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Active Measures of Spatial Cognition

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Abstract

Spatial cognition is how we navigate and perceive the space around us. Distance estimation is one of the elements of spatial cognition. A previous study was done to test if the presence of boundaries has an effect of distance estimation. In the present study, this same phenomenon was tested using an action-based task to examine how this affected distance estimation. Participants were asked to stand at the end of three runners and throw bean bags at a target on the other end of the runner. One runner had an open throwing path, another runner had a doorway in the throwing path, and the last runner had a board in the throwing path. Distances of the runners and the targets were all the same. The reported analyses contrasted the thrown distances across each of these stimulus conditions. The results found that there was no significant difference in distance thrown between each condition. The results also did not find any significant difference in the order in which they completed the conditions or between each individual toss. These inconclusive findings are in contrast with previous research and suggests a possible difference between explicit quantified distance estimation and how we perform distance relevant actions.

Key words: Spatial cognition, distance estimation, action-based task

Perception involves being aware of things around you and how you understand them. Constantly, we are taking in information from our environment and our brains are processing that information into meaningful interpretations. Perception involves being aware of things around you through your senses which then allows you to interpret and memorize those stimuli in a meaningful way. This could be as simple as evaluating a room and seeing what is inside. This example includes seeing and sensing your environment and then processing that information that you received from your senses. Seeing a well-known car and trying to figure out what model year it is involves retrieving prior knowledge that you might have about cars and then analyzing the car that is in front of you. The impressive thing about perception is that this process happens almost instantaneously.

Perception is an automatic and natural process that people do not necessarily have immediate control over. Despite the sophistication of our brains, our perception can sometimes make errors, fail to notice things, or be biased. These errors can take many forms. An example of a form of bias that we might not notice is confirmation bias. Confirmation bias is when we seek out information that affirms our previous ideas about a subject and therefore reaffirms our perception of those things. Misconceptions or misunderstandings can alter how we interpret information in order to align with our beliefs (Sleegers, Proulx, Van Beest, 2019). Or there is self-serving bias which leads to us accepting accomplishments and often blaming failures on other factors (Coleman, 2011). These are examples of biases or errors show that our perception is not always as sound as we think and that our minds can be tricked. We can have ideas of how our mind works but we are more vulnerable to internal and external bias and influences than we realize.

The way our mind and perception evaluate the world around us is called spatial cognition. Spatial cognition involves how people describe their environment, navigate through it, and plan routes through it. One of the basic principles in spatial cognition is the idea of a cognitive map. Navigating through space is as basic as finding your way to the kitchen from your front door. This map helps us understand where things are around us and eases our movement around a space. Once we navigate through an area, our brain creates a mental representation of the space in something that Tolman (1948) describes as a cognitive map. This process allows us to have an idea of our environment and aids in navigating that space. With this map, we can make estimations of how far away we are from our destination. The process of spatial cognition comes in three parts: landmark knowledge, route knowledge, and survey knowledge (Helstrup & Magnussen, 2001). Landmark knowledge involves taking note of the uniqueness of objects and their locations. Route knowledge involves travel paths that connect landmarks along the way. Survey knowledge is understanding how routes and landmarks are interconnected and aids in finding shortcuts or taking new routes (Helstrup & Magnussen, 2001). Navigating through space requires these fundamental elements and combines them to comprise spatial cognition.

As with all processes in the brain, spatial cognition has a certain area of the brain that controls this mechanism. The hippocampus has power over spatial memory and awareness. The hippocampus also plays a great role in working memory which is the process that takes in sensory information and makes sense of it so that the brain can use that information and act accordingly. The extent to which the hippocampus plays a role in spatial cognition was first showcased in the Morris (1984) water maze experiment. Morris found that rats who had hippocampal lesions were not as successful at completing a maze as those without. Doeller, King, and Burgess (2008) found that the right-side hippocampus is responsible for spatial memory when landmarks are removed. This shows that the hippocampus is instrumental in navigating a space while completing a task.

Constantly, people judge the size or distance of things in relation to other things in the environment. When presented with a location or a landmark the brain creates a mental snapshot of the environment. Although when a memory is brought back up to the surface it is just as vulnerable to change as when it was first formed. Once an environment is presented, the mental snapshot is stored in our memory. If presented with the same environment, with changes to certain aspects of the space, an individual's perception can be thrown off and lead to distance estimation errors. When determining how far things are in relation to other objects in the environment the parietal cortex also plays a very significant role (Committeri, Galati, Anne-Lise Paradis, Pizzamiglio, Berthoz, and LeBihan, 2004). Much of the spatial information that we encode is organized in our brains in the form of a "cognitive map" that helps us remember where things are located in the relation to us and other things in the environment (O'Keefe & Nadel, 1978). This cognitive map, that is involved in navigating through space also allows us to estimate the distances between us and an object.

There are often boundaries that may affect our judgement of distances that we are not even aware of. This phenomenon is called the categorical boundary effect. An example of this would be judging how far away certain cities are from you. Many would consider traveling from Statesboro to Atlanta as closer than driving to Jacksonville, merely because you have to cross a state border, but it is actually much closer to drive to Jacksonville than to Atlanta (Stevens & Coupe, 1978). The state boundary that is drawn on a map acts as an illusory boundary. These kinds of illusory boundaries are all around us and can affect how we perceive distance. A study done by Huttenlocher et. al. (1991) investigated how category effects influence location memory.

These participants were tasks with replacing a dot in a circle as they recalled it. Four experiments were done with various distributions of dots within each circle. This study found that when dots were not located in an obvious quadrant, participants were more likely to make an error when replacing the dot. This shows that when people categorize a shape or space, they are more likely to make errors when interpreting location. If looking into a room with a doorway, according to gestalt principles it is natural for us to try to enclose this other room and consider it separate from your current location (Overvliet, Krampe, Wagemans, 2012). This closing-off of the separate room suggests that an object or target would seem further away since there is now this omnipresent boundary in between the participant and their goal.

When looking down a path it is normal for people to judge the distance of that path. Brunec, Javadi, Zisch, and Spiers (2017) conducted a study that measured how people judge distance to a goal and the time it takes to complete that path. This study provided different routes to get to a target. One path was a straight path to the destination and the other had many obstacles and turns in its path. The participants underestimated the time and overestimated the distance of the straight path to the target; however, they underestimated the time and overestimated the distance to the target far more significantly when circumnavigation was required. This study showed that people's time and distance judgements are further enhanced when circumnavigation is involved (Brunec et al., 2017). These breaks and boundaries that interfere with our goal can cause breaks in our memory and interpretation of the route or of objects. This phenomenon occurs because when there is a boundary interrupting our view, or judgement, then our memory is hindered (Horner, Bisby, Wang, Bogus, & Burgess, 2016). In this study, participants navigated through different rooms in a virtual reality setting. Each room was separated by a closed door and had either one or two tables inside of it with an object on each table. Participants had to interact with each object and denote if it was natural or man-made. After interacting with each object, they either went to the next table in the room, or they went into the next room. The results yielded that participants were more likely to recall the sequence of the items they saw when they were within the same room. When the items were in different rooms, separated by the doorway boundary, memory was adversely affected. Similar research has also been done testing how doorway boundaries and the separation between rooms affects people's spatial memory (Radvansky & Copeland, 2006). This study's procedures were very similar to the previous study, the only thing that as altered was that individuals had to either carry and object to the next room or carry it to another table within the same room. The object disappeared while they were carrying it from place to place. Once they placed the object on the next table, either within the same room or in the next room, they had to recall what object they were carrying. They found that when carrying an object to a separate room, they had a harder time recalling what the object was.

There has been extensive research and debate on the effects of one's ability to complete a task and its perceived difficulty level. When given a heavy backpack to carry, people perceived a hill to be steeper compared to people who did not have a heavy load on their back (Bhalla & Proffitt, 1999). A similar phenomenon occurred when people were asked to walk through a doorway and then report how wide it was (Stefanucci & Geuss, 2009). The change in one's ability to complete a task affect their perception of their capabilities (Yang & Beilock, 2011). If an activity seems to be challenging, then we anticipate more work and effort to be expended while completing this activity. The more work involved in a task, the more there is to overcome and more that could potentially go wrong. With potential boundaries or other factors that limit one's ability to complete that task, people could potentially be intimidated, and this might cloud their judgement. Some critics claim that the change in perception when given a backpack or some other item that challenges the participant was an occurrence of the paternalistic vision hypothesis (Firestone 2013). Paternalistic vision hypothesis can be explained as when participants change their behavior or responses because they may know what the researcher's hypothesis is. How questions are asked, and tasks are explained might clue participants to the result that researchers are trying to prove (Firestone & Scholl, 2016). This theory aims to pose questions for how some past experiments were conducted in that may have had some unintentional leading questions or instructions for their experimental tasks. The debate between Firestone and Scholl and Proffitt aims to offer a different way to conducting research that involves performance-based tasks. The debate lies in how tasks are presented to participants and whether these kinds of studies actually support that perception can be affected by spatial conditions. This conversation is important to mention because extra precaution must be used when setting up an action-based experiment.

The present idea that we intend to explore is whether or not an illusory boundary, or one that is not actually a boundary, can affect one's distance perception. Sturz and Bodily (2016) presented participants with a distance estimation task on a computer. Participants were shown a wall and were asked to quantitatively estimate how far away they thought it was. The participants were shown images with no potential boundaries and then images that did have potential boundaries, or illusive boundaries, in the form of a hallway that ended before the wall at the other end. The hallway acted as an illusory boundary because it was not actually blocking anything, it merely divided the space. The purpose of this was to investigate how this illusory boundary would change how far away the participant perceived the wall to be. The results showed that when there was an aspect of the scene that created the percept of an illusory boundary that it caused people to overestimate the distance. As noted earlier, the participant could have perceived the boundary as something that they needed to get past to get to the wall, a boundary that divided them and the wall acting as division and thus implying further distance between them and the wall, or as mentally defining that area as a separate space, again implying separation and increased distance.

There is a gap in this literature when it comes to how this phenomenon spills over into a real-life scenario. There have been many studies conducted that examine changes in distance perception through computer tasks, but none that create a physical environment and pair it with the same task. The difference between a computer program and how we are conducting our study is similar to the relationship between virtual reality (VR) and augmented reality (AR) in that they are essentially showing individuals the same thing, but they are presenting it in different ways. In virtual reality, the developer creates a space for the participant to navigate through that feels like they are really there. The developer can make things seem as close or as far away as he sees fit in this virtual environment. Augmented reality uses the participant's own depth perception and can be related greater to one's natural perception. The implementation of VR has been a growing trend in research but are different from the actual reality present. AR is a hybrid of virtual reality and actual reality in the sense that it uses one's surroundings and adds virtual components to them. Krichenbauer, Yamamoto, Taketom, Sandor, and Kato (2018) have found that there are significant differences in one's perception from virtual to augmented reality. This poses the question of how the phenomenon that occur in a computer-generated environment crossover to an action-based task. The main purpose of our study is to take what we already know about spatial perception when boundaries are presented on a computer simulated environment and apply it to a real-life situation.

In this study, we aim to answer the question of the impact of boundaries on spatial cognition through an action-based task. The aim of this experiment is to test how people's distance perception varies as a function of the features surrounding and environment varies in an action-based task. Thusly, the stimuli were three throwing stations. One condition was through a doorway that was half-way down the mat, another condition was over a wall boundary half-way down the runner, and the last condition was a control variable with no boundaries at all. At each station, the participant received three bean bags that they were instructed to toss at a target on the floor one a time. The important element is not these bags are thrown to the target, but it is the difference between each station. Based on the previous literature, we predict that participants will toss bags further in the Doorway and Wall Conditions than the No Boundary Condition. The rationale here is that if the doorway creates the percept of an illusory boundary, or if participants are tossing the bags over the wall that represents an actual boundary, then they should use more force in their throws and throw them further. We will also be investigating if distances vary from toss to toss and if the order in which they completed the conditions has an effect. This information would be valuable due to the frequency that the need for distance estimation occurs people's daily lives. Understanding how boundaries influence our perception will add to understanding of how we interact with our environment. Hopefully conducting a distance estimation task paired with an action-based task will lead to similar alternative set ups for spatial cognition research.

Method

Participants

This study had 60 participants from the Georgia Southern student-body and Statesboro community. Researchers set the experiment at the university's recreational activity center (RAC) and recruited participants as they walked by. This method of data collection was chosen due to the high amount of foot traffic the area receives every day and the ideal environment for our stimuli. Participants were rewarded a candy bar for their participation in the study. Of the 60 participants, 28 were male and 32 were female. Ages ranged from 18-27 with an average age of 20 years old. All participants were either Georgia Southern students or staff.

Stimuli

The set up for this experiment included three 15ftx3ft (LxW) runners of AstroTurf with an "X" 2 feet from the edge of the runner that participants were instructed to aim for. The room used for this experiment was an empty racquetball court. This allowed for a doorway and open space within the room. The Doorway Condition's runner was laid halfway outside of the room with the target point inside of the room. The Wall Condition was set up along the left side of the room. Doorway through which participants threw the bags was 3 feet wide and lines up with the edge of the runner. The wall that participants threw bags over was a 4ftx3ft (WxH) poster board that participants can see over. Both the doorway and the wall were positioned half-way down the runner at the 7.5ft mark. The No Boundary condition was set up along the right side of the room. Bean bags, weighing approximately 14-16 ounces, will be thrown "corn-hole style", as they will be small, square bags that are easy for participants to throw. The target was made from masking tape placed on the runner and allowed the bean bags to hold their position when they land. A tape measure was used to measure how far participants threw each bag.

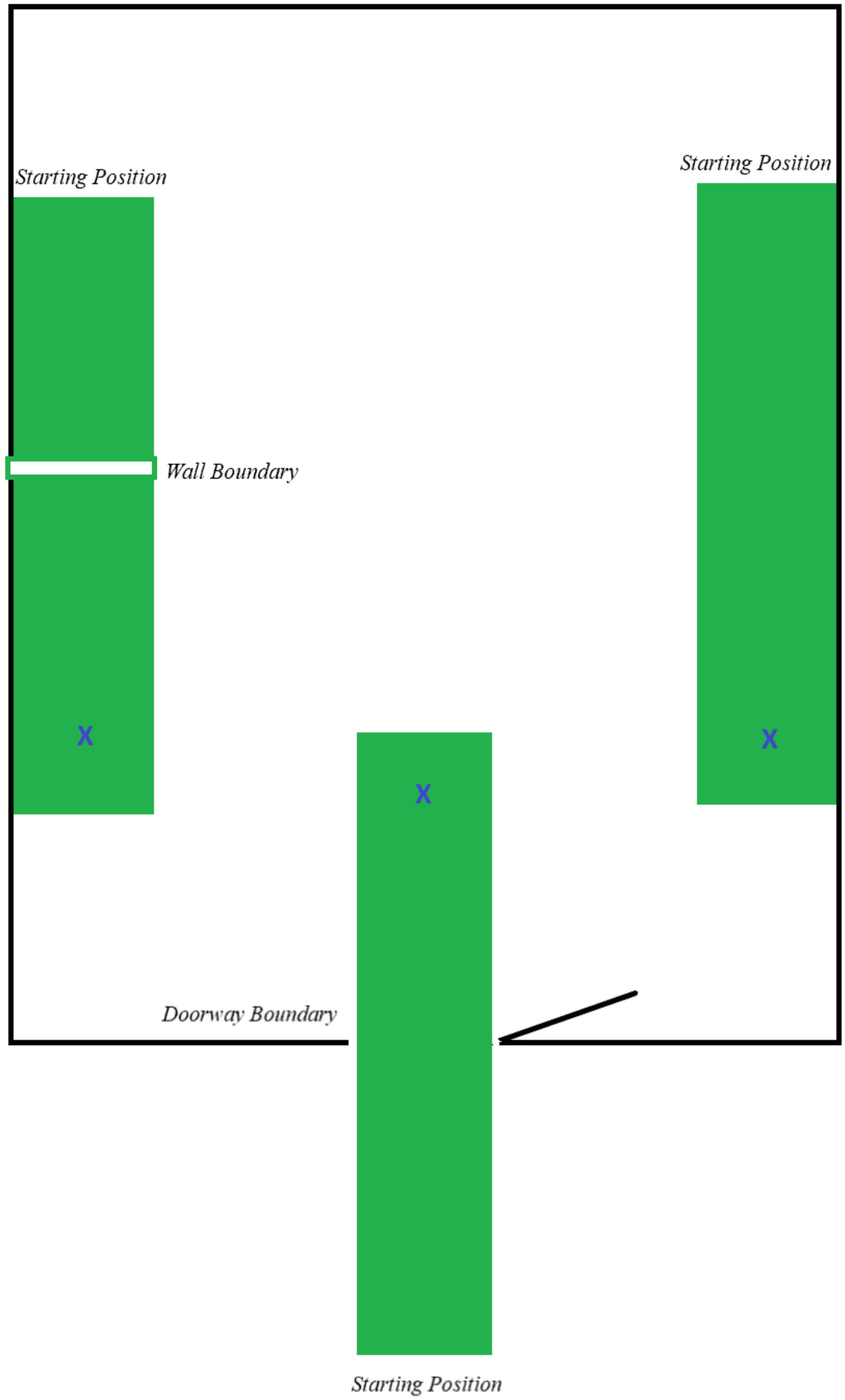

Figure 1. *Bird's-eye view illustration of the experiment in each of the three conditions.*

Procedure

After reading informed consent, each participant was randomly assigned an order in which to complete each condition. In each condition, the participant was instructed to stand at one end of the runner and throw their bean bag at the “X” at the end of the runner. They threw three bags, one at a time, with throw distance measured between each bag at each of the conditions in a repeated-measures design. Collection was conducted by the researcher measuring how far participants’ toss lands from the intended target at each location. The actual distance that they throw the bag is not important, but what we are interested in is the difference between when there was no barrier present and when there was a barrier present. We predicted that the participants would throw the bags further in the Doorway Condition and Wall Conditions than the No Boundary Condition because of the boundaries that were present. The apparatus we will use to measure this data was measuring from the end of the runner to make collection easier for the researcher. When participants asked why we were measuring from the end of the mat they were told that it was just to save time and that we knew how far the “X” was from the end of the runner. Once measurements were made, the results were recorded as how many inches the bag was thrown from the end of the mat. In data analysis, these values were converted to total inches thrown from the starting end of the mat. Because there were many participants waiting to participate, participants were only asked what they thought about the experiment. Not all participants were interested in the purpose of the experiment, so feedback varied between participants. After briefing after the experiment, participants received a candy bar for their participation in the study.

Results

Raw Distances Thrown

At the time of collection, the measurements were recorded in relation to the end of the runner closest to the target. Positive values were used for bags that landed past the end of the mat and negative values were used for bag that landed short of the end of the mat. To make analysis easier, data was converted to total inches from the starting end of the runner. The runner was 180 inches long, so the positive values were added to the length of the mat and the negative values were subtracted from the length of the mat. This made the data more uniform and easier to work with.

Order of Condition

Each participant was randomly assigned an order in which to complete the conditions. This was an *a priori* manipulation implemented to account for and offset potential order effects between the conditions. There were 6 permutations of this manipulation. These orders were labeled Order 1, Order 2, and so on.

Mixed Model ANOVA

The data analysis run for this experiment was a 3x3x6 mixed-model analysis of variance (ANOVA). The three independent variables of this analysis are condition (3), trials (3), and order completed (6). The two within-subjects factors are condition and trial while the between-subjects factor is the order completed. The analysis revealed no significant effect by condition F(2,108) = 2.49, p = .087, η_p^2 = .044. Though not statistically significantly different, participants threw bags furthest in the Doorway Condition (*M* = 164.4 - inches, *SD* = 15.6), then in the No Boundary

Condition (*M* = 164, *SD* = 13), then in the Wall Condition (M = 161.7, SD = 12.8). The analysis also revealed no significant effect by trial F(2,108) = 2.80, p = .065, η_p^2 = .049. When collapsing across all other factors, the participants threw bags furthest in trial 3 (*M* = 164.9, *SD* = 13.5), then in trial 2 (*M* = 163.7, *SD*= 12.7), then in trial 1 (*M* = 161.3, *SD* = 15.3). The analysis revealed no significant effect by order F(5,54) = 0.647, p = .665, η_p^2 = .057. The ANOVA also revealed no statistically significant interactions effects. The analysis revealed no significant interaction between condition and order F(10, 108) = .378, p = .95, = .034, trial and order F(10,108) = 1.38, p = .198, = .114, condition and trial F(4,216) = 1.59, p = .178, = .029, or condition, trial, and order F(20,108) = 1.57, p = .061, = .127.

Table 1

Mean bag throw distances (SD), in inches, for each condition per trial

Condition	Trial 1	Trial 2	Trial 3	Total
Doorway (in)	160.8 (16.1)	164.7, (12.6)	167.7, (17.2)	164.4, (15.6)
Wall (in)	158.8, (13.3)	163, (12.6)	163.4, (12.3)	161.7, (12.8)
No Boundary (in)	164.6 (15.9)	163.6, (13)	163.8, (9.6)	164, (13)
Total	161.3, (15.3)	163.7, (12.7)	164.9, (13.5)	

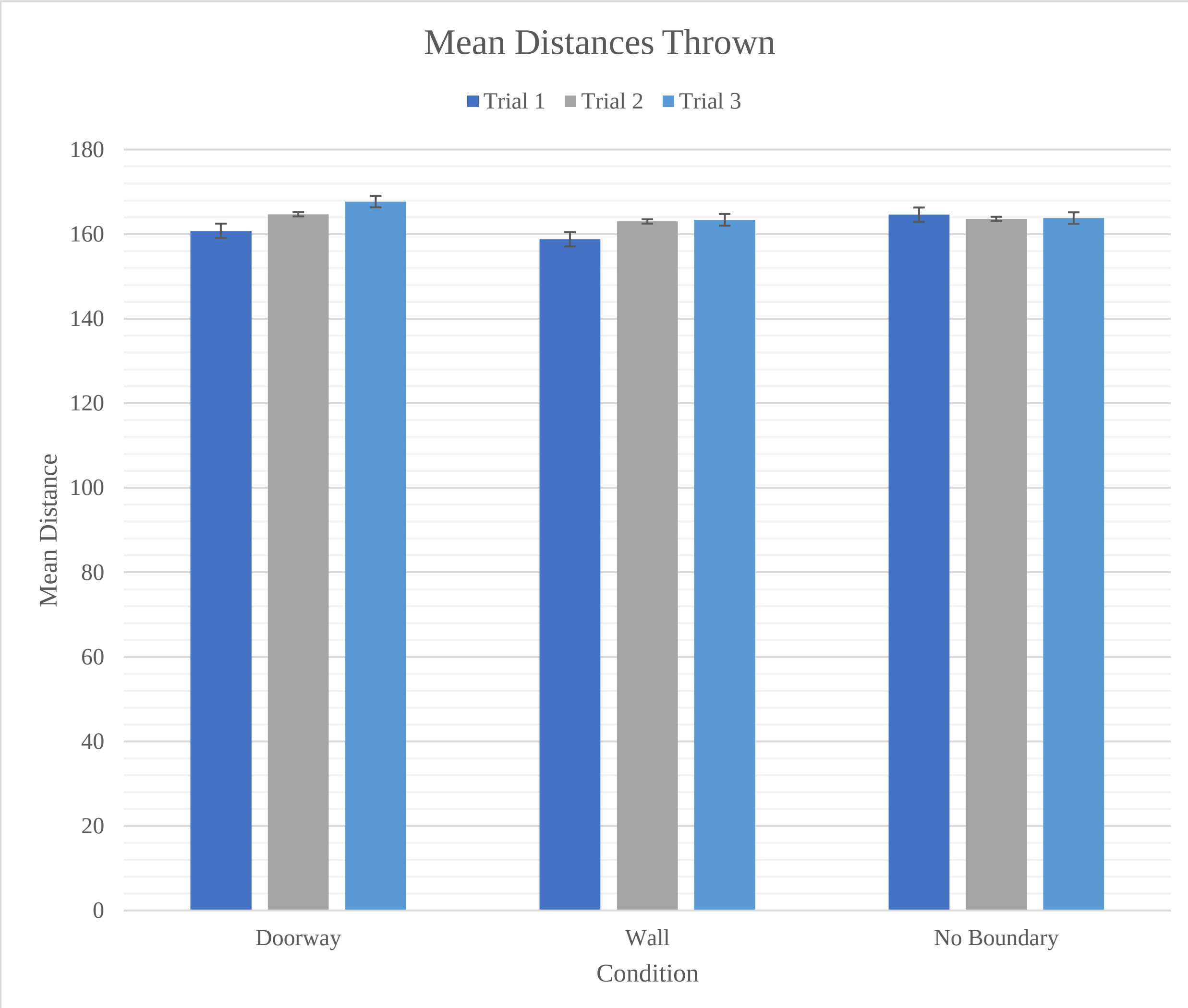

Figure 2: Bar graph comparing means of trial conditions.

Discussion

The aim of this study was to further the research on how boundaries affect spatial cognition and distance estimation by testing it with an action-based task. Based on the findings of Sturz and Bodily (2016), we predicted that participants would overestimate distances, and therefore throw the bags further, when throwing the bags through a doorway, as a function of the doorway giving a perceived illusory boundary. The findings did not support this hypothesis. Nonetheless, we will explore the findings that were obtained.

There was a slight difference in the means of the condition variable. The analysis reported that the Wall Condition had the smallest mean of the three that were tested. This contradicts the predictions that were made that the conditions with boundaries would yield the furthest bag tosses. The participants did, in fact, throw the bags the furthest in the Doorway Condition, but it was less than one foot further than the No Boundary Condition. This does not align with the findings that we saw in the Sturz and Bodily (2016) paper that this experiment was based off. Because the results differed from predictions, this topic requires further investigation. Perhaps a replication study with a larger sample size would be able to discern whether the trends observed in the present findings are an indicator of a possible effect.

The previous literature suggested that distance estimations should have been greater in the Doorway Condition and the Wall Condition because of the boundaries that were present. People generally overestimate distance, whether there are boundaries present or not, but when obstacles and boundaries are present the overestimation is exaggerated (Brunec et al., 2017). That study showed that when circumnavigation is required that people judge distances to be further away than when it is a straight path with no boundaries present. We also predicted that the Doorway Condition and Wall Condition throws would be further because of past research conducted by Bhalla and Proffitt (1999). These researchers compared participants' distance estimations to the top of a hill with and without a heavy backpack on their back. Because they found that distance estimations were greater with the backpack on, we believed that distance estimations in our study would be greater when there was a boundary that participants and to throw over or through. Though our study did not align with the findings of past research, it could suggest that there is a difference in how we perceive distance when there is an action-based task involved.

Our predictions were also supported by research that investigated how separate rooms affect perception. In a study where participants were instructed to recall objects from room to room, participants had a harder time with the objects that were in separate rooms rather than in the same room (Radvansky & Copeland, 2006, Horner et. al., 2016). These findings suggest that the Doorway Condition should have yielded much different results from No Boundary Condition because of the doorway boundary that was present. The present study's results reported that these two conditions were almost identical in mean distance thrown.

There was no formal briefing during this experiment and reactions to the experiment were not systematically recorded. Participants were never told that this experiment was a competition or that there was any competitive element, but many of the participants wanted to know if they had "won". This was not an intended element of the experiment, but anecdotal observation of participant's behavior suggests that they were motivated to do well in this experiment. There were a few participants that caught onto the fact that the runners were all the same length. Researchers did not answer any questions while participants were actively completing the experiment. Once the nature of the experiment was revealed after completion, some participants said the boundaries made them more nervous about hitting the target. This supports research done by Bhalla & Proffitt (1999) in that there is a difference in perception of a task when there is another component of difficulty added to the task. In this research, this added level of difficulty was the presence of a boundary. Though the throwing distances did not yield significant results, the reports of the participants suggest that this theory was occurring. No specific strategies were reported by participants other than trying to hit the target at the end of the runner.

Limitations

This project had some limitations. The nature of recruiting made it more difficult to fully debrief participants after the experiment because there was a line of people waiting outside to complete it as well. The aim of this recruiting method was to recruit random participants as they passed by; however, having appointments would have allowed for better feedback from participants. Though the power analysis reported that only 60 participants were needed to complete this study, future research might want to consider using more participants because of the lack of results in our findings.

Implications for future research

Initially, this was meant to be a pilot study that would eventually lead to a follow-up study that included a sporting aspect to it. In golf, shots are often lined by trees, sand traps, or spectators. It would be interesting to see if these same kinds of illusory boundaries influence the distance perception of a player. This would provide a deeper understanding of how an action can be influenced by the spatial perception of the individual because of the increased complexity of the action.

Conclusion

Overall, this experiment did not reveal any statistically significant results. There were trends that offer more questions about this topic. Based on the means, participants threw bags furthest in the Doorway Condition, but this was closely followed by the No Boundary Condition. Based on past research the participants should have thrown bags furthest in the Doorway Condition and Wall Conditions, where a boundary was present. This showed an interesting difference between online experiments and action-based tasks. The lack of a finding might suggest that distance estimations are different when an action-based task is involved.

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