The Maze Experiment - Multiple Resources and Frames of Reference

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ABSTRACT

In the research project designed by Colleen Patton, she seeks to prove that egocentric and allocentric spatial frames of reference are separate resources. She plans to do this by having participants traverse a maze through either an egocentric or allocentric frame of reference while also listening to and answering audio cues. Our group aided this research by creating a Unity program that would simulate these research specifications. Our application allows the users to specify their own constraints, or have them be read in from a file. These constraints will determine the number of attempts, perfect runs, timeouts, and maze type. While navigating the maze the user will also answer some audio cues, in either allocentric or egocentric perspectives. All the results will be recorded into a ".csv" format. A user can also add their own mazes and audio cues, as described in our documentation. The goal is to prove whether differing egocentric/allocentric navigation and audio cue combinations have a significant effect on performance. If this experiment is able to prove that egocentric navigation with egocentric audio (same with allocentric) performs worse than a combination of egocentric navigation and allocentric audio, this will disprove these frames of reference as being the same resource.

KEYWORDS

Multiple Resource Theory, Egocentric, Allocentric, Frames of Reference, Mental Maps

INTRODUCTION

Colleen's research is about the performance of time sharing between different frames of reference. The experiment will have the participants run through mazes of either egocentric or allocentric perspectives while answering audio cues of the same or differing frames of reference. By measuring the performance of those within the same frame of reference for navigation/audio and those of mixed ones; one can infer whether these frames of reference are the same resource or not. The main preface for this experiment comes from the multiple resource theory (MRT). Our literature review goes into detail about multiple theories surrounding MRT and how they can correlate with Colleen's research.

We chose to build the application in Unity. Unity is a cross platform gaming engine that is used by animators, developers, artists and researchers. It has hundreds of built in tools, large libraries, and an active community to keep the product alive. Unity was chosen to lessen the learning curve and take advantage of the pre-existing tools/libraries.

Due to the complications that arose from COVID-19, our group was unable to perform in-person or online experiments. It was agreed that from a coding standpoint the project was sufficient. It was then decided that we would no longer be performing the experiment with participants due to our current progress and the unavailability of in-person experiments. Instead we provided documentation to prepare for the next group. They would be responsible for turning this project into an online platform with a database/website.

RELATED WORK & LITERATURE REVIEW

Multiple Resources

The paper *Multiple Resources and Mental Workload* written by Christopher D. Wickens[8], discusses multiple resource theory and how it can be used as a guideline in design, as well as a way of predicting workload overload. Multiple resource theory suggests that humans only have so many resources available at a certain time, that is, we can only really focus simultaneously on tasks which utilize different mental operations. An example of this is how we are able to listen to music and drive at the same time. Wickens goes on to talk about the results, which indicate that there is a strong correlation between what the theory predicted and the resulting data. This research is directly related to our experiment because it discusses MRT and how well people are able to multitask with different resources.

MRT can also be seen in *Multiple resources and performance prediction* by Christopher D. Wickens[7], where the author describes how multiple resource theory has taken account for dual task interference; also known as multitasking. Wickens discusses the origin of MRT which goes back to the bottleneck theory. This 'single channel bottleneck' is a neurological limitation on performing more than one high speed task simultaneously and is the basis for MRT. Wickens stated that the difference in efficiency could not be solely attributed to the quantitative demands, but rather the qualitative demands of the task. He gives an example of this with a participant driving a car, who is given audio tasks. This example is very close to our research with navigating a maze and answering audio cues. We wish to show how multitasking is affected by multiple resource theory with a significant difference in performance on the tasks given. Wickens' theory will support that having the audio cues playing while navigating the maze will affect performance. This paper is different from ours because it describes more of the history, creation, and examples of MRT. Wickens shows many examples of how this theory has a role on efficiency of tasks.

Again, MRT and its implications are discussed in *Compatibility and Resource Competition between Modalities of Input, Central Processing, and Output* which is written by Christopher Wickens, Diane Sandry, and Michael Vidulich[11]. In it, they conducted two different experiments involving auditory displays and speech recognition, which was done in order to examine the differences between modalities of input. Given that complex systems, such as those in aircrafts and helicopters, require a heavy workload on perception and responses, it would be best to ease this load by utilizing advancements in voice recognition. By knowing the compatibility of certain tasks, when viewing either encoding or response modalities, we can create an overall more efficient and effective system. In the first experiment, they had participants timeshare a tracking task and memory search reaction time task. The reaction time task was first examined by itself in order to determine how participants performed without the additional workload of the tracking task. After experiment one, they concluded that tasks compete for visual input channels and manual response channels. In addition to that, they found that the advantages of separate I/O modalities increase along with the increase in workload. In the second experiment, they examined the combined effects of a control task and resource competition. They came to three conclusions: resource competition interferes with performance, compatibility and resource competition go hand in hand, and compatibility and resource competition are amplified by increases in workload.

Frames of Reference

The paper *Design Applications of Visual Spatial Thinking: The Importance of Frame of Reference* by Christopher D. Wickens[12] represent a solid introduction to frames of reference. In it, he discusses the use of spatial cognition when performing tasks involving the manipulation of an object which is in a different frame of reference. A frame of reference is defined by three axes of location and three axes of rotation. This forces the user to transform from one frame of reference to another. This transformation of frames of references shows how different models of efficiency and performance can be made. We can then apply this to our own experiment, when it comes to the audio cues being played from an egocentric or an allocentric perspective, and recognize the resources that are used when the frame of references changes. In the egocentric perspective, the user does not need to transform the frame of reference, and so theoretically performance with egocentric audio cues should always be slightly better than performance with allocentric audio cues.

The study *Frames of Reference for Navigation* by Chistopher D. Wickens[6] explores the use of different frames of reference and how they perform in different tasks. These three tasks were movement control, awareness of surrounding, and a map view in relation to a forward facing view. The most relevant to our experiment are movement control and awareness of surroundings. Wickens states that navigation requires three forms of knowledge, where am I (ego state), where do I need to go (goal), and how do I get there (action). The last form, action, is actually hidden in our experiment; they do not know where the goal is and how to get there as they are solving a maze. When Wickens did his testing on movement control, he found that immersion, or first person, made more sense than any other perspective. This is because it is a more natural and realistic approach, and is easy for people to learn and understand. When it comes to awareness of surroundings, the immersed view suffers. This is due to the “looking through a keyhole” effect. One is unable to see the full picture of one’s environment and because of this, they suffer in navigation. This is especially true for solving a maze. To make top down harder when solving, we had to also apply this “keyhole” effect by only allowing the user to see their immediate options. Finally, we added to this idea of how to get to the goal. While there are different options for this, such as a map, we can not use this as Wickens did. We added a “learning map” with different sections being different colors. This is done so that, when learning the maze the user can then recognize where they are when they reach the testing phase.

The next paper is *Navigation in virtual environments using head-mounted displays: Allocentric vs. egocentric behaviors* by Hadziq Fabroyir and Wei-Chung Teng[1]. This experiment used virtual reality headsets to show virtual environments in both egocentric and allocentric perspectives. There were also multiple types of input being tested with participants, using either a gamepad or a multitouch screen to navigate and complete a given task. What was found was a difference in preference and performance based on both gender and gaming experience. Females would often favor allocentric perspectives and tasks, while males prefered egocentric. Also, if a user was said to have past gaming experience, they would almost always perform better in the egocentric environments. This experiment is different from what we will be doing, as we will only be using one form of input for the user. Instead of testing forms of input, we will be testing how their ability to solve a maze in different perspectives changes when given an audio cue. We will examine how performance changes when a user has to multitask by solving a visual maze and an audio riddle. We will then be comparing performance when they are just solving the maze, as well as testing participants in different perspectives. We will see if we experience similar results between gender and video game players.

The research paper *Allocentric and Egocentric Spatial Representations: Definitions, Distinctions, and Interconnections* by Roberta L. Klatzky[2] provides more in-depth egocentric and allocentric definitions. This paper was the first to create a formal definition for egocentric and allocentric perspectives. It also discusses how the brain interprets and derives these different perspectives. There are also empirical studies included on how well a person performs within the differing spatial views. It is relevant to our research because it was the first study to thoroughly describe the egocentric and allocentric views from the human perspective. This paper also shows how the human mind processes information differently through egocentric and allocentric viewpoints. Klatzky’s research is focused on general definitions and in depth analysis on the views, where ours is more focused on comparing resources. Our research seeks to determine if egocentric and allocentric tasks affect a persons' performance on solving a maze. By differing the view and tasks of the participant on egocentric and allocentric, our research can show which has the greatest effect on multitasking.

The article *Exploring the dimensions of egocentricity in aircraft navigation displays* by Christopher Wickens and Tyler Prevett[10] discusses a difference in perspective effects in aircraft navigational displays. The authors start by going into detail about the differences between egocentric and exocentric as a preface for their experiment. By setting up a virtual aircraft navigation display in these two different environments, the writers seek to compare tracking ability. Their results showed that the egocentric display produced much better tracking than the exocentric display. They attribute these results to reduced scanning of the display, as well as the combination of the two axes for the egocentric display. The combination of the two axes provides better lateral and vertical tracking for the user. This paper is very similar to our project because it seeks to compare two different perspectives and how it affects the users' performance. While they are measuring tracking ability, our experiment would measure time. It differs from our project because of the aviation aspect as well the lack of auditory input and responses.

Mental Maps & Navigation

In the article *Mental Representations of Spatial Relations* by Timothy P. McNamara[3], the author discusses spatial relations during cognition and how these are encoded into memory. McNamara begins by discussing spatial relations in general, showing how nearly all human activity contains some form of spatial relation. The author believes that language is deeply and evolutionarily embedded with spatial relations, and this shows how relevant these theories are for human cognition and performance. McNarma then goes into detail on multiple theories of spatial relations. Before giving any examples, the author discusses the four ways in which spatial representations can be distinct: form, function, structure, and contents. These four distinctions are critical in differentiating the theories. The author then has a section for each theory he is comparing: nonhierarchical, strongly hierarchical, and partially hierarchical. Nonhierarchical theories claim that spatial relations are represented in propositional networks and have analog representations with constant variance. This means that all spatial relations are on the "same level", thus differing it from the upcoming theories. The strongly hierarchical theories claim that spatial relations are not stored in between sections of the hierarchy, meaning that these relations must be directed from higher levels of knowledge within the hierarchy. In partially hierarchical theories, information can be encoded in between different hierarchies. With this theory, information encoding would be retrieved at much higher rates than that of the other theories. This article is very similar to our research because of how it relates to multiple resource theory. The different theories given in the article (like the partially hierarchical theory) can be applied to multitasking while performing tasks with varying spatial relations. By varying egocentric and allocentric spatial audio cues, different amounts of encoding will occur, thus showing a difference in performance among the hierarchies.

In the article, *Electronic Maps for Terminal Area Navigation: Effects of Frame of Reference and Dimensionality* written by Christopher Wickens, Chia-Chin Liang, Tyler Prevett, and Oscar Olmos[9], they examine the effects of dimensionality on changing frames of reference. To test this, they examined two experiments involving pilots, and their use of fixed and rotating map displays in different dimensions. In experiment one, they tested each pilots' ability to stay on track and be aware of their surroundings while using combinations of a rotating map, a fixed map, a two-dimensional view, and a three-dimensional view. They found that rotating displays gave a better performance overall, providing better flight guidance and less interference on pilot awareness. Given the results of experiment one, in experiment two, they used a rotating 2D display as well as an updated version of the rotating 3D display. After experiment two, they found that vertical control performance increased as a result of the 3D display, but lateral control performance did not.

In the reading *Three Kinds of Spatial Cognition*, Nora Newcombe[4] explains how spatial cognition isn't just one single domain of thought. She says that there are actually three different functions that we do when in an environment. All three of these have a different function, but each play a greater role in how we truly interact with our surroundings. Navigation is the first of the three. Humans use navigation to visualize the area and to be able to track their own movement. Within navigation is the ability to encode different locations and use this information later to know where they are. One's ability to navigate and internalize their surroundings into a cohesive mental map is not something that everyone does at the same level. Tool use and invention is the second that Newcombe describes. She states that intrinsic coding is the ability to imagine an object in one's mind differently than it appears in reality. The example she uses is having a pear and imagining what the pear would look like had it been cut in half. The last topic she hits on is the concept of spatialization. This includes a variety of things from symbols, language, gestures, maps, and mental images. She says that the ability to use spatialization is key to fully learning an environment.

In the paper *Cognitive Maps: Some People Make Them, Some People Struggle* Weisberg and Newcombe[5] explain how people have different abilities to create a mental map of their surroundings. This ability to create cognitive maps for some people are accurate and precise, while others are fragmented or rely on knowing one route. The experiment consisted of groups traveling in different routes in a city in VR. They would then have to identify different buildings in the city on a 2D map after the walk. There were two types of routes used: two were considered within routes and had all of the buildings needed to be recognized, then there were in-between paths that connected the within paths. The between paths were harder to make a map for as one would have to still relate where they were to building locations on the map. Overall, people were put into three groups, integrators (performed well within and in-between), non integrators (performed well on within-routes poor on in-between), and imprecise navigators (did poorly on both types).

SYSTEM DESIGN & IMPLEMENTATION

This project is entirely software focused. The program used to run and collect the data was developed in Unity. Scenes were designed in the Unity engine, scripts were written in C# and attached to game objects in those scenes. Maze files are created through this interface as well, and are used for the experiment based on number (Figure 1). Audio cues are also needed for this experiment and are stored in resources. They are then answered in the maze after a designated random range of moves; the user will answer with keys Y/N for yes/no.

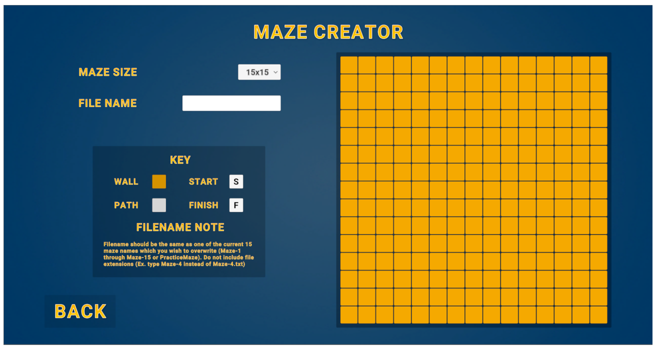

Figure 1. Maze Creator Tool used in Unity

There were two types of mazes that needed to be designed and given player controls. The participant will be automatically moved to the next intersection to reduce input and improve the ease of use. The user can use the arrow keys or WASD to navigate the mazes. Egocentric mazes are navigated in the first-person, the user can move forward and rotate the camera to look down different hallways (Figure 2). Allocentric mazes are navigated from a top-down perspective with limited vision (Figure 3). Input is taken from the user to move up, down, left, or right. The coloring for both mazes are indicators to assist in memory retention of the maze structure and are randomized. The colors are maintained throughout attempts and phases, but are randomized again if they switch from an egocentric maze to an allocentric maze or move onto the next maze.

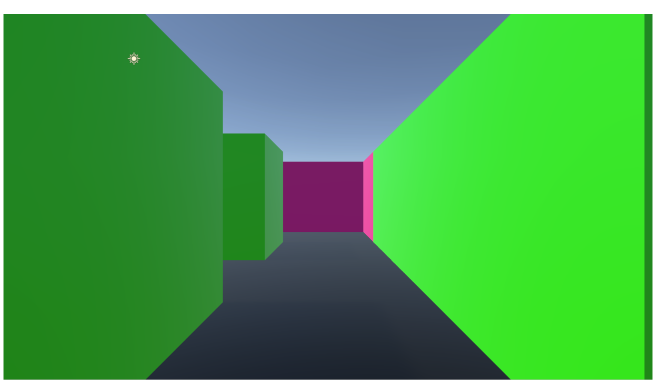

Figure 2. Egocentric, first person, maze.

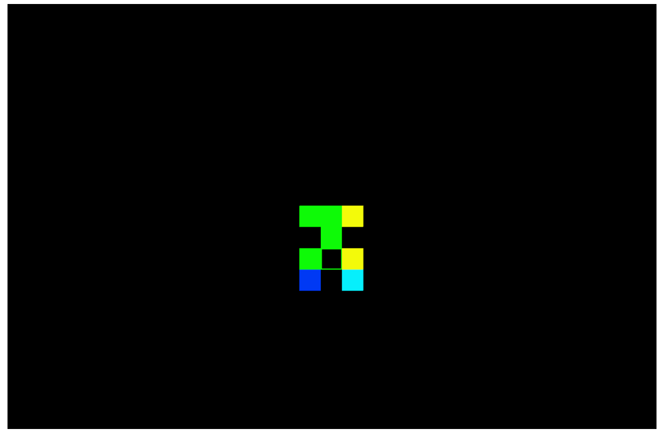

Figure 3. Allocentric, top down, maze.

Errors affect whether a run is considered to be perfect and added to the total perfect runs. An error is added when a participant visits an intersection more than once during a single attempt. The other type of error is when answering an audio cue. After an audio cue is played the participant will have a short time to answer. If they answer the question wrong, or not in the allotted time, an error is added to the total number or errors. More documentation about code structure can be seen in the attached documentation for classes and method description.

EXPERIMENTAL DESIGN

This experiment consists of a mix of between-subjects and within-subjects design. The mazes are between-subjects since participants are randomly assigned either an egocentric or an allocentric set of mazes (Figure 4). On the other hand, the audio cues are within-subjects since all participants will do five mazes with egocentric audio cues, five mazes with allocentric audio cues, and five mazes with no audio cues. The constraints (or parameters) of the experiment are as follows: participant number, maze type (egocentric, allocentric, or both), condition (A, B, or C), timeout per maze, number of attempts, and number of perfect runs. Only one of the following needs to be completed to move from the training phase to the testing phase for each maze: timeout, number of attempts, or perfect attempts.

The mazes are split into three sections of five mazes, each in a randomized order. The order of the sets of mazes will be determined by the condition that the participant is set to, that being either A, B, or C (Figure 5). Each set of five has a separate audio type. This is done to ensure that no single maze is consistently tied to a specific audio file.

The experiment will begin by informing the participant about the experiment, and then getting their consent. After this, they will be given detailed instructions which will be tailored to egocentric or allocentric, depending on which mazes they have been assigned. Once the consent and instructions are given, the participant will have two attempts on a practice maze so that they understand the controls. These runs will not be recorded in the excel file. They will then start on their first maze and have a training phase, where they will try to learn the maze layout as best they can while answering audio cues. Once one of the constraints is satisfied, they will move onto the testing phase. In the testing phase, they will have two attempts to run through the maze from a pseudo-random starting location in order to test how well they have learned it. Once the experiment is complete the user will complete a survey. The survey asks the participant about their gender and the number of hours that they typically spend playing video games per week.

	Egocentric Audio	Allocentric Audio	No Audio
Egocentric Maze	Participant 1	Participant 1	Participant 1
Allocentric Maze	Participant 2	Participant 2	Participant 2

Figure 4. Mixed-factors design for experiment

		Audio Type		
		Allocentric	Egocentric	None
Condition	A	1-5	6-10	11-15
	B	11-15	1-5	6-10
	C	6-10	11-15	1-5

Figure 5. Condition set up for experiment

COVID-19 CHANGES & FUTURE ADDITIONS

Once classes had gone online, we had met with Professor Ortega and Colleen Patton to discuss what would need to be changed. It was agreed that from a coding standpoint the project was sufficient, it just needed to be finalized and given to Colleen. It was decided that we would no longer be performing the experiment with participants due to our current progress and the unavailability of in-person experiments. We discussed how our group would need to produce a lot of documentation to prepare for the next group to complete it, as well as suggestions as to how the experiment could be put completely online.

CONCLUSION

Overall, we believe our application met all of the specifications initially discussed. There is, however, much to do in terms of putting the project online. This program is still able to perform in-person experiments and produce data. With this data, Colleen seeks to prove that egocentric and allocentric spatial frames of references are different resources.

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