An Evaluation of Ideal Route Models of Indoor Navigation

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Abstract: Traditional wayfinding and navigational models usually concern movement in larger, open spaces. Such models would, however, also be useful for indoors navigation in close quarters. In order to acquire a base for studying indoor navigation, a method for studying such situations was constructed, and an experiment using the method was conducted in order to evaluate the approach. In the experiment, 21 test subjects walked a path while equipped with a video camera recording their movement patterns. The results of the evaluation show that the constructed method was not sufficient for collecting sufficiently detailed data, and that quantitative analyses methods other than central measurements would be required for studying the movement patterns. The results of the method are not secure, but they show that a mid-corridor model with a fluctuation of plus/minus 15 percent of corridor width describes the majority of the test subjects' movement patterns. The results further show that women tend to keep to the middle of the corridors with less deviation than do men.

Keywords: Wayfinding, Cognitive maps, Indoor navigation, Close quarters, Indoor positioning

Introduction

The inspiration for this thesis is twofold. Firstly, there is a project based need for accurate simulation algorithms of human navigation in delimited areas. This context is described in the following part of this introduction of the thesis. Secondly, the authors were inspired by a psychological aspect of "micro format" human navigation, namely the influence on route choice posed by factors and artifacts of the surrounding environment. A theoretical backup of this effect has not been found in any published work.

Context

While the above can in part be seen as a possible generalization of the thesis result, there is also a specific context inciting the thesis project. This context should be known by the reader in order to better evaluate the methodological choices made here.

Since fall 2001, a project called AMSIDO (Agent-based Micro-world Simulation of Information Distribution in Organizations) has been conducted as a collaboration between the Swedish National Defense College (SwNDC) and Mid Sweden University (MSU). The purpose of this project is to construct a simulation of how information distributes through a socio-technological system, in this case a C2 (Command and Control) exercise modeled according to current NATO standards. The AMSIDO project currently functions as a framework for a number of smaller and delimited projects with the common aim of contribute subsystems to the intended future simulation software.

The difference between the AMSIDO project and other simulations of data- or information distribution is that AMSIDO intends to include all that is important for information distribution, not only the physical technological infrastructure. Thus, the intended simulation has to include models of the individuals participating in the information system[1], as the individuals often distribute information without using the technological tools. As an example, individual A can have received important information that individual B needs. When they accidentally meet in the lunch room, individual A mentions the information to individual B, thus a chance information distribution event has occurred.

In order to model and simulate such chance encounters, all individuals participating in the information system has to be modeled in a trustworthy way, as an example including navigational behavior. The individuals have to go to the bathroom or fetch a cup of coffee as usual in order for the chance information distribution events to occur.

So far, the prototype versions of the simulation software have included a very crude model for indoor navigation. The navigational algorithm has basically been a brute-force route discovery calculation based on the assumption that if you first go to the middle of the area, you can then go in a straight line to the next area intersection. It is commonly accepted within the AMSIDO group that this navigational model is crude and not trustworthy, and that it may lead to chance encounters where there should have been none, and to missed chance encounters.

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[1] An information system is here defined as all that which contributes to the distribution of information within an organization, such as humans, routines and technological artifacts.

Thus the incentive for this thesis is the need for a better navigational model. The AMSIDO group hopes that the thesis work will result in an optimal model, or at the least contribute a way to evaluate possible navigational models.

Wayfinding and cognitive maps

Wayfinding refers to the ability to navigate effectively through an environment. The term was introduced in the early 60's by the architect and urban planner Kevin Lynch (1960) who used the term to describe the knowledge, perceptions and abilities needed to find one's way through a built environment. He noted that wayfinding seemed to be a rather straight-forward process of consistent use and organization of definite sensory cues from the external environment as opposed to the previous suggestions of wayfinding being some kind of mystic innate instinct. Lynch also introduced five basic elements that has been widely used for describing environmental cues; Paths, which are the actual ways that people travel; Edges, which are boundaries like walls or shorelines; Nodes, that can be thought of as intersections of paths; Landmarks, used as reference points and usually visible from a distance, and Districts, which are large areas with some common characteristics.

The term "cognitive map" is generally used to describe the mental representations that people form of their spatial environment. The representations may not be isomorphic to reality, but they make a good-enough resemblance to enable a person to easily navigate the environment. Cognitive maps and wayfinding are closely related and share common ground in the research performed by Lynch and other urban planners.

In a familiar environment successful wayfinding is dependent on the accurate recall or recognition of known routes, and in unfamiliar environments navigation is usually the result of external aids, e.g. signs, maps or help from others (Blades, 1997).

Finding the way can be accomplished by learning and then recalling the actual physical route from one point to another in the form of successive turns at specific times. The "route definition" is often used in conjunction with landmarks (buildings, bridges etc.) or guidances and trajectories, steered in relation to the position of a distant landmark (Foreman & Gillett, 1997). This is usually referred to as "Route Knowledge" or "Terrain Level Perspective". Another way of navigation, "Survey Knowledge", or "Bird's-eye View", consists of a mental representation that is formed by either direct experience by traveling through an environment, or indirectly from maps, models or photographs which represent that environment (Blades, 1997). In most cases, the actual wayfinding process involves a combination of both Route and Survey Knowledge. Apart from Route and Survey knowledge, Siegel and White (1975) argued that there is an initial stage where the landmarks are recognized and structured, but without being actually connected to a Route Map. A more simplified explanation of the wayfinding ability might be, according to Hunt (1984), to be able to 1) recognize landmarks and 2) knowing where the place or object is located in space.

The recognition of landmarks requires that the route has been traveled on a previous occasion. Cornell et al. (1994) found that sometimes, people get lost and keep wandering on the wrong path because they start judging landmarks, not previously seen, as familiar in order to alleviate the anxiety caused by the feeling of possibly being lost. In the same experiment, a model for wayfinding on repeated routes was constructed by using an algorithm for the choice among possible paths at an intersection. It was postulated that the wayfinder would choose the path on which some familiar landmarks could be spotted, in favor of those on which there were no such landmarks.

Kushigian (1998) showed a significant difference between different forms of instruction on wayfinding in an actual building. The experiment was conducted by supplying different groups of people with the same information, how to get from where you are to a certain spot located elsewhere in the building, in three different forms (as defined by Siegel & White, 1975). After the instruction, the participants were guided along an “ideal route” while being narrated by the experimenter. The different groups were told different forms of descriptions of the route and the buildings. The most efficient form of instruction was the “Configuration Instruction” which aimed at giving the participant a certain amount of Survey Knowledge of the environment, while the other forms; “Landmark Instruction” and “Route Instruction”, gave the participant a Route Knowledge which was found to be less effective, especially when the participants in a second test were asked to return to the same target spot by traveling through another part of the building.

In an earlier experiment, Moeser (1988) found that in a complex environment, naïve persons that have been memorizing floor-plans prior to visiting an actual building, outperforms experienced dwellers of that same building on measures of cognitive mapping. This result indicates that Survey Knowledge is not developed automatically in all environments, and that pre-visit information on the spatial characteristics of the environment to be traveled, clearly improves the wayfinding ability. Similar results were drawn by Hunt (1984) who found that persons, who had been traversing a simulated model of a building, acquired a better and more useful understanding of the previously unknown environment compared to persons who had visited the actual building. The degree of familiarity with the environment is obviously a powerful influence on the wayfinding behavior. However, Weisman (1981) concluded that there is no particularly simple relationship between wayfinding behavior and the familiarity facets tapped in his study.

In 1998, Raubal developed a computational model of wayfinding which consisted of two critical elements; choices and clues. Therefore, the model is called the “choice-clue wayfinding model”. In the model, a choice is a decision point where a person must select among one or more different paths. If the person has only one obvious choice to continue, the choice point is called a “enforced decision point”, while a multiple-choice point is a “decision point”. A clue is a property of the environment that people use to make wayfinding decisions. Clues can be divided into “good clues” which are complete clues that give correct information on how to go on from there, and “poor clues” which are incomplete or misleading clues that do not enable the wayfinder decide about the continuation. The combination of choices and clues gives a good measure of the complexity of an environment, and can therefore be used as factors in a computer simulation of a real-world application such as a wayfinding task. The aim of the study was primarily to develop a model that could be used as a tool for the identification of architectural problems with regard to wayfinding prior to construction, but the findings are applicable also for predicting human navigation in other contexts.

In another attempt to formalize the wayfinding process in humans, Raubal and Worboys (1999) defined wayfinding as a goal-driven chain of actions that starts with an imperfect observation of the environment. The action leads to new observations which result in derived knowledge of the environment and, recursively, further actions until the goal is reached or the wayfinder gives up. One factor that influences the actual path chosen is how objects in the surrounding environment are found to have affordances desirable to the wayfinder. Their conclusion was that their model allowed computer simulations on wayfinding, at least at an approximate level.

One difficulty involved in investigating human navigation in large-scale environments is the wayfinder's interaction with factors in the environment. Interference from flow of traffic and non-verbal social interaction reduces the level of experimental control. The wayfinding behavior can also be affected by other required tasks like keeping the balance and avoiding obstacles (Gärling et al., 1997). Another factor that has to be considered is the path asymmetry, investigated by Bailenson et al. (1998). In their study, the subjects were shown a map with three different routes from point A to point B. One route was the shortest, and the other two were variants where the total distance to be traveled was about 50 % larger, but the layout of the path was different. The main difference was that where the shortest route was equally winded, the two others had one long, straight, section and a heavily winding section in one end. The latter routes were mirrored so that one started with the straight section while the other started with the winding section. The result shown was that the subjects most often chose the route that started with the straight section, despite the fact that there was another, much shorter, alternative at hand. This preference for routes starting with a long, straight, section was referred to as "Road Climbing".

Ideal models

As the study focuses on evaluating a method for the evaluation of ideal models, and that therefore the models in themselves were not the critical issue, we chose models based on our assumptions of what we thought could best describe indoor navigation. In the following, we will use two categories of models: the asymmetrical and the symmetrical models. The asymmetrical models include:

? *The magnet model:* In this model the path was calculated through regarding the goal area and the open path as attractors and obstacles as repelling forces. By weighting the attractors and repellants together, a moment by moment directional force vector were calculated and used as the next step on the path[2].

? *The optimal path model:* The path was drawn as the shortest possible route through all path segments. Thus the path was drawn close to corners and diagonalling across the corridor.

The symmetrical models expect that a person walk on a straight line in a corridor. The symmetrical models are represented as ten percent intervals of corridor width. As an example a person might choose to always walk along the left wall of the corridor, or in the corridor's middle.

The symmetrical models are operationalized as five different lines across the X axis, namely lines at 30, 40, 50, 60 and 70 per cent of corridor width. It should thus be noted that there are five different symmetrical models.

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[2] The inspiration for this model was fetched from an unpublished article draft from a certain H. Warren. The ideas were later published in "Journal of Vision", but unfortunately we could not get that article (as the library could not get a copy of it since Journal of Vision is only published electronically and require subscription for access).

Problem

The overall problem is the need for a navigational model of the above mentioned kind. However, such a model is not immediately attainable, since the method for collecting and evaluating its background material is not obvious. To collect and analyze data underlying such a model, a structured approach with sensible method tools is required. The problem therefore has to be addressed in more than one step. Thus the problem as formulated for this thesis is the lack of a good method for acquiring navigational data, or in continuation, the lack of knowledge about how people navigate in close quarters.

Purpose

The purpose of this thesis is to construct and use a method for evaluating and comparing a number of ideal route models for navigation during a limited set of circumstances, in order to a) test the evaluation method, b) describe the fitness of the models, and c) present limited information about human navigation acquired during the evaluation.

Hypotheses

As a basis for the analysis, the following hypotheses were used. All hypothesis tests were conducted on a 0.05 level of significance where relevant unless otherwise is stated.

Hypothesis A (for each of the ideal models and each gender):
The ideal model is a good prediction.

Hypothesis B:
There is a difference between genders.

Apart from the formal hypotheses open for hypothesis testing, we also have the hypothesis that our approach for collecting and evaluating data is sufficient for constructing a navigational model. This hypothesis cannot, however, be evaluated through quantitative means.

Expected result

We expect to be able to conclude whether the used approach for acquiring and evaluating navigational data is sensible. Further we expect to be able to suggest improvements and further research. Finally we expect to be able to point out a few limited tendencies towards an understanding of human indoor navigation.

Method

The empirical objective consisted of collecting navigational data from a number of test subjects. The analytical objective consisted of comparing the collected data with a number of ideal models in order to evaluate the procedure.

Methodological background

The construction of a method for acquiring acceptably accurate and precise positional data for indoor navigation ran into a few obstacles during the early phases of the project. Most technological positioning methods expect an outdoor environment, wide open areas, small test areas, or an advanced and expensive electronic infrastructure.

The first approach that came to mind was the use of GPS (Global Positioning System), which utilizes triangulation against satellites for its positioning. This was, however, unusable, since it supposes close to free sight to the said satellites. GPS does simply not work in an indoor environment. Further, in spite of later development within the area, GPS is still not more exact than a meter in expected error in the best of conditions.

A second approach might be the use of theodolites which are used for geodetic measurements, for example when planning roads. This does, however, suppose open spaces and a lot of manual handling. Further this method is very slow, which would hinder test subjects from behaving normally.

Further ideas for positioning might include equipping test subjects with a box measuring movement through inertia and gyros. These methods work reasonably for autopilots in hobby model helicopters, but have to be reset frequently to a new zero position, as they deviate significantly over longer distances. Constructing a device resetting itself in, say, each corridor segment would be possible, but frankly beyond our competence.

Finally, there are commercially available electronic products for indoor positioning. Among others these are Active Badge, Active Bat and RADAR (Jonsson & Ögren, 2003). These function well for their purpose but were unusable in our context for several reasons. Firstly, they are not very exact, either because they poll the position too seldom (one position per three seconds is too inexact), or because they are not precise enough (position only says in which area a person is). Furthermore they require a detailed infrastructure with carefully placed transponders in a tight grid. Finally they are far beyond our financial scope to use.

As an anecdote we can also mention that we got several interesting and creative suggestions when investigating possible paths for positioning. These were, amongst many others, to have people drink a radioactive solution and trace the emissions, having people carry around bags slowly leaking colored sand, covering the floor with wheat flour or arranging uninsulated wires in a grid over the whole path so two wires short-circuit when one step on them.

Eventually we decided that the below described method was the best one available. Though not perfect, it was at least possible to use, inexpensive and more or less foolproof.

Participants

The sample (n=21) consisted mainly of high school students with some additional university students. The gender distribution was 12 female and 9 male subjects. Most subjects were class-mates with an age of 16-17 years, and the total age range was 16-36 years. Note that the exact age of the subjects was not recorded, as it was not used in anyway in the study. Apart from gender, no personal data was recorded in order to grant complete anonymity.

Material

The collection of navigational data was conducted through letting a number of test subjects execute a given task consisting of walking along a certain indoor path. The test subjects carried a video camera (see figure 1) in order to record the path they walked. The path contained ground markers (see figure 2) in order to enable accurate positioning. The position data recorded on the video tape was digitalized through the use of a custom-made video analysis tool. The statistical calculations were conducted in SPSS.

The ideal path models were fetched from a common sense modeling of the predicted path. The operationalizations of the models were done in custom-made path simulation software[3].

Figure 1. Test subject with camera

Figure 2. Path with ground markers

[3] All custom-made software mentioned in the thesis should be available on an accompanying CD. If not, please contact the authors.

Procedure

The test was conducted during an afternoon session in the "Wargentinskolan" high school. The group was gathered in a classroom adjacent to the experimental setup location. The purpose of the test was described and the test subjects were given the opportunity to ask questions. Any subjects reluctant to participate were allowed to leave at this point. After briefing the entire group, the subjects were led one by one to the test location, which they had not been allowed to see in advance when equipped with ground markers. See figure 3 for an overview of the test site. The subject was equipped with a video camera (see figure 1) and was instructed to fetch a token at the end of the test track. Unaccustomed subjects were also briefly informed about the layout of the track. After having returned with the token, the test subject was instructed not to return to the classroom to join the subjects who had not yet been engaged in the test.

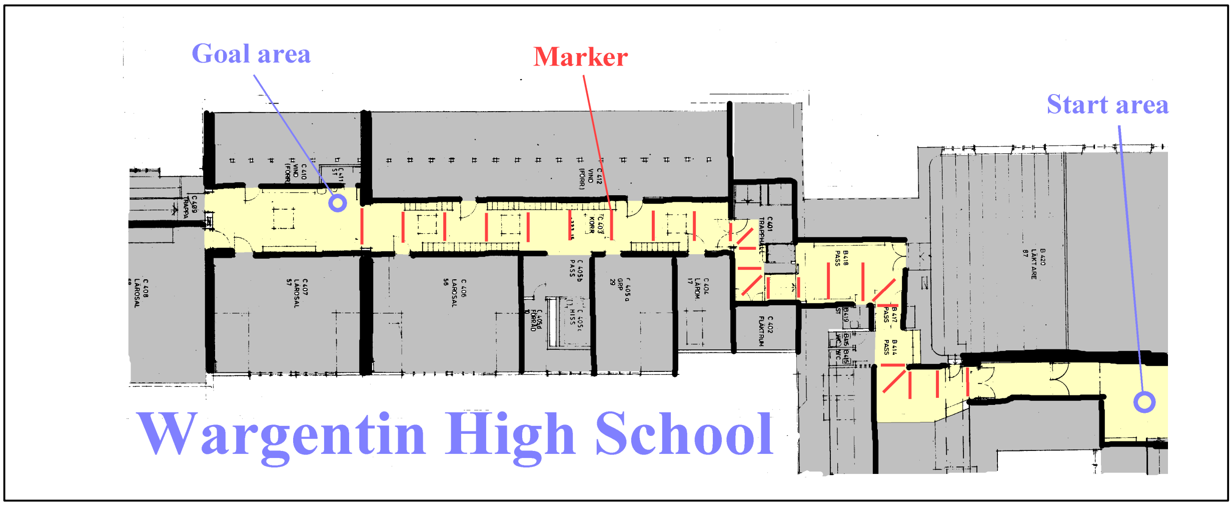

Figure 3. Overview of the test site.

Calculations

The collected data was analyzed using both calculations for continuous variables in the case of mean routes and discrete variables in the case of preferred ideal models. This does in practice mean analyzes of variance (ANOVA) and Pearson's Chi-square test, respectively. Important points for evaluation were:

- Gender
- Mean route (the average sidewise position for a test subject)
- Preferred model (the sidewise positions grouped as deviation from an expected ideal model, see path evaluation below).

Descriptions of distribution and skewness are included for completeness.

Path evaluation

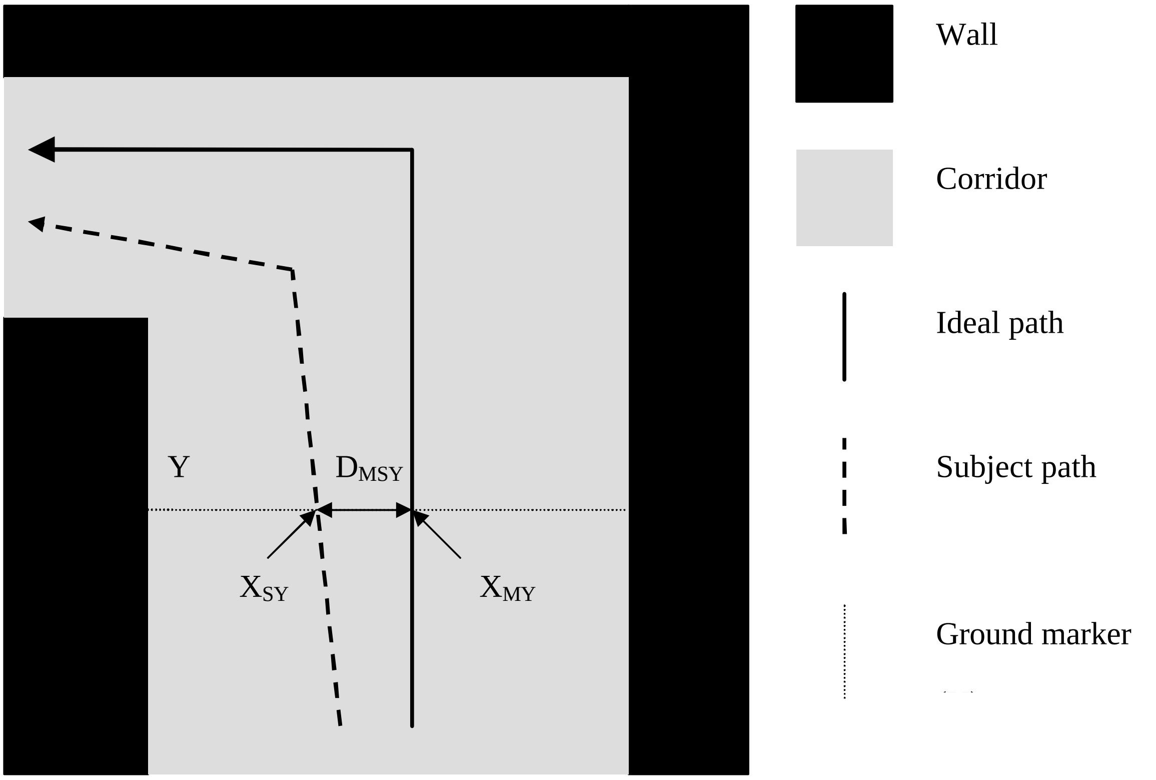

Figure 4. Sample path calculation illustration

Y is defined as the axis aligning to the direction. Thus the direction of Y changes in corners. X is the axis between the walls in the corridor segment, thus usually 90 degrees apart from Y. Note that the X values are normalized: X is measured in percent units of corridor width. Thus the middle of the corridor is always 50, no matter how wide or narrow the corridor is.

The difference D in side position X at depth position Y between the ideal path model M and a subject path S is described as:

$$D_{MSY} = \left| X_{MY} - X_{SY} \right|$$

Thus we describe the fitness score, the average difference, for one subject S and one ideal path model M, where N_Y is the total number of path segments, as:

$$D_{MS} = \frac{\sum_{Y=1}^{N_Y} \left| X_{MY} - X_{SY} \right|}{N_Y}$$

D_{MSY} (and thus D_{MS}) is calculated as the average absolute difference rather than the square root of the average of the squared differences since the latter would give minor fluctuations more importance than we feel necessary.

If we define a model's fitness score F_M as an aggregate of the average differences for a group of N_S test subjects, it follows that F_M is described as:

$$F_M = \frac{\sum_{S=1}^{N_S} \left(\frac{\sum_{Y=1}^{N_Y} \left| X_{MY} - X_{SY} \right|}{N_Y} \right)}{N_S}$$

With the above, we get a F_M value for each model and test subject group, that is to say ten F_M, to compare. The comparison is conducted through simply finding the model with lowest average deviation.

Video analysis

The data was collected on a video tape, which was then analyzed using manual observation while registering the values through a custom-made analysis tool (see figure 5).

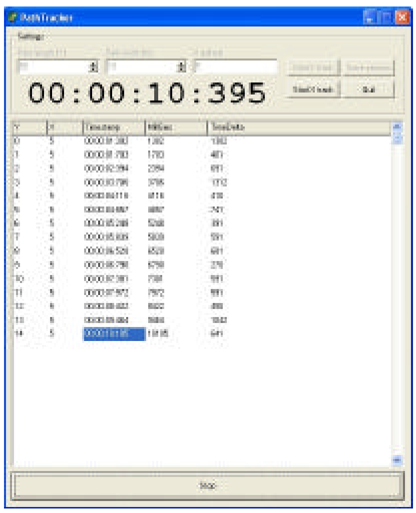

Figure 5. Screenshot of the analysis software

The video analysis for each test subject consisted of two runs. In the first run, the actual time each person passed a floor marker was registered. In this run, the video was played in real-time. In the second run, the video tape was replayed at 25% of the true speed. This time the positions collected in the first run were completed with information about which marker had been passed. The markers were coded 1, 3, 5, 7 and 9, while the spaces between the markers were coded 2, 4, 6 and 8. In the analysis, the marker (or space) being closest to the middle of the bottom of monitor when passed was chosen as passed sidewise position. The positions were later normalized into per cent of corridor width.

Results

Distribution

The total frequency distribution over all test points is normal (see figure 6).

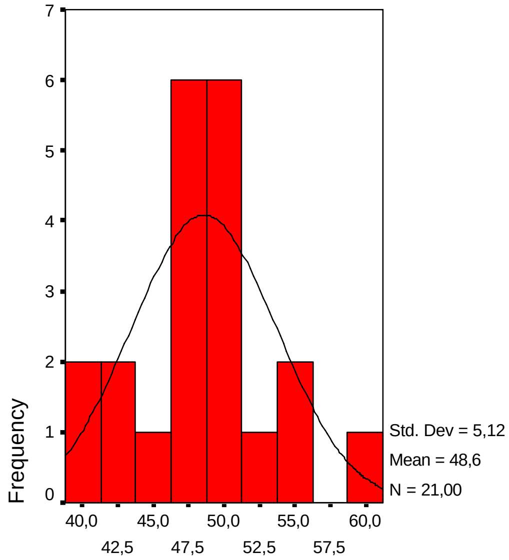

Figure 6. Frequency distribution over all test points

In comparing the frequency distribution between genders, the box plots in figure 7 shows that the positional distribution is visibly smaller amongst women than amongst men, or in other words that the female subjects had a stronger tendency to keep towards the middle of the corridor than did the male subjects. It should be noted that with the degrees of freedom relevant for this small sample, we cannot say that the difference in variance is significant as he critical F value for $F_{11,8}$ is 3.31, while the sample showed an F value of around 2. However, we believe this is at least partly caused by the use of this method on such a small sample, and thus choose to treat the deviation visible in the box plots as a "tendency".

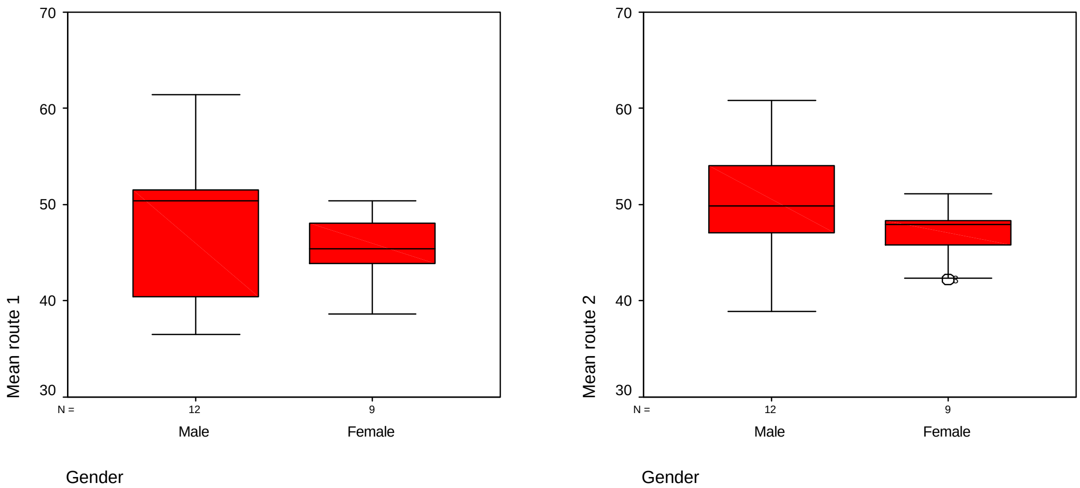

Figure 7. Frequency distribution comparing genders for departure and return path, respectively.

Speed

While speed was not an important parameter in the study, we did nevertheless measure it since we thought that it might have an impact on the chosen symmetrical model. We have found that this is not so, but that there is a correlation between the speed and the mean route. The difference between the "mean route" and the "preferred symmetrical route model" is that the former is simply the average sidewise position in the corridor, while the latter is the deviation from an expected corridor position.

Table 1. Correlations between speed and mean route.

	Time depart	Time return	Mean route 1	Mean route 2
Time depart	1	,887**	-,474*	-,065
Time return	,887**	1	-,504*	,071
Mean route 1	-,474*	-,504*	1	,411
Mean route 2	-,065	,071	,411	1

**. Correlation is significant at the 0.01 level (2-tailed)
*. Correlation is significant at the 0.05 level (2-tailed)

In table 1, we see that the time it takes to go from the starting area to the farthest point (Time depart) have significant correlations with the average route chosen both on that stretch and on the return stretch (Time return). Surprisingly enough, the time it takes to return does not have a significant correlation with the mean route on the return stretch.

In general, the test subject speed did not vary in any large degree. The actual test, excluding instructions and preparations, took between roughly 55 and 65 seconds for all test subjects.

The average walking time of the subjects in each direction was 27.7 s (SD=1.9 s) for the departure stretch and 27.4 s (SD=2.5 s) for the return stretch.

No significant differences related to gender could be observed for neither the departure path ($F_{1,19}$=2.15, p=.16) nor the return path ($F_{1,19}$=2.10, p=.16).

Visual analysis

We soon discovered that it was difficult to acquire a functional overview of the test statistics, since the movements seemed rather erratic. In order to do a first sorting, the routes were plotted in a kind of route diagrams[4], which were then analyzed visually. In the first analysis, it was discovered that corner positions were quite discernibly deviant when compared to the rest of the overall pattern. Subsequently, corners were excluded from the overall statistical analyses, and also from the route diagrams.

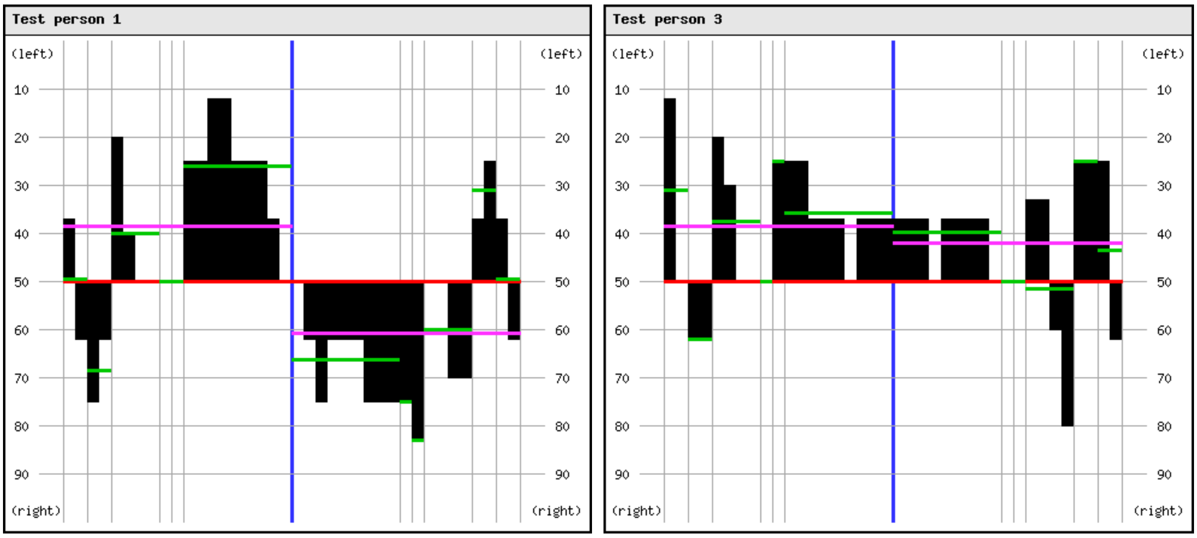

Figure 8. Sample route diagrams.

In the sample route diagrams of figure 8, we see that different persons clearly follow different movement patterns. The parts of the diagrams are as follows: The red horizontal line is the middle of the corridor. Positions above it is to the left in the movement direction, and positions below it to the right. The blue vertical line is the turning point, the position where the test subject picks up a token and returns to the start position. Thus it should be noted that upwards describes different geographical directions in the left and the right part of the diagram. The purple line describes the mean route for one direction, that is, either the departure stretch or the return stretch. The vertical grey lines delimit corridor sections. The horizontal green lines describe mean routes for each corridor section. The black bars mark position on the width axis of the corridor. The vertical gray lines delimit the corridor segments of the path.

The left diagram of figure 8 shows a marked "same wall" person, that is to say a person who follows the same wall in both directions thus walking left in one direction and right in the other. The rightmost diagram shows a marked "always left" person, or in other words a person who has a bias towards the left part of the corridor independently of stretch direction.

All route diagrams are collected in Appendix A. Apart from the above variants, we also identified their mirrors, and a "prefer middle of corridor" person. These symmetrical route models are treated more quantitatively in the section "Symmetric route models" below.

[4] The route diagrams were produced through a custom-made script written in the programming language "perl" with the aid of the graphics library "GD". The source code for this script should accompany this document. If this is not the case, please contact the authors.

Corners

The corners were excluded from the major analysis, since they did not fit into the larger-scale movement patterns. Furthermore, the corners were measured with floor markers placed in a 45-degree line radiating from the corner. Thus, these positions were not immediately comparable with the other positions which were marked in 90-degree lines as measured from the corridor walls.

For the record, we shall here merely mention that most test persons rounded the corners over the "inner lap" position. That is to say, if the corner was to a corridor which turned left from the current direction of travel, the corner was passed on a position close to the extreme left position.

Table 2. Corner passing positions.

Position ID	Min	Max	Mean	S.D.
R3	37	87	63.90	11.39
R6	12	37	30.00	9.25
R11	66	100	82.19	8.46
R13	16	50	22.48	10.02
R36	50	83	66.95	9.76
R38	0	50	17.71	11.75
R43	75	87	80.71	6.14
R46	12	37	20.62	7.39

In table 2, we see that some corners are more marked in this regard than others. In position R43 as an example, we see that test subjects passed the corner floor marker on an X-position of 75 or higher. In the corridors apart from the corners, such extreme positions are unusual.

Asymmetric route models

As mentioned in the method section, we planned to calculate fitness to a few asymmetric route models. After having done the data collection, we found that the measurement methods we had used were too crude for us to be able to do these calculations.

While the symmetric route models (see below) could be calculated by treating the whole path as one section, the asymmetric models would not benefit from such a treatment. By and large, in order to do for example "optimal route" calculations, more floor positions than one would be needed in a corridor stretch.

As it were, only two corridor sections had a sufficient amount of floor markers. One of these was the C400 corridor with ten markers. The two planned asymmetrical route models would in this corridor have become very similar to the symmetrical models.

A longer discussion about the exclusion of these calculations, and the consequences of this, can be found in the Discussion.

Symmetric route models

In order to analyze the preferred symmetrical models, the fitness scores were calculated as described in the method for each stretch and for the ideal route models describing corridor positions at 10 % intervals of corridor widths from 30 % to 70 %.

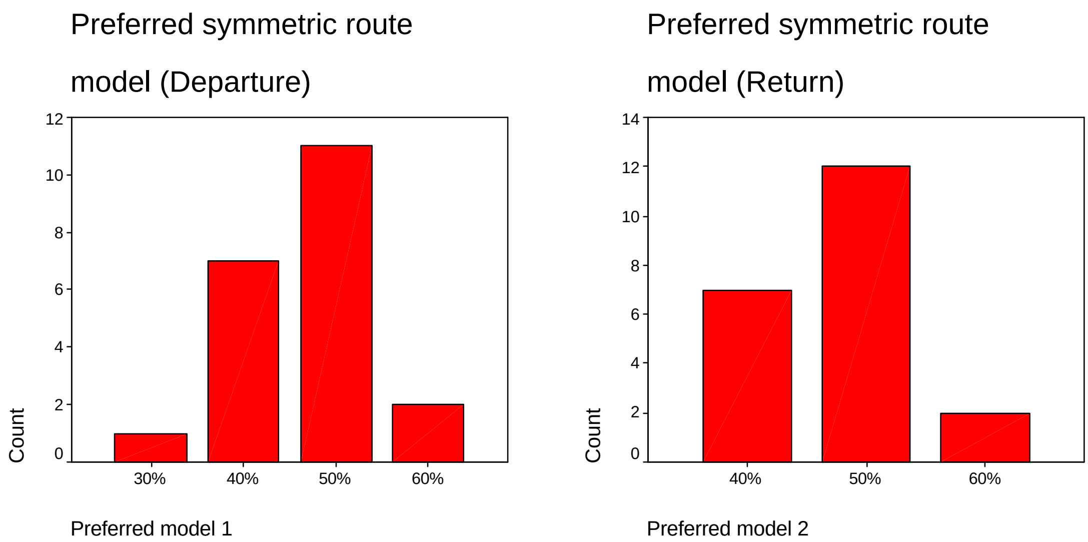

Figure 9. Frequencies of preferred symmetric route model.

The diagrams in figure 9 describe the frequencies of the preferred symmetric route model. A test subject is deemed preferring a route model when the fitness score for that model is lower than for the other models. As described in the method, the fitness score is the mean deviation from the expected corridor position for a test subject, and thus a lower fitness score is a better fit. A fitness score of zero would be an exact fit.

In the diagrams of figure 9 above, and in table 3 and 4 below, we see that the mid corridor model is the most preferred, with a bias towards the left. We feel that the bias may be a method error though, since we have seen suspected camera angles which probably were consistent in direction.

Table 3. Preferred model 1.

Position ID	Frequency	%	Cumulative %
30 %	1	4.8	4.8
40 %	7	33.3	38.1
50 %	11	52.4	90.5
60 %	2	9.5	100.0
Total	21	100.0	

Table 4. Preferred model 2.

Position ID	Frequency	%	Cumulative %
40 %	7	33.3	33.3
50 %	12	57.1	90.5
60 %	2	9.5	100.0
Total	21	100.0	

Mean Route

The mean route describes the average sidewise position over a direction (departure or return). All mean routes in this test fell inside the range 35 to 65.

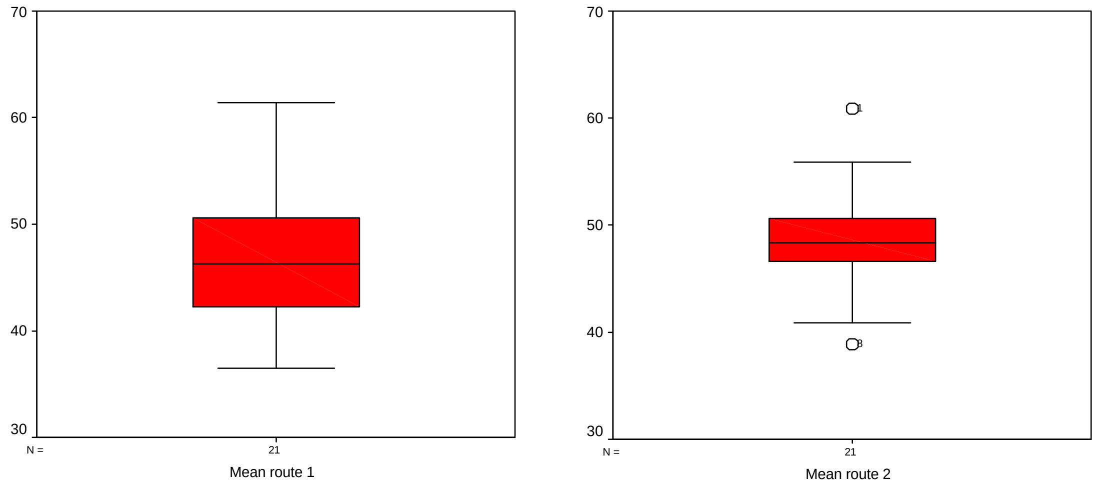

Figure 10. Mean routes (Departure and Return path).

Disregarding the possible left-bias skewness caused by the camera mounting (mentioned under “Known sources of errors” in the Method section), we see in the box plots of figure 10 that the mean routes by large coincide with the middle of the corridor. The same tendency expressed in numbers is that the mean value of the departure path is 46.7 (SD=6.1) and for the return path 48.6 (SD=5.1). By and large, the mean routes look rather similar to the results seen in the symmetrical models section.

We were not able to detect any significant differences related to gender for neither the departure path ($F_{1,19}$=.63, p=.44) nor the return path ($F_{1,19}$=1.76, p=.20).

Gender

A Chi-Square test shows no relation between the variables "gender" and "preferred model 1" ($?^{2}$=2,864; $?^{2}_{df=3, 0.05}$=7.81). We are aware that this test result is not so relevant considering our sample size, but we chose to include it here as an indicator of tendency. The corresponding test against "preferred model 2" shows approximately the same figures.

Discussion

Our main intention with this study was to construct a method for acquiring a data base for building a navigational model, and evaluate this approach. Our secondary purposes were to draw some limited conclusions about navigational behavior and to suggest improvements for future studies within the area.

Known sources of error

During the data collection and analysis work, we found certain factors that most likely affected the result in a way that was not controllable at the time.

? Some subjects seemed to become affected by the floor markers. We received comments on dizziness caused by the straight lines of colored markers and also questions like "which color shall I follow". This implied that a more subtle way of marking the route would have been preferred.

? Even though precautions were taken in order to affix the video camera in the same way on each of the subjects, the mounting seemed to be non-sufficient in some cases where an offset might have occurred.

? Some subjects reported that other people were either dwelling in or traveling through the test environment.

? The environment was not "clean". There were obstacles (such as wastebaskets) in the walked path.

? The floor markers were not completely resistant to the wear and tear caused by several classes of high school students running over them before the actual test began. Some of the markers thus moved or got lost completely. In these cases some extrapolation was required in the video analysis following the test.

The method

All things considered, the approach we used as our method was the only one feasible and good enough to use with the resources we had available. This does not by necessity mean that it was actually a *good* method in an absolute sense. Indeed, we have some doubts in this regard. In the following discussion, we divide the method into two parts: the data collection and the analysis, each with its own problems.

We got interesting data from the data collection, although we would have wished for some improvements in this regard. The collected data was by necessity not very fine-grained, something which was true along both axes. The markers could not have been placed more closely along the Y-axis (that is, in the direction of the path), since we would then not have been able to mark the speed in the video analysis. Along the X-axis (or in other words across the corridor), it would not have been relevant to use more floor markers, since the appraisal of which marker was closest to being passed was as inexact as it was anyway. More floor markers would have meant smaller markers, which would have made the video analysis even harder.

Another problem with the floor markers was that they themselves influenced the test persons. The markers were in bright colors to be easily discernible on the video, which might have disturbed the test persons in an unfortunate way.

It became necessary to limit the data analysis because of the problems with the data collection. The data was not fine-grained enough to calculate evaluations of asymmetrical models. This coarseness may also have resulted in us missing some points which may otherwise have been discovered.

The major problem with the analysis, however, is that the calculations we used did not describe the navigation in a good manner. The visual analysis of the route diagrams suggested definite differences in preferred route models, but also a large variation along the positions for each test person. We feel that the groupings and averages we calculated did not describe the richness and variation of the movement patterns in a good way. However, we are not aware of a better approach to use in this situation. We may speculate along the lines of pattern analysis or neural network analyses, but these forms of analyses are frankly above our level of competence.

Apart from the above discussion which describes the general method, we also need to point out that the data situation might have become better if our approach had been conducted otherwise. We could for example have used a larger sample, and used a less cluttered path area.

Route models

With the method discussion in mind, we have drawn a few conclusions about the navigational behavior of the test subjects. Given the quantitative approach we used, the first tendency we have enough data do be able to draw any conclusions about, is that a symmetrical model following the middle of the corridor, with a variation of plus/minus 15 percent units, is the best way to describe how people move through a set of corridor sections. We have not seen strict "wall-hugging" behavior in any of the test subjects.

Furthermore, we can conclude that there are very few significant differences in behavior dependent on gender. The only difference we have been able to detect in our material, is a (non-significant) tendency towards that the women in our sample tended to be stricter about keeping to the middle of the corridor, while the men had a larger variation in their X-axis position.

Notes for future research

Finally, we intend to point out a few areas for improved and continued research. The test method evaluated in this thesis can be used for studying the triggers that make people use one or more of the theoretical models described. During the current work, a number of ideas regarding how to achieve relevant results of such a study emerged. These ideas are summarized as follows.

Sample size and background factors

Due to the relatively large number of possible route models, the sample should be large enough to comprise a number of subjects possibly choosing each of the route models. A sample consisting of subjects from many different populations would probably improve the distribution among the route models.

Suggestions for comparative studies could be one or more of the following factors;

? Gender

? Familiarity with the test environment

? Age

? Left/Right-handedness

Route marking and registration

The ideal test setup would be an environment in which the route registration is completely invisible to the subject. In case this situation is hard to achieve, the following details could be worth considering;

? The marking device on the test track has to be subtle enough not to affect the subjects. If the markings are dominant, they might act as a tracking device or simply confuse the subject so that he/she will not act in a normal way during the test.

? The device used for registering the route choice has to be as discrete as possible. The more obvious device, the more the subject will be aware of the registration and thus possibly choose a route that is not normal.

Environmental factors

It is of great importance that any factors that cannot be controlled for are avoided. Examples of such factors are other persons moving about in the environment, varying illumination conditions, automatic doors, elevators, sun blinds, TV monitors or other artifacts that could draw attention from the subject.

Expansion of the experiment

When the researchers feel secure in their test setup, the study could be expanded to contain more choices and events. Examples of such could be

? Having several test persons to move simultaneously in the same area to study how meeting a person in the corridor affects the navigation

? Having different possible paths to reach the same goal to see under which circumstances one path is chosen over another. In this study, there was only one possible set of corridors to use in order to reach the goal.

Conclusions

In the discussion above, we have seen that it is possible to measure basic human navigation through placing floor markers and recording each test subject's path with a video camera hanging on the subject's back, filming the floor. This method is feasible, but there are a number of problems with the data collected this way. The main problem is that the data is not very fine-grained, making analysis difficult. Furthermore, the use of central measures does not describe the navigational data in a satisfactory way.

With these deficiencies in mind, we can still conclude that the best description of the navigational behavior used in the sample, is through a mid-corridor model with a variation of plus/minus 15 percent units of corridor width.

We have not been able to see significant differences in speed nor chosen route model depending on gender. The only difference we have seen is that the women in the sample tended to be stricter about keeping to the middle of the corridor.

If continuing with this kind of research, care should be taken to make the floor markers less obvious in order to avoid having the test subjects influenced by them. It would also be necessary to find a way to get more fine-grained data, and to perform the test in an area being less cluttered than the one used in this study.

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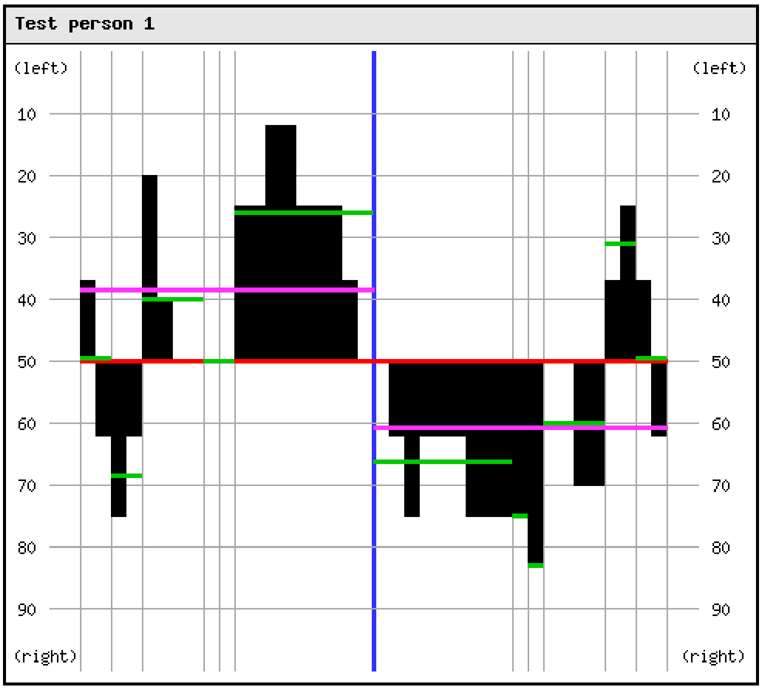
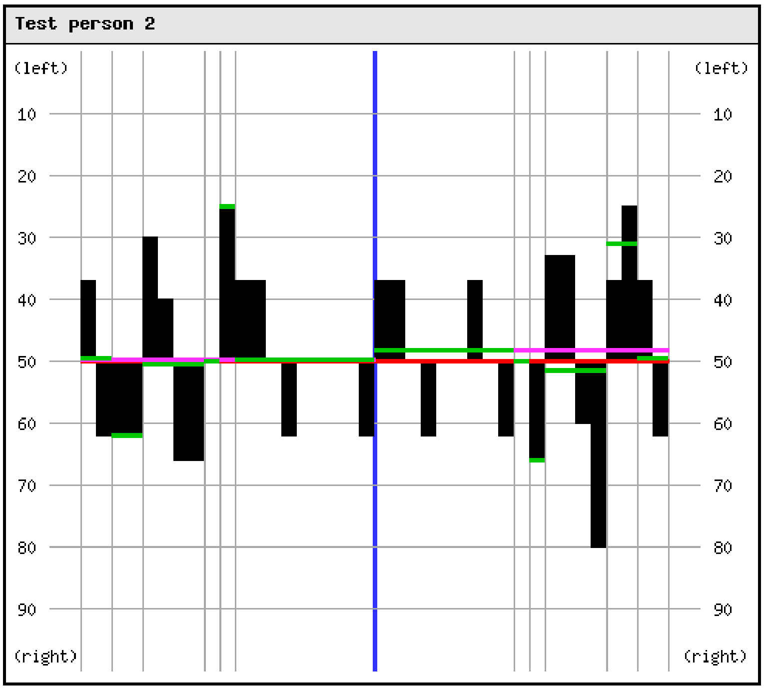
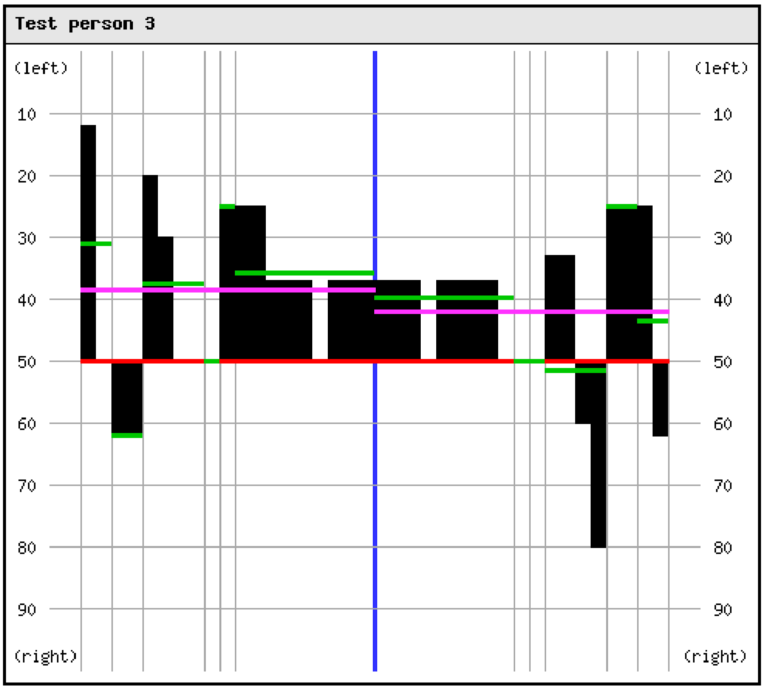
Appendix A - Route Diagrams



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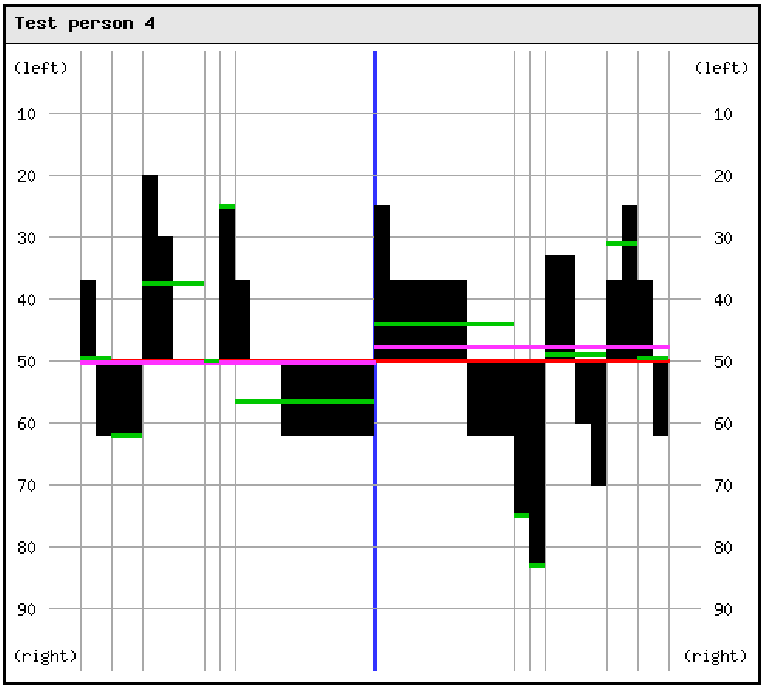
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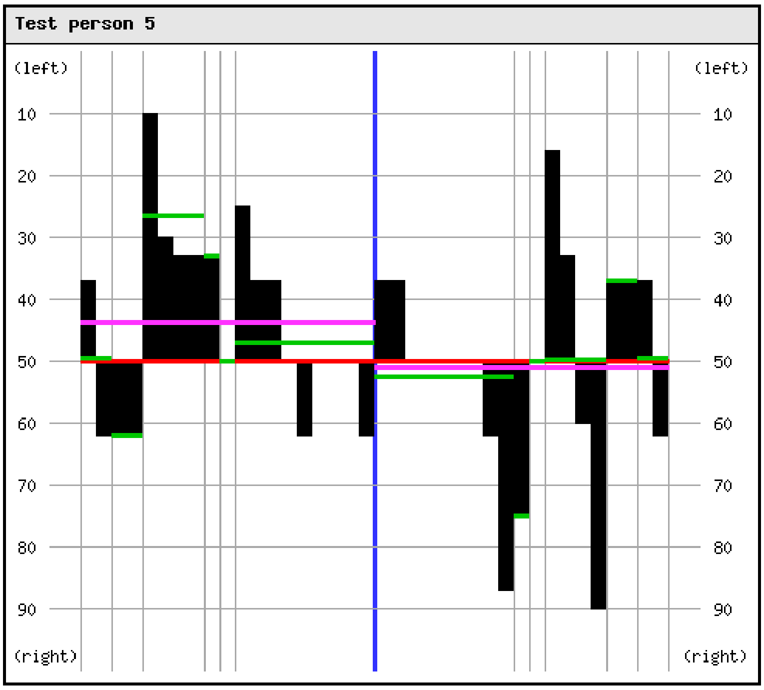
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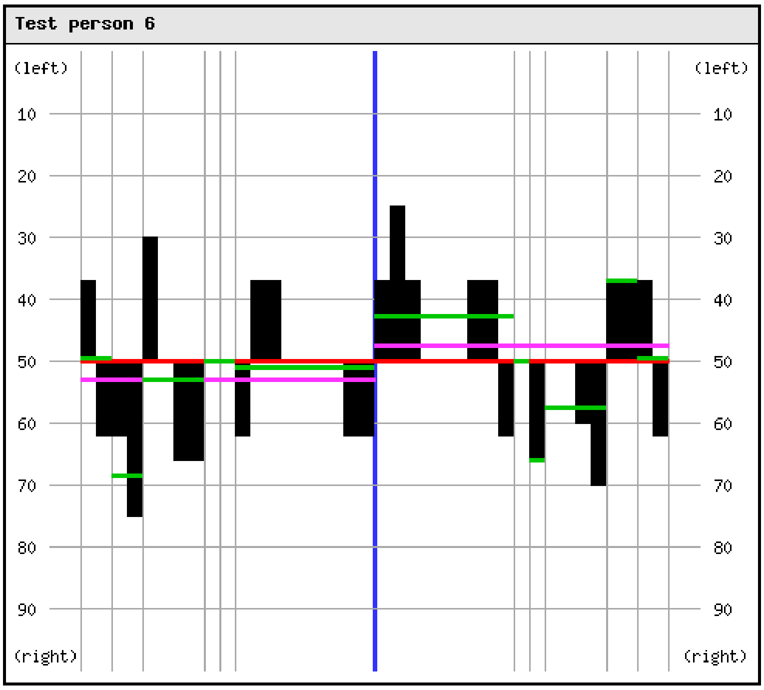
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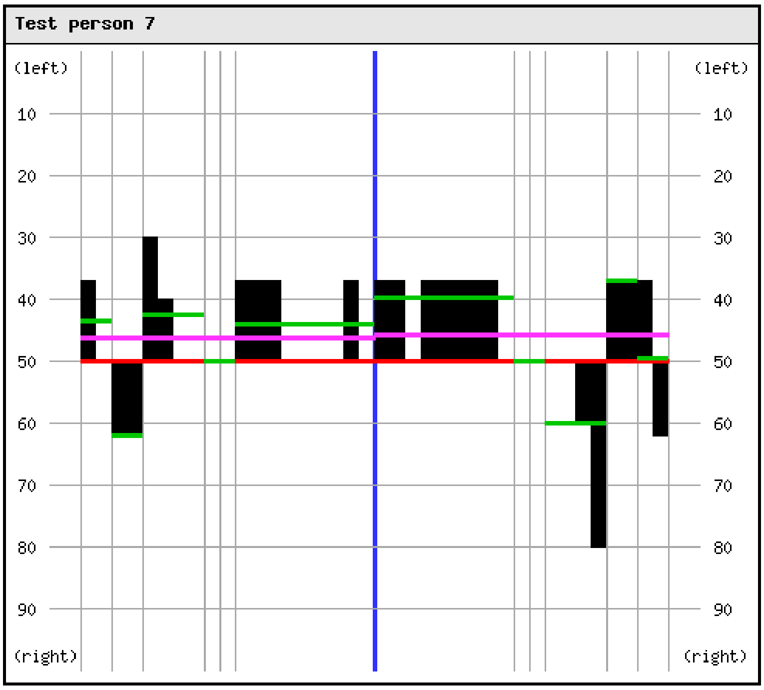
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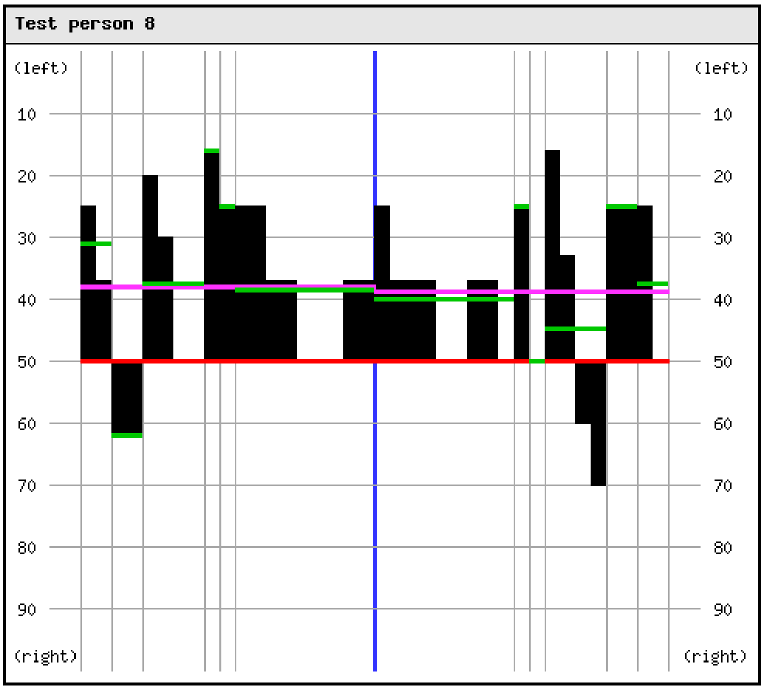
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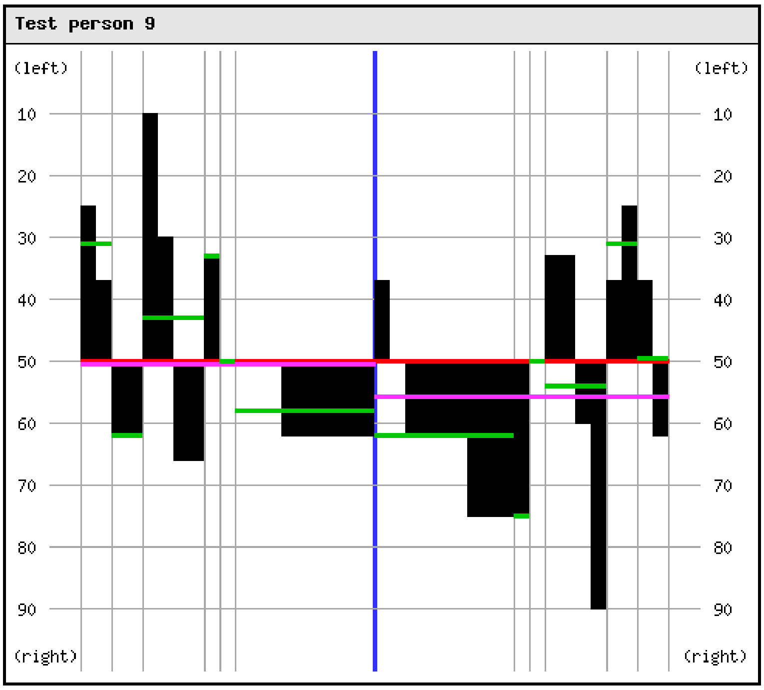
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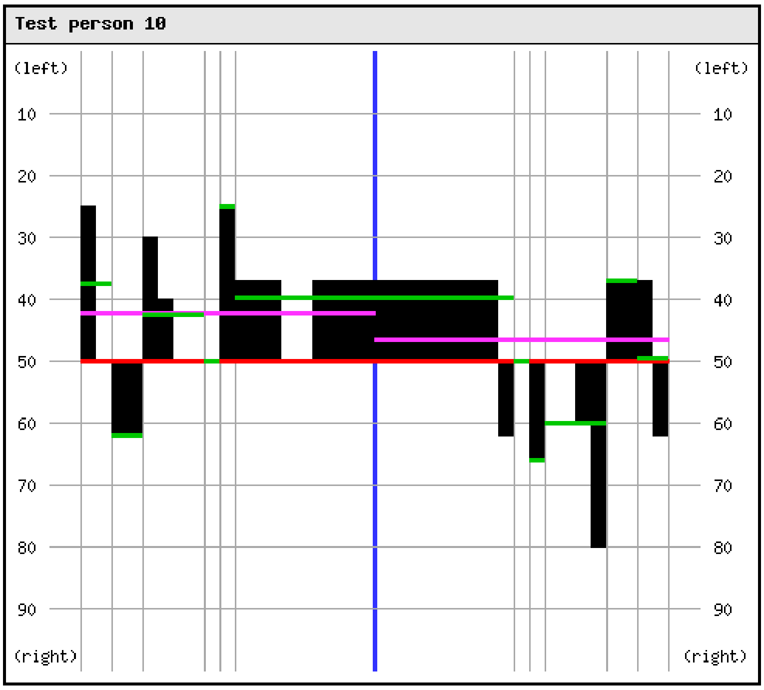
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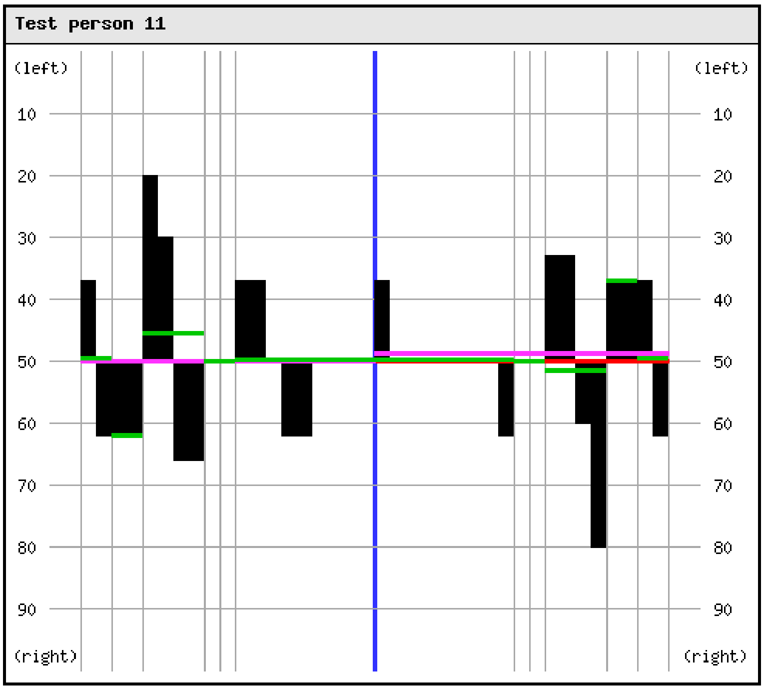
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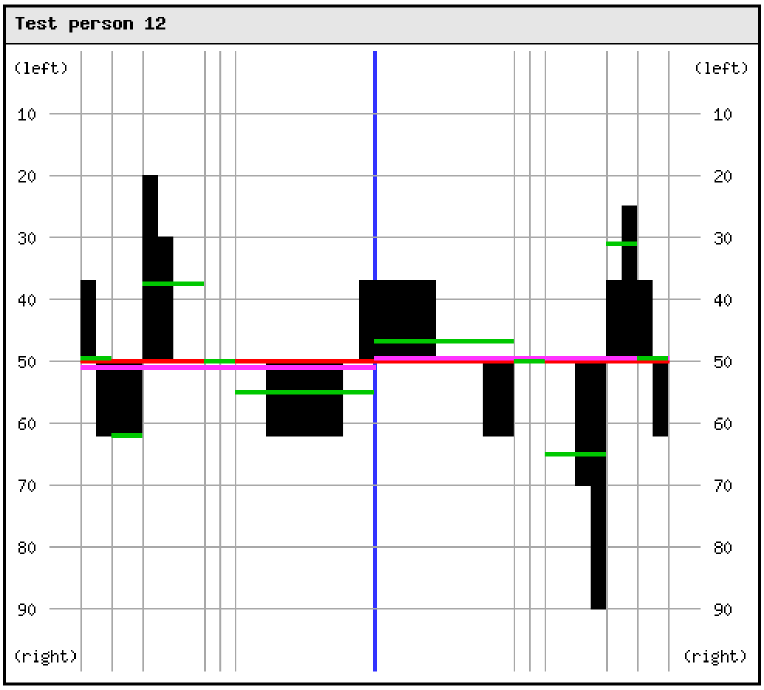
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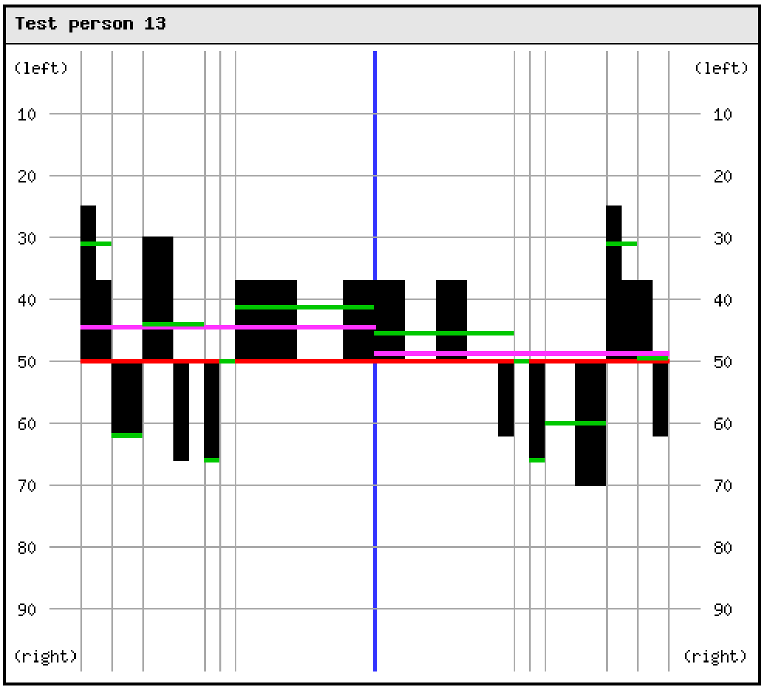
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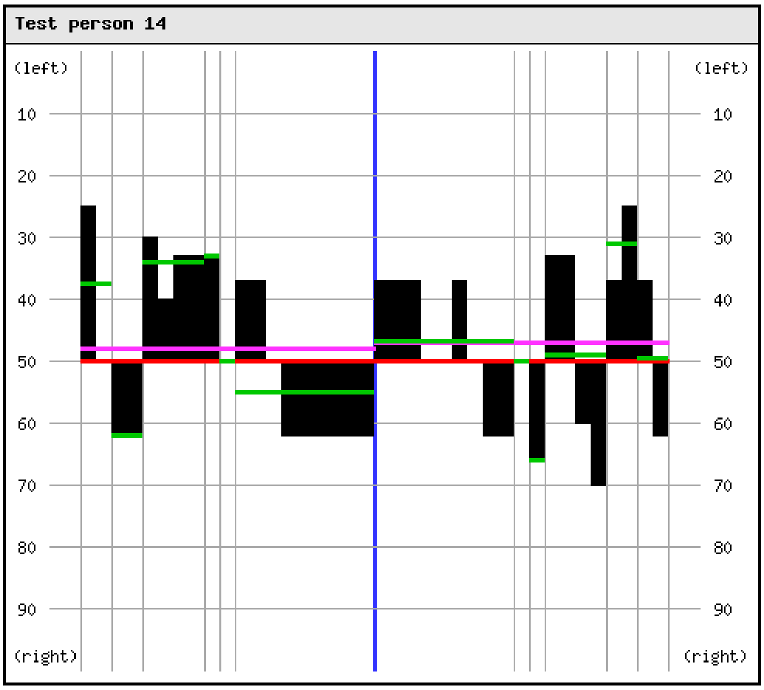
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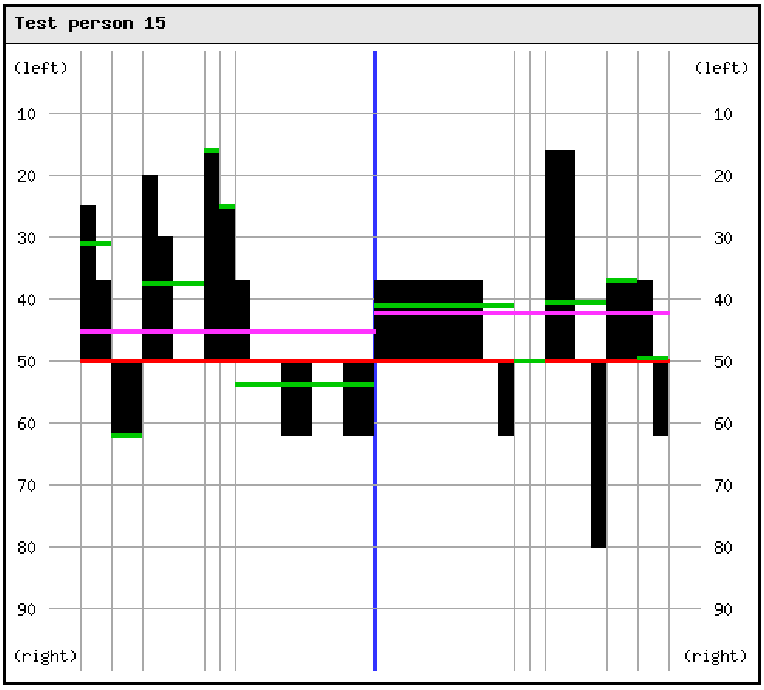
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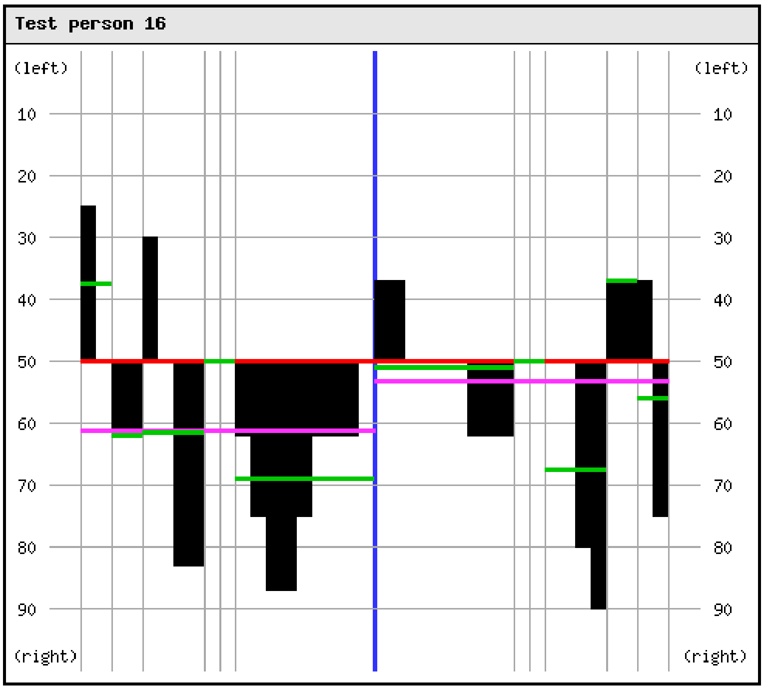
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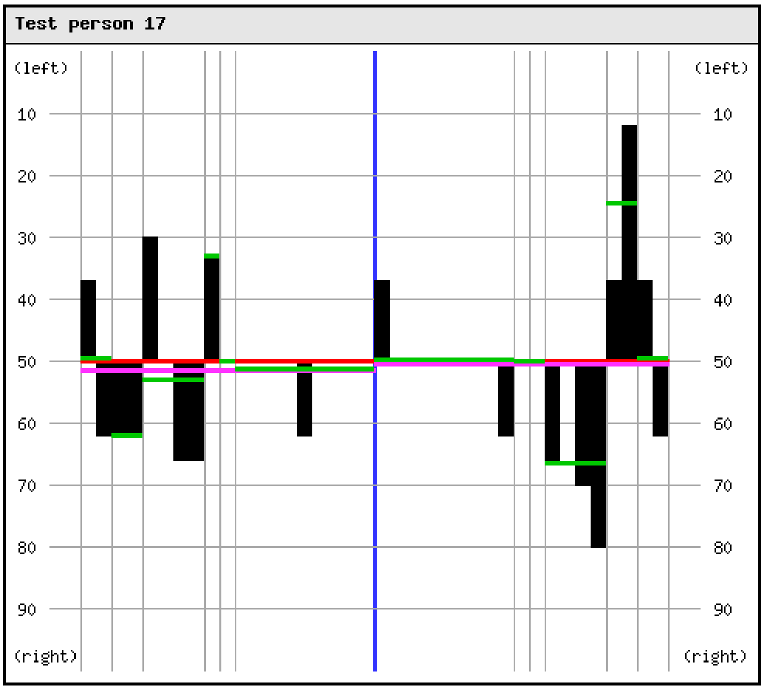
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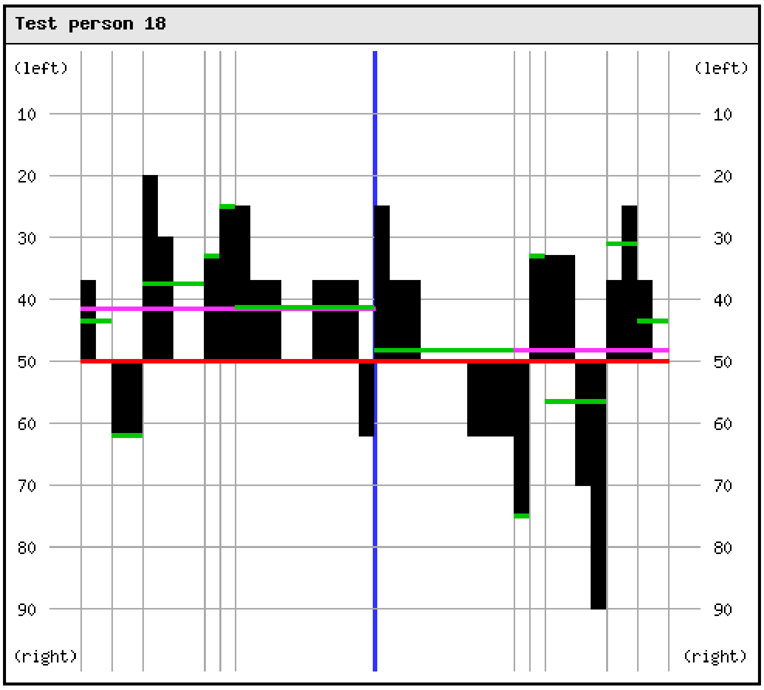
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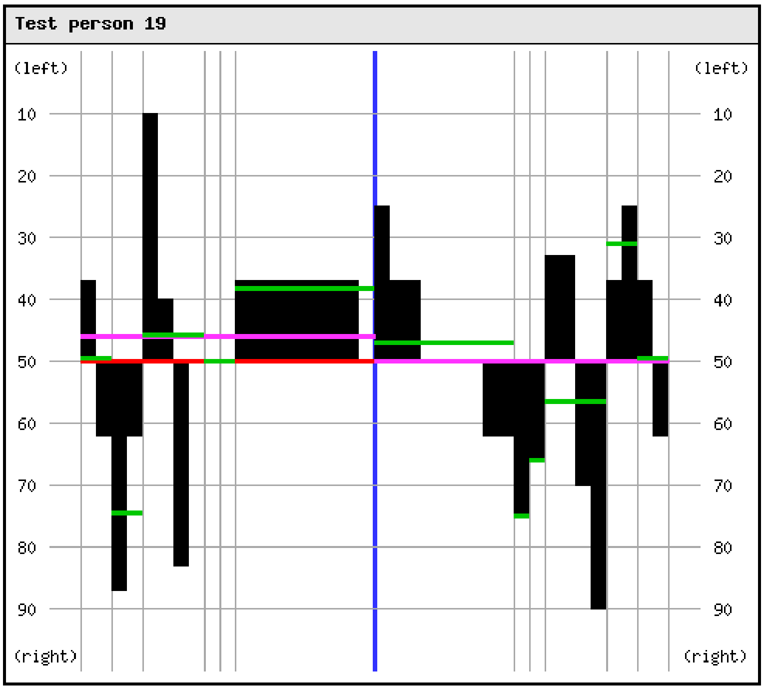
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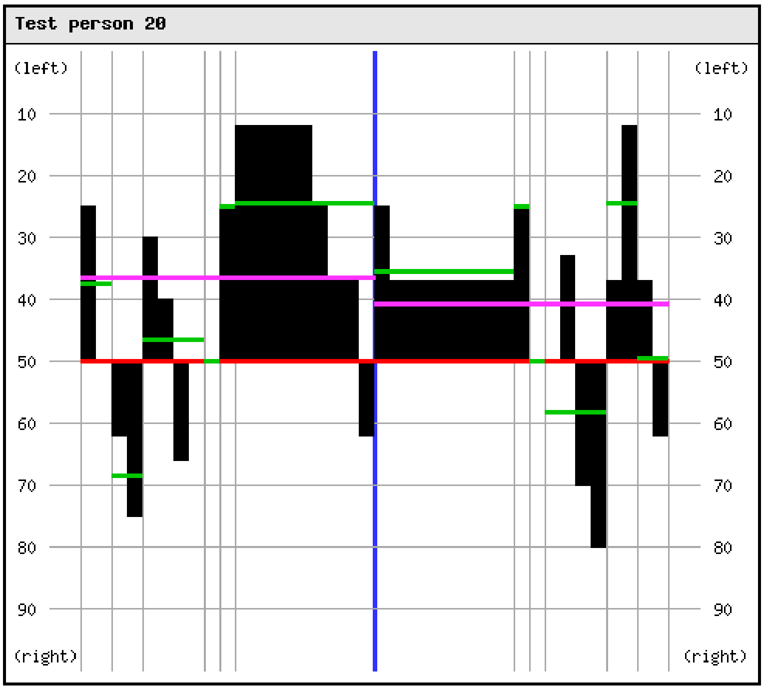
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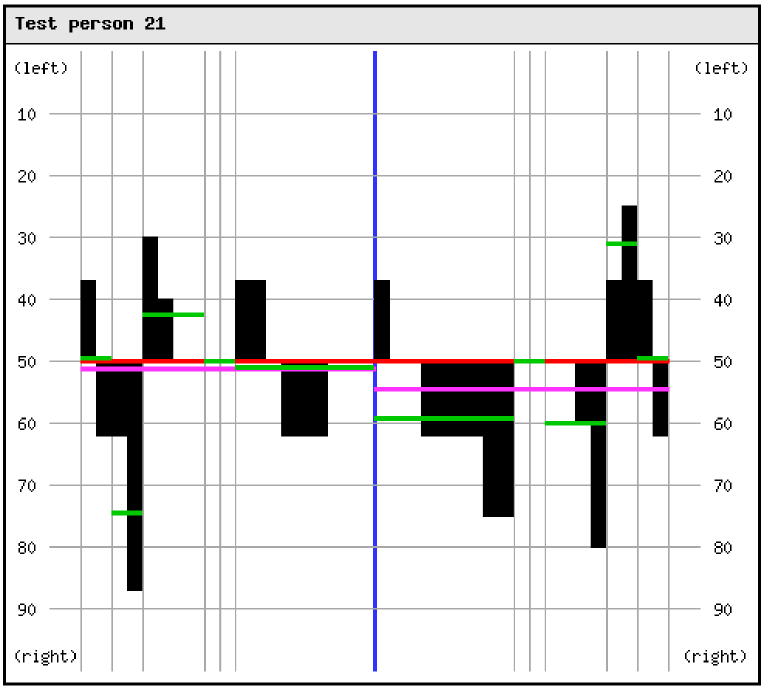
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