Aalborg University

Medialogy

Master's Thesis

Comparison of Diegetic Navigational Aids in Virtual, Audio-Exclusive 3D Environments

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Preface

This report is a Medialogy Master's Thesis at Aalborg University. The project period was from February 2015 to May 2015. The DVD attached includes the following: this report in pdf-format, an A/V production and a receipt for upload to the student's project database.

Reading Guide

The citation style of this report is the ASME style, where references is noted with a number in brackets. All references can be found in the Bibliography section on page 44–45.

An example of the use of citation in the text:

"...which is uncommon in a real world scenario [27]."

The source in the bibliography:

[27] P. Zahorik, D. S. Brungart, and A. W. Bronkhorst, "Auditory Distance Perception in Humans: A Summary of Past and Present Research," Acta Acustica united with Acustica, vol. 91, no. 3, pp. 409–420, May 2005.

Figures, tables and appendices are referenced to as Figure, Table and Appendix along with the chapter they are in and their number.

A danish summary is included on page 4.

Danish Summary

Projektet startede med at være todelt ved både at indeholde en demo af et spil og en klinisk undersøgelse, begge foregående i et virtuelt miljø. Projektet er designet til at kunne anvendes af binde og indeholder derfor ingen visuelle elementer. Projektet undersøger tre forskellige navigationsmetoder hvor diegetisk lyd er det eneste der anvendes til at vejlede spilleren.
Motivationen kom fra, at blinde computerspil entusiaster er en forholdsvis nedprioriteret minoritet for spilindustrien og at vi, igennem vores undersøgelse, ønsker at kunne informere lydspilsudviklerne om hvilke beslutninger de bør tage når det kommer til navigation uden visuelle elementer. Under udfoldelsen af projektet, blev undersøgelsen prioriteret højere end spildemoen for at kunne få brugbare informationer om sammenligningen af de tre navigationsmetoder. Disse metoder er baseret på anvendte metoder inden for lydspils miljøet og har grundlag i to typer af navigation: ledende- og forklarende lyd.
Den fundamentale forskel på de to navigationstyper er, at ledende lyd får spilleren til at følge en bestemt lyd i det virtuelle miljø, hvor imod at forklarende lyde leder med informationer som f.eks. retning. De tre anvendte navigationstyper er: en hund der leder ved at gå foran spilleren som gør når promptet, dåser der rasler ved det næste mål og kort samt kompas der giver spilleren hans nuværende retning, og den retning han bør vende for at nå næste mål.
For at øge præcisionen af lydene i det virtuelle miljø, anvendte vi Two Big Ears' 3Dception, en lyd motor, da vi, i forrige artikler har bevist at 3D lyd udgør en signifikant forskel for hvor præcist en person kan udpege en lyd i et virtuelt miljø.

Undersøgelsen blev udført med en Xbox 360 spil controller og foregik uden visuelle elementer. Før den egentlige undersøgelse, blev vores testpersoner udsat for en træningsfase, hvorunder de fik mulighed for at gøre sig bekvæmt med navigationsmetoderne og miljøet de skulle udføre undersøgelsen i.
Under den egentlige undersøgelse skulle testpersonerne navigere gennem en gang med en række 90° sving, for til sidst at skulle besvare et spørgeskema om deres mening om den navigationsmetode de lige havde anvendt. Vi brugte et within subjects design, så alle testpersoner gennemgik et nærmest identisk scenarie for hver navigationsmetode, dog med den undtagelse at gangen de skulle navigere gennem blev ændret for at undgå at de kender vejen.
Med tre forskellige gange samt tre forskellige rækkefølger af navigationstyperne, svarede det til 36 permutationer til de i alt 36 gennemførende testpersoner, resulterende i et komplet test design. Udover de 36 gennemførende testpersoner, blev ni testpersoner fraskilt, grundet at de ikke kunne gennemføre testen, hvilket var grundet mangel på erfaring med spil af lignende natur – med eller uden visuelle elementer.

Som det sidste i undersøgelsen blev testpersonerne bedt om at besvare endnu et spørgeskema hvor de skulle rangere de tre navigationstyper op imod hinanden i tre kategorier: helhedsindtryk, hurtigste type og letteste type at anvende. Dette gjorde det let at kunne se deres præference.

Undersøgelsen viste at de to navigationstyper: dåser og hund var signifikant meget hurtigere til at end at anvende kortet. Dog gjorde brugen af kortet at testpersonerne kunne navigere signifikant mere målrettet og end de to andre typer.
Der var ikke signifikant forskel mellem dåser og hund i både tid og distance brugt.

Contents

Chapter 1

Introduction

This chapter will introduce the project, its motivation and its goals. Blind gamers are viewed as a minority within a minority [5]. They amount to a very small percentage of gamers, easily ignored from a marketing perspective. As such, it is an issue rarely brought up by game publishers and developers. As the saying goes: "out of sight, out of mind." Unfortunately, most games released cannot be completed by a visually impaired person as the games dominantly rely on visual feedback [26].

In spite of long periods of waiting between worthwhile releases, there exists patient online communities of audio game enthusiasts. One such community is AudioGames.net, where most users are completely blind (see Appendix B). This is a community where players and developers have bonded together to nurture their hobby, the developers posting their releases and the players providing prompt, honest feedback. As a result, games released through the site are developed by smaller teams for the collective minority compared to more popular entertainment on the standard gaming market. Resultant games are on a much smaller scale than most releases on the standard gaming market, the teams behind mostly consisting of only a few people.

Due to our prior work within the field of 3D audio, and subsequent exposure to these communities, we took it on ourselves to study some of the methods of navigation that make it possible to navigate 3D environments without any visual feedback. We began the creation of our own audio-exclusive game to have a basis for testing, but at the time of writing, this game was incomplete.

1.1 Motivation

The prime motivator for our project was to have a positive impact on the audio gaming community, by contributing research that might answer some quite relevant hypotheticals: how do we best guide a player through an environment without any visual elements? Can it be done only using diegetic sounds, as opposed to non-diabetic sounds? What are some of the pitfalls to avoid? The first of these questions goes largely unanswered in prior research, at least on basis of comparison. In terms of diegetic sounds, a setting for a game world needs to be set, which also hold the secondary motivator for the project: the development of a game. The game development aspect of the project played a minor part, but it motivated some of the choices in regards to the navigational aid picks. The development of the game, including the story and implementation, can be found in Appendix A.

We looked to preexisting audio games for inspiration for the navigational aids. AudioQuake, for instance, makes use of scraping noises to inform the player of their proximity to the wall, and their velocity whilst walking against it at an angle [12]. AudioQuake's creators also make an effort to allow the players to navigate easily into adjacent rooms, through novel design choices that utilize sound occlusion through walls. These are only examples of some of the different ways we can enable navigation in an audio-exclusive game. We posed a question to the users of AudioGames.net, regarding which navigational aid they prefer between a voiced compass and beacon sounds. Their general reply was that all methods were good, in their eyes. Backed by this information, we could have chosen to use a broad range of methods in our experiment, each type activated with different keystrokes. We decided against this in order to keep the test clinical, and to observe fewer in detail. We hypothesized that the inclusion of multiple methods requiring interaction could result in participants simply learning one and sticking to it, ignoring the rest. We chose three navigational aids to test upon, inspired by those that we saw potential in testing. All three were related closely to interactions we had seen before, in audio games. Two of these make use of spatial sound cues to guide the player, and the last is a verbally descriptive aid type.

Though unrestricted movement in a 3D environment sounds like an overly complex task to convey exclusively through auditory feedback, it is important to remember that the setting of the project is based on a real environment with gravity. Simply put, gravity ties the player to the ground. Had our system allowed for jumping, the player character would only be suspended in air for a very short time. While it does not make the auditory landscape any less complex, it does make navigation quite a bit easier, effectively reducing the navigational complexity to a plane [12].

1.2 Goal

Our goal with this research is to determine which navigational aid is preferred, and which allows the most efficient navigation. It is worthy of note that efficiency should not necessarily constitute the choice of which method to choose in an artistic medium such as video games. Due to the scarcity of the demographic, we tested on normally sighted people. The reasoning behind this was that their vision would not necessarily give them an advantage or disadvantage, as long as their hearing was normal. We expected that the blind gamers would fare better when using any of these aids than the sighted, due to years of practice with similar aids.

We hope that the results of this report might help influence choices in regards to navigational aids for developers of future audio games.

1.3 Research Question

Guided by our motivation and goal for the project, we phrase the research question thusly:

In a virtual, audio-exclusive environment, which of the three chosen navigational aids serve best to guide the player? Which do they prefer and which is the most efficient in regards to completion time and distance travelled?

Chapter 2

Background

This chapter introduces research that influenced the project.

2.1 Spatial Audio

Distance is difficult to estimate from sound alone, particularly so when both source and listener are standing still, which is uncommon in a real world scenario [27]. Movement in conjunction with audio gives cues about the distance relation; however, these cues are not nearly as strong as they are for the visual counterpart. Lines and parallel formations are strong cues in the human visual system that have no auditory equivalent [24].

In virtual environments, distinction between areas, sections and rooms can be accomplished by giving each a distinct background noise or reverberation configuration. This allows the player to identify rooms they have already explored. Such distinction is extremely important, as it lets the player know if they are backtracking should they get turned around [12].

The echoes of a room aid the visually impaired in the real world to determine the size of a room, as well as their proximity to walls [16]. This is not easy to make use of in a virtual environment that uses approximations to simulate reverb. These approximations rarely take distance between player character and wall into account. Additionally, reverberation can worsen the results of navigational tasks, increasing search times and error rates [19].

It is important to ensure that the player has a digestible amount of audio at all times. Complete silence will leave the player wondering if the game is even working, and it will seem noticeably off-putting if other parts of the game have audio present constantly. Too many sounds will obscure the objectives and navigational aids, leaving the player confused [20, 22]. With sight, it might be easy for a person to abstract from distracting visuals, but this is much more difficult with audio, even in visual environments [14]. The main strength that hearing has over sight, is that with sound, we are able to attain information about visually obstructed audio sources [23].

Though being able to detect walls through audio is a good start, how does one identify objectives? To convey information through audio about a point in virtual space, the information needs either to be explanatory in the form of speech, or spatially identifiable, often referred to as beacon sounds. Each of these have their strengths and weaknesses. Audio beacons are easy to understand and navigating to them is intuitive because it emulates how we perceive sound in the real world. They are unable to convey complex information, such as obstacles, which path to follow and any descriptive information. As an example, their nature does not allow them to describe the color of a car. Speech is able to convey a great deal of detail, but these cues are unlikely to be as brief as audio beacons. A cue can be both explanatory and spatial, but speech does not make for a good spatial sound to follow [25].

2.2 Binaural Audio

Audio engines able to render binaural audio with spectrum deformation through head-related transfer functions (HRTFs) have proven better for pointing and navigation tasks than traditional audio engines in a sterile virtual environment [17]. We will refer to binaural audio with HRTFs as 3D Audio, which encompasses both the HRTF and the aspects of duplex theory (i.e. interaural intensity difference (IID) and interaural time difference (ITD)) [18]. As mentioned earlier in this chapter, having too many active audio sources at a given time obscures the objective sounds, hindering navigation [20, 22]. It has been proven that 3D audio systems make it easier for users to separate individual sounds and focus on critical sounds [22]. However, all sounds are not equal in terms of effective localization as differences in aspects, such as duration, onset, offset and use of frequency spectrum, will affect how optimal a sound is [18]. The specifics of these aspects are described below.

Duration: A minimum sound duration of 600-800 ms is necessary to encompass the effects of head movements.

Onset/Offset: On- and offsets below 1 ms, have shown localization errors less than 3°, as opposed to on- and offsets at 100 ms which hold errors ranging from 5°–15°, for frequencies 400–6400 Hz.

ITD to IID crossover: ITD is best at low frequencies, and IID is best at high frequencies. The effectiveness of localization based on ITD and IID is weakest in the crossover frequency range of 800–1600 Hz.

Front-back differentiation: The most important frequencies for front-back differentiation are located at 4-16 kHz.

Up-down differentiation: The most important frequencies for up-down differentiation are located at 6-12 kHz.

2.3 Case Study of Accessible Games

A look at a few accessible games, most of which were mentioned by the forum users of AudioGames.net (see Appendix B). Five accessible games that cover different navigational aspects, and two games for sighted that can be classified as accessible games as they allow for play by the visually impaired.

2.3.1 AudioQuake [12]

A full modification of Quake, a first-person shooter, enabling blind gamers to play against each other. AudioQuake uses a lot of spatial sound cues for the players to navigate rooms and hallways, as well as find and shoot other players.

Wall Scraping The developers added to the preexisting "ugh" when colliding with a wall, by having the character specify: "ugh, I ran into a wall". Spatial positioning of this sound makes enables the player to perceive his position relative to the wall. When moving alongside the wall and still being in contact with said wall, a scraping sound plays at the point of collision.

Room and Hallway Design Aside from a general focus of simplistic level design, the developers took measures for players to be able to identify their orientation and the exits of each room they entered. Every hallway had the auditory representation of an air-conditioning unit. This helped players identify the exits of each room. The noise emitted was also slightly different, depending on the compass heading of the hallway, further helping the players keep track of their location in the level. Lastly, they promote the practice of keeping every room different, so players can identify them by sound and gain familiarity with the level design.

Earcons More descriptive earcons took the place of most actions and pickups in the game, for players to be able to easily distinguish the different cues.

2.3.2 Extant [7]

An audio-exclusive game demo with only a few objectives. It uses up a lot of the possible sound space with the ambient background sound (e.g. horror music, wind, and rain).

Dog Sound Beacon: The objectives in Extant can be found through spatial audio navigation aided by a virtual dog which the player is able to send to one of four wanted locations. It can be considered a diegetic approach for simple beacon sounds. The dog will run to the wanted position, then keep on barking until the character reaches the destination.

Buildings: Extant used an alternative approach to the virtual construction of buildings such as a house. The buildings are circular from above and any point on the "wall" is considered a door through which the player can enter. The same goes for leaving the building. There are no additional rooms inside the building. You are either inside or outside and cannot walk from one building to another without first going outside. The character will also verbally confirm entering a building with sentences similar to "This must be the church".

2.3.3 Swamp [10]

A first-person shooter game with real-time multiplayer action and shooting of zombies. It has a radar and a voiced compass, which both fits the setting.

Compass Direction Selector: Pressing the "w"-key will give the player the current heading. The left and right arrow keys turns the character to 45° angles corresponding to the eight primary directions on a compass. The direction is also announced after turning.

Directional Radar: The directional radar in Swamp gives a possibility to choose a direction for the radar to analyze. The player can choose all directions simultaneously but this is not quite as useful. It has a clockwise rotation from above, and thus scans from left to right when used for a forward scanning. Additionally there are both a short range and a long range version of the radar. It is used to detect blocking objects like walls or other obstacles which have different sound feedback.

Chat Messages: As the game is multiplayer it has a sort of chat functionality, with multiple chat channels. The interesting part about this is that the player emits a beeping sound when sending a message, which can be heard spatially by other players.

2.3.4 Entombed [6]

An accessible game with little to no visual feedback. It is a top down dungeon crawler with tile based movement. The game does little to inform the player about the control scheme. It is expected, of the player, to go to the wiki page, for Entombed, to play the game as intended. The page reveals that more than 20 keys are needed.

Wall bumping: Entombed uses a non-loopable feedback sound, when the player moves into a wall. If a movement key is held down the sound is repeatedly played. As the sound is very short, this makes the repeated sound unpleasant.

Coordinate system: By the press of a key the player receives the location of the character in numbers corresponding to x- and y-coordinates. The player is also informed whether or not they have been on the current tile before.

2.3.5 Terraformers [11]

Terraformers is an accessible game playable both with and without graphics. It has a large array of tools that provide navigational aid. This comes at the price of using more than 20 keys to play properly, but is taught through a long introductory tutorial covering each tool, including both navigational- and otherwise game-related features. Even after this introduction the functionality of the keys can be difficult to remember, making it require effort to be able to play using all the tools. The futuristic setting of Terraformers allows for a lot of unfamiliar sounds to be used diegetically.

Wall Scraping: A non-loopable sound is used, while "touching" the wall.

Wall bumping: Terraformers uses a non-loopable sound as feedback for bumping into a wall. The mechanics of which are not very well implemented.

Semi Spatial Compass: The game uses left and right arrow keys turning. A repeating spatial "bub"-sound positioned north of the player gives a notion of direction. The sound is pitched lower when facing the southern region between east and west. The compass has toggle and only plays the sound while turning. As an example, the player knows where east is when pointing towards east and hearing the northward sound in the left ear.

Compass Direction Selector: Using numpad keys the player can choose compass directions: north(8) north-east(9) east(6) etc. using all numbers excluding 5 and 0.

Sonar: A tool providing information about distance to, importance of and type of a given target. Loudness indicates distance, the louder the closer, and importance is indicated through change of sound. The type measurement is verbal feedback describing the object you are facing. Sonar was not well implemented along with the Compass Direction Selector, as it does not update the sonar feedback after choosing a compass direction, only once the player starts moving is the sonar feedback updated.

Room Describer: Pressing a button to get a prerecorded description of the room that the character is currently positioned in. These descriptions cover, environment related things such as describing the material of the floor or dryness of the air. They also covered whether or not there were anything of interest in the room.

Character Coordinates: A one button interaction to get the coordinates of the player. This was only available when the player was not in any mode of interaction e.g. no lists open, or no interaction with the environment going on.

Listed Items in the Room with Coordinates: With the press of a button, a list of items in the room could be brought up. The list would indicate how many items were on the list when opened. The list was voiced when changing item and once on a desired item the coordinates of said item could be played. These coordinates were not related to the coordinates of the character, thus some memorization was in order for comparison.

2.3.6 SkullGirls [9]

This game was developed mainly for sighted, but during development, the developer changed his focus to increase the accessibility of the game [1]. The game is a 2D fighting game that is not very dependent on navigation.

Text To Speech Support: Menus in the game supports third party text to speech software, which enables visually impaired to use the menu without need of memorizing them.

Simple Short Feedback: The feedback for running, hitting and getting hit has very short and simplistically different sounds in both pitch and timbre, which makes it a possibility to have multiple sounds playing at the same time but still being easily distinguishable.

Descriptive Fighting: The game has its characters tell some of the moves they are making out loud e.g. “feel my heels” for a kick attack and “this kitty has claws” for a scratch attack.

2.3.7 Resident Evil 6 [8]

A third-person real-time game for sighted that has been reported playable by a user from AudioGames.net. With the use of auto camera movement features the game is, to some degree, accessible.

Auto Camera Movement: By pressing a button the camera will turn in the direction of the next checkpoint.

2.4 Navigational Aids in Audio Games

We define navigational aids as systems that might help a user navigate a virtual, audio-exclusive environment. Obstacles and walls cannot be avoided ahead of time if there is no prior auditory information about the wall. A realistic approach is to use sound reflecting on the wall, but these cues are typically so dampened and subtle that they will be drowned out by other sounds present in the virtual environment. Alternatively, they could emit beacon sounds. The creators of "AudioQuake," a blind-accessible modification to the old multiplayer game "Quake," chose to make wall collisions perceivable through directional scraping noises [12]. This not only allows the players to perceive the edges of a room; but also conveys speed and angle better than the change in footstep frequency does on its own. This enables the player to get a sense of the room in a way that blind people might in a real room [2, 15]. The easiest way to enable a consistent method of navigation in audio games is to keep the level design simple, regardless of which other design choices one might make [12]. Quake has never been a game tied to realism in term of its visuals, nor its sounds, so diegetic sounds seem less important. What they stand to gain by using earcons is brevity and diversity, making it more straightforward for the players to identify differences [13].

Chapter 3

Test and Method

The test subjected participants to three different conditions in the form of diegetic navigational aids, the names of which are abbreviated thusly: Cans, Dog, and Map. Dog and Cans are similar, in that they are guiding audio cues, relying mostly on their spatial cues. Map uses a method that could be described as explanatory, offering information through speech. All of the navigational aids had the ability to be interacted with. This interaction was initiated by pressing the Use Key.

The following are short summaries of the three conditions:

Cans: The participant held a rope, connected to a bunch of cans. The participant yanked the rope with the Use Key and the closest can would rattle in response. Each can was located at a checkpoint. Upon reaching a can, the participant picked it up, and the next can on the path would rattle when the rope was yanked.

Dog: Participants were asked to follow a temporary companion: the dog. It walked in front of the participant so long as he was moving in the right direction. While moving the dog emitting footstep sounds, which the participant could follow. If the participant moved the wrong direction, the dog stood still at its current position. The participant could then prompt it using the Use Key, which made it bark until the player located it.

Map: When the Use Key was pressed, the participant referred to his map, was told in which direction he needed to go and which direction he was currently facing. If the participant kept pressing the Use Key, the character kept saying which direction he was facing, by speaking his direction when facing a new one. The directions would be one of eight possible (e.g. north, northeast, or east).

The differences between Cans, Dog and Map are what we want to explore through the analysis of game metrics and a questionnaire, and further details can be found in Section 3.4.

In terms of making the navigational aids the best we can, we chose to go with an audio engine using binaural audio and HRTF for better localization and navigational performance [17]. One such engine is the audio engine from Two Big Ears [3] (TBE), named “3Dception” but often referred to simply as TBE. TBE has a free trial version limited to 10 audio sources which was deemed suitable for the project (see Appendix A.2).

3.1 Experiment design

The test was segmented into a block for each condition, with a training period at the start referred to as the training phase. The participants had the chance to familiarize themselves with the navigational aid during this phase before starting the actual test of the given condition. After a set amount of checkpoints, with both the facilitator's and the participant's agreement, the systems were allowed to progress to the non-training phase, in which the performance metrics between seven checkpoints were recorded.

After finishing each navigational aid, the participants were asked to fill in an evaluating questionnaire with 7-step Likert scales, specific to the aid they just completed. After having explored and rated all navigational aids, the participants were asked to rank the navigational aids as well. This was done to get a comparative rating of the tools, hopefully telling the same story as the previous ratings. This also gave us qualitative information about the users' preferences, unrelated to the efficiency of the trial.

The experiment employed a complete and balanced design in order to counter biased effects. There were three different navigational aids, making for six permutations of the order in which the navigational aids were introduced. Secondarily, there were also three different paths to navigate during the test, making for six permutations also. The result of which was 36 permutation, in which we expected no difference between paths due to the parameters of which they were constructed. These parameters ensured an identical amount of turns and an identical length for each path. If no statistical difference will be found between the three paths, the experiment would be considered an within-subjects experiment.

We had 36 participants complete the test in total, and an additional nine participants who failed, and whose participant slot in the complete design was replaced by new participants. All of the test participants were male students who reported having normal hearing, aged from 19 to 28 ($M = 23$, $SD = 2.12$).

In order to utilize time and resources optimally a setup able to facilitate two participants simultaneously was used. The two systems were not identical, the attributes of which can be read in Section 3.2. The test had been set up in such a way that the participants were facing a wall, giving them as little visual stimuli as possible. In order for the facilitator to observe both participants, they were seated close to each other. During the presentation of the test we attempted to make it clear to the pairs of participants that this was no competition and that there was no ground for comparison.

During the initial phase of testing, we witnessed that an alarmingly high amount of test participants were unable to complete the test within an acceptable timeframe, defined by the length of the test participant's patience and ours. This translated roughly to 6-8 minutes of no progression during any training phase after which we had to discard the participant. We mainly attributed this to inexperience with games and gaming controllers, but also to the degree of help we initially exhibited. The reason for the first assumption was based on an observed correlation between participants' proclaimed knowledge and use of games, and the reason for the latter was found through observations during test and talks with the participants.

We made efforts to improve the introduction and training phases to accommodate the aforementioned problems and had to discard much fewer participants afterwards. One of these efforts was done by introducing the participants to the attributes of controls (e.g. movement speed and rotational speed) through a pre-test scenario with visuals, where the attributes were kept identical to the test. For a user with experience in navigating 3D virtual environments, these attributes can quickly be taught, but even for inexperienced users the pre-test scenario helps to establish an understanding of the environment and controls. This gave way for a much smoother training phase. Another action made to mitigate discarding participants was done by seeking test participants with at least some confidence in their own experience with video games, and began taking test participants exclusively from students related to computer science studies.

3.2 Apparatus and Control Scheme

The main difference introduced by using a two system setup is contributed to the difference between the systems. System 1 used a Sennheiser Momentum (full cup) headset. System 2 used a Sennheiser 360 G4ME headset. It is noteworthy that the first headset exhibited greater sound exclusion than the latter. They were both running Windows 7 and used Xbox 360 controllers of the same make for user input.

The control scheme was simple: left stick controlled forward, backwards and sideways movement (i.e. strafing). The right stick controlled turning with only the horizontal axis. The left bumper, right bumper and the "A" button all acted as the Use Key. See Figure 3.1 for an illustration of the controller with the used buttons labeled.

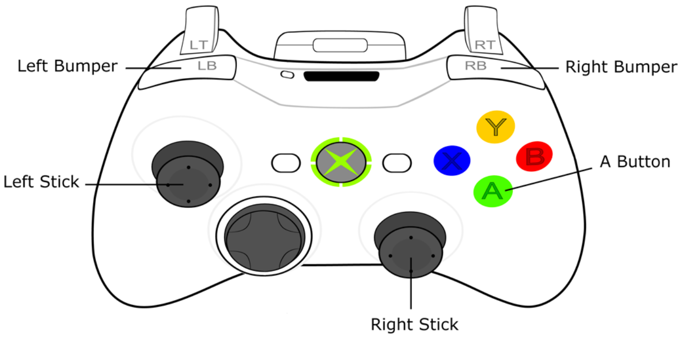

Figure 3.1: Xbox controller with relevant buttons labeled.

3.3 The Virtual Environment

The design of the environment was kept simple. All turns were 90°. Initial observations and talks with participants revealed that this was seldom apparent before they used the Map. The demo scene used for familiarization of controls did not exhibit the same design, leading participants to expect the level designs to have a variety of turns.

The soundscape setting was kept simple, but the participants were exposed to fragments of a story through introductory dialog. There was very little background sound, so as not to interfere with the navigation. There was no reverberation used, as this can obscure the clarity and affect results [19]. There was no sound occlusion when a wall came between the participant and a checkpoint. The training phase had the participant navigate inside of a square, with four blocks segregating the space into a symmetrical set of hallways. An illustration of this path can be seen in Figure 3.2. At every intersection, a checkpoint could appear. During training, a checkpoint would instantiate at an intersection within proximity of the participant. Upon reaching the checkpoint, the next would appear at another intersection, once more in proximity to the player. The system never tasked the participant with going back the way they came.

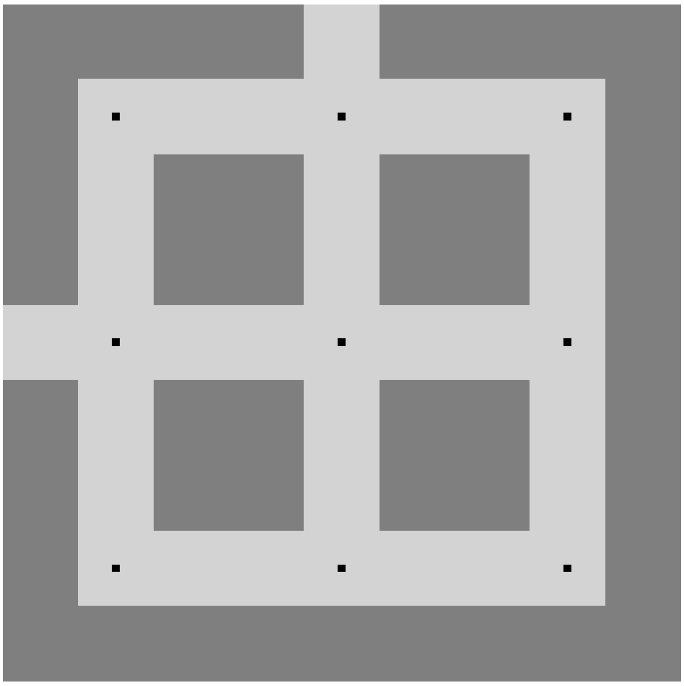

Figure 3.2: The training environment. Each small black square is a potential node. The training path would be generated randomly allowing the participants to stay in training as long as they liked. The path to the left is where they enter training and the top path is where they exit.

After a minimum of four checkpoints, the character would inform the participant that he was ready to proceed. If the participant- and facilitator felt that the participant was ready, the participant was allowed to proceed. The participant then had to navigate to a door, which was just another checkpoint, after which the diegetic door sound would act as a cue to the end of the training phase. The actual test environment was one of three navigational path presets, these can be seen on Figure 3.3. The three paths were constructed according to a set of rules which ensured equal length and amount of turns between the paths. Through these identical variables, we expect no significant difference between paths. The reason there are three is to avoid potential bias from learning a path by heart.

Figure 3.3: The three possible paths participants had to navigate post-training. The paths are identical in length, and in how many turns they have. The bottom of the path is where they enter and the top of the path is where they exit.

3.4 Navigational Aids

We decided to design our own navigational aids for the project, rather than using a preexisting game or project. There are a few reasons as to why this decision was made. In order for spatial beacon sounds to work optimally, we wanted for the test to utilize 3D audio, in order to increase the spatial detection accuracy and minimize search times [17]. Not only would this alteration alone make it a requirement for the game or project's code to be fully accessible, but gathering of metrics also requires access to a game's internal workings. By creating the software, we were able to fully access exact completion times, player navigation paths and rotation, storing every minute detail at about thirty samples per second. Additionally, we were able to create a clinical test environment, in which similar navigation tasks could be attempted with distinctly different navigational aids within the same environment. Lastly, full control of the test also allowed us to keep the interactions equally complex, in regards to participant input. This would simply not have been possible without access to a game's code. The process of exact replication is almost a task as large as creating something from scratch, as even slight altercations might skew results.

Based on our case study of audio games, we decided to test upon three navigational aids that we found to be the most essential. The number was arbitrary, and chosen simply because we felt that our three candidates were the most distinct. The prime requirements for these were that their full function needed to be possible to replicate entirely through diegetic sound and they needed to be able to stand on their own. In order to minimize training and a potential complexity difference between the navigational aids, to activate them, interactions were based on a single button: the Use Key.

Beacon sound: playing a sound from where exactly the player needs to go to. This category fits Cans.

Following and guiding sound: a spatially localizable sound similar to a beacon sound, playing next to the player, in the direction in which the player needs to go, such as in the case of Dog.

Directional guidance: tells which direction the player needs to go compared with the direction he is currently facing, equivalent to Map.

In addition to these three types, we also supplemented with a fourth, which sole purpose was to detect walls, a feature largely untouched by the three types listed above. The wall detection was used with all three navigational aids. Following the aforementioned requirements and what we have learned from audio games prior, we have designed the navigational aids as follows:

Beacon sound: Cans

When the participant pressed the Use Key, cans would rattle, placed at the next checkpoint. There was no idle sound for this navigational aid, and the sound source was static. The sound was accompanied by the sound effect of the protagonist character pulling at rope, as the story had introduced it as cans hanging along a long stretch of rope. The sound of the rope was placed close to the character at a fixed distance towards the location of the checkpoint. This navigational aid was of a spatial, guiding nature, requiring the participant to navigate to its perceived location in the environment. Upon reaching it, the player character could be heard collecting the contraption as he went. This beacon sound was inspired by Extant's dog [7] and Terraformers' spatial compass [11]. It is also similar to Swamp, in which zombies and players emit sound when within proximity of the player [10]. Lastly, the way players had to detect opponents in AudioQuake was also by spatial sound cues. Pickups and hallways emitted sound as well [12].

Following and Guiding Sound: Dog

When moving in the right direction, dog steps would play in front of the player character, indicating a dog moving in front of him. If the character started moving in the wrong direction, the dog would stop and wait for the player character. At any time, the participant could press the Use Key to make the dog bark, creating a short distance beacon sound emitted from the dog. This function was necessary if the participant got lost from the dog.
When the dog reached the position of a checkpoint, it would emit a small bark and make a turn. It separates itself from the other two by not relying on checkpoints in the same fashion. The Cans and Map both have distinct moments of pause upon reaching the static checkpoints, contrary to Dog. It is similar to Cans in the fashion that they are both guiding sounds, conveying spatial information through non-speech beacon sounds. This navigational companion was also inspired by Extant's dog [7], but is otherwise unique. It is rare for audio games to require their players to follow a moving audio source, except for when said source is an opponent player or creature. AudioQuake designed it so players could hear other people's footsteps, bumps and pickups, falling closest to our Dog in terms of conveyed information through spatial sound [12].

Directional Guidance: Map

Until interacted with, there are no cues offered by this navigational aid. When activated with the Use Key, the player character announced which direction he needed to be facing in order to reach the next checkpoint, and in which direction he is currently facing. If the Use Key was held down, he continuously stated any change in heading. After reaching a checkpoint, the protagonist character then announced that he needed to look at the map to identify where he needs to be going. The method for interacting with this navigational aid is different from the others. It uses speech to aid the participant in the task of navigation, and it can be argued that the event of holding the Use Key is different from simply pressing it. We felt that not offering the option would give the participant too much repeated information. The Map interaction was inspired by Swamp [10] and Terraformers [11], both of which featured compass interactions.

Wall Detection: Wall Scraping

In a virtual environment where you control a character, the extension of a virtual arm can reveal a wall ahead of time. We wanted for the participant to be able to tell that they were walking alongside a wall, by playing soft scraping sounds as if the avatar held out a hand and scraped it lightly against the wall as the avatar walks forward, similar to strategies used by the visually impaired [15, 16]. The primary reason for this choice is to give the player information about the room structure. The player can effectively feel the extent of the wall if he continues to walk alongside it. It effectively serves as a reference point. This method of interaction is inspired by an article describing the creation of AudioQuake [12]. As mentioned earlier, this navigational aid was present during all periods of the experiment. We chose to do this, because we felt it the best way to inform the participant of the obstacles in their way. While the goal of our work is to evaluate the navigational aids separately, we feared that the lack of such a system would impede the participants to a level of frustration. It is also worth noting that it does not enter the domains of explanatory- or beacon sounds, standing entirely on its own. This auditory aid is based on Terraformers' [11] and AudioQuake's wall scraping system [12], as well as Entombed's wall bumping [6].

Checkpoints

When navigating the test, there were two types of triggers that would determine when a checkpoint was found. The first method was a static trigger object in the shape of a cross with a box in the middle (see Figure 3.4). This shape was chosen to ensure that it was not possible to move past a node without reaching it. This trigger object was placed with the center at where the navigational aids would tell the participant to go to. This method was in use when navigating using Cans or Map. When using Dog, another trigger method was in use: distance. The trigger distance for the Dog was seven virtual meters (vm). This distance was set to ensure that the character could not move past the dog when turning a corner, as the dog does not cut the corner, but a participant might (see Figure 3.5).

3.5 Sound

Unity's default sound system, fmod, was supplemented with 3Dception, an audio modeling engine by Two Big Ears [3]. This engine allows 3D audio, and thus, better spatial accuracy through sound [17]. Two Big Ears, the developer of 3Dception,

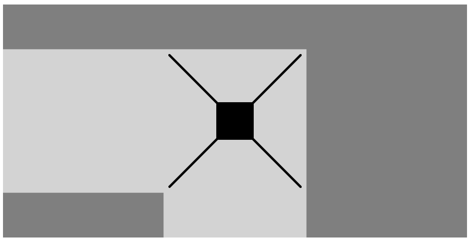

Figure 3.4: Cross-shaped trigger zone for Cans and Map.

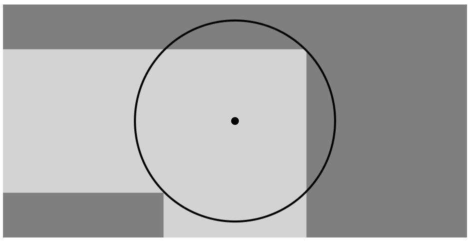

Figure 3.5: Trigger zone for Dog. The dog is at the position of the dot.

keeps their proprietary algorithms secret prior to patenting their technology, making the specifics of the engine largely unknown. The engine bases its HRTFs on a best-case approximation of multiple anthropomorphic parameters, and not a single head's properties. Two Bear Ears claim that the engine achieves a spatial resolution of one degree, see Appendix F.

The sounds used in the game were kept diegetic to the theme the game that is under development. The reason to keep sounds diegetic is based on a desire to keep the navigational aids non-intrusive. Non-diegetic sounds can be more effective when acting as beacon sounds, due to a free reign on frequencies. The frequency range and onset of a sound has a large impact on how easy it is to pinpoint the accurate direction of an audio source. That means that acoustic sounds vary greatly in how easily they can be located within an environment, virtual or otherwise.

The spatial sounds pertaining to navigation, Cans and Dog, each consisted of two different sounds. The cans navigational aid had cans hitting each other and a rope pull sound. The dog navigational aid had barks, and paws hitting the ground. How well the attributes of these pertain to localization and binaural findings can be seen on Tables 3.1 – 3.4. It is clear from these attributes and summaries that the sound used for Cans and Dog do not exhibit the best possible onset, duration and use of the frequency spectrum. Finding a diegetic sound that does exhibit this could prove a large project in itself

Table 3.1: Summaries for the "cans hitting each other" sounds

Onsets:	3–14 ms	Sound durations:	90–340 ms
Sequence:	2–5 hits	Total durations:	566–790 ms

– The hits have a considerable energy level in the weak ITD to IID cross over area, but most less energy than the rest of the signal.
– Can hits have low energy in lower half (0.4-3.4k Hz), and very low in the upper half (3.4-6.4k Hz) of the frequency area best contributing to avoiding front-back errors.
– The duration of the individual can hits are below 600 ms and are thus not suited for head/character rotation. We cannot say whether sequence of clunks helps on this.
– Most of the energy exists in the 0.4-6.4k Hz domain. Onsets are closer to 1 ms than 100 ms which could lead to localization better than 5-15° errors, maybe even close to 3° errors.

Table 3.2: Summaries for the "rope pull" sounds

Onsets:	194–200 ms	Sound durations:	400–425 ms
Sequence:	1 pull	Total durations:	400–425 ms

– The rope pull sound had a considerable energy level in the weak ITD to IID cross over area, but most less energy than the rest of the signal.
– Rope pulls have low energy in the upper half (3.4-6.4k Hz) of the frequency area best contributing to avoiding front-back errors.
– The duration of the individual rope pulls are below 600 ms and are thus not suited for head/character rotation.
– The sound is positioned very close to the character in the direction of the sound of cans hitting each other.
– Most of the energy exists in the 0.4-6.4k domain. Onsets are above 100 ms which would lead to localization with around 5-15° errors or possibly worse.

Table 3.3: Summaries for the "dog bark" sounds

Onsets:	55–80 ms	Sound durations:	206–357 ms
Sequence:	1–3 barks	Total durations:	456–692 ms

– The Barks have a considerable energy level in the weak ITD to IID cross over area.
– Barks have low energy in lower half (0.4-3.4k Hz), and very low, worse than cans, in the upper half (3.4-6.4k Hz) of the frequency area best contributing to avoiding front-back errors.
– The duration of the individual barks are below 600 ms and are thus not suited for head/character rotation. We cannot say whether or not sequence of barks helps in this.
– Most of the energy exists in the 0.4-6.4k domain. Onsets are above 100 ms which would lead to localization with around 5-15° errors or possibly worse.

Table 3.4: Summaries for the "dog steps" sounds

Onsets:	1–2 ms	Sound durations:	205–237 ms
Sequence:	1 or more steps	Total durations:	456–692 ms

– No considerable energy spike in the weak ITD to IID cross over area. The spectrum is rather flat until around 9k Hz.
– The steps exhibit mostly the lower half of the robust front-back frequency area, but in comparison with rest of the spectrum, with a considerably high amount of energy.
– Durations of the dog steps are below 600 ms and are thus not suited for any head/character rotation. Again, a sequence of steps might help, but we cannot say.
– Most of the energy exists in the domain 0.4-6.4k Hz. Onsets are slightly above 1 ms which could lead to localization better than 5-15° errors, maybe even as good as 3° errors. However as this was largely an uncontrollable sound in regards to user interaction, it was harder to rely on.
– The steps were low in volume.

3.6 Logging of Game Metrics

During the test, two types of data logging was undertaken: continuous and event based logging. The continuous logging was done every 100 ms while the event logging only happened when an event of a certain type happened.
Logging was done to text files, which the program automatically created at startup or when needed.

The metrics being logged continuously were the following:

- Current time – The current time for the logging.
- Character position – The position in x and y for the character.
- Character rotation – The rotation of the character in degrees.
- Character movement locked – True or False.
- Test mode – Training or Testing.
- Type of navigational aid – Cans, Dog or Map.
- Index of the current segment – Index between 1 and 3 indicating the index of the segment.

The event logging consisted of the same metrics as the continuous data logging, but had a few additions:

- Event type from an enum of events – Enum type (examples in the next list).
- Additional information of the event – E.g. name of the audio being played or which hand is used to touch the wall.

Each time a certain event happened, the event logging would happen. The following list contains a few of the events that would trigger the event logging:

- TriggerDown – When the Use Key is pressed.
- TriggerUp – When the Use Key is released.
- WallEnter – When the character enter collision with a wall.
- WallExit – When the character exit collision with a wall.
- ChangeMode – When the mode changes from training to test or vice versa.
- AudioPlaying – When a sound is being played.
- AdvanceInTest – When a node is found.

All text files were formatted for easy extraction for data analysis.

3.7 Limitations

The project and method had a series of limitations, which mostly revolves around unused potentials, as well as applicability of the results. This section seeks to point out the most critical ones.

The first limitation is that of the participants. We tested on sighted male students ages 19 to 28. As a demographic the participants give no good holistic representation, but the primary issue is of course that they are sighted. The implications of this can of course vary.

Faster Introduction: Due to sight, we were able to introduce the environment quickly. This might have been harder if they were visually impaired.

Experience with audio only: It is plausible that experienced audio gamers would have a perceptual advantage through experience, giving them the ability to better use the systems we designed.

Impatience: We believe that the sighted participants might have been more impatient than the visually impaired forum users of AudioGames.net. This is based on the sole observation of how hard it would be to learn some of the accessible or semi-accessible games that were revealed through their questionnaire responses.

The data gathered during the experiment was sought to encompass all that we felt could be interesting to look into. The written responses were however not analyzed thoroughly, and mostly used as interesting notions. Game metrics, such as rotation, wall enter and -exit, were never used further than the point of capture, but could have brought forth interesting aspects. Observations were done very informally and were not written down during the experiment, with no video capture either.

The last limitation might have been the setup, which included two participants at a time. We have no way to tell if we were able to counteract a possibly competitive setting through the introduction we gave. The motivation through competition is in and of itself not a problem. A high motivation was in fact appreciated, but the effects of frustration could very well be a much bigger problem than we wanted for the experiment.

Chapter 4

Results and Discussion

This section includes a statistical analysis from two types of data: game metrics and questionnaire answers. The analysis of the game metrics was done using the logged data described in Section 3.6 while the questionnaire data was gathered from the questionnaire included in Appendix D. For the statistically analysis, we follow the scientific standard of significance levels with $\alpha = 0.05$ as threshold for significance.

This chapter will also include observations to identify some approaches to data analysis. This includes some of the written responses from the questionnaires as well as observations of the test participants' strategies and behaviors.

Conclusive to the chapter, we compares the three navigational aids against each other to find advantages and disadvantages for each of the navigational aids.

4.1 Game Metrics

We observed that some of the test participants were confused when they progressed from the training phase the actual test, resulting in them standing still in the environment, waiting for further instructions. We decided to exclude a part of the initial data to accommodate this tendency without having it effecting the results. To identify the tendency, we mapped each time a participant stood still for more than three seconds without moving or pressing the Use Key. This mapping can be seen in Figure 4.1 where each position is illustrated with a black dot. The horizontal black line right above most of the dots is the threshold at which we excluded data, to minimize the effects most of the unwanted stops. Figure 4.2 shows the path of each participant after the first section has been excluded.

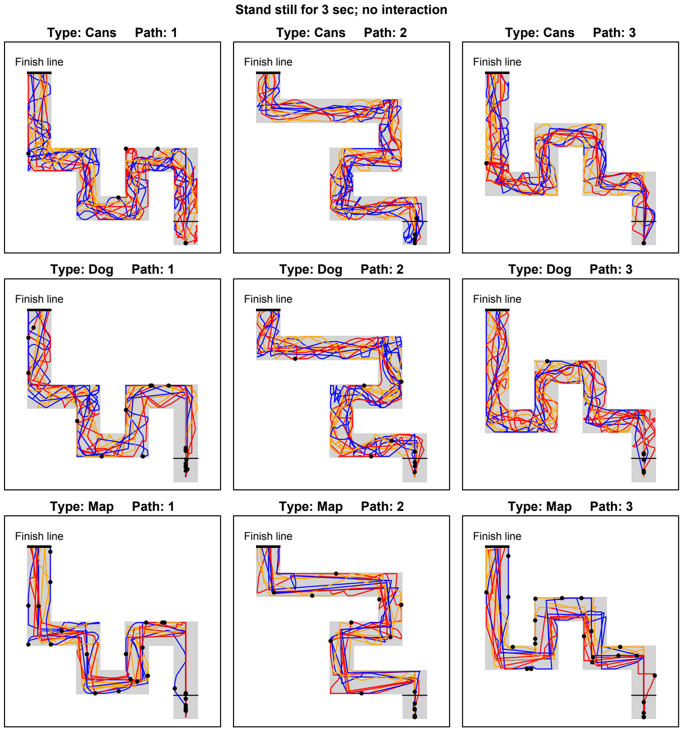

Figure 4.1: Plot of each participant's path. Each line represent the walked path and the dots represent each time a participant stood still in more then 3 seconds without making any interactions.

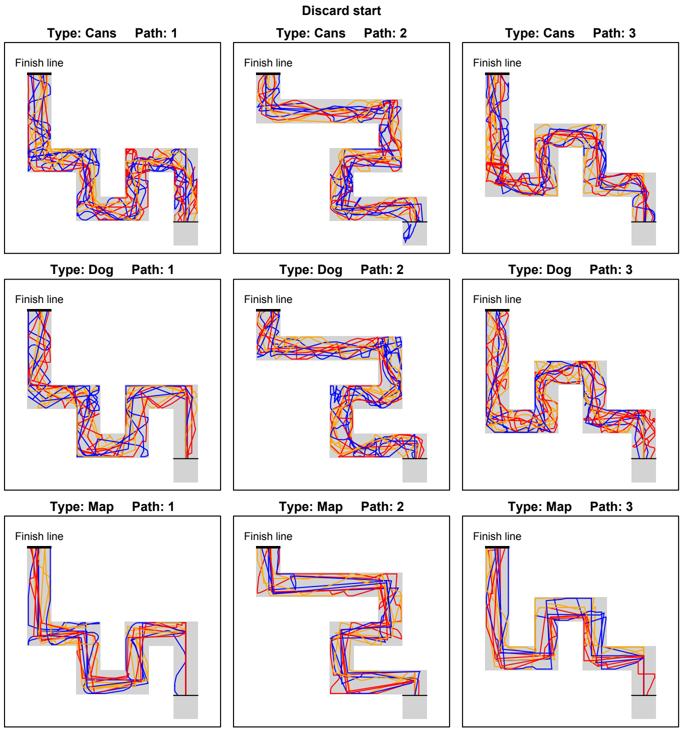

Figure 4.2: Plot of each participant's path after first section has been removed.

By observing the Q-Q plot for time, we concluded that the data was not normally distributed (see Figure 4.3) and non-parametric tests were used for further analysis.

Based on the positional data, a distance metric was calculated, corresponding to the distance covered by a participant on a single trial. This metric will simply be referred to as distance and is measured in virtual meters (vm).

We ran two non-parametric Friedman tests to compare the three navigational paths. The tests showed no significant difference between the three navigation paths in either time ($p = 0.3578$) or distance ($p = 0.8948$). Because we cannot refute the null hypothesis, we consider their influence negligible.

A data overview of the primary game metrics, completion time and distance traveled is shown in Figure 4.4. At first glance, Cans and Dog seem very similar in terms of mean and median, with the main exception that Cans have greater outliers. Map seems to be the slowest in terms of time but most efficient in terms of distance.

Comparisons between each of the three navigational aids were performed, using non-parametric Friedman tests. For completion time, there was no significant difference between Cans and Dog, placing them in group a (see Table 4.1). There was a significant difference in completion time between Map and the two others ($p = 0.0011$), placing it in group b. Dog and Cans were therefore the navigational aids that allowed for the fastest navigation in our test. As for distance, Map was significantly different than the other two ($p < 0.001$), placing it alone in group a (see Table 4.2). There was no significant difference between Cans and Dog, placing them in group b. The Map was therefore the most efficient navigational aid in regards to distance, allowing participants to navigate the most direct route. When comparing the amount of button presses between the navigational aids, there was a significant difference between all three aids ($p < 0.001$) grouping them separately. A heatmap of the clicks can be seen in Appendix C.2. Map was the type with the fewest amount button presses, Dog came second and Cans third with the highest amount button presses. It is noteworthy that Map could provide navigational assistance while holding down the button, and that Cans was the only aid that provided no assistance at all when passive.

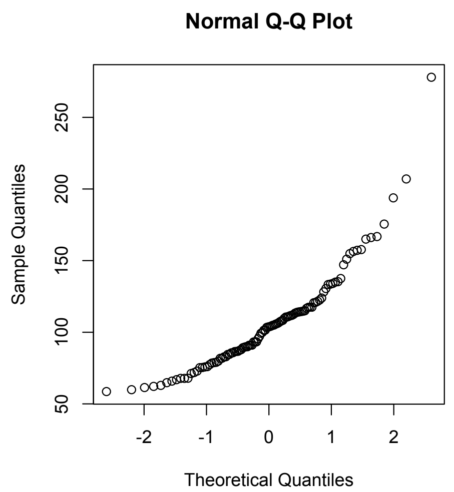

Figure 4.3: Q-Q plot for the time of the data.

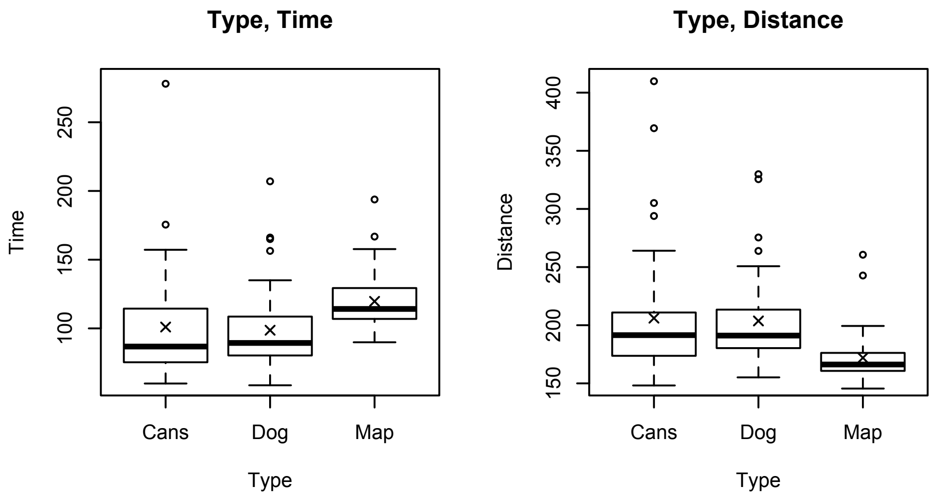

Figure 4.4: Box plots including each navigational aid in regards to completion time (s) and distance (vm).

Table 4.1: Grouping, Means and standard deviations for completion time in seconds.

Aid	Group	Mean (s)	SD (s)
Dog	*a*	98.67	32.36
Cans	*a*	101.00	42.20
Map	*b*	119.66	21.14

Table 4.2: Grouping, Means and standard deviations for distance in virtual meter.

Aid	Group	Mean (vm)	SD (vm)
Map	*a*	171.97	22.35
Cans	*b*	206.09	57.81
Dog	*b*	203.68	40.17

Taking a closer look at the outliers in Figure 4.4, we find some odd navigational behavior.

There was one participant for each of the navigational aids whose data were an outlier in terms of both time and distance. The plotted paths for each of the three outliers for the respective navigational aid can be seen in Figure 4.5. In Figure 4.6, shows an example of a participant whose performance was at worst average.
The outlier for Cans was participant 32, with a completion time on 278 s and a distance travelled of 409.81 vm compared to the means of 101 s and 206.09 vm. We observed that this participant had some difficulty with the direction of the Cans. Whenever he was in doubt, he would turn the side to the emitted sound, to maximize the volume in one of the ears and then walk sideways in the direction of the target.
For Dog it was participant 31 who was an outlier with a completion time on 207 s and a distance on 325.58 vm compared to the means of 98.67 s and 203.68 vm. He was observed to have some difficulty localizing the sound which the dog emitted, which might explain his data.
For the Map, participant 2 was the outlier with a completion time of 157.7 s and a distance of 242.75 vm compared to the means of 119.66 s and 21.14 vm. This participant was observed to overshoot and forget to check for direction.
All means can be seen in Table 4.1 and 4.2. The path of all individual participants can be seen in Appendix C.

Other participants, like participant 5, were an outlier in distance but not in time (see Figure 4.7). This indicated that they kept walking even though they were unsure about the direction.

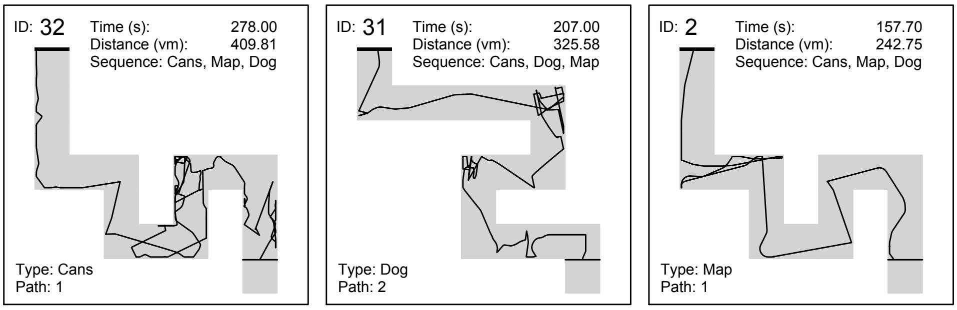

Figure 4.5: Plots for outliers in both time and distance. Participant 32 was outlier in Cans, participant 31 in Dog, and participant 2 in Map.

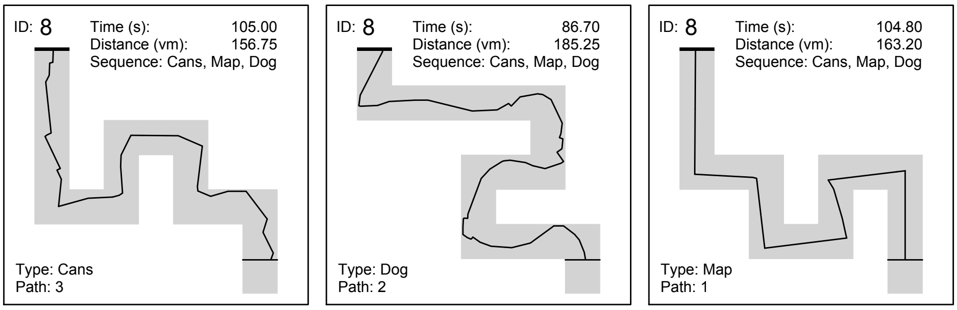

Figure 4.6: Plot of participant 8, which was not an outlier in any category.

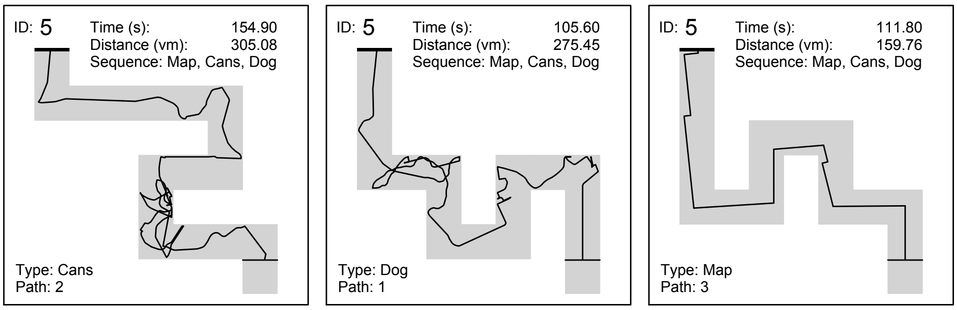

Figure 4.7: Walked path for participant 5 who was an outlier in terms of distance for both Cans and Map.

4.2 Questionnaires

As already mentioned each participant rated the three navigational aids two times: first time was, individually for each aid, on a 7-pointed Likert scale and last thing in the test, a ranking between each aid between 1–3. The rating and ranking were done in the three categories: overall, speed, and difficulty. On Figure 4.8 and 4.9 the scores from the Likert scale and ranking is shown respectively.
By looking at the 7-point Likert ratings, we see that the data does not look to fit a bipolar distribution, making it possible to rank the data into values comparable with the data from the ranking questionnaire.
By performing a Kendall Rank Correlation test is was found that their ranks scores was not significantly different from their ranked Likert scores, with a p-value lower than 0.001 for all three categories.

Three non-parametric Friedman tests were used to compare the three navigational aids in all three categories and found the following:
For the overall ranking, there were no significant difference between Cans and Map ($p = 0.0458$), neither between Map and Dog, grouping Cans in a, Dog in b and Map in both a and b (see Table 4.3). Resulting in Cans and Map being the ones they liked the best overall.
For the ranking of speed, there were significant difference between Cans and the two other aids ($p = 0.0047$), while there were no significant difference between Dog and Map. Group a consists of Cans and group b of Dog and Map (see Table 4.4). The participants ranked the Cans best in regards of speed and Dog and Map tied on second place.
For the difficulty rank, there were no significant difference between Cans and Map, but significant difference between Dog and the two others ($p = 0.004$). Cans and Map were placed in group a and Dog in group b (see Table 4.5). The Cans and Map did best in terms of difficulty while Dog were the most difficult to use, recording to the participants.

Table 4.3: Questionnaire grouping for overall rank.

Aid	Group
Cans	a
Map	ab
Dog	b

Table 4.4: Questionnaire grouping for speed rank.

Aid	Group
Cans	a
Dog	b
Map	b

Table 4.5: Questionnaire grouping for difficulty rank.

Aid	Group
Cans	a
Map	a
Dog	b

To see if their rating of speed would fit their actual completion time, a Kendall rank correlation test was used, after each type was ranked for each of the participants. The result showed that there were a significant difference between the actual completion time and the speed ranking they did ($p < 0.001$), suggesting that some of the navigational aids might have made participants lose track of time used.

Comparing the grouped results, Cans is the clear winner being in group a in all three categories. Map comes in at second place being in group a in the difficulty ranking while Dog is in group b. Dog, being in group b in all three categories lie on third place.

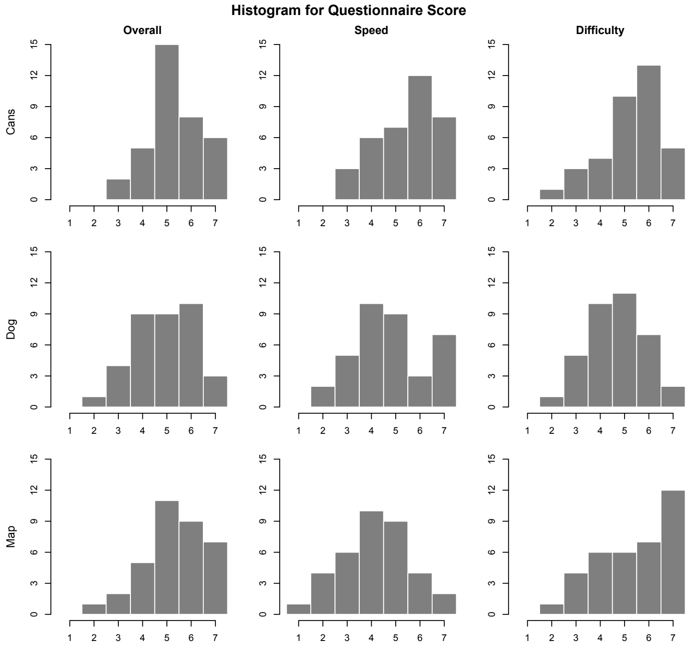

Figure 4.8: Histograms of Likert scale ratings for Cans, Dog, and Map, in categories: Overall, Speed, and Difficulty, where 1 corresponds to very- bad, slow, hard, and 7 corresponds to very- good, fast, easy, respectively in regards to the categories.

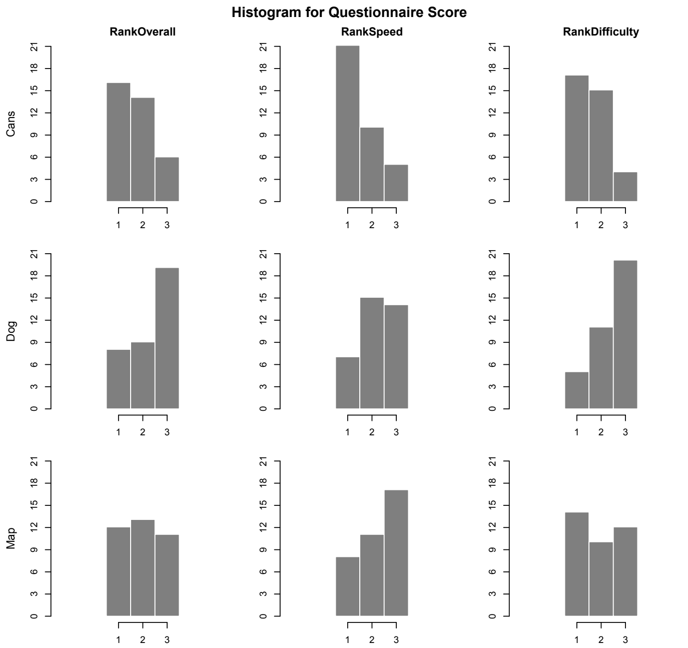

Figure 4.9: Histograms of rankings for Cans, Dog, and Map, in categories: Overall, Speed, and Difficulty, where 3 corresponds to very- bad, slow, hard, and 1 corresponds to very- good, fast, easy, respectively in regards to the categories.

4.3 Observations and Written Responses

A few things can be said about the performance and preferences of participants based on the written responses and observations. Some are worth mentioning, even though this should not be considered.

Lack of Sound Occlusion

It became clear that the lack of sound occlusion would sometimes cause major issues, especially for Cans.
Some participants would reach a checkpoint and by accident go the wrong way. This was not necessarily a problem, but their accidental missteps could put them in an unfortunate scenario. A scenario in which they were facing the sound correctly, but a wall would be in the way, without giving hints to the direction they would need to go to get around the wall.

Talks With Participants

Talking with participants after the experiment revealed that some felt Cans to be more motivating. It had game like elements through the collection of the individual cans.
Multiple participants indicated a wish for two Use Keys for Map. One for objective direction and another for heading.

Written Answers

If participant 28 had to choose a navigational aid again the choice would fall on: "Dog, 'cause having a companion was comforting, who cares if Cans were slightly faster".

Participant 33 felt that the order of navigational aid played a role: "I might have rated the dog one better if it wasn't first – more experience seemed to help regardless of method".

Player Strategies

During the training phase, players were intended to figure out the workings of the navigational aids as well as possible strategies of use. When the training phase ended they were encouraged to do exactly what they felt as being the best use of the navigational aid. The use of the aid and the corresponding strategies varied quite a bit between participants. The strategies are listed below:

- Little to no rotation.
- Strafing as primary movement.
- Turning while moving.
- No-Turning while moving.

- Avoiding walls.
- Clinging to walls.
- Correct direction after reaching a wall.

The strategies were not mutually exclusive. Some could be used along side each other while some could not.

The aforementioned outlier identified in Section 4.1, participant 32, seemed to have some issues in localizing the spatial sounds. He ended up adapting the “Strafing as primary movement”-strategy, where he would turn his side towards the sound and find the angle at which the sound was the loudest for the respective ear.

Player Behavior

Head rotations were observed in some participants. It is unclear if it was a repositioning of the head as a result of comfort, or some misguided belief that it would affect or help them during the navigational task. Multiple participants would, on and off, play with their eyes closed. Maybe to focus better on their hearing, or to imagine their virtual surroundings.

The Use of Wall Scraping

During both the training- and testing phase the participants made use of wall scraping. Two occasions made visible through plotted paths are seen on Figure 4.10 and 4.11.

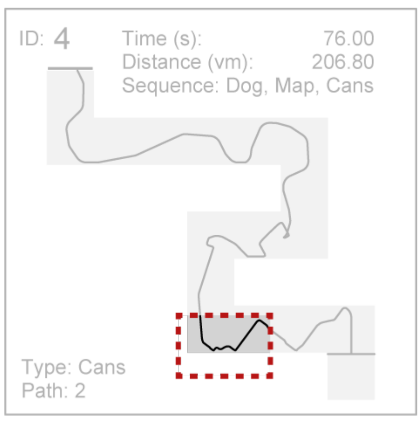

Figure 4.10: A sawblade like movement for participant 4, showing his reactions to the feedback from wall scraping.

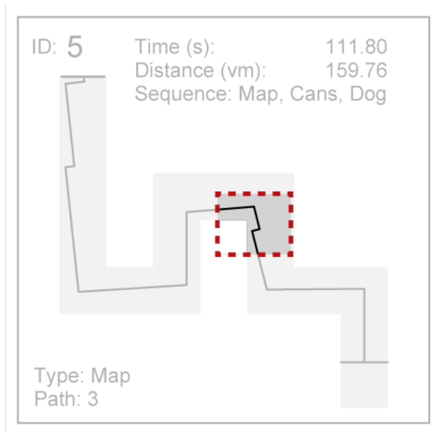

Figure 4.11: Participant 5 reacts to the feedback from wall scraping as he is about to collide with the wall.

4.4 Discussion

When comparing the navigational aids through all tests, the following advantages/disadvantages were found:
Map is efficient in terms of distance moved and number of interaction clicks. It should be noted that number of interaction clicks is reduced by design, as the user can hold down the Use Key to further the functionality. Map would be the best fit for games where you need to move as little distance as possible, e.g. for saving fuel or energy, or game play sections where non-hectic behavior is wanted. The Map is however the worst choice of the three if the player has to navigate the path within a certain amount of time, since the map was significantly slower than both Cans and Dog.
Dog was efficient in terms of time but did not rank well on all other categories. The dog had some advantages as well: as the aid was offered two viable options for navigation, participants could rest their fingers from pressing the Use Key when they were close behind it. This was likely the reason for the difference in button presses from Dog to Cans. Furthermore, a few participants really liked Dog due to the companionship it provided and stated that they rated it higher just because of this, even though it was not necessarily the best aid for them.
Cans had the benefit that the player could get feedback on how much further they would have to go the current direction, as distance changes would alter the sound volume. Unlike Dog which instead would have the user move forward until told otherwise. The game-like element of picking up the individual cans gave a relatable purpose for walking the path. These game-like elements could ultimately be the deciding factor for the preference towards Cans over Dog.
An overview of all the groupings done through Friedman tests for each navigational aid can be seen in Figure 4.6.

Table 4.6: An overview of the Friedman scores for each of the navigational aids.

	Cans	Dog	Map
Time	*a*	*a*	*b*
Distance	*b*	*b*	*a*
Overall	*a*	*b*	*ab*
Speed	*a*	*b*	*b*
Difficulty	*a*	*b*	*a*

The measure of time as well as the perceived speed of the navigational aids did not necessarily translate into a “better or worse”-comparison. One aspect is that games can of course be designed to take longer or move and move at a slower pace. Another aspect is that the whole experience might be enjoyable in itself and thus could be preferred to play for a longer duration.

The biggest observed issue was the lack of sound occlusion. The problems it introduced would stop some participants from completing either training or the navigational task. In some cases the participant would be asked start over, and in other cases we would have to stop the experiment and discard the data. It was also a huge impeding factor on the completion time and distance when unlucky participants got stuck, until they by chance would correct their mistake.

Sound based detection of walls which have been used successfully by the accessible games, Terraformers and AudioQuake. Wall Scraping was similarly used effectively by some participants. This tells us that Wall Scraping was a worthy addition as a secondary navigational aid. The fact that it could coexist with the primary navigational aid also shows that combining some navigational aids is possible.

Chapter 5

Conclusion

By comparing the game metrics, Cans and Dog did best in terms of completion time, with no significant difference between one another, but both had the drawback that they made significantly bigger deviations from the direct path than when using Map. The implications of this is that beacon sounds fare better for tasks that are required to be performed with haste. The players did not need to stop moving with these, which could implicate that they fare better in a game scenario that urges the player to react promptly. Map, being a verbal aid, had participants pause at each checkpoint whilst getting their bearing. Participants requested a secondary button in order to just hear their facing, and not which facing they needed to head, first.

When looking at the questionnaire data Cans were the most liked, being in group *a* in all three categories (overall, speed, and difficulty). Map came second being in groups *a* in both the overall and difficulty category. Dog was the least liked being in groups *b* in all three categories.

5.1 Future Work

The first clear alteration to make in a future iteration of the project would be to test on the community of blind gamers. This would give much more specific and useful feedback, as they already are experienced with the use of similar navigational tools. It would also help us to identify potential pitfalls that we may not have realized yet. The test would have to be automated and polished for this to work, and instructions made abundantly clear. It would also require us to make the test digitally distributable. The participants would, in such a scenario, not be able to interact with a test facilitator, requiring the criteria for progressing from training to trial to be more severe to ensure that participants would be fully comfortable with each interaction aid. A more direct communication with the community between iterations would also be crucial for the unfinished game to reach a playable state that could be improved upon through rapid user feedback iteration cycles. A fully fledged game experience would also add appeal to the experience, in which the navigational aids would be interlaced with the game, as described in Appendix A.

Another approach to take would be try to catalogue more navigational assistance tools and interaction methods for the blind, as well as look into the multiple variables

for each, and document the changes that altering said variables might have. We only examined three navigational aids in the scope of our test, and neglected navigational aids such as the coordinate systems used in Terraformers [11] and Entombed [6]. It would not be difficult to extend the scope of the research by assessing more games and virtual environments.
A signaling navigational aid, for instance, was not included. Such an aid is non-spatial and non-speech, confirming a player's facing by altering a sound's pitch or frequency based on how close he is to the right facing. How would a speech beacon sound fare? A hybrid that is both spatial and explanatory speech? In spite of a documented increase in acquisition time and a decrease in accuracy [25], what if this voiced beacon sound described its own location?

Given the occasional head movement of participants, it might be interesting to observe which navigational aid caused more head movement in participant. This could be measured under two conditions: when the system replicates head movement in the virtual environment and when it does not.

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Appendix

Appendix A

The Game

Throughout the duration of the project, we intended to release a small audio game that were to be build on top of the foundation of our test scenario's mechanics. In the very early stages of research, we even intended for the test to be run inside of the game. We would have participants simply play the game and record the relevant data during controlled testing sections of the game. For this reason, a lot of decisions made about the game or the test bled into eachother. For this reason, the test itself still retains fragments of a story, and the placeholder audio that had been intended for the game. The project therefor utilized diegetic audio to shape the auditory impression, to preserve immersion and scenario integrity [21].

The game follows a set narrative structure, that allows interchangeable elements in between three main story/action sections. These interchangeable elements serve as the more clinical trial of our project, and when reduced to base components, are little more than navigational tasks in 3D space with different auditory interactions for finding one's way (see Figure A.1).

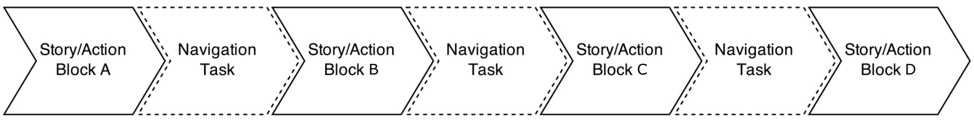


Figure A.1: The general structure of the game. Each of the story/action sections represent unshifting phases in which most of the story plays out. The stippled navigation task blocks represent the test segments, in which the three different navigational aids are tested. These change, depending on the participant ID.

A.1 The Story

A strange fungus was what ended the world. Generally mistaken for a harmless byproduct of a new pesticide praised for it's complete repellent of insects and general harmlessness amongst mammals, the fungus was soon prominent worldwide, following the agricultural popularity of the pesticide. The fungus' toxin had an incubation of a whole year, and it took much too long for mankind to realize why all grain-fed mammals and humans fell deathly ill with no recent additions to general food supply, nor any natural- or manmade disasters of note. One in 133 people were, at the time of the fungi's introduction in worldwide grain distribution, genetically intolerant of the gluten protein. Only about half of them completely avoided wheat ingestion for the following years. As a result, roughly 26 million people are alive today. Infrastructure fell into a rapid decline, and the world returned to a savage state, in which man's basic needs were reduced to those associated with survival.

You find yourself stranded in a major city along with a single companion. The companion will introduce you to the elements of the game and serve as an tutorial. Furthermore, his purpose is there to convey information about what cannot be seen, as well as provide the objectives of the game. The game takes the player through the streets of an abandoned city, in search of a working vehicle. The player and his companion traverses the streets and rooftops, undertaking various tasks along the way. For the end of the game, they see the vehicle and escape. The scope was kept relatively small length-wise, so as not to overwhealm our small team, but it still proved too extensive a task to be a biproduct of the project.

A.1.1 Gameplay

Throughout the game's sections, several gameplay features were planned. These events were: chopping down a door with an axe, jumping from rooftop to rooftop, picking locks and a fighting sequence against a creature intended to be of a frightening nature. Most of these events were intended to make use of the game controller's rumble feature.

Within the game, the player has a limited amount of choices. The game follows a story line, which the player is bound to follow to advance. The player can, however, move freely and explore the surroundings before advancing to the next section of the game. The player can, however, not move back to previous locations. The game might be described as a story-game with limited exploration outside of the forced storyline.

The game is designed so that the player cannot die. At the end of the game, the player has to fight a monster using only an axe. The player has a limited number of times he can withstand damage from this monster. If the player do not manage to fight off the monster before he suffers too much damage, the battle will count as a defeat, where the player will get bitten and the companion will rush in to shoot the monster. The only effect this defeat has to the gameplay is that the player limps for the rest of the game.

A.1.2 Level Design Considerations

The levels in the game had to be easy to navigate without a lot of turns. An important factor is that there has to be as few obstacles as possible since these would just lead to frustration from the player.
The levels only have 90° turns to simplify the design.

A.1.3 Elaboration of the Story

Contains most of the dialogue, including notes, for the story sections of the game, as well as the navigational tasks and game events.

Throughout this section, when dialogue is described ”P” stands for player, ”C” stands for companion, and ”R” stands for radio, for when the companion guides the player over the radio.
Text within < and > represents inner monologue.

Story Section A

Your character slowly wakes up from sleeping on a spring mattress in the safehouse (echoes, reverb), grunting. You hear a voice calling you across the room.

C: ”Hey! Wake up! We have slept long enough, we have to get going”

Sounds indicate rising from spring mattress, whilst a small monologue explains the game’s premise further.

P: <”Hrm. My head hurts, like it always does. Not enough water. Never enough water. But we have funelled fuel from wrecks for months, and we finally have enough to make it. Today’s the day.”>

The player assumes control, and walks across a concrete, garbage littered surface. The characters that the player approaches start speaking within a certain distance.

C: ”How are you doing? Are you ready?”
P: ”My head’s pounding. Do you have some water?”
C: ”Not much left. Here, but don’t drink more than half.”

The sound of a half-empty canteen being handled to the player.

P: ”Thanks.”

The player drinks from the canteen and hands it back.

C: ”Alright. We are headed out of the city, to try and find a car with all four wheels still attached. A week or so back, I saw one that wasn’t too banged up, near the outskirts. Here, take this radio. I replaced the dead batteries for you.” The player receives a radio. It squelches once, as the player assumingly tests the batteries.”
C: ”Follow me. We’re headed out the back door.”

Companion walks through the safehouse and opens the back door for you. The door shuts. The player is outside.

Story Section B

The player proceeds on a straight street and hears Companion calling in the distance, on a rooftop.

C: "Up here! Use the ladder, it's right below me!"

Companion comes with encouraging remarks until the player starts to ascend the ladder. This action is performed by simply any direction after reaching the ladder. The player shuffles onto the roof. Footsteps change as a result of this, to the sound of a tin protected roof. The player is hindered in falling off, by the sound of skittering steps and a <"Whoa!"> if he comes too close to the edge. Companion explains the situation.

C: "Alright, we've got some ways to go. This is a personal shortcut of mine, but don't worry, I'll make it possible for you to keep up. Alright, follow me!"

Companion runs and the player can follow the footsteps if he's fast. They reach a fence, and Companion waits on the other side, encouraging the player with sound cues. The player crawls over the fence and Companion takes the lead again. A few corners are turned, another fence is crawled over. Companion then leaps across a building and shouts to the player, ahead of time.

C: "Jump to the other building! Build some speed! I'll tell you when to jump! Don't look down!"

The player's speed is automatically increased. Companion will prompt the player to "Jump!" and the player then either:

A: Jumps within an acceptable timed interval. (Setoff, flying in the air, landing)

B: Staggers and pauses on the edge, muttering: "Hm, more speed or I won't make it".

Once over, Companion encourages the player.

C: "Nice! Alright, this way!"

Another fence is leaped and another jump is attempted. After that, the companion slows down.

C: "There's a way down over here. Comeon, we are returning to street-level."

Both the companion and the player descends the ladder.

Story Section C

Axe on wood is heard, as Companion tries to force down a door. When the player comes close, Companion asks the player to give it a go.

C: ”There you are! Hey, could you take a few swings at this door? I'm no good at this sort of thing.”

You hear the Axe being thrown and grabbed by the player. The player gets to axe the door, and Companion exclaims that he is impressed.

C: ”Good job! Alright, you hold onto that.”

You step through the storefront, following Companion's steps. The floor changes to tiles(something we already have), trash and shattered glass. Companion calls on the player to join him if the player falls behind. They exit a short while later, and Companion exclaims.

C: ”Whoa. Alright, look at this.”

Companion then overtakes the player and runs off into the distance, calling the player over. When the player comes close, Companion talks again:

C: ”Look at this thing. Have you ever seen anything like it?”
P: ”What- Is that? It doesn't look human.”
C: ”Their howls will keep you up at night, friend. Be glad this one is dead. They aren't just night creatures, either, so be on your guard.”
P: ”I'll- Keep that in mind. What if we come across one of them? What do I do?”
C: ”Well, you've got that axe, don't you? And I've got a revolver. Only one bullet left in it, though, so best we avoid them, when given a choice. Alright, let's keep going.”

Story Section D

The navigation task ends, and the player climbs a fence by pressing forward. As he comes over the fence, there is a sound of cloth ripping. The player curses to himself.

P: ”No way I am able to climb back over that.”

A monster sound is heard a little further ahead.

P: ”Shit. Shit shit shit. That’s one of those monsters from earlier. Shit! I have to defend myself!”

The monster can be heard rapidly coming closer. With a cue, it attacks, coming close enough to the player that the player can hit it with his axe. If the creature is hit first, it whimpers and stops. If the player is hit, the hit can still impact and injure the monster. At three hits, the creature dies. At three hits to the player, Companion shoots the creature.

If the player loses:

C: ”Hm. I told you to avoid them. Can you still walk?”

P: ”Yea, I think so. Barely.”

The game then continues, but with the player limping.

If the player wins:

C: ”Wow, you- Killed it! I heard the noises and had to find a way down from the roof quickly. You’re a lucky man! Were you injured?”

P: ”No, I’m fine. Let’s keep going.”

Companion finds another door.

C: ”Through here. Put that axe to use.”

AXE EVENT, the door breaks down.

C: ”Good job. Alright.”

They keep going and exit the other end of the building, with Companion simply unlocking the door.

C: ”Much easier when you are actually on the inside.. *Click*”

The player follows Companion. Turning a corner, Companion exclaims: ”There! Over there! That’s the van I have been scoping out!”. Companion’s footsteps start running, and the player follows. Companion pours gas on in the car and the player gets in the drivers seat. BUTTON MASH rigs the car to start. Companion exclaims joy.

C: ”Fuck yeah!”.

And the player drives off, but can’t crash. For obvious reasons.

Navigation Task 1 – Cans

Companion yanks the rope and cans rattle.

C: "Alright, throughout these next couple of streets I set up this system- Well, it's really just a long rope with cans on it, but I used them as a warning system. I would like for you to collect them, and if you ever get in doubt of where the next one is at, yank at the rope, alright?"

Companion is heard running off.

R: "Follow the sounds of the cans in the distance. Press the USE KEY to yank the rope, causing the cans to give off sound."

Navigation task is performed.

P: "Alright, that was the last of them."

Navigation Task 2 – Dog

Companion whistles hard.

C: "There's a local I want you to meet. He's quite a good guide to pass through these particular streets. There he comes!"

A dog runs over, panting and barking happily.

C: "Alright, alright, boy. You help my friend here, alright? I will take to the roofs to keep look-out. Just follow the dog, alright? He knows where to take you."

Companion is heard running off.

R: "Follow the dog. He will wait for you, if you fall behind. Press the USE KEY to call out to him. He will respond with a bark. This will tell you where he is."

Navigation task is performed.
The dog is heard running off at high sprint.

P: "Wait- Damnit."

Navigation Task 3 – Map and compass

A loud monster roar is heard in the distance.

C: Shit, what was that? Ok, I am headed to the rooftops to check that out. Here, take the map- and compass. I will meet you up ahead, and guide you on the radio if you get lost, alright?"

Companion is heard running off.

R: "Press the USE KEY to check your compass and map for directions. It will tell you in which direction you are headed- And in which direction you need to go."

Navigation task is performed.

P: "Easy as pie. The street is straight, from here."

Game Event – Axe Chopping

Player needs to chop down a wooden door.

Causal audio:	Breathing in, cloth sounds, grunting, maybe voiced.
Feedback audio:	Whooshing from axe, "release of strength" from character, impact sound (positive and negative for successfulness of the impact), sword edge swing
Haptic feedback:	Shake on impact Powerful and short for positive, weaker and lingering for negative

Game Event – Roof Jumping

The player leaps from one roof to the other. This is done by distancing the player from the edge, then having him move towards the ledge and increasing his perceived speed. The companion will prompt him to jump at the right time. If he does not have enough speed, he staggers before the edge and tries again.

Causal audio:	Quickened breath, cloth sounds, companion's voice.
Feedback audio:	An exclaimed grunt as he jumps, impact on other roof
Haptic feedback:	Shake gently as he gains speed, pause in flight, heavy rumble on landing.

Game Event – Monster Fight

The player wields a fireaxe from earlier in the game. Like the axe-chopping event, he must hold- and release to swing. The creature circles the player and then approaches. If the player lands the first hit, the enemy retreats and circles the player again. If the enemy has it's first hit, the player loses health. The enemy can still be hit on it's retreat.

Causal audio:	Quickened breath, cloth sounds, snarling, grunting.
Feedback audio:	An exclaimed grunt as the player slashes, a screech from the enemy on impact, A death howl on third hit.
Haptic feedback:	Shake on impact

A.2 Implementation

The test was created in Unity, a 3D Game Engine[4] combined with the use of Two Big Ears' Sound Engine[3].

A.2.1 Audio Source Handling

An enum with values for each audio type was used to play sounds. An array with a custom class containing the audio type enum, an importance value, volume, and a private array of used indexes was used to add multiple sound clips to each audio type, to ensure that i.e. it was not the same audio clips playing each time the character took a step.
Each time a sound needed to be played, a function call was made with the audio type enum and a position as parameters. The function would then get a random audio clips from the audio clips array with the choosen audio type value. The index of the audio clips would then be compared to the array of used index. If the index did already exist, a new random audio clip would be choosen and its index would be compared. If the index did not exist the index would then be added to the array and the last added index would be deleted, to open up the old audio clips. The array of used indexes were mostly the length of the half of the length of the audio clip array.

Handling the TBE Sound Engine

The free version of Two Big Ears' sound engine only allows 10 audio sources, which lead to a system being developed to enable swapping between the 10 audio sources based on an importance variable. This variable were calculated by using a static importance value for the current sound being played and a dynamic value between -1 and 1 depending on the distance of the sound to the player.
If all 10 audio sources were already in use, the importance value of the new audio type and the already playing audio with the lowest value would be compared to one another. If the importance value of the new sound is higher or equal to the already playing audio, the old sound would stop and the new sound will be played. If all 10 audio sources were not already in use, the new audio would play without having to compare its importance value.

Rare Sound Events

A system to handle rare audio events were developed to make it possible to encounter rare events like the character's shoe hitting a small stone, the character stepping in a small puddle or a bird flying by. This system were developed by having a variable which would be increased by one each time the function is checking if the event should happen. The counter variable would then be divided by 10 and the outcome would be round down to zero decimals. Then a function generating a random number between 0 and 100 would check if 100 subtracted by the counter variable would be equal or higher with the random number generated, the sound event would trigger. With this solution the first 10 checks would have 0% chance to trigger.

A.2.2 Input

We wanted the game to support both keyboard and Xbox game controller. The reasons why the keyboard needs to be supported, is diversity. A keyboard is a standard computer equipment while the game controller is not a standard computer equipment. The reason for why we would like the game to support game controller is to be able to add haptic feedback in the shape of vibration from the game controller.

Appendix B

Questionnaire from AudioGames.net

Very early in the project we reached out to the visually impaired gaming community through the website AudioGames.net. We put out a simple questionnaire with intents to figure out how many on the forum was visually impaired as well as get some insight into their game preferences. The following are the result from 31 submissions of this questionnaire.

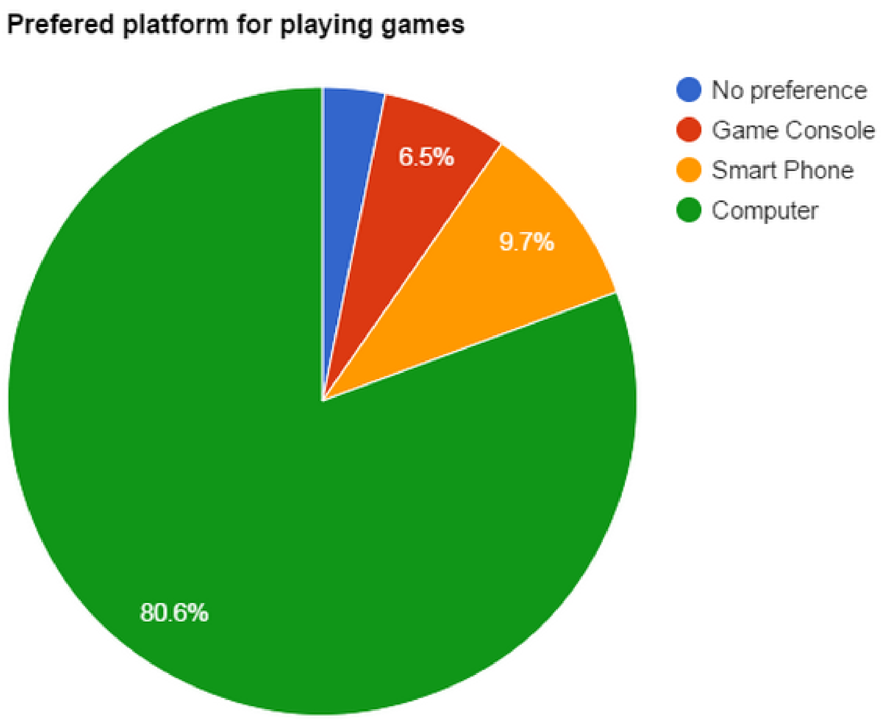


Figure B.1: Preferred platform for gaming, for user of AudioGames.net.

Summary: 31 submissions from 30 male and 1 female aged 14 to 37 (mean: 23.3, SD: 6.8), 25 of whom were totally blind and 6 were legally blind. Each were asked about their favourite games, as seen on Table B.1. They largely preferred playing games on a computer rather than game consoles and smart phones, see Figure B.1.

In terms of games for sighted people, comments indicated that some games needs a great deal of memorization, be that the structure of the main menu or whole level layouts for navigation. Others hint at spectacular sound cues, as well as clever and accessible friendly mechanics (e.g. Resident Evil 6 has a button for facing the camera towards the next checkpoint.)

Table B.1: Favourite Games for user of AudioGames.net

Favourite Games for Sighted
DeadSpace
Dice World
Divekick
EA Sports: Cricket
EA Sports: Rugby
Fifa
King of Dragon Pass
Injustice: Gods Among
KODP
Mario
MegaMan
Metroid
Mortal Kombat
Resident Evil 6
Silent Steel
SkullGirls
Sword and Sandals
Trivia Crack
Vagrant Story
Watchmen: The End is Nigh

Favourite Accessible Games
Entombed
Papa Sangre II
Shades of Doom
Shadow Line
SoundRTS
Swamp
Tactical Battle
Top Speed 3

Results

Question asked:
In audio games, which elements do you like the best for navigation and why? *(Examples of elements guiding navigation are: Beacon sounds, voiced compasses, etc.)*

Answers:

1. It depends upon the game. In first person games audio works well provided the sounds and directions are clear and there are sufficiently good mapping tools, sinse getting lost isn't fun. In text or menu driven games there isn't an issue. Generally I'd like to see more games that are based on the player's judgement and less based on a boppit hear it, hit it type of principle.
2. I like both.
3. beacon sounds, voiced compass, directional sounds
4. I usually prefer sounds, because voice sometimes can break the game's feel.
5. I prefer getting as close to the mainstream as possible (so, for example, camera panning and compasses as opposed to object lists and sonars), but in practice, I have the best results with cane-like radars (Swamp, Bokurano Daibouken 3) and the ability to snap to compass directions (Swamp, Sara). If either of these could be reduced or rendered more realistically (without funging against accessibility), that'd be great. (I think the canedar can be managed reasonably enough; the direction snapping is kinda weird if the perspective is first person, even if it could be something realistic like aligning one's self to a wall.)
6. i like when every object has it's own sound because that makes the game more realistic and by panning you can know where is that object.
7. The game should be as immersive as possible. I prefer appropriate game sounds over voiced prompts/messages.
8. voiced compasses, good environment sounds.
9. Voice cumpases, voiced weapon names, high-quality sounds, help menus (optional), a fully written manual, and a method of extending the game.
10. Depends on how complicated the environment is. That's a design choice that really depends on how the rest of the game works, and what will fit with it.
11. the navigation elements that I mostly want is a voice-based compass, because with this feature, you'll know what dirrection the characters are facing
12. Any form of navigation helper is okay for me outcluding every type of numbers, coordinates etc. Matching is always bad for me and great audio game for me means *AUDIO* not Coordinate based gameplay. If everything will be presented with sound it will be okay for me.
13. Beacon soundsyyby
14. Well descriptive text, voice guidence including compases, beaconns, target beeps I guess, 3d and binoral audio, all those add to the gameplay experience, a good soundtrack helps as well.
15. All of them.

16. I'd prefer echos and sound cues to direct the player. For example, when walking down a hallway, one may hear wind or an echo off to the left which means that they can turn and walk in that direction.
17. sound signles.
18. sound and description, because I can understand those the best.
19. I like good audio positioning
20. positional audio, directional compass, coordinate system
21. Voice compass, beacons, audio landmarks so you can hear where you are, maybe birds or other natural sounds which can help you to navigate the area, side steping and coordinats.
22. soft, unintrusive beacon sounds, dynamic ambiences. As in, not one single ambience file, but rather many. It helps orientation a lot. A compass is nice, too.
23. in audio games, I think navigating by using background ambiences placed in the environment helps a lot. also, in many games a coordinate system is used to show the player's position. in games where objects do not make noise, a looking feature would be useful.
24. Beacon sounds. This was proved to work most affectively in the game "Swamp" and was probably the best navigation system I ever encountered in an audio game.

Appendix C

Additional Results

Questionnaire Results: On **page 63** the results from the questionnaires are illustrated in stacked barplots.

Interaction Heatmap: A interaction heatmap is located on **page 64**. The heatmap illustrates each time the participant used the trigger button for each of the navigational tools.

Time and distance table: On **page 65** completion time and distance is shown for each participant.

Individual Navigation path: On **pages 66 – 74** individual navigation paths for each participants are illustrated.

C.1 Questionnaire Results

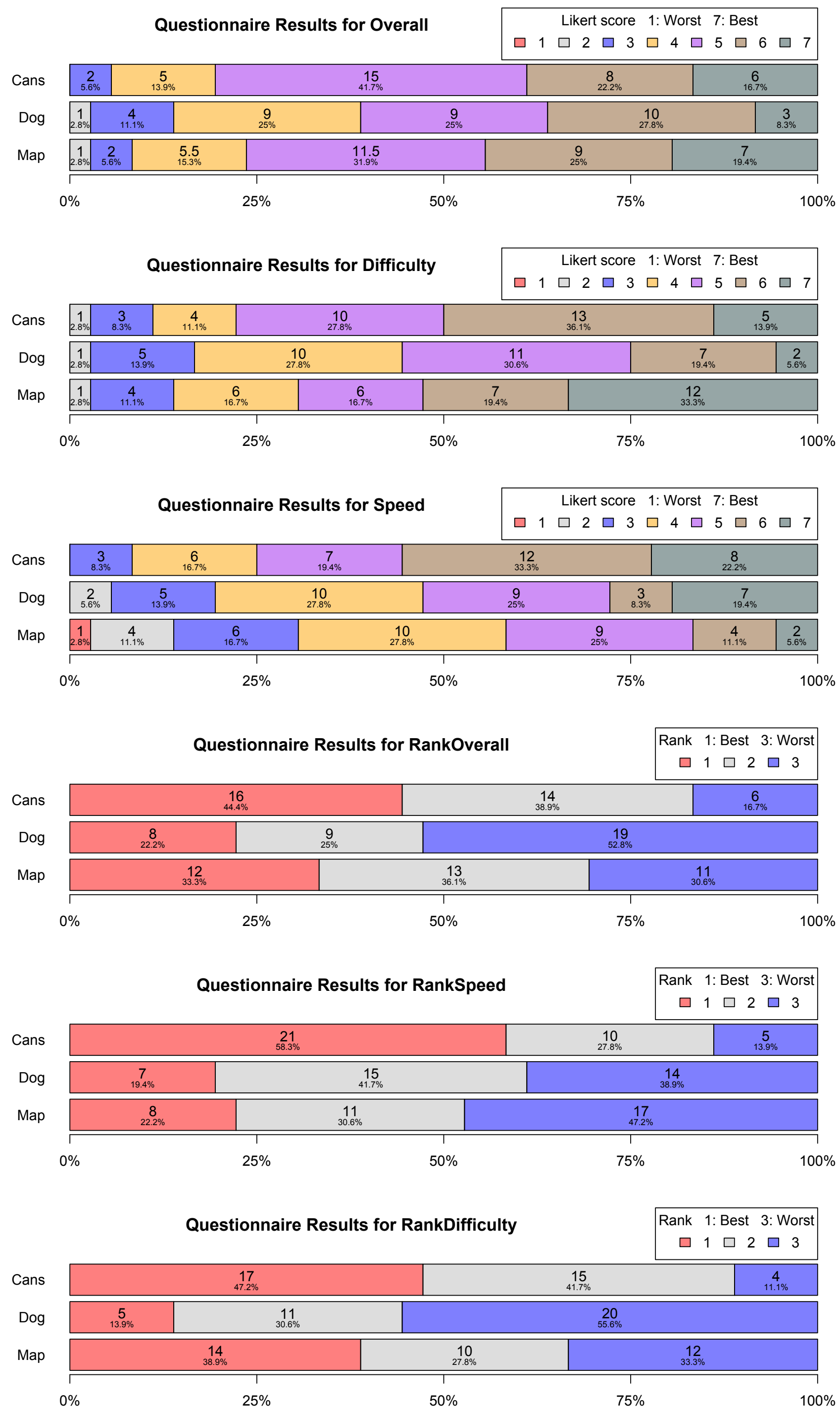


Figure C.1: Questionnaire Results.

C.2 Interaction Heatmap

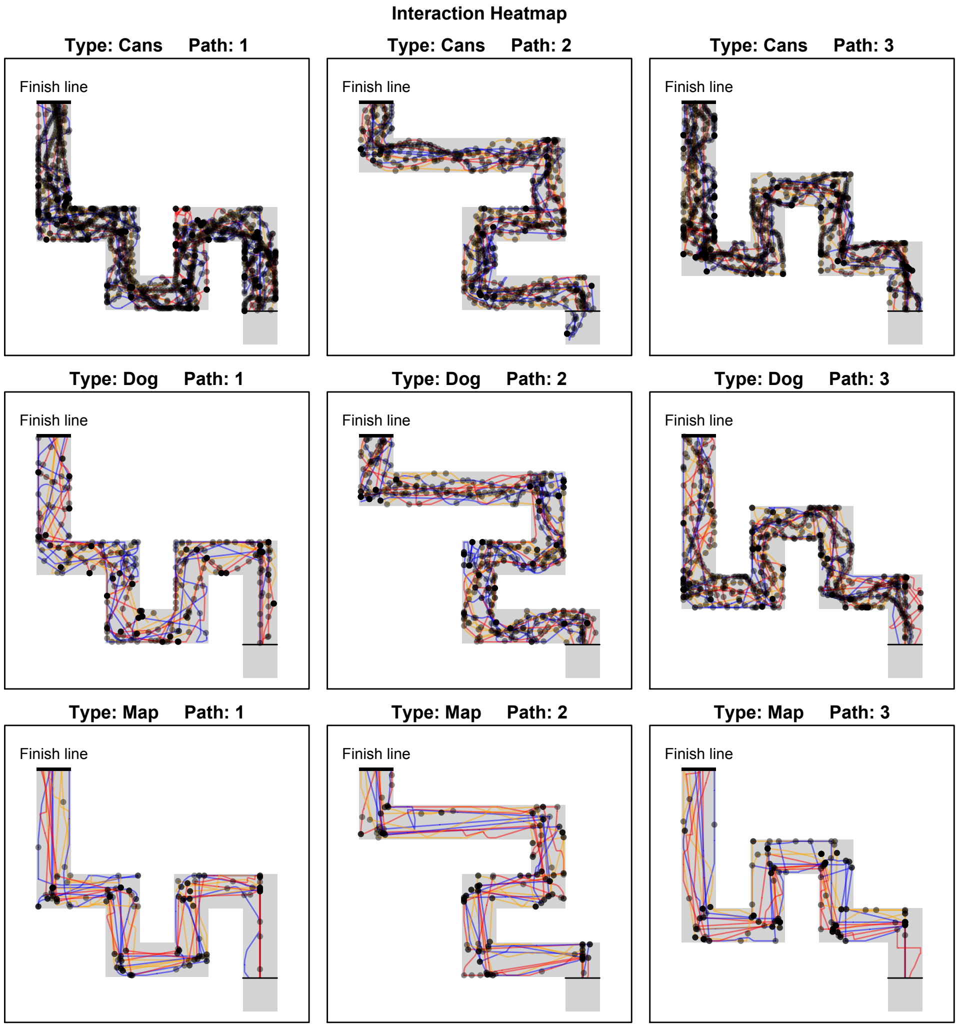


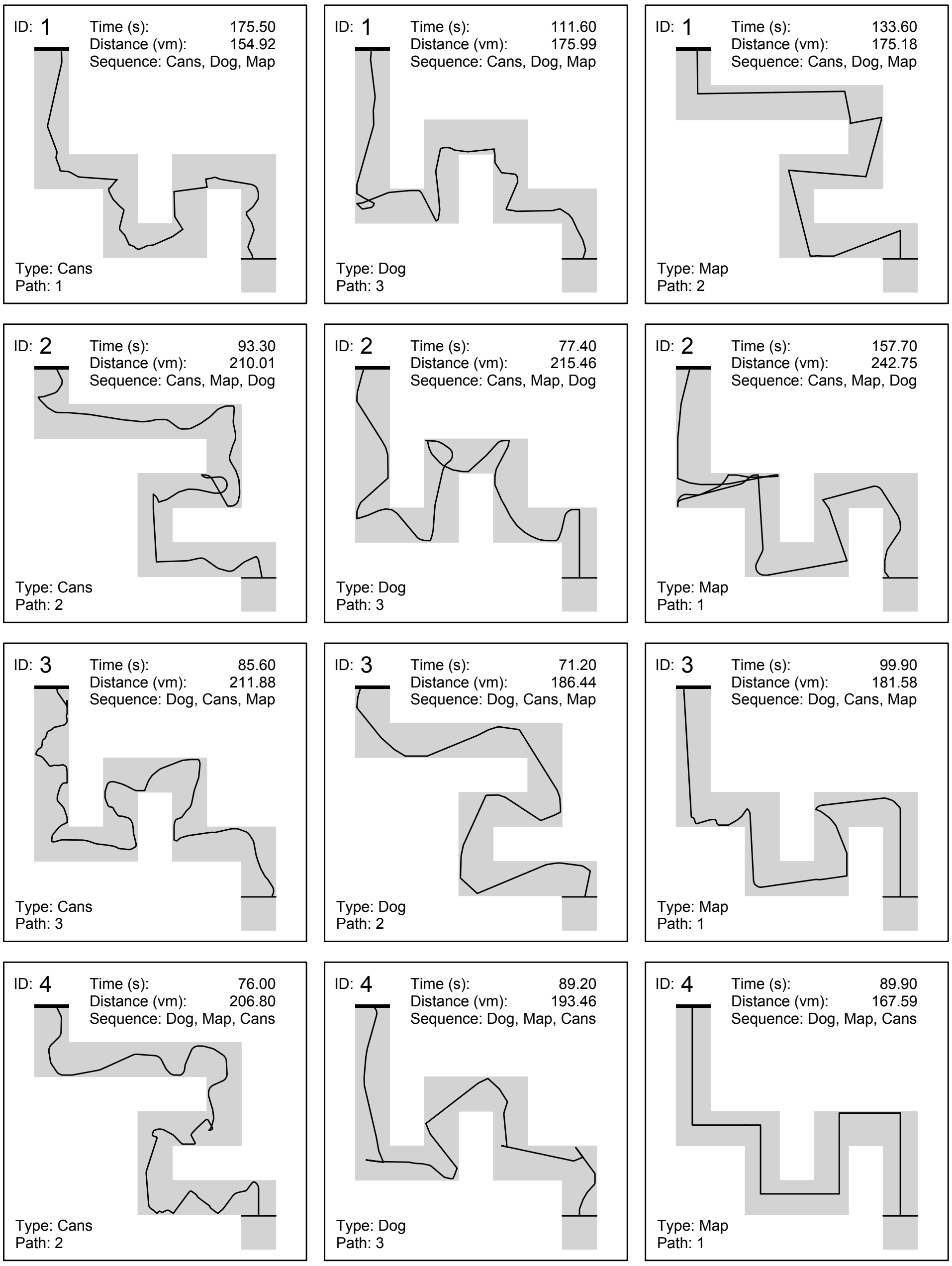
Figure C.2: Interaction heatmap. Each of the black dots represents a button press. Each row represent the navigational tool while each column represent the navigational path.

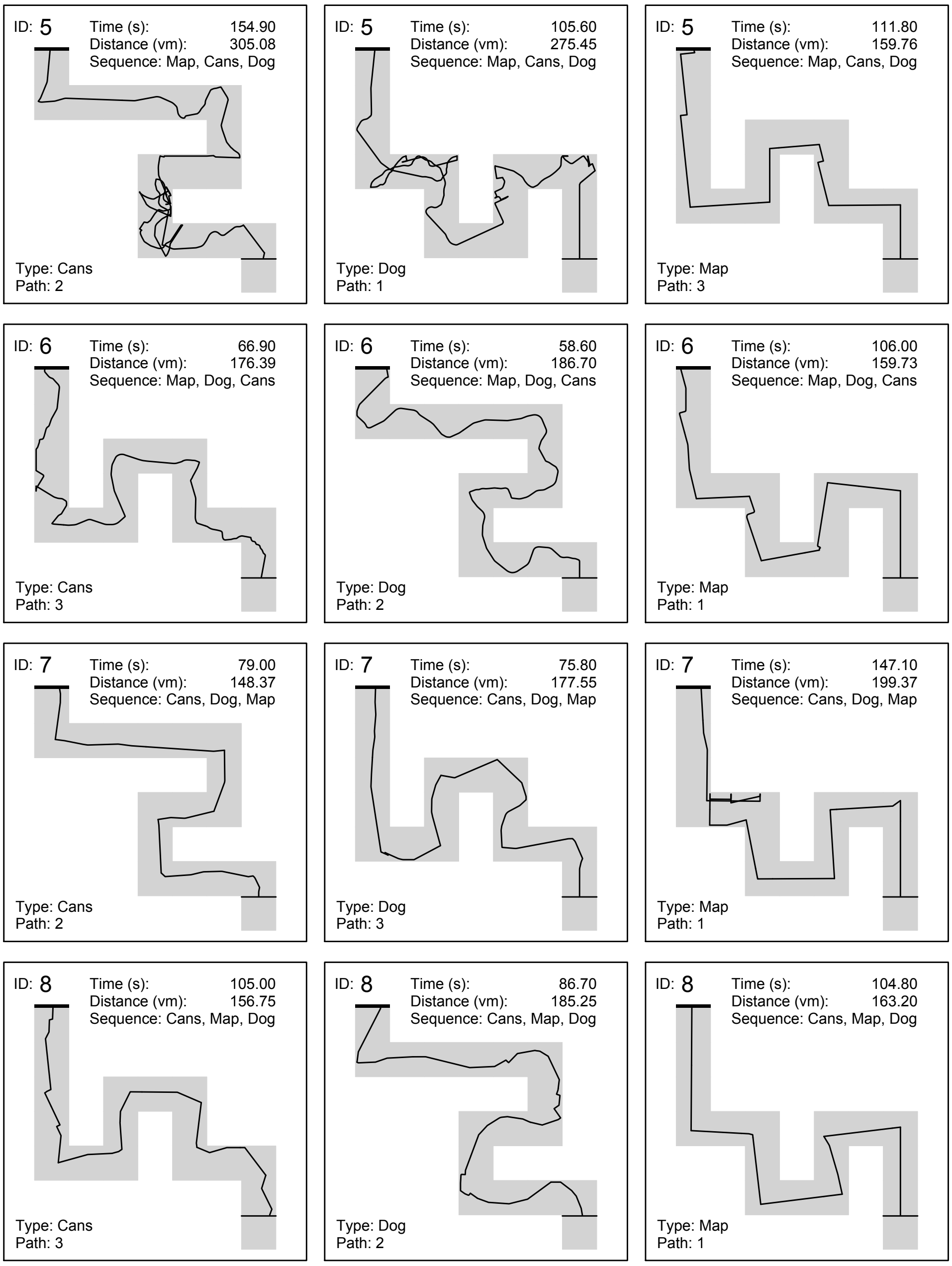
C.3 Time and distance table

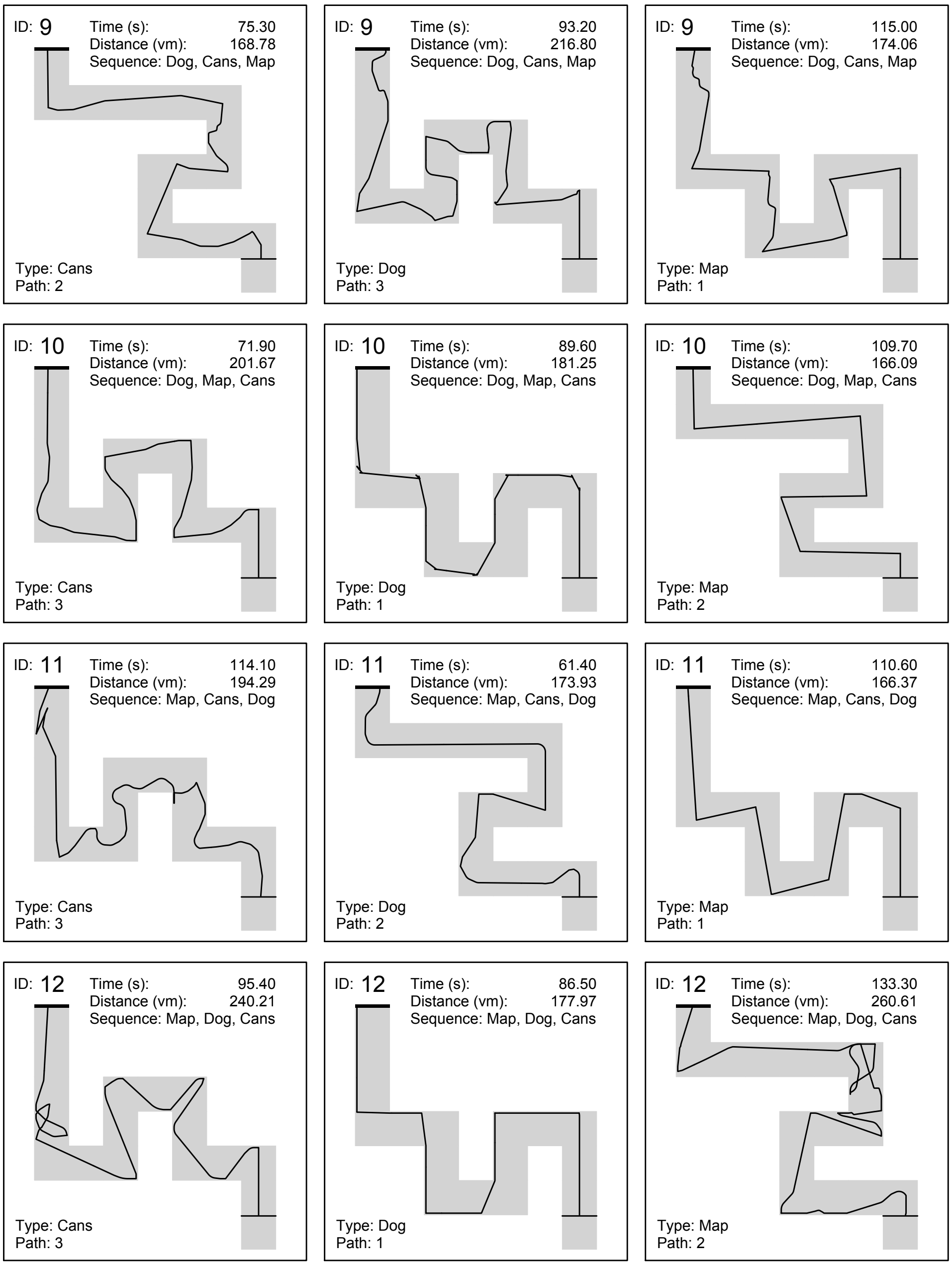
Table C.1: Time and distance for each participant for all three navigational tools.

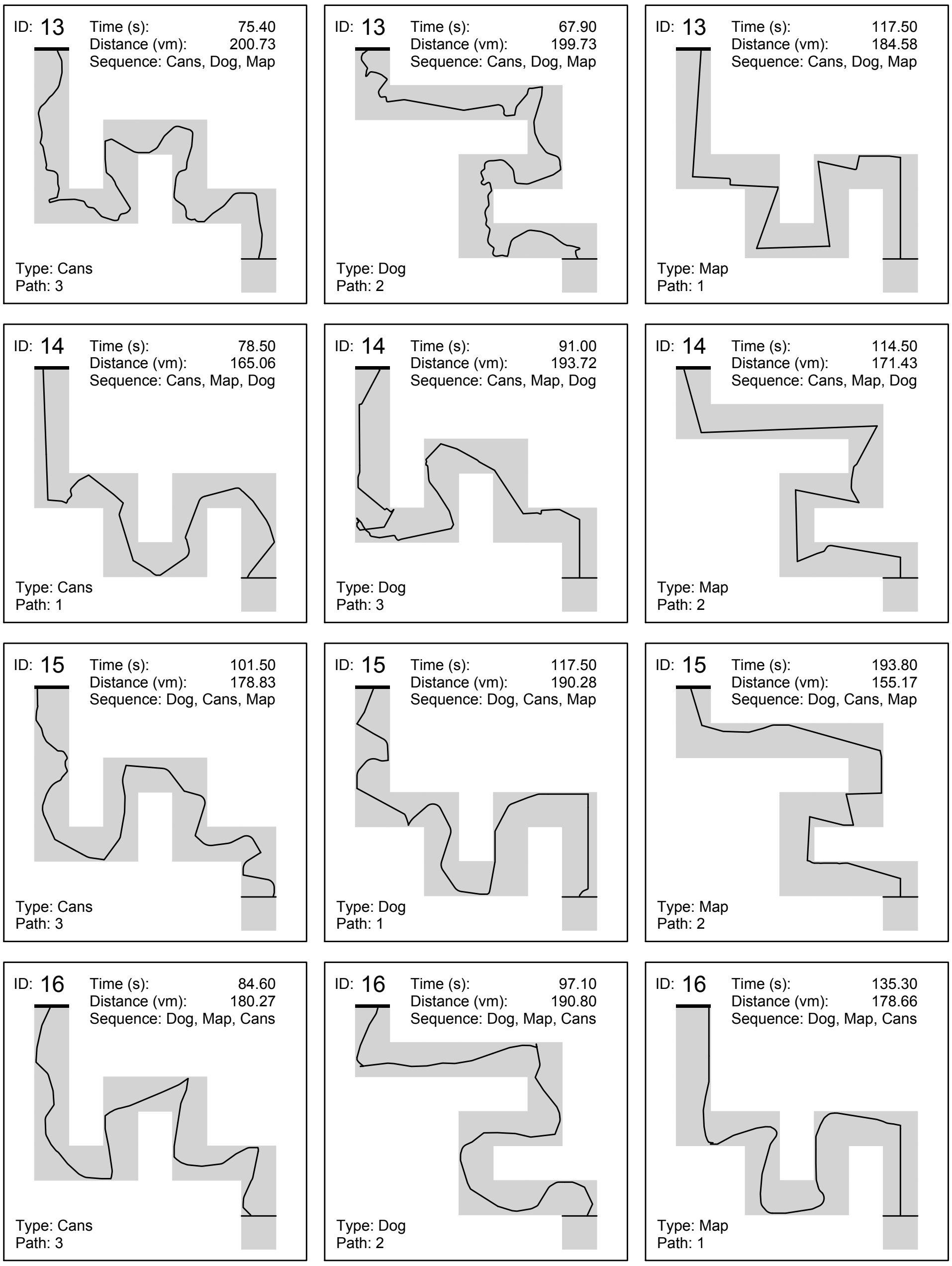
		Cans		Dog		Map	
ID	Sequence	Time (s)	Distance (vm)	Time	Distance	Time	Distance
1	C D M	175.5	154.9	111.6	176.0	133.6	175.2
2	C M D	93.3	210.0	77.4	215.5	157.7	242.8
3	D C M	85.6	211.9	71.2	186.4	99.9	181.6
4	D M C	76.0	206.8	89.2	193.5	89.9	167.6
5	M C D	154.9	305.1	105.6	275.5	111.8	159.8
6	M D C	66.9	176.4	58.6	186.7	106.0	159.7
7	C D M	79.0	148.4	75.8	177.6	147.1	199.4
8	C M D	105.0	156.8	86.7	185.3	104.8	163.2
9	D C M	75.3	168.8	93.2	216.8	115.0	174.1
10	D M C	71.9	201.7	89.6	181.2	109.7	166.1
11	M C D	114.1	194.3	61.4	173.9	110.6	166.4
12	M D C	95.4	240.2	86.5	178.0	133.3	260.6
13	C D M	75.4	200.7	67.9	199.7	117.5	184.6
14	C M D	78.5	165.1	91.0	193.7	114.5	171.4
15	D C M	101.5	178.8	117.5	190.3	193.8	155.2
16	D M C	84.6	180.3	97.1	190.8	135.3	178.7
17	M C D	134.1	168.2	103.9	189.6	120.9	151.5
18	M D C	59.9	171.0	87.4	181.7	107.3	154.4
19	C D M	151.0	229.8	112.4	263.9	117.4	167.5
20	C M D	90.9	191.1	65.9	155.2	113.8	169.2
21	D C M	85.7	220.1	156.4	201.3	103.7	165.4
22	D M C	62.2	180.7	78.8	161.6	166.8	164.5
23	M C D	120.6	293.9	86.6	229.6	106.5	160.3
24	M D C	87.9	191.8	135.0	189.8	123.9	162.3
25	C D M	81.9	196.1	101.4	221.2	137.5	145.5
26	C M D	79.8	192.8	81.8	179.4	122.5	166.4
27	D C M	157.2	369.4	166.1	329.9	104.3	183.6
28	D M C	67.8	189.4	62.9	193.0	108.3	161.9
29	M C D	91.0	193.0	114.3	211.4	107.9	165.7
30	M D C	64.8	186.9	82.8	191.4	110.7	157.4
31	C D M	114.7	151.5	207.0	325.6	130.5	180.0
32	C M D	278.0	409.8	103.4	250.7	116.7	158.6
33	D C M	67.8	188.9	93.2	177.4	89.9	171.0
34	D M C	113.3	148.2	165.0	162.3	99.3	177.2
35	M C D	72.9	182.4	82.9	202.6	128.2	161.1
36	M D C	121.6	264.1	84.5	194.3	111.1	161.3

C.4 Individual Navigation path




ID: 5
Time (s): 154.90
Distance (vm): 305.08
Sequence: Map, Cans, Dog
Type: Cans
Path: 2
ID: 5
Time (s): 105.60
Distance (vm): 275.45
Sequence: Map, Cans, Dog
Type: Dog
Path: 1
ID: 5
Time (s): 111.80
Distance (vm): 159.76
Sequence: Map, Cans, Dog
Type: Map
Path: 3
ID: 6
Time (s): 66.90
Distance (vm): 176.39
Sequence: Map, Dog, Cans
Type: Cans
Path: 3
ID: 6
Time (s): 58.60
Distance (vm): 186.70
Sequence: Map, Dog, Cans
Type: Dog
Path: 2
ID: 6
Time (s): 106.00
Distance (vm): 159.73
Sequence: Map, Dog, Cans
Type: Map
Path: 1
ID: 7
Time (s): 79.00
Distance (vm): 148.37
Sequence: Cans, Dog, Map
Type: Cans
Path: 2
ID: 7
Time (s): 75.80
Distance (vm): 177.55
Sequence: Cans, Dog, Map
Type: Dog
Path: 3
ID: 7
Time (s): 147.10
Distance (vm): 199.37
Sequence: Cans, Dog, Map
Type: Map
Path: 1
ID: 8
Time (s): 105.00
Distance (vm): 156.75
Sequence: Cans, Map, Dog
Type: Cans
Path: 3
ID: 8
Time (s): 86.70
Distance (vm): 185.25
Sequence: Cans, Map, Dog
Type: Dog
Path: 2
ID: 8
Time (s): 104.80
Distance (vm): 163.20
Sequence: Cans, Map, Dog
Type: Map
Path: 1


ID: 9 Time (s): 75.30 Distance (vm): 168.78 Sequence: Dog, Cans, Map
Type: Cans Path: 2
ID: 9 Time (s): 93.20 Distance (vm): 216.80 Sequence: Dog, Cans, Map
Type: Dog Path: 3
ID: 9 Time (s): 115.00 Distance (vm): 174.06 Sequence: Dog, Cans, Map
Type: Map Path: 1
ID: 10 Time (s): 71.90 Distance (vm): 201.67 Sequence: Dog, Map, Cans
Type: Cans Path: 3
ID: 10 Time (s): 89.60 Distance (vm): 181.25 Sequence: Dog, Map, Cans
Type: Dog Path: 1
ID: 10 Time (s): 109.70 Distance (vm): 166.09 Sequence: Dog, Map, Cans
Type: Map Path: 2
ID: 11 Time (s): 114.10 Distance (vm): 194.29 Sequence: Map, Cans, Dog
Type: Cans Path: 3
ID: 11 Time (s): 61.40 Distance (vm): 173.93 Sequence: Map, Cans, Dog
Type: Dog Path: 2
ID: 11 Time (s): 110.60 Distance (vm): 166.37 Sequence: Map, Cans, Dog
Type: Map Path: 1
ID: 12 Time (s): 95.40 Distance (vm): 240.21 Sequence: Map, Dog, Cans
Type: Cans Path: 3
ID: 12 Time (s): 86.50 Distance (vm): 177.97 Sequence: Map, Dog, Cans
Type: Dog Path: 1
ID: 12 Time (s): 133.30 Distance (vm): 260.61 Sequence: Map, Dog, Cans
Type: Map Path: 2


ID: 13 Time (s): 75.40
Distance (vm): 200.73
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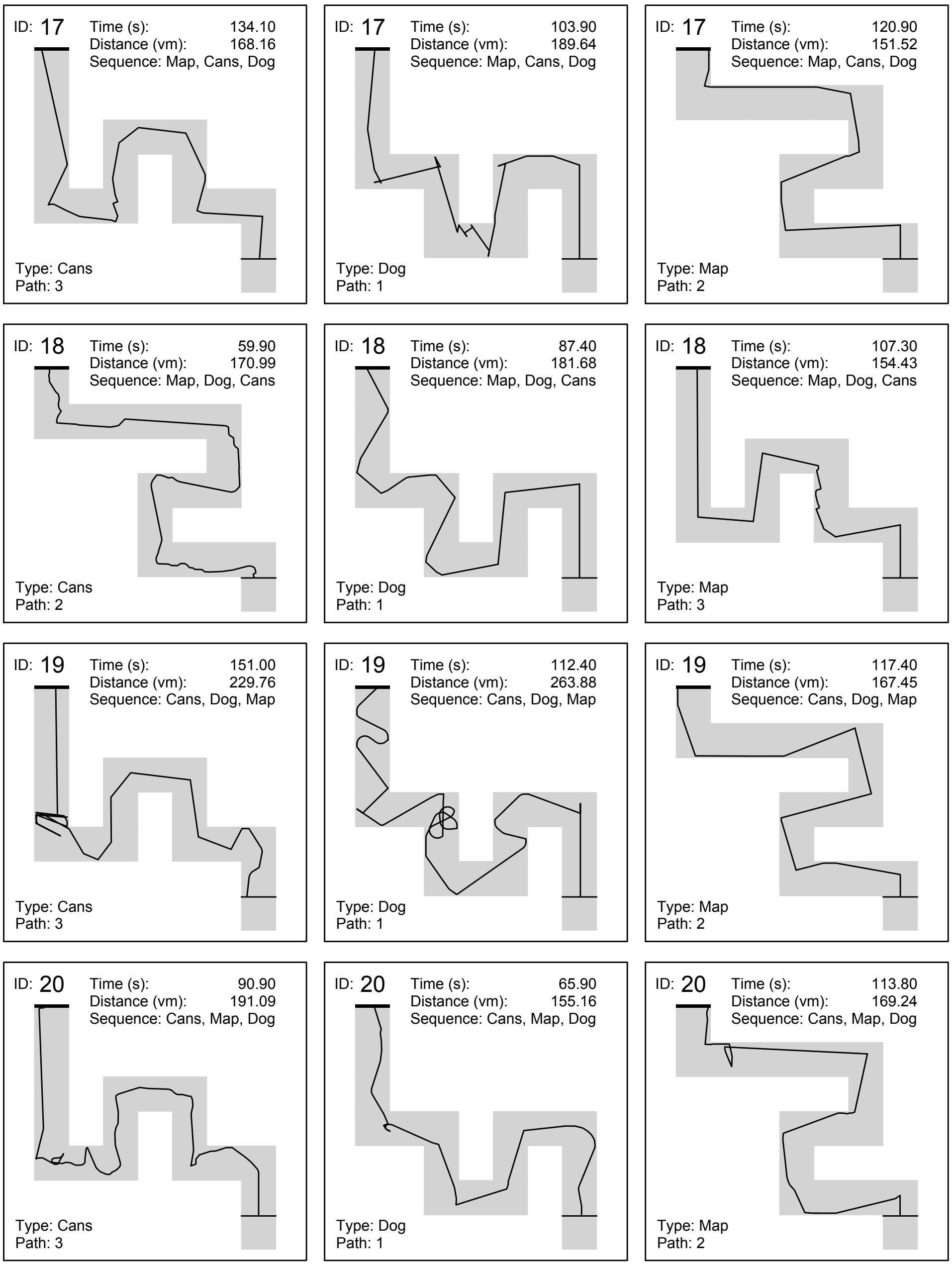
Type: Cans
Path: 3
ID: 13 Time (s): 67.90
Distance (vm): 199.73
Sequence: Cans, Dog, Map
Type: Dog
Path: 2
ID: 13 Time (s): 117.50
Distance (vm): 184.58
Sequence: Cans, Dog, Map
Type: Map
Path: 1
ID: 14 Time (s): 78.50
Distance (vm): 165.06
Sequence: Cans, Map, Dog
Type: Cans
Path: 1
ID: 14 Time (s): 91.00
Distance (vm): 193.72
Sequence: Cans, Map, Dog
Type: Dog
Path: 3
ID: 14 Time (s): 114.50
Distance (vm): 171.43
Sequence: Cans, Map, Dog
Type: Map
Path: 2
ID: 15 Time (s): 101.50
Distance (vm): 178.83
Sequence: Dog, Cans, Map
Type: Cans
Path: 3
ID: 15 Time (s): 117.50
Distance (vm): 190.28
Sequence: Dog, Cans, Map
Type: Dog
Path: 1
ID: 15 Time (s): 193.80
Distance (vm): 155.17
Sequence: Dog, Cans, Map
Type: Map
Path: 2
ID: 16 Time (s): 84.60
Distance (vm): 180.27
Sequence: Dog, Map, Cans
Type: Cans
Path: 3
ID: 16 Time (s): 97.10
Distance (vm): 190.80
Sequence: Dog, Map, Cans
Type: Dog
Path: 2
ID: 16 Time (s): 135.30
Distance (vm): 178.66
Sequence: Dog, Map, Cans
Type: Map
Path: 1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Distance (vm): 168.16
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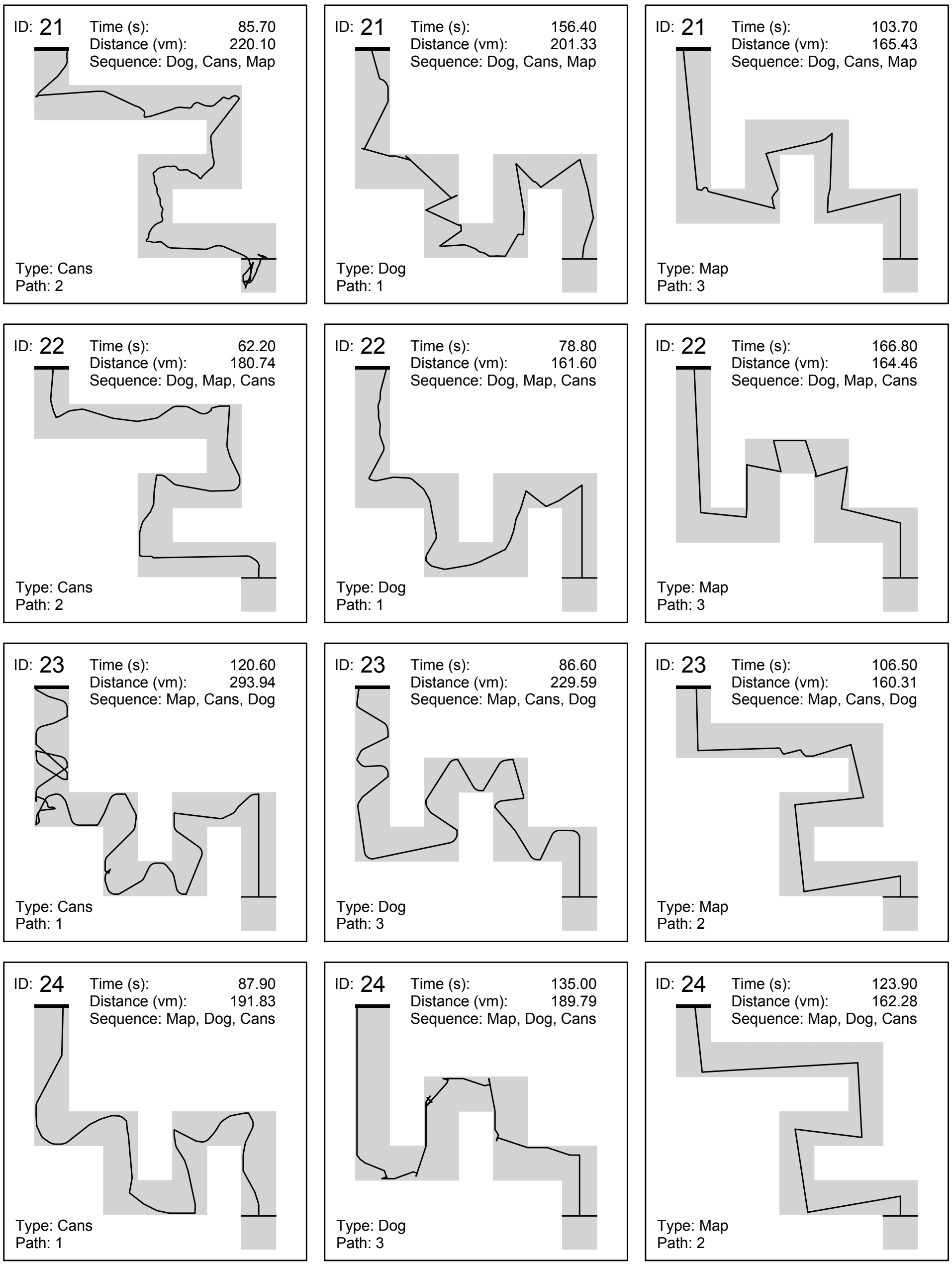
Path: 3
ID: 17
Time (s): 103.90
Distance (vm): 189.64
Sequence: Map, Cans, Dog
Type: Dog
Path: 1
ID: 17
Time (s): 120.90
Distance (vm): 151.52
Sequence: Map, Cans, Dog
Type: Map
Path: 2
ID: 18
Time (s): 59.90
Distance (vm): 170.99
Sequence: Map, Dog, Cans
Type: Cans
Path: 2
ID: 18
Time (s): 87.40
Distance (vm): 181.68
Sequence: Map, Dog, Cans
Type: Dog
Path: 1
ID: 18
Time (s): 107.30
Distance (vm): 154.43
Sequence: Map, Dog, Cans
Type: Map
Path: 3
ID: 19
Time (s): 151.00
Distance (vm): 229.76
Sequence: Cans, Dog, Map
Type: Cans
Path: 3
ID: 19
Time (s): 112.40
Distance (vm): 263.88
Sequence: Cans, Dog, Map
Type: Dog
Path: 1
ID: 19
Time (s): 117.40
Distance (vm): 167.45
Sequence: Cans, Dog, Map
Type: Map
Path: 2
ID: 20
Time (s): 90.90
Distance (vm): 191.09
Sequence: Cans, Map, Dog
Type: Cans
Path: 3
ID: 20
Time (s): 65.90
Distance (vm): 155.16
Sequence: Cans, Map, Dog
Type: Dog
Path: 1
ID: 20
Time (s): 113.80
Distance (vm): 169.24
Sequence: Cans, Map, Dog
Type: Map
Path: 2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Time (s): 85.70
Distance (vm): 220.10
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ID: 21
Time (s): 156.40
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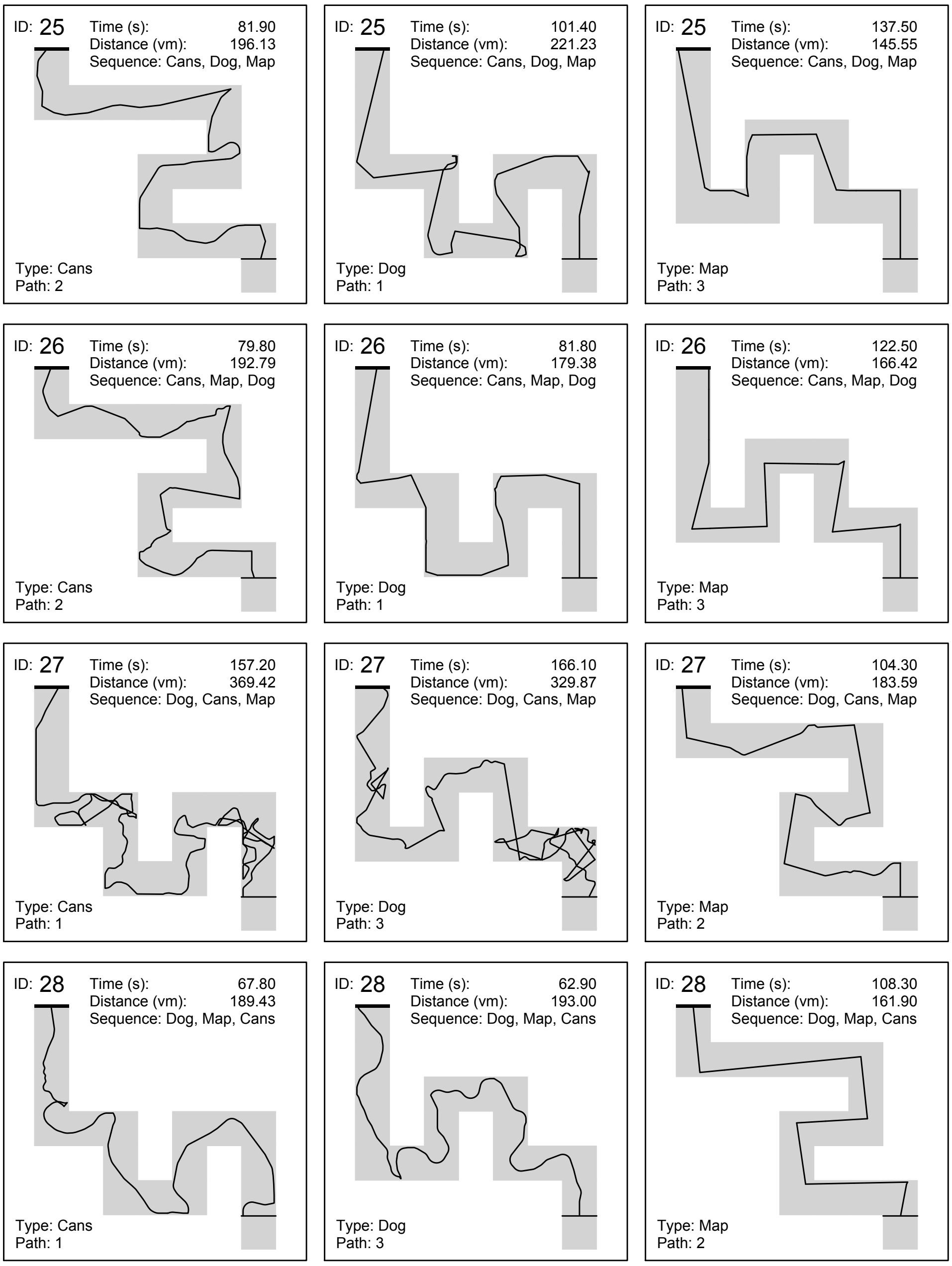
Type: Dog
Path: 1
ID: 21
Time (s): 103.70
Distance (vm): 165.43
Sequence: Dog, Cans, Map
Type: Map
Path: 3
ID: 22
Time (s): 62.20
Distance (vm): 180.74
Sequence: Dog, Map, Cans
Type: Cans
Path: 2
ID: 22
Time (s): 78.80
Distance (vm): 161.60
Sequence: Dog, Map, Cans
Type: Dog
Path: 1
ID: 22
Time (s): 166.80
Distance (vm): 164.46
Sequence: Dog, Map, Cans
Type: Map
Path: 3
ID: 23
Time (s): 120.60
Distance (vm): 293.94
Sequence: Map, Cans, Dog
Type: Cans
Path: 1
ID: 23
Time (s): 86.60
Distance (vm): 229.59
Sequence: Map, Cans, Dog
Type: Dog
Path: 3
ID: 23
Time (s): 106.50
Distance (vm): 160.31
Sequence: Map, Cans, Dog
Type: Map
Path: 2
ID: 24
Time (s): 87.90
Distance (vm): 191.83
Sequence: Map, Dog, Cans
Type: Cans
Path: 1
ID: 24
Time (s): 135.00
Distance (vm): 189.79
Sequence: Map, Dog, Cans
Type: Dog
Path: 3
ID: 24
Time (s): 123.90
Distance (vm): 162.28
Sequence: Map, Dog, Cans
Type: Map
Path: 2


ID: 25
Time (s): 81.90
Distance (vm): 196.13
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Type: Cans
Path: 2
ID: 25
Time (s): 101.40
Distance (vm): 221.23
Sequence: Cans, Dog, Map
Type: Dog
Path: 1
ID: 25
Time (s): 137.50
Distance (vm): 145.55
Sequence: Cans, Dog, Map
Type: Map
Path: 3
ID: 26
Time (s): 79.80
Distance (vm): 192.79
Sequence: Cans, Map, Dog
Type: Cans
Path: 2
ID: 26
Time (s): 81.80
Distance (vm): 179.38
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Type: Dog
Path: 1
ID: 26
Time (s): 122.50
Distance (vm): 166.42
Sequence: Cans, Map, Dog
Type: Map
Path: 3
ID: 27
Time (s): 157.20
Distance (vm): 369.42
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Type: Cans
Path: 1
ID: 27
Time (s): 166.10
Distance (vm): 329.87
Sequence: Dog, Cans, Map
Type: Dog
Path: 3
ID: 27
Time (s): 104.30
Distance (vm): 183.59
Sequence: Dog, Cans, Map
Type: Map
Path: 2
ID: 28
Time (s): 67.80
Distance (vm): 189.43
Sequence: Dog, Map, Cans
Type: Cans
Path: 1
ID: 28
Time (s): 62.90
Distance (vm): 193.00
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Path: 3
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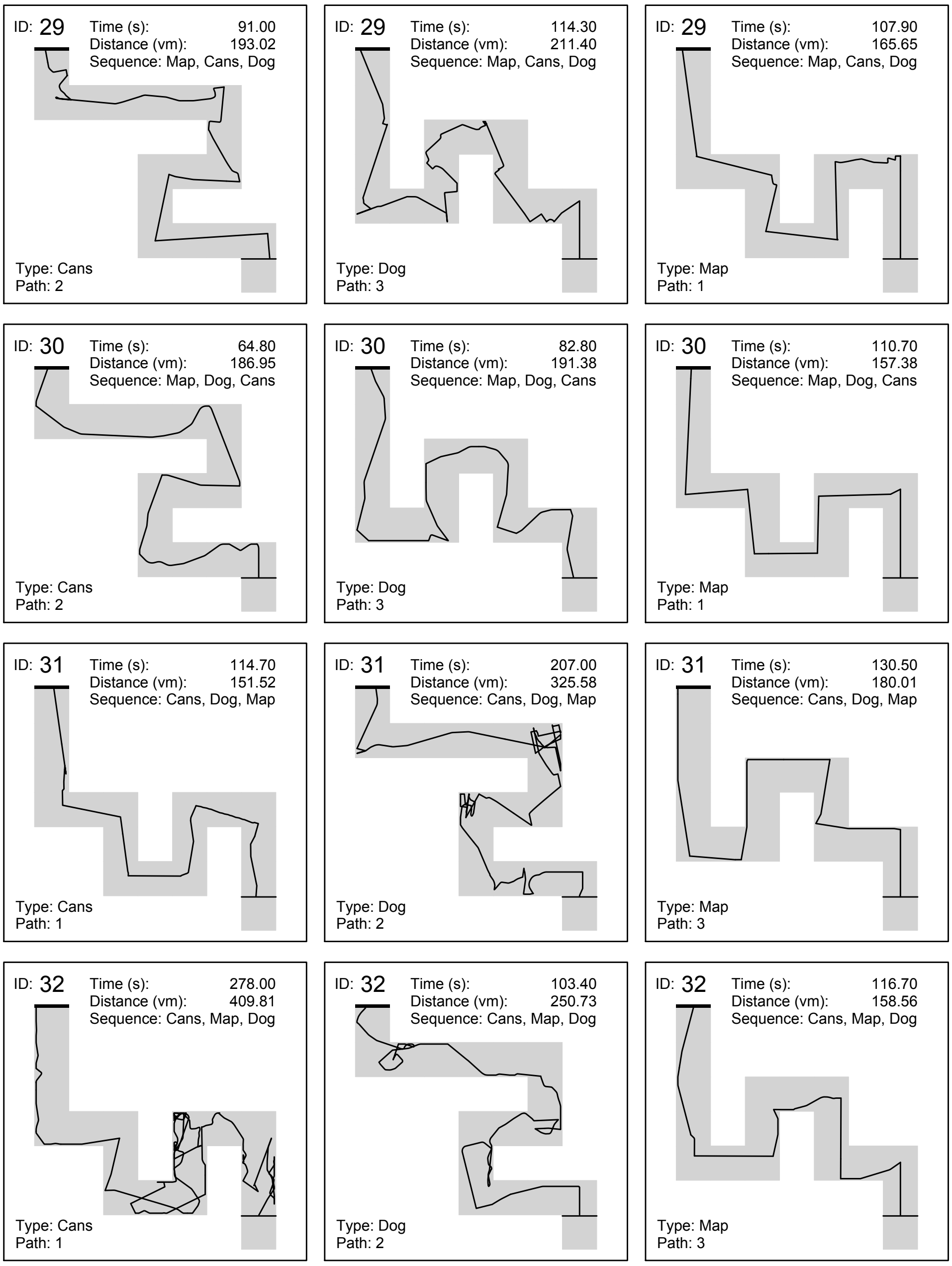
Distance (vm): 161.90
Sequence: Dog, Map, Cans
Type: Map
Path: 2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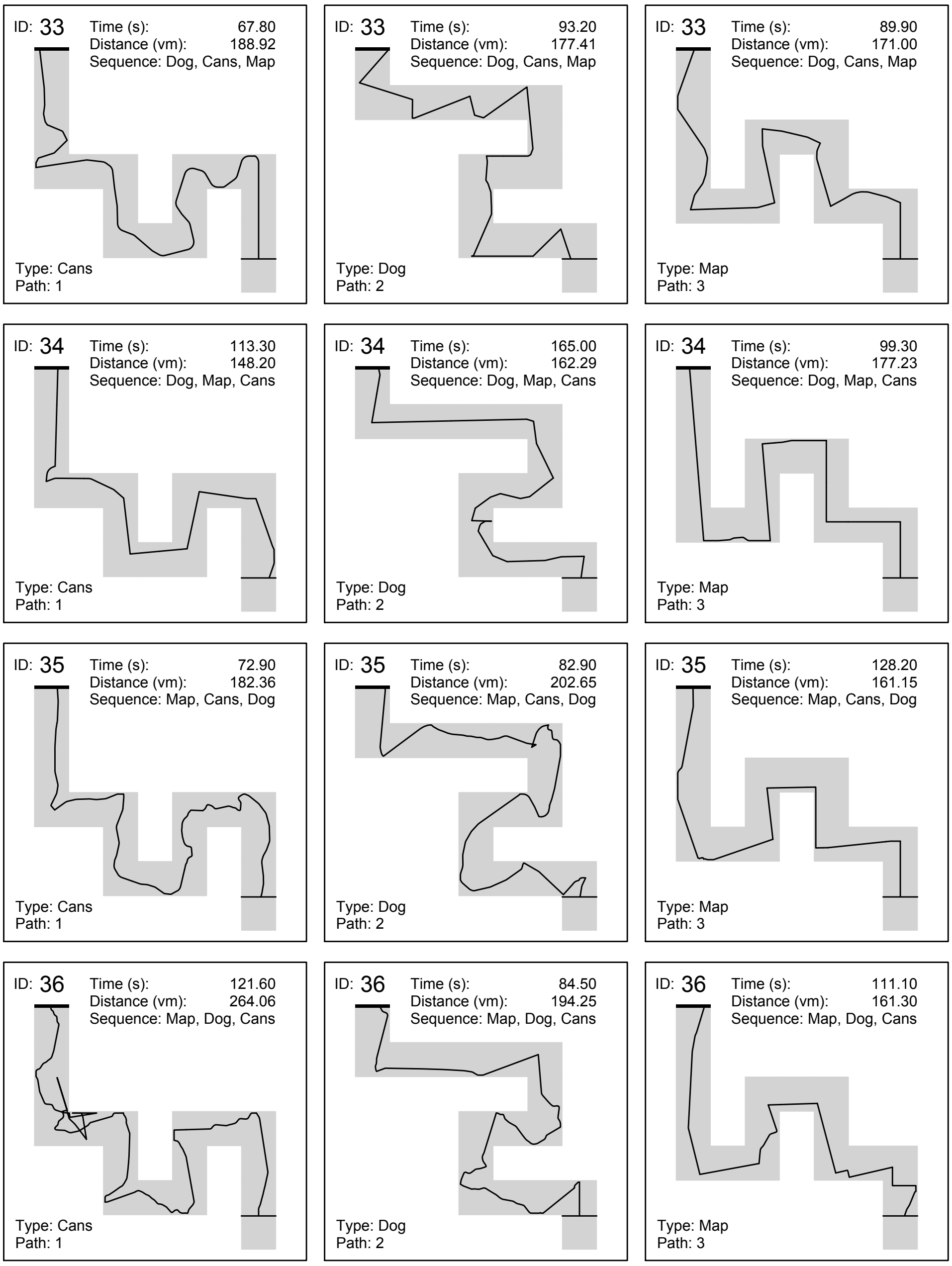
ID: 29
Time (s): 114.30
Distance (vm): 211.40
Sequence: Map, Cans, Dog
Type: Dog
Path: 3
ID: 29
Time (s): 107.90
Distance (vm): 165.65
Sequence: Map, Cans, Dog
Type: Map
Path: 1
ID: 30
Time (s): 64.80
Distance (vm): 186.95
Sequence: Map, Dog, Cans
Type: Cans
Path: 2
ID: 30
Time (s): 82.80
Distance (vm): 191.38
Sequence: Map, Dog, Cans
Type: Dog
Path: 3
ID: 30
Time (s): 110.70
Distance (vm): 157.38
Sequence: Map, Dog, Cans
Type: Map
Path: 1
ID: 31
Time (s): 114.70
Distance (vm): 151.52
Sequence: Cans, Dog, Map
Type: Cans
Path: 1
ID: 31
Time (s): 207.00
Distance (vm): 325.58
Sequence: Cans, Dog, Map
Type: Dog
Path: 2
ID: 31
Time (s): 130.50
Distance (vm): 180.01
Sequence: Cans, Dog, Map
Type: Map
Path: 3
ID: 32
Time (s): 278.00
Distance (vm): 409.81
Sequence: Cans, Map, Dog
Type: Cans
Path: 1
ID: 32
Time (s): 103.40
Distance (vm): 250.73
Sequence: Cans, Map, Dog
Type: Dog
Path: 2
ID: 32
Time (s): 116.70
Distance (vm): 158.56
Sequence: Cans, Map, Dog
Type: Map
Path: 3


ID: 33 Time (s): 67.80 Distance (vm): 188.92 Sequence: Dog, Cans, Map
Type: Cans Path: 1
ID: 33 Time (s): 93.20 Distance (vm): 177.41 Sequence: Dog, Cans, Map
Type: Dog Path: 2
ID: 33 Time (s): 89.90 Distance (vm): 171.00 Sequence: Dog, Cans, Map
Type: Map Path: 3
ID: 34 Time (s): 113.30 Distance (vm): 148.20 Sequence: Dog, Map, Cans
Type: Cans Path: 1
ID: 34 Time (s): 165.00 Distance (vm): 162.29 Sequence: Dog, Map, Cans
Type: Dog Path: 2
ID: 34 Time (s): 99.30 Distance (vm): 177.23 Sequence: Dog, Map, Cans
Type: Map Path: 3
ID: 35 Time (s): 72.90 Distance (vm): 182.36 Sequence: Map, Cans, Dog
Type: Cans Path: 1
ID: 35 Time (s): 82.90 Distance (vm): 202.65 Sequence: Map, Cans, Dog
Type: Dog Path: 2
ID: 35 Time (s): 128.20 Distance (vm): 161.15 Sequence: Map, Cans, Dog
Type: Map Path: 3
ID: 36 Time (s): 121.60 Distance (vm): 264.06 Sequence: Map, Dog, Cans
Type: Cans Path: 1
ID: 36 Time (s): 84.50 Distance (vm): 194.25 Sequence: Map, Dog, Cans
Type: Dog Path: 2
ID: 36 Time (s): 111.10 Distance (vm): 161.30 Sequence: Map, Dog, Cans
Type: Map Path: 3

Velocity

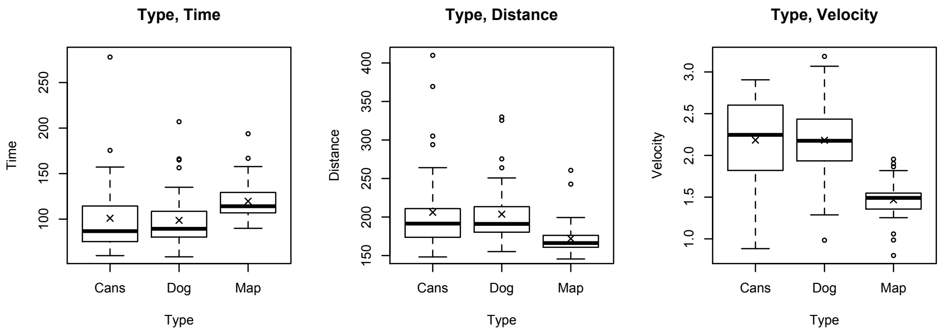


Figure C.3: Box plots for each navigational type in regards to completion time, distance and average velocity.

Table C.2: Means and standard deviations for completion time in seconds.

Type	Mean	SD
Cans	101.00	42.20
Dog	98.67	32.36
Map	119.66	21.14

Table C.3: Means and standard deviations for distance in virtual meter.

Type	Mean	SD
Cans	206.09	57.81
Dog	203.68	40.17
Map	171.97	22.35

Table C.4: Means and standard deviations for velocity in virtual meter per second.

Type	Mean	SD
Cans	2.183	0.54
Dog	2.182	0.49
Map	1.467	0.24

Appendix D

Questionnaire

The questionnaire which the participants were asked to fill out during the test.
To save space only the page for Cans is included, since the ones for Dog and Map were identical with the only difference being the type name.

Participant ID: __________

By signing this document, you agree to being filmed, and that the footage may be used in an A/V production.

Date: ____________ Signature: ____

Age: __________

Gender: __________

Normal Hearing: Yes / No (circle your answer)

Participant ID: ___________

Navigation Type: Cans

How would you rate the navigational tool overall? (circle your answer)

Very bad						Very good
1	2	3	4	5	6	7

How would you rate the navigational tool in regards to speed? (circle your answer)

Very slow						Very fast
1	2	3	4	5	6	7

How would you rate the navigational tool in regards to difficulty? (circle your answer)

Very hard						Very easy
1	2	3	4	5	6	7

Any thoughts about the navigational tool you just used?

____

____

____

____

____

____

____

____

____

Participant ID: __________

Please rank the navigational tools against each other. The rankings range between 1-3 where **1 is the best** and **3 is the worst**.
(Your navigation sequence were: ________, ________ and ________)

Rate which navigational tools did best overall:

Navigational tool	Dog	Cans	Map
Rank			

Rank which navigational tools did best in speed:

Navigational tool	Dog	Cans	Map
Rank			

Rank which navigational tools was the easiest to use:

Navigational tool	Dog	Cans	Map
Rank			

If you had to navigate another level, which navigational tool (**dog**, **cans** or **map**) would you choose and why?

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Appendix E

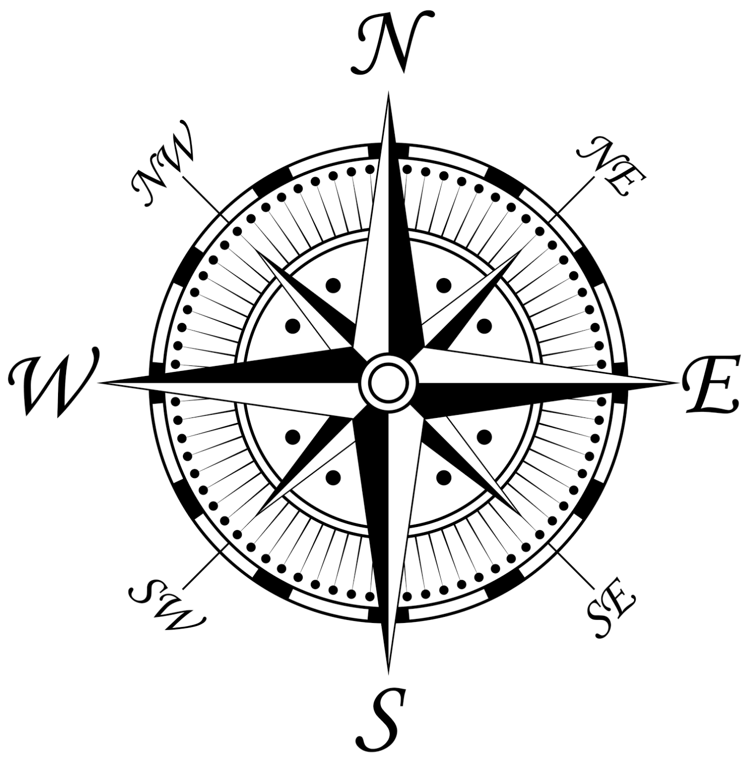
Test Introduction

At the start of the test, the introduction was told the participants. To ensure that they had understood and heard correct, the text was written on a paper which were in front of them.

A compass was included on the paper in case some participants had trouble with coordinates.

“Welcome. The test is segmented. You will be introduced to **three** different **navigational** methods. You will be **allowed** time to **practise** the methods as you encounter them in a training phase. After using the method for a bit, and when you **feel confident** in the method, **tell** the test **facilitator** across from you that you are **ready** to proceed.
After announcing that you feel ready, you will need to walk a bit further. When you reach the end of the training phase you will hear a door opening and closing, after which you will need to navigate a course on your own. Please **refrain** from **asking** any **questions** outside of the training phase.”

Compass Directions



Appendix F

Email correspondence with Two Big Ears

The email correspondence with Two Big Ears, containing most of what we know about the 3Dception sound engine.

Gmail by Google

David Lauritsen <seqlog@gmail.com>

Specs of 3Dception engine

Abesh Thakur (Two Big Ears) <support@twobigears.com> 15. maj 2015 kl. 18.20
Send svar til: Two Big Ears <support@twobigears.com>
Til: David Lauritsen <seqlog@gmail.com>

##- Please type your reply above this line -##

Your request (219) has been updated. To add additional comments, reply to this email.

Abesh Thakur (Two Big Ears)
May 15, 17:20

Hello David,

I think your arguments are totally valid, and not insensitive at all. I'll shed some light on why I cannot divulge details even under an NDA, and hopefully that will make it clear rather than a blanket statement of facts from our end.

The technology that we have doesn't use commonly used HRTF processing techniques. We have worked on and perfected the technology over the course of time, which is why it has such a massive increase in efficiency and quality over other competing solutions. We are in the process of patenting our technology at this moment, and hence, we are under strict instructions from our lawyers about divulging any part of the information.

We want to help the community and especially students, which is why we have free evaluation versions and even give out unrestricted full working versions to researchers. At no point of time was I aware that you had to discuss specifics of implementation, which is why I didn't bring up the point in the beginning as well. Other students who are using 3Dception in their labs haven't made this request so far so this is a first for us too.

I totally understand that when publishing a scientific paper, you would need to discuss certain aspects to prove your claims, else the peer reviews can be quite unforgiving. It's unfortunate in this case, since our hands are tied and any information which can be used to disseminate the process that we use will harm our technology and the community in general.

I can talk about stats such as efficiency levels, but cannot talk about how we made that possible. It's not just the algorithms, but the design process which makes 3Dception unique and it is protected by knowhow. So even if I were to sign an NDA with you, I can't since that renders our patent application process useless and we can never protect what we have worked so hard to build. It's our secret sauce and hence, can't talk about it :)

I can tell you this, that the algorithms are modelled on real head(s). It is not a single head, but a best case approximation of multiple anthropomorphic parameters. Additionally, the algorithms that we use give us a spatial resolution of 1 degree.

You should take a look at this article, if it helps :) It puts 3Dception as the best solution in the market at the moment, and it is done with a lot of extensive testing. Since this was published on one of the most widely read sound design websites, will this add to the credibility of you own research?

I'm looking forward to helping you guys with as much knowledge as we have gathered and are allowed to talk about. But this is where Academia is different from Commercial software. We can talk at lengths about features and benefits, but not what goes on in our labs.

I apologise once again, but I hope my reasons now seem valid? Please feel free to let me know how else we can help in this regard.

Cheers
Abesh Thakur

David Lauritsen
May 15, 14:07

Hello Abesh,

We have had a partnership with AM:3D a few semesters back, and we were able to get this information without a hitch, to be honest. This, of course, was under a full disclosure agreement, and the details were not avaliable publically, kept specific to the university. I had thought it nothing more than statistics, and the information doesn't have any cue towards the algorithms, so I am honestly a little suprised that you cannot divulge the information. But what do I know, perhaps you have something revolutionary that sets yours aside from the competition, fair enough. It isn't the end of the world, but had we known that these things would not have been avaliable, we would probably have found an alternative.

The reason for this is simple: the scientific community is a harsh critic. Progression is difficult, if you have to prove each and every new sound engine's spatial superiority over stock, panning audio solutions. In our case, we have taken the validity for granted, as our prior semesters' research have already proven this, but with a different engine.

Would it be possible to sign off on a contract to give us the information, and then we simply keep the report exclusive to our University? Just for the sake of curiosity.

Is it based on a single, real head, or the average of a few? Or perhaps the best representing single head you have tested on?

In regards to the research, is it possible for you to tell us the title(s)?

And lastly, I am sorry if this email is phrased a little insensitively. It isn't meant to, I only wrote it in a hurry because I have a tran to catch!

Have a nice weekend,

M.v.h.
David Skødt Lauritsen

2015-05-15 13:36 GMT+02:00 Abesh Thakur (Two Big Ears)
<support@twobigears.com>:

[Citeret tekst er skjult]

[Citeret tekst er skjult]

Hello again!

[Citeret tekst er skjult]

[Citeret tekst er skjult]

This email is a service from Two Big Ears. Delivered by Zendesk.

Message-Id:7QSVCVPA_55561ce88a58d_b443f8b482cd3381325c3_sprut