geometry. Therefore, we examined whether the number of featural cues present during training (i.e., three or four features) influenced the encoding of geometry. Second, little is known as to whether distinct features influence the encoding of angular information. Therefore, we examined whether the presence of distinctive features positioned in the corners of the training environment influenced the encoding of acute- and obtuse-angled corners. Third, discrete features have been shown to overshadow the encoding of wall length cues by women, but it remains to be known if these findings extend to the encoding of angular information as well. The present study therefore investigated whether gender differences would emerge if men and women were initially trained with discrete features and subsequently tested for their encoding of angles.

To investigate these questions, participants were first trained to select one of four response patches that were located in the corners of a parallelogram-shaped virtual room. The training room contained four visually distinct features; one feature was situated in each corner of the room and was directly adjacent to a response patch. An equal number of men and women were assigned to one of four groups: groups that were trained with a target response patch located at either a 60º or a 120º corner of the room and could see either three or four features during training. Testing in a featureless parallelogram-shaped room allowed us to examine whether participants could orient using the geometry of the room alone. Testing in featureless rectangular- and rhombic-shaped rooms allowed us to examine whether participants had encoded wall length and angular cues, respectively. Finally, testing in a featureless mirror image parallelogram-shaped room, a transformation that placed wall length in conflict with angles, allowed us to examine whether participants weighed wall length or angular cues more heavily.

Chapter 2: Method

Participants

A total of 128 participants were recruited from the University of Manitoba's first-year undergraduate research participant pool in exchange for course credit (64 men and 64 women, with an average age of 19.2 years for both sexes). All participants had normal or corrected-to-normal vision. An equal number of men and women were randomly assigned to one of four groups: groups that were trained to select a response patch located in either a 60° or a 120° corner in a virtual room that contained either three features (herein referred to as the "Three Feature 60° Group" and the "Three Feature

120° Group”) or four features (herein referred to as the “Four Feature 60° Group” and the “Four Feature 120° Group”).

Apparatus

Virtual environments were rendered in Microsoft Visual Studio Express 2010 using Open Graphics Library. Virtual environments were presented on a desktop computer (Processor speed: 2.66 GHz, Graphics Card: NVIDIA GeForce 9500 GT) with a 17 inch LCD monitor (1440 x 900 pixels). Participants were not able to navigate within the virtual environments but rather used the left and right arrow keys on a keyboard to change their viewpoint. A mouse was used to make responses during trials. Auditory feedback was provided through headphones worn by participants. Responses made by participants were recorded by the computer.

Virtual Environments

Practice. A square-shaped practice room [side length x height: 15 x 8 virtual units (vu)] was initially used to familiarize participants with the procedures of the experiment (see Figure 2). During practice trials, participants learned how to change their viewpoint of the environment as well as how to make responses during trials. A single two-dimensional circular response patch [radius: 0.65 virtual units (vu)] was located on the floor in one corner of the room (4 vu away from each wall that made up the corner). The practice room had uniform beige walls, a grey floor and a black ceiling. The viewing perspective was maintained at a height of 6 vu. The vertical angle of view (i.e., viewing perspective from left to right) was 80° and the horizontal angle of view (i.e., viewing perspective from ceiling to floor) was also 80°.

Training. A parallelogram-shaped room (length x width x height: 20 x 10 x 8 vu) was used to train participants (see Figure 3). One pair of opposite corners projected 60° angles whereas the other two corners projected 120° angles. Four objects that were distinct in colour and shape were located an equal distance from the corners of the environment (yellow cone-shaped object: radius of base = 0.5 vu, height = 1 vu; pink pyramid-shaped object with a square base: side length of base = 0.6 vu, height = 0.6 vu; a red sphere-shaped object: radius = 0.45 vu; blue cube-shaped object: length x width x height = 0.75 x 0.75 x 0.75 vu, herein referred to as "features"). Since the present study employed a reference memory task, the location of the features within the room remained consistent across all training trials. Response patches, identical to the one used in the practice environment, were situated adjacent to each of the four features and were positioned an equal distance from the corners of the environment. Participants assigned to the Four Feature Groups had a viewpoint of the training room in which all four features were visible during a trial (see Figure 3A). Participants in the Three Feature Groups experienced similar viewpoints, with the exception that only three of the four features in the training room were visible during a trial (see Figure 3B). Both groups were able to see all four response patches in the training room. All other aspects of the training room were identical to that of the practice room (i.e., colour of walls, floor, ceiling, viewing perspective and vertical and horizontal angle of view).

Testing. Four separate virtual rooms were created for the purpose of testing participants. Featural cues that were initially present during training were not present in any of the test rooms. A parallelogram-shaped room was used for the Geometry test. The dimensions of this room were identical to that of the training room (length x width x height: 20 x 10 x 8 vu; two 60° corners and two 120° corners; see Figure 4A). A rectangular-shaped room was used for the Wall Length test. The dimensions of this room were identical to that of the training room, except that all corners projected 90° angles (length x width x height = 20 x 10 x 8 vu; see Figure 4B). A rhombic-shaped room was used for the Angle test. The angular amplitude of the corners as well as the height of this room were identical to that of the training room, however all walls were of equal length (length x width x height = 15 x 15 x 8 vu; two 60° corners and two 120° corners; see Figure 4C). Lastly, a mirror image parallelogram-shaped room was used for the Cue Conflict test. The dimensions of this room were identical to that of training room (length x width x height: 20 x 10 x 8 vu; two 60° corners and two 120° corners; see Figure 4D), except that the relationship between wall length and angles were reversed. For example, during training, a corner with a long wall to the left of a short wall projected a 60° angle, but during the Cue Conflict test, a corner with long wall to the left of a short wall projected a 120° angle, thereby reversing the relationship between wall length and angles.

All testing rooms contained four response patches that were identical to those in the training room. The response patches were situated an equal distance from the corners of each of the test rooms. All other aspects of the test rooms were identical to that of the training room (i.e., colour of walls, floor, ceiling, viewing perspective and vertical and horizontal angle of view).

Procedures

Practice Trials. Practice trials were provided for the purpose of teaching participants about the experimental procedures. The participants position was always stationary throughout the experiment, thus participants had to learn how to change their viewpoint so as to view as all of the available features. During practice trials, the participants' goal was to simply select the response patch that was situated on the floor of the room. The response patch could only be activated once the participant had changed their viewpoint of the room. Participants had to use the arrow keys on the keyboard to look left and right until the response patch changed colour from black (inactive) to white (active). Once activated, the response patch could be clicked on using the mouse pointer, at which point the trial ended and the next practice trial began. Once participants had successfully completed three practice trials in the square-shaped room, they were directly transitioned to training.

Training Trials. Participants in the Three Feature and Four Feature groups were trained to select a single response patch that was situated in either a 60° corner or a 120° corner. The trained response patch (herein referred to as the "positive response patch") was consistently associated with one of the objects in the environment (e.g., for one quarter of the participants in each group the positive response patch was always situated in the corner with the yellow cone, for one quarter of the participants in each group the positive response patch was always situated in the corner with the pink pyramid, and so on for the four objects). The position of the response patches and objects relative to each other remained stable across all training trials.

Participants were shown a total of three viewpoints of the training room, one viewpoint from each corner that was not associated with the positive response patch. During each trial, the participant's position remained stationary. Participants were required to change their orientation within the room in order to activate the response patches and make a choice. If the positive response patch had been selected, the participant heard a bell-like sound through the headphones, which indicated that a correct choice had been made. In this case, the trial ended, a white screen appeared for one second, and the participant was placed in a different location of the room with the task of finding the correct response patch once again. If an incorrect response patch had been selected, the participant heard a thud-like sound through the headphones, which indicated that an incorrect selection had been made. In this case, the participant was given as many additional opportunities to find the correct response patch as required. The positive response patch (and the associated object) was counterbalanced across participants in each of the groups. There was no time limit during the training trials as trials only ended once the positive response patch had been selected.

Participant's accuracy was calculated after every six training trials (grouped as a block of trials). The three training viewpoints were each repeated twice in random order during a single block of training. Participants who made a correct selection with their first choice during five out of six trials of a training block advanced to testing. Participants who did not achieve this criterion were given an additional block of training trials and accuracy was recalculated from the most recent block of six trials. Participant's continued to experience training blocks until either they met the accuracy criterion and successfully advanced to testing, or until 30 minutes had elapsed.

Testing Trials. During testing, participants experienced baseline trials, control trials and test trials. Baseline trials were identical in all aspects to the training trials and were presented in order to maintain accurate responding during testing. There were total of 48 baseline trials (i.e., the three training viewpoints were each repeated 16 times). Control trials were identical to the training trials, except that auditory feedback was not provided following a choice and trials terminated after a single choice. Control trials were provided for the purpose of examining whether the lack of feedback during testing influenced participants choice accuracy. There were a total of 24 control trials (i.e., the three viewpoints were each repeated eight times).

There were four types of test trials: Geometry, Wall Length, Angle and Cue Conflict. Test trials occurred in featureless environments to ensure that participants could only use the geometric cues to reorient. The Geometry test occurred in a parallelogram-shaped room with identical dimensions as that of the training room. This test examined whether participants could reorient without the features, using the wall length and angular information provided by the corners of the room. The Wall Length test occurred in a rectangular-shaped room. Since the corner angles in this room were all equal (90°), participants had to rely on wall length alone to reorient. The Angle test occurred in a rhombic-shaped room. Since the lengths of the walls in this room were all equal (15 vu), participants had to rely on the angular information of the corners alone to reorient. The Cue Conflict test occurred in a mirror image parallelogram-shaped room. Since wall length information was in conflict with angles, participants had to rely on either wall length or angular cues to reorient. During all tests, auditory feedback was not provided following a choice and trials ended after a single choice had been made. There were a total of 24 test trials (4 tests x 3 viewpoints x 2 repetitions). Trials were presented in a manner that ensured that each of the four test types (Geometry, Wall Length, Angle and Cue Conflict) were presented once before repetition in a randomized order, while ensuring that no single test type was presented consecutively. In addition, no two test or control trials were ever presented consecutively.

Statistical Analyses

Data was analyzed using analyses of variance (ANOVA). Participants' performance on each test (i.e., Geometry, Wall Length, Angles and Cue Conflict) was analyzed individually since separate predictions were made for each test. Two separate ANOVA's were conducted for each test. The first ANOVA examined choice accuracy during the first test block. This was used to examine whether the geometry had been encoded when participants first experienced the test environment. The second ANOVA examined choice accuracy across all test blocks. This was used to examine whether participants responded consistently across all blocks of testing. Significant interactions and main effects were analyzed using Tukey-Kramer Multiple Comparison tests. Participants' accuracy on each test was also compared to chance using a one sample t-test to determine whether the specific geometric property being tested had been encoded. The probability of choosing a specific corner by chance is .25 as there are 4 possible corner choices in all of the environments. Since there were always two geometrically correct corners on a given test, the probability of choosing the geometrically correct corners by chance was .50. The criterion for significance for all statistical tests was $p < .05$.

Chapter 3: Results

Results are based on data collected from 128 participants (64 men, 64 women) that completed the experiment.

Training Trials

A between-subjects ANOVA examining the number of training blocks to achieve the accuracy criterion with Feature (three or four), Training Corner (60° or 120°) and Gender (men or women) did not show a main effect of Feature, $F_{(1, 120)} = .011$, $p = .912$, Training Corner, $F_{(1, 120)} = 2.082$, $p = .152$, or Gender, $F_{(1, 120)} = 2.773$, $p = .098$. There was a significant interaction between Training Corner and Gender, $F_{(1, 120)} = 7.701$, $p = .006$. Women trained with a 60° corner ($M = 2.031$, $SE = .141$) required a greater number of training blocks compared to men trained with a 60° corner ($M = 1.406$, $SE = .141$) and women trained with a 120° corner ($M = 1.430$, $SE = .141$), however their performance did not differ from that of men trained with a 120° corner ($M = 1.590$, $SE = .141$). All other interactions were not significant [Training Corner x Feature: $F_{(1, 120)} = .012$, $p = .912$; Gender x Feature: $F_{(1, 120)} = .013$, $p = .912$; Training Corner x Gender x Feature: $F_{(1, 120)} = .314$, $p = .581$].

Control Trials

Control trials were identical to training trials, except that auditory feedback was not provided following a choice. To determine if there were group differences in choice accuracy during control trials, a between-subjects ANOVA was conducted using Feature (three or four), Training Corner (60° or 120°) and Gender (men or women) as factors. Results showed no main effect of Feature, $F_{(1, 120)} = .010$, $p = .929$, Training Corner, $F_{(1, 120)} = .010$, $p = .929$, or Gender, $F_{(1, 120)} = 3.510$, $p = .063$. There were no significant interactions between any of the variables [Feature x Training Corner: $F_{(1, 120)} = 2.300$, $p = .132$; Feature x Gender: $F_{(1, 120)} = .200$, $p = .656$; Training Corner x Gender: $F_{(1, 120)} = .960$, $p = .328$; Feature x Training Corner x Gender: $F_{(1, 120)} = 3.510$, $p = .063$]. A one-sample t-test showed that participants chose the positive response patch significantly above the level of chance (.50), [$t_{(127)} = 129.51$, $p < .000001$, $M = .979$, $SE = .003$], thereby indicating that accuracy had been maintained in the absence of feedback.

Test Trials

Geometry Test

First Block. A between-subjects ANOVA was conducted to examine choice accuracy during the first test block with Feature (three or four), Training Corner (60° or 120°) and Gender (men or women) as factors. There was no effect of Feature, $F_{(1, 120)} = .838$, $p = .362$, showing that the number of features that participants were trained with did not influence the encoding of geometry (see Figure 5A). In addition, there were no main effects of Training Corner, $F_{(1, 120)} = 2.891$, $p = .092$, or Gender, $F_{(1, 120)} = .154$, $p = .696$, and no significant interactions between any of the variables [Feature x Training Corner: $F_{(1, 120)} = .154$, $p = .696$; Feature x Gender: $F_{(1, 120)} = .017$, $p = .896$; Training Corner x Gender: $F_{(1, 120)} = 2.070$, $p = .153$; Feature x Training Corner x Gender: $F_{(1, 120)} = .428$, $p = .514$]. A one-sample t-test showed that participants chose the geometrically correct corners significantly above the level of chance (.50), [$t_{(127)} = 9.040$, $p < .0001$, $M = .769$, $SE = .029$], thereby indicating that geometry had incidentally been encoded.

All Blocks. Since group differences were not found during the first block of testing, a between-subjects ANOVA was conducted to examine whether accuracy had been maintained across all blocks with Feature (three or four), Training Corner (60° or 120°) and Gender (men or women) as factors. There was a main effect of Training Corner, $F_{(1, 376)} = 5.455$, $p = .020$ in which group 60° ($M = .841$, $SE = .024$) was found to be more accurate than group 120° ($M = .763$, $SE = .024$). However, both groups 60° and 120° chose the geometrically correct corners above chance (0.50), $t_{(191)} = 15.659$, $p < 0.00001$, $t_{(191)} = 10.397$, $p < 0.0001$, respectively (see Figure 5B).

There were no main effects of Feature, $F_{(1, 376)} = .606$, $p = .437$, or Gender, $F_{(1, 376)} = .218$, $p = .641$ and no significant interactions between any of the variables [Feature x Training Corner: $F_{(1, 376)} = .097$, $p = .756$; Feature x Gender: $F_{(1, 376)} = .097$, $p = .756$; Training Corner x Gender: $F_{(1, 376)} = 3.491$, $p = .062$; Feature x Training Corner x Gender: $F_{(1, 376)} = .024$, $p = .876$]. To examine whether participants had distributed their choices equally between the correct and rotational corners, choices across all three blocks were examined so as to represent each of the three starting position equally. Results showed that participants distributed their choices equally between the correct ($M = .431$, $SE = .178$) and rotational ($M = .368$, $SE = .174$) corners during geometry test trials, $t_{(766)} = 1.941$, $p = .050$. Overall, results from this test showed that the participants had incidentally encoded geometry during the first test block. Furthermore, performance was maintained, as when accuracy was examined across blocks, all groups were found to have encoded geometry, although overall groups trained with the 60° corner were found to be more accurate than groups trained with the 120° corner.

Wall Length Test

First Block. A between-subjects ANOVA was conducted to examine choice accuracy during the first test block with Feature (three or four), Training Corner (60° or 120°) and Gender (men or women) as factors. There was no effect of Feature, $F_{(1, 120)} = .924$, $p = .338$, showing that the number of features that participants were trained with did not influence the encoding of wall length cues (see Figure 6A). In addition, there were no main effects of Training Corner, $F_{(1, 120)} = 1.528$, $p = .219$, or Gender, $F_{(1, 120)} = .018$, $p = .891$ and no significant interactions between any of the variables [Feature x Training Corner: $F_{(1, 120)} = 3.189$, $p = .077$; Feature x Gender: $F_{(1, 120)} = .019$, $p = .891$; Training

Corner x Gender: $F_{(1, 120)} = 1.528$, $p = .219$; Feature x Training Corner x Gender: $F_{(1, 120)} = .925$, $p = .338$]. A one-sample t-test showed that participants chose the corners with the correct wall length cues significantly above the level of chance (.50), [$t_{(127)} = 7.248$, $p < .0001$, $M = .707$, $SE = .028$], thereby indicating that participants had incidentally encoded wall length information.

All Blocks. Since group differences were not found during the first block of testing, a between-subjects ANOVA was conducted to examine whether accuracy had been maintained across all blocks with Feature (three or four), Training Corner (60° or 120°) and Gender (men or women) as factors. There was a main effect of Feature, $F_{(1, 376)} = 6.181$, $p = .013$ in which the Three Feature group ($M = .703$, $SE = .026$) was found to be more accurate than the Four Feature group ($M = .612$, $SE = .026$). There was also a significant interaction between Feature, Training Corner and Gender, $F_{(1, 376)} = 9.329$, $p = .002$. All other main effects and interactions were not significant [Training Corner: $F_{(1, 376)} = 2.225$, $p = .136$; Gender: $F_{(1, 376)} = 3.678$, $p = .056$; Feature x Training Corner: $F_{(1, 376)} = .247$, $p = .619$; Feature x Gender: $F_{(1, 376)} = .005$, $p = .943$; Training Corner x Gender: $F_{(1, 376)} = 3.154$, $p = .077$].

Two ANOVA's were used to examine the performance of the Three Feature and Four Feature groups, separately. A between-subject ANOVA was conducted to examine choice accuracy of the Three Feature group using Training Corner (60° or 120°) and Gender (men or women) as factors. There were no main effects of Training Corner $F_{(1, 188)} = 2.036$, $p = .155$, or Gender, $F_{(1, 188)} = 2.036$, $p = .155$, but there was a significant interaction between Training Corner and Gender, $F_{(1, 188)} = 12.010$, $p = .0007$. The accuracy of men in group 60° ($M = .542$, $SE = .051$) differed significantly from that of men in group 120° group (*M* = .792, *SE* = .05) and women in group 60° (*M* = .792, *SE* = .051), but not from women in group 120° (*M* = .688, *SE* = .051). When choice accuracy was compared to chance (.50), men in group 60° had not encoded wall length information above the level of chance (.50), $t_{(47)} = .703$, $p = .485$, whereas all other groups were found to encode wall length information above chance [Women 60°: $t_{(47)} = 6.592$, $p = 0.0001$; Men 120°: $t_{(47)} = 6.247$, $p = 0.001$; Women 120°: $t_{(47)} = 3.545$, $p = .037$, one-sample t-tests (see Figure 6B)]. These findings indicate that although the men in the Three Feature 60° had encoded wall length information during the first block of testing, they decreased their reliance on this geometric cue as the test trials progressed.

Next, a between-subject ANOVA was conducted to examine choice accuracy of the Four Feature group using Training Corner (60° or 120°) and Gender (men or women) as factors. There were no main effects of Training Corner $F_{(1, 188)} = .481$, $p = .489$, or Gender, $F_{(1, 188)} = 1.657$, $p = .199$ and the interaction between Training Corner and Gender was not significant, $F_{(1, 188)} = .795$, $p = .374$. When choice accuracy was compared to chance (.50), results showed that the Four Feature group had chosen the corners that were correct according to wall length significantly above chance ($t_{(191)} = 4.259$, $p = 0.00003$, $M = .612$, $SE = .026$, one-sample t-test). Overall, findings from this test showed that wall length information had incidentally been encoded by participants during the first block. When performance was examined across all blocks, men in the Three Feature 60° Group reduced their reliance on wall length information, whereas the rest of the groups continued to choose the response patches that were correct according to wall length information.

Angle Test

First Block. A between-subjects ANOVA was conducted to examine choice accuracy during the first test block with Feature (three or four), Training Corner (60° or 120°) and Gender (men or women) as factors. There was no main effect of Feature, $F_{(1, 120)} = .160$, $p = .689$, showing that the number of features that participants were trained with did not influence the encoding of angles. However, there was an effect of Training Corner, $F_{(1, 120)} = 5.142$, $p = .025$. The choices made by group 60° ($M = .602$, $SE = .041$) were significantly more accurate compared to the choices made by group 120° ($M = .469$, $SE = .041$). When choice accuracy was compared to chance (0.50), group 60° selected the response patches with the correct angular information significantly above chance, $t_{(63)} = 2.422$, $p = 0.018$ whereas group 120° did not, $t_{(63)} = .753$, $p = .454$, one-sample t-tests (see Figure 7A).

There was also a significant effect of Gender, $F_{(1, 120)} = 4.004$, $p = .048$. The choices made by men ($M = .594$, $SE = .041$) were found to be more accurate in comparison to the choices made by women ($M = .477$, $SE = .042$). When accuracy was compared to chance (0.50), men selected the response patches with the correct angular information significantly above chance, $t_{(63)} = 2.260$, $p = .027$, whereas women did not, $t_{(63)} = .554$, $p = .581$, one-sample t-tests (see Figure 7B). There were no significant interactions between any of the variables [Feature x Training Corner: $F_{(1, 120)} = .872$, $p = .352$; Feature x Gender: $F_{(1, 120)} = 2.153$, $p = .145$; Training Corner x Gender: $F_{(1, 120)} = .160$, $p = .689$; Feature x Training Corner x Gender: $F_{(1, 120)} = .445$, $p = .506$].

All Blocks. Since some groups were unable to encode angles during the first block, choice accuracy was examined by test block as this would clarify whether the groups that were initially unable to encode angles would encode angles when given additional experience in the test room. A mixed-factor ANOVA examining choice accuracy was conducted using Feature (three or four), Training Corner (60° or 120°) and Gender (men or women) as the between-subject factors and using Test Block (block 1, block 2 or block 3) as the within-subject factor. There were no main effects of Feature, $F_{(1, 360)} = .304$, $p = .582$, Training Corner, $F_{(1, 360)} = .519$, $p = .472$, Gender, $F_{(1, 360)} = 1.245$, $p = .265$ or Test Block, $F_{(2, 360)} = 1.425$, $p = .242$. There was a significant interaction between Gender and Test Block, $F_{(2, 360)} = 4.708$, $p = .009$. The choice accuracy of men during Block 2 ($M = .664$, $SE = .045$) differed significantly from that of Block 3 ($M = .476$, $SE = .045$) and also differed from the accuracy of women during Block 1 ($M = .476$, $SE = .045$; see Figure 8). All other interactions were not significant, F's < 2.082, p's $> .126$. Overall results from this test show that participants incidentally encoded angles when trained with a 60° corner but not when trained with a 120° corner. Furthermore, men had incidentally encoded angles whereas women were not found to incidentally encode angles.

Cue Conflict Test

First Block. A between-subjects ANOVA was conducted to examine choice accuracy to the corners with correct wall length during the first test block using Feature (three or four), Training Corner (60° or 120°) and Gender (men or women) as factors. There were no main effects of Feature, $F_{(1, 120)} = .122$, $p = .727$, Training Corner $F_{(1, 120)} = .666$, $p = .416$, or Gender $F_{(1, 120)} = 1.646$, $p = .202$, and no significant interactions between any of the variables [Feature x Training Corner: $F_{(1, 120)} = .014$, $p = .907$; Feature x Gender: $F_{(1, 120)} = .014$, $p = .907$; Training Corner x Gender: $F_{(1, 120)} = .014$, $p = .907$; Feature x Training Corner x Gender: $F_{(1, 120)} = .122$, $p = .727$]. A one-sample t-test showed that participants selected the corners with the correct wall length ($M = .386$, $SE =$

.033) significantly below the level of chance, $t_{(127)} = 3.442$, $p = 0.0007$, thereby showing a preference for angles over wall length when the cues were presented in conflict (see Figure 9A).

All Blocks. Since group differences were not found during the first block of testing, a between-subjects ANOVA was conducted to examine whether choice accuracy had been maintained across all blocks with Feature (three or four), Training Corner (60° or 120°) and Gender (men or women) as factors. There were no main effects of Feature, $F_{(1, 376)} = .015$, $p = .892$ or Training Corner $F_{(1, 376)} = .671$, $p = .415$, but there was a main effect of Gender $F_{(1, 376)} = 6.000$, $p = .015$. Men ($M = .427$, $SE = .027$) chose the corners with the correct wall length significantly more than women ($M = .333$, $SE = .027$). However, both men and women chose the corners with the correct wall length information significantly below the level of chance (0.50) [men: $t_{(127)} = 2.570$, $p = 0.023$; women: $t_{(127)} = 6.490$, $p = 0.000001$, one-sample t-tests], thus showing that both men and women consistently preferred angles over wall length information (see Figure 9B).

There were no significant interactions between any of the variables [Feature x Training Corner: $F_{(1, 376)} = 1.501$, $p = .221$; Feature x Gender: $F_{(1, 376)} = .911$, $p = .341$; Training Corner x Gender: $F_{(1, 376)} = .073$, $p = .786$; Feature x Training Corner x Gender: $F_{(1, 376)} = 2.242$, $p = .135$]. Overall, results of the Cue Conflict test indicated that participants consistently selected the response patches associated with the correct angles, rather than the response patches associated with the correct wall length. Although men were found to choose the corners with correct wall length significantly more than women across blocks, both men and women chose angular information above chance levels.

Chapter 4: Discussion

The main goals of this study were to: 1) examine whether restricting an individual's viewpoint to a fewer number of featural cues would influence the encoding of geometry, 2) examine whether the presence of distinct objects during training would influence the encoding of acute- and obtuse-angled corners, and 3) examine whether gender differences might exist in the encoding of angles when discrete features were available during training. Participants were trained to select a single response patch located at either a 60° or a 120° corner of a virtual room that contained either three or four discrete and distinctive features. Participants were given four tests in featureless rooms to examine which of the geometric properties had been encoded. Specifically, we examined response accuracy when wall length and angles were presented together (Geometry test), when each cue was presented individually (Wall Length test and Angle test) or when the cues were presented in a conflict situation (Cue Conflict test). Results showed that the number of features present during training did not influence the encoding of geometry during any of the four tests. Although all groups were accurate at selecting the correct response patches during the Geometry and Wall Length tests, performance was variable during the Angle test. Participants trained with the acute corner were found to incidentally encode angles, but those trained with the obtuse corner had not encoded angles. Furthermore, women were significantly less accurate at encoding angles in comparison to men. Despite the fact that some groups had difficulty encoding angles, all groups were found to choose the response patches associated with the correct angles rather than those associated with correct wall length when the cues provided conflicting information.

Number of Features

In order to learn the relationship between all of the features in the training room, the Three Feature group had to integrate information about the features during training, whereas the Four Feature group did not have to do this since all of the features were visible during training. Despite this, the Three Feature group encoded geometry with equivalent accuracy as the Four Feature group during all of the tests, showing that the number of featural cues present during training did not influence the encoding of geometry. Past research has shown that when all of the features of an environment cannot be seen, humans are capable of combining information about features learned from multiple viewpoints into a representation of the environment (Castelhano, Pollatsek & Rayner, 2009; Friedman et al., 2011; Friedman & Waller, 2008). View combination has been shown to occur with little training or exposure to an environment (Castelhano & Pollatsek, 2010; Friedman & Waller, 2008; Ullman, 1998). Had participants in the Three Feature group been using view combination to create a representation of the featural cues, this would have required little effort and consequently may not have influenced the encoding of geometric cues. Another possibility is that participants may have only learned about the feature closest to the positive response patch, as this feature could have been used as a beacon to make responses during training. Whether participants used a beacon or a landmark-based strategy to orient, or whether all of the features present during training had been encoded cannot be determined as the present study was not specifically designed to examine these possibilities. Nonetheless, our findings show that the number of featural cues present during training did not influence the encoding of (or failure to encode) either wall length or angles or both cues when they were presented together or in conflict.

Few studies have examined whether the orientation ability of animals is influenced by the number of features that are available during training. Sutherland (1987) found that when visual and physical access was restricted to one half of an environment (i.e., only two of four distal features were visible), rats were less accurate at locating a target when released from the previously restricted part of the environment. In contrast, rats that had full visual and physical access to the training environment were accurate at locating the target when released from novel start positions. Hamilton, Driscoll and Sutherland (2002) replicated these findings with humans using a virtual task. Similar to rats, participants' accuracy at finding the target was highly dependent on their ability to view and navigate the full training environment. In a similar vein, Canovas, Garcia and Cimadevilla (2011) showed that when allowed full visual and physical access to an environment, humans were accurate at locating a target regardless of whether they were trained with one, two or seven distal landmarks. Taken together, these studies suggest that the number of landmarks required to locate a goal may only be important when visual and physical access to an environment is restricted. However, the geometric cues used by participants in the abovementioned studies (distance and direction from landmarks to a target) differ greatly from those used in the current study (wall length and angles), thus care must be taken when attempting to generalize these previous findings to our present study. As it stands, the findings of the present study suggest that the encoding of wall length and angles is not influenced by the number of features present during training. These findings would be strengthened if future studies are able to show that training with even fewer features (i.e., two or one) that are not located in the positive corner (using landmarks instead of beacons) also do not influence the encoding of wall length and angles by humans.

Geometry

Angles. Although the number of features did not influence the encoding of angles by participants, the distinct visual properties of the features may have influenced the encoding of angles. Results from the Angle test showed that participants trained with a 60º corner had encoded angles with greater accuracy than participants trained with a 120º corner. Additionally, participants trained with the 60º corner had incidentally encoded angles, whereas those trained with the 120º corner had not encoded angles. Past research has shown that humans find larger angles more difficult to encode when trained without features (Reichert & Kelly, 2011), but are capable of encoding these angles when featural cues are present during training (Lubyk et al., 2013). However, the featural cues used during training in the Lubyk et al. study were only positioned in the positive corners and were identical to each other. Thus there is a lack of clarity as to whether the presence of features or their strategic placement in the environment (only in the positive corners) facilitated the encoding of larger angles by participants in the Lubyk et al. study. In the present study, we examined whether distinct features positioned in the corners of the training environment would influence the encoding of obtuse angles. Results showed that obtuse angles had not been encoded, implying that the presence of distinct features during training overshadowed the encoding of obtuse angles.

A study by Kosaki et al. (2013) also reported similar findings in which distinct features were found to overshadow the encoding of obtuse angles by rats. In this study, rats were trained to locate an escape platform in one corner of a rhombic-shaped water maze. A single feature was located in the positive corner and could have been used as a beacon to locate the escape platform. Results showed that the feature overshadowed the encoding of acute and obtuse angles, but the effect was more pronounced for obtuse angles. These findings may be attributed to the fact that the feature predicted the platform location 100% of the time, whereas angular information predicted the platform location only 50% of the time. Since the feature was more predictive of the goal location, it may have overshadowed the encoding of obtuse angles. In a subsequent experiment, Kosaki et al. found that when features and geometry were equally predictive of a goal location (i.e., there were two pairs of identical features situated in diagonally opposite corners; features and geometry both predicted the goal location 50% of the time), the features overshadowed the encoding of obtuse angles but not acute angles. Despite these findings, in the Lubyk et al. (2013) study, obtuse angles were not overshadowed even though features and geometry equally predicted the goal location (identical features were located in the geometrically correct corners). However, in this study features were only situated in the geometrically correct corners of the environment. The possibility remains that the positioning of these features resulted in participants only attending to the corners in which features were available. The present study builds on the findings of Kosaki et al. to show that when features better predict a goal location, they can overshadow the encoding of obtuse angles by humans.

One reason why featural cues may compete with obtuse angles more than acute angles may pertain to the way in which angular cues are encoded. Reichert and Kelly (2012) found that the amplitude of angles influenced the strategies used by humans to encode these geometric cues. During an angle discrimination task, participants were trained to search for a target near one of two L-shaped panels that projected either 50º or 75º angles. Participants were later tested with their training angle and a novel angle that ranged from 30º to 90º. During testing, participants trained with the 50° angle were found to use an absolute strategy, in that a large proportion of choices were directed to test angles that were close to 50°, showing that the precise metrics of the 50° angle had been encoded. Participants trained with the 75° angle were found to use a relative strategy as all angles that were larger than 75° were chosen at equally high rates, showing that participants were using a relative rule of choosing the larger of the two test angles. Although interesting, these results only pertain to acute angles. Hence further research is required to determine whether smaller and larger obtuse angles, when presented together, are also encoded using absolute and relative rules, respectively. Such findings will help to determine whether differences in strategies are related to the encoding of smaller and larger angles, or whether they are related to the encoding of acute and obtuse angles.

Overall, the idea that smaller angles are encoded using an absolute strategy suggests that these angles are attended to quite precisely. The presence of nearby features may therefore not influence the encoding of these smaller angles. Larger angles are more difficult to discriminate from each other, and might therefore not be attended to as precisely. Hence, a nearby feature may be encoded in favor of a larger-angled corner, since the feature can be used to predict a target location more accurately than the angle alone.

Wall Length. Despite the fact that some groups had difficulty encoding angles, all groups were found to weigh angles more heavily than wall length information during the Cue Conflict test. These findings, when evaluated within the context of past studies, imply that wall length information may have facilitated the encoding of angles during the Cue Conflict test. For instance, Lubyk, Dupuis, Gutierrez and Spetch (2012) found that humans were able to orient with acute and obtuse angles when they were trained in a featureless enclosed environment that contained angular cues as well as wall length cues. However, Reichert and Kelly (2011) found that participants were unable to orient with larger angles when trained with a featureless array of discrete angular cues (no walls were present). The presence of wall length information in the Lubyk and Spetch study could have facilitated the encoding of angles by participants. Our findings show that training with distinct featural cues may overshadow the encoding of obtuse angles when angular cues are tested alone. Nevertheless, the presence of wall length information during testing may facilitate the encoding of obtuse angles.

The idea that wall length information may facilitate the encoding of obtuse angles does require further investigation. According to Weber’s Law, the just noticeable difference between two stimuli is proportional to the magnitude of difference between those stimuli (Fechner, 1860/1966). Taken in the context of our findings, if wall length plays a role in the perception of obtuse angles, then large differences between the lengths of the walls of an environment (e.g., 10 x 40) should result in participants being more accurate at detecting obtuse angles compared to small differences in wall lengths (e.g., 10 x 12). To further investigate this idea, future studies can train participants using identical methods as the current study. Participants can then be tested in environments where angular information is available and stable but the walls of the test environment vary in length (e.g., 10 x 10 vu, 10 x 15 vu, 10 x 20 vu, 10 x 25 vu and 10 x 30 vu). The findings of such a study can be used to verify whether the facilitation of obtuse angles by wall length cues follow the tenet's of Weber's Law.

Gender Differences

Findings from the Angle test showed significant gender differences; men had incidentally encoded angles above the level of chance whereas women were not found to encode angles. Previous studies have shown that men and women attend to geometry differently when featural cues are also present in an environment. For instance, when surface features are present during training both men and women are able to encode wall length information (Kelly & Bischof, 2008), yet when discrete features are present during training, they overshadow the encoding of wall length information for women but not for men (Kelly & Bischof, 2005). The results of the present study extend these findings to show that discrete features also overshadow the encoding of angles by women. One question remains – why did the discrete features not overshadow the encoding of wall length for women in the present study similar to that of the previous study (Kelly & Bischof)? One possible explanation might be related to the methods used by the present study. During training, participants had to change their orientation within the environment and so were exposed to a dynamic view of the environment. However, in the Kelly and Bischof study, participants only saw static images of the environment during training. The idea that dynamic motion facilitates the encoding of scenes and objects has previously been documented (Christou & Bulthoff, 1999; Friedman, Vuong & Spetch, 2009, 2010) and may explain why wall length cues were encoded by women in the present study, despite the presence of discrete features.

The idea that men and women attend to features and geometry differently was recently investigated using an eye-tracking task (Andersen et al., 2012). Participants were trained to locate a target within a virtual radial arm maze that contained landmarks and were later required to retrieve the target when it was hidden. Although men and women were accurate at using the landmarks to orient, eye-tracking data showed that men initially attended to the landmarks, but shifted their gaze to the surfaces of the environment over the course of the trial. Women were found to continually attend to the landmarks and therefore showed a greater number of landmark fixations compared to men. To add to these findings, many studies have reported a female advantage at object location memory tasks which may explain why women attend to featural cues more precisely (Silverman, Choi & Peters, 2007; Silverman & Eals, 1992; Voyer, Postma, Brake & Imperato-McGinley, 2007).

It would be interesting to determine whether the number of distinct properties a feature contains (i.e., shape, colour, texture) will influence the salience of features when geometric cues are also present. This idea can be examined by training participants to locate a target in a rectangular-shaped environment with four features that are distinct according to either colour or shape. Subsequent testing without the features can help to determine whether features that are less salient also influence the encoding of geometry by women. Although it is difficult to equate the physical properties of colour and shape, such findings may help to determine whether features that are less salient (i.e., contain only a single visual property) also influence the orientation ability of women.

Conclusions

Overall, the findings from this study have contributed significantly to our current knowledge of orientation. First, these findings show that the encoding of wall length and angles is not influenced by the number of featural cues present during training. When interpreted within the broader context, there are many instances in real-world environments where animals must orient with sparse visual cues. Regardless of the number of features that have been learned, encoding the geometry an environment ensures that if features change in appearance or are no longer available, animals can still rely on geometry to find their way around an environment. Second, although the encoding of geometry appears to be robust and is generally not overshadowed by features, our findings suggest that the encoding of certain types of geometric cues (obtuse angles) may not be as robust. For instance, obtuse-angled corners are more difficult to discriminate, making it taxing for an individual to match up these angles with other obtuse angles that have been learned. Hence, when featural cues are also present, features may be encoded in favor of obtuse-angled corners as features may serve as more reliable cues. Third, we show for the first time that discrete features overshadow the encoding of angular cues by women, thus indicating that discrete features are not just more salient than wall length but are more salient than geometry in general, for women. Lastly, cue facilitation has previously been observed with featural cues facilitating the encoding of geometric cues (Graham, Good, McGregor & Pearce, 2006; Horne & Pearce, 2011; Kelly, 2010; Pearce, Graham, Good, Jones & McGregor, 2006). However, our findings show for the first time, that one type of geometric cue (wall length) can facilitate the encoding of another (angles). Wall length cues are considered to be salient global cues since they encompass the entire environment, whereas angular cues projected by the corners of a space are considered to be local cues. Global geometric cues (wall length), may have been used by participants to determine the general area of the goal, at which point local geometric cues (angles) could have then been used by participants to accurately locate the goal.

In summary, our results show that the encoding of geometry is not influenced by the number of featural cues that are present in an environment. However, the specific properties possessed by featural cues (i.e., colour and shape, whether they are discrete objects or integrated into the surfaces of a space) may influence the encoding of certain geometric cues. Furthermore, salient geometric cues (i.e., global wall length information) may help an individual attend to local parts of the environment (i.e., angles). Overall, the findings of this study have furthered our understanding not only of the influence of features on the encoding of geometry, but also of the differential reliance shown by men and women on these spatial cues to orient.

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Figure 1: Schematic Diagram of Cheng's (1986) Experiment

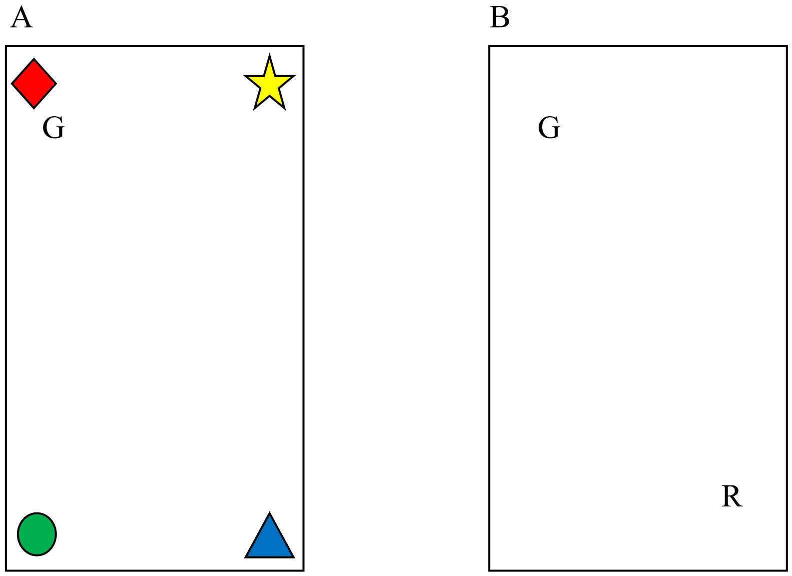


Figure 1. Schematic representation of the environment used in Cheng's (1986) study. A) The coloured symbols represent distinct panels that were placed in each corner of the training and testing environments. As an example "G" represents the goal location where a group of rats were trained to search for food; the location of the hidden food was counterbalanced across the groups. B) The rectangular environment shown without the distinctive features present. "G" represents the goal location and "R" represents the rotationally equivalent, or geometrically identical, location in the enclosure.

Figure 2: Practice Environment

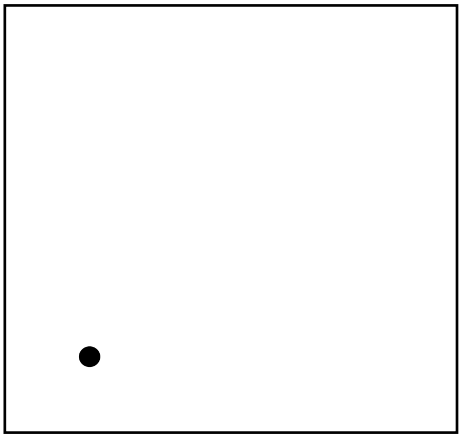


Figure 2. Schematic representation of the square-shaped virtual practice environment. The black circle represents the two-dimensional response patch that participants were trained to select.

Figure 3: Training Environments

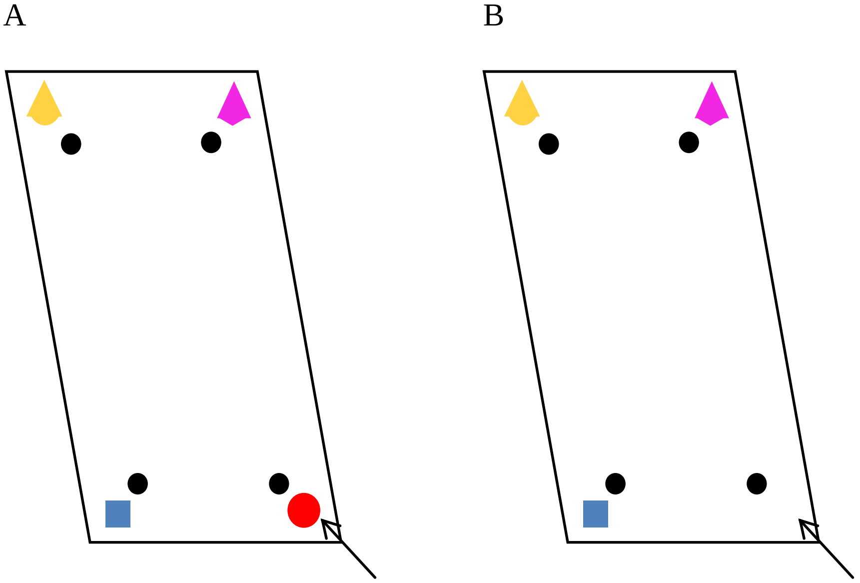


Figure 3. Schematic representation of the training environment of the A) Four Feature group and B) Three Feature group. The coloured symbols in the corners represent the three-dimensional objects (featural cues) that were situated in the rooms. The identical black circles located next to each of the featural cues represent the two-dimensional response patches. As an example, the black arrows at the bottom right corner of the figures represent the stationary position of the participants during one of the training trials. Although participants were not able to navigate the environment, they were able to change their viewpoint (i.e., look left and right) from this stationary position during training. The size of the room relative to the objects and response patches is not drawn to scale.

Figure 4: Testing Environments

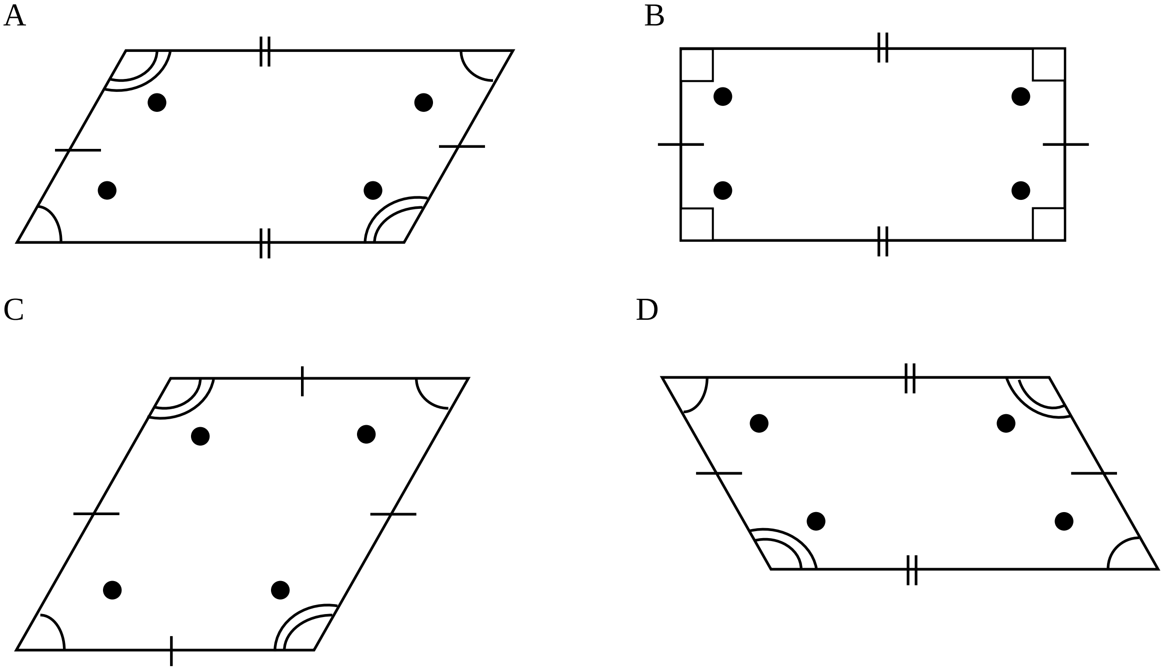
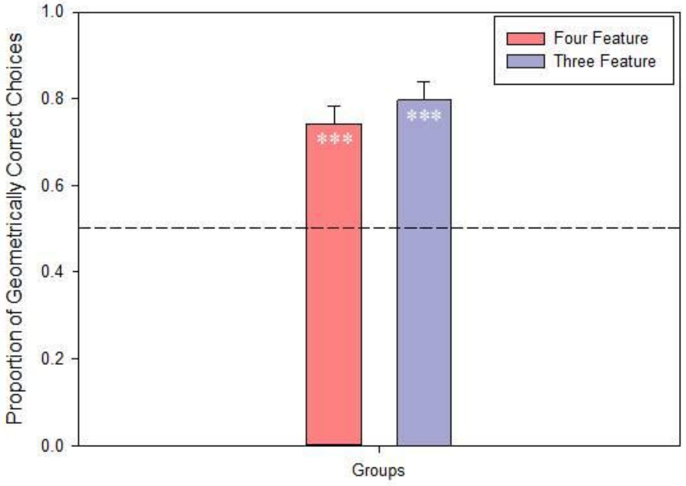


Figure 4. Schematic representations of the virtual testing environments. The black circles represent the two dimensional response patches. A) Geometry test room, B) Wall Length test room, C) Angle test room and D) Cue Conflict test room. The sizes of the test rooms relative to the response patches are not drawn to scale.

Figure 5: Choice accuracy during the Geometry test

A)



B)

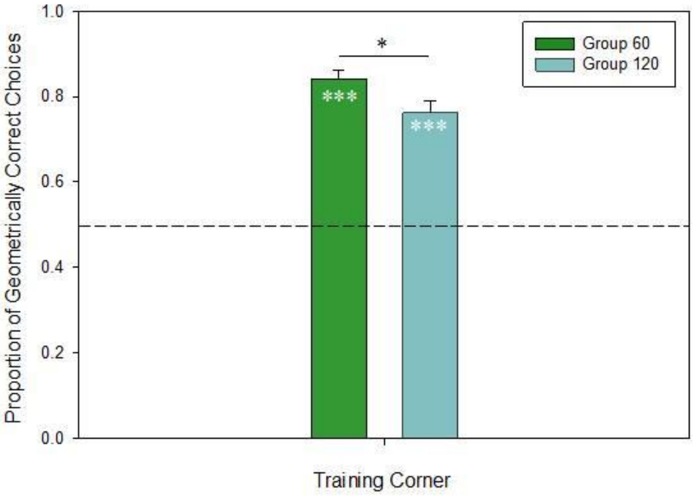


Figure 5. A) Choice accuracy of the Three Feature and Four Feature groups during the first block of the Geometry test compared to chance (.50). B) Comparison of the 60º and 120º groups and overall choice accuracy compared to chance (.50) during all blocks of the Geometry test. * indicates significance at $p < .05$; *** indicates significance at $p < .001$.

Figure 6: Choice accuracy during the Wall Length test

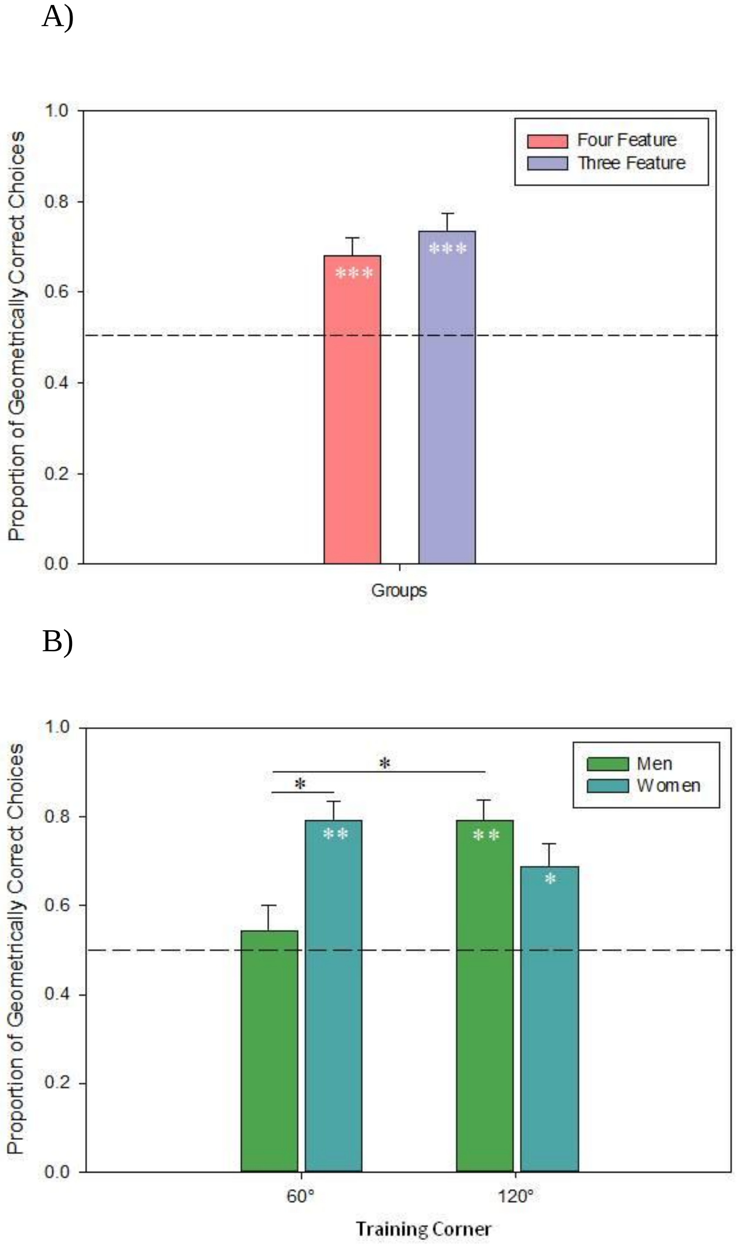
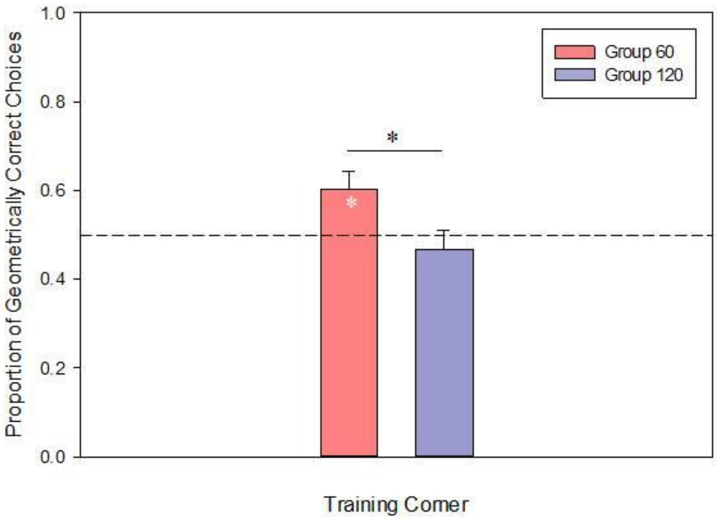


Figure 6. A) Choice accuracy of the Three Feature and Four Feature groups during the first block of the Wall Length test compared to chance (.50). B) Differences between Training Corner and Gender for the Three Feature group and overall choice accuracy compared to chance (.50) during all blocks of the Wall Length test. * indicates significance at $p < 0.05$; ** indicates significance at $p < 0.01$; *** indicates significance at $p < .001$.

Figure 7: Training corner and gender differences during the Angle test

A)



B)

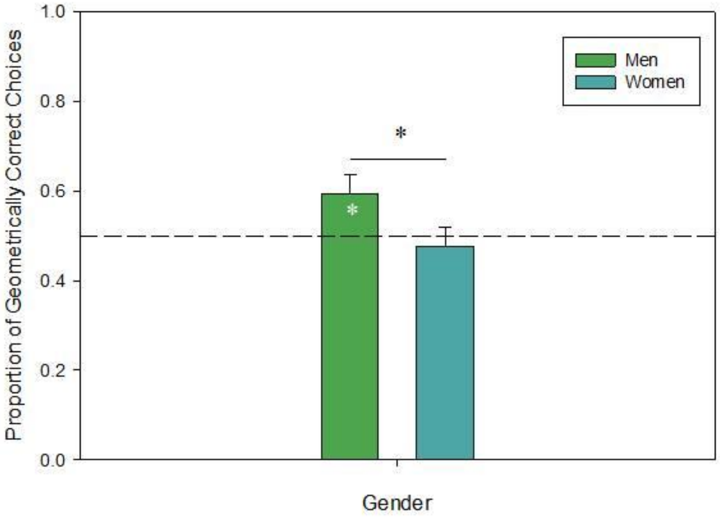


Figure 7. A) Differences between group 60º and group 120º as well as choice accuracy of the groups compared to chance (.50) during the first block of the Angle Test. B) Gender differences as well as choice accuracy of men and women compared to chance (.50) during the first block of the Angle Test. * indicates significance at $p < 0.05$.

Figure 8: Gender differences across blocks of the Angle test

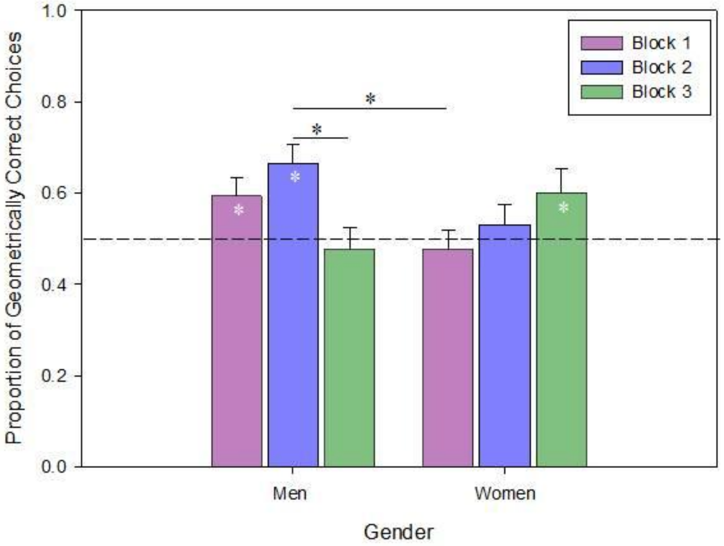


Figure 8. Gender differences across blocks as well as overall choice accuracy compared to chance (.50) during the Angle Test. * indicates significance at $p < 0.05$.

Figure 9: Choice accuracy during the Cue Conflict test

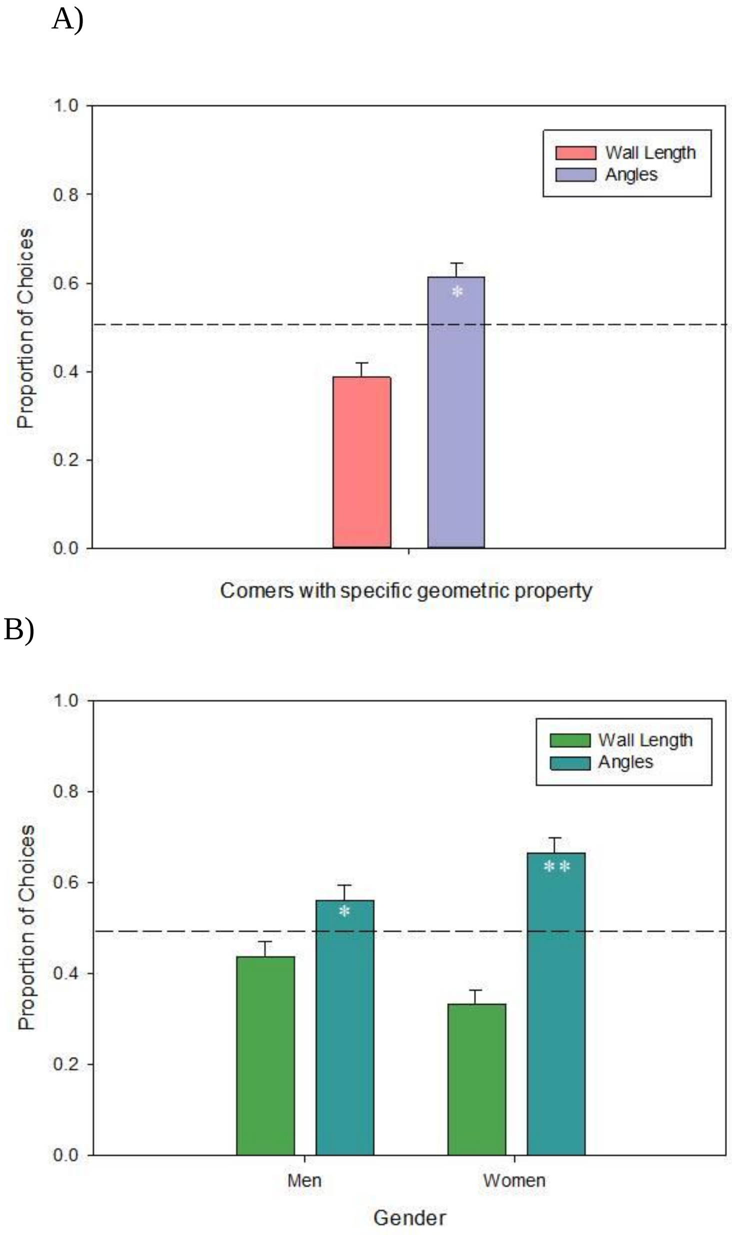


Figure 9. A) Choices to corners with correct wall length or angles compared to chance (.50) during the first block of the Cue Conflict test. B) Gender differences and overall choice accuracy to corners with correct wall length or angles compared to chance (.50) during all blocks of the Cue Conflict test. * indicates significance at $p < 0.05$; ** indicates significance at $p < .01$.