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Design Issues for Multi-Modal Attention in Autonomous Robot Systems

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1 Introduction

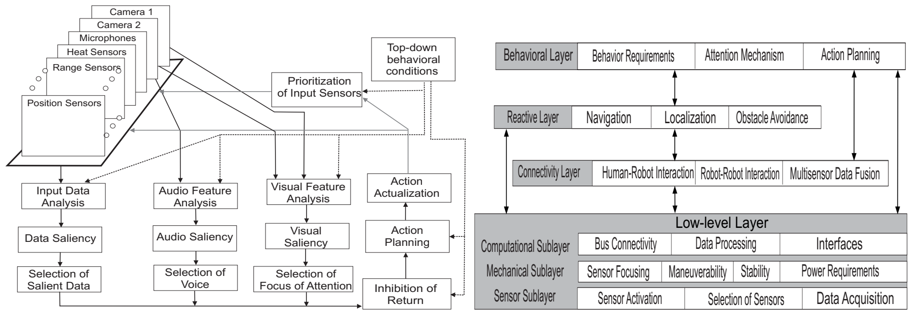
The performance of autonomous systems can be significantly improved by incorporating attention mechanisms [1] of biological systems in which only relevant information from senses is processed in detail by the brain. We propose the design of a general purpose multi-modal attention system capable of autonomously performing cognitive behaviors. In this regard, a conceptual paradigm of cognition that follows a sense, think, and act strategy is modified by adding a select step between steps of sense and think. We consider the inclusion of four types of behavior for demonstrating multi-modal attention on mobile robots, namely exploration, searching, reflex response, and detection of changes. Robots able to perform such behaviors will find applications in many areas such as driver assistance, assistance of disabled persons, rescue robots, exploration robots, security and surveillance.

2 Proposed Multi-Modal Attention Framework

Non-visual sensors have rarely been included in attention models. The inputs from stereo microphones [2], [5], laser range finder [4], and heat sensors [3] are a few known examples. The proposed model is designed to include feature maps for all the input channels according to the nature of the sensed data. Due to the diverse nature of data perceived by different sensors, specific methods to find saliency and perform inhibition of return are proposed for each data type. The cyclic process of attention needs feedback to provide information to the main controlling entity because system requirements can dynamically change according to the encountered situation. The selection and prioritization of sensors will be governed by the feedback mechanism or by the pre-defined top-down conditions so that the final target of attention may cover the actual requirements at a given time. The proposed model is illustrated in figure 1(a).

3 Design Issues

We propose a stack layer architecture as shown in figure 1(b) to incorporate the multi-modal attention system into autonomous systems. The low level layer collects data from the different types of sensors, maneuvers the sensors, and then



(a) (b)

Fig. 1. (a) Framework of multi-modal attention system (b) Stack layer architecture of multi-modal attention system

performs fundamental computations for data manipulations and motion control. It can be divided into three sub layers, namely sensor sublayer, mechanical sublayer, and computational sublayer. These layers deal with the functions of managing the sensors input, the transformation of data into format understandable to the upper layers, the mechanical structure necessary to accomplish the attention mechanism, and the interfaces required to transmit the data obtained from the wide range of sensors. The connectivity layer establishes the interaction of a particular robot system with other robotic systems, human operators, and other centralized or distributed networks. It also performs a multi-modal sensor fusion to improve the perception in cognitive attention processes. The reactive layer performs the critical tasks of navigation, obstacle avoidance, and localization and is dependent on the data obtained through lower layers as well as from upper ones. The behavioral layer is responsible for realizing the conceptual framework of multi-modal attention.

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STRATEGY SELECTION DURING EXPLORATORY BEHAVIOR: SEX DIFFERENCES IN UNCERTAINTY AND RISK MANAGEMENT

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Introduction

Exploratory behavior is a fundamental prerequisite for the construction of a spatial representation. Indeed, acquisition of such a representation relies on the selection of appropriate strategies and the capacity to adapt behavior to the complexity of the task to be solved.

At least two main cognitive processes should control exploratory and spatial behavior: 1/ Information processing that extracts, selects and encodes relevant information provided by internal and external worlds. 2/ Decision or choice processes allowing selecting a strategy. Moreover, these two operations are altered, respectively, by attentional mechanisms that change discrimination capacities, and by beliefs concerning the likelihood of uncertain events. Indeed, information processing is tuned by the attentional level that acts like a filter on perception, while decision-making processes are weighed by beliefs expressed as a subjective probability of risk.

This experiment tests the hypothesis that these two mechanisms differ in males and females and result in a dimorphic "a priori" strategy used to explore and then solve spatial task.

Materials and method

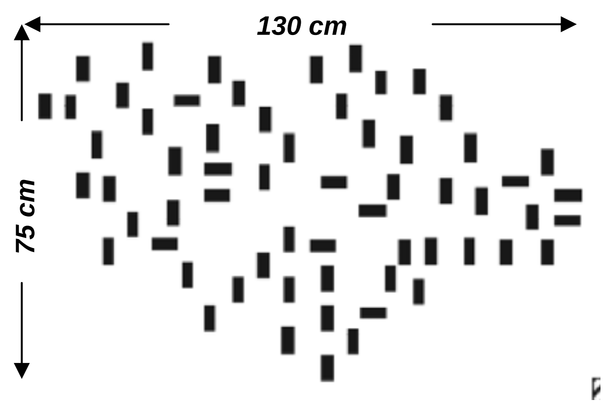
Participants

180 volunteers (90 males, 22.9±1.4, 90 females 23.5±1.2) recruited from the UNIL campus.

Apparatus

A set of hundred cards differentiated by homogenous males and females cartoon characters was used.

For experiment 1 (exploration phase), a two-dimensional pattern (fig. 1) was created in placing 62 cards (3 x 5 cm) on a large board (130 cm x 75 cm). The remaining set of 38 cards was used for (discrimination phase)



Procedure of testing

Exploration phase

The board lay on the floor of the experimental room with the card turned the wrong side up. The duplicate of the goal turned right side up was put on the right corner of the board (fig. 1).

Participants were asked to find the hidden goal in a set of 62 pictures -turned the wrong side up- in turning up as few pictures as possible and leaving them exposed.

After having found the goal, they were asked to turn up the rest of the cards. Double blind shuffling of cards made different strategies (e.g. systematic or random) equivalent with regard to the resulting risk distribution

Discrimination phase

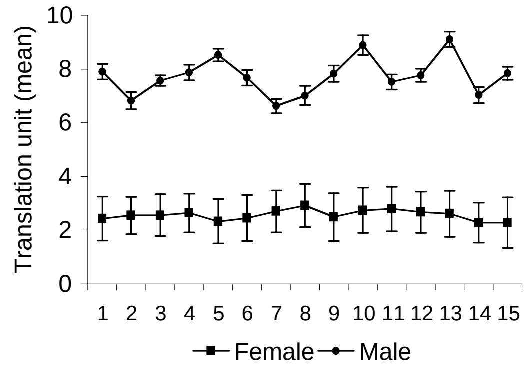
Hundred pictures (62 already shown in experiment 1 and 38 new) were presented one by one to the participants. The task was to discriminate between the pictures already shown (signal) and the one never shown during experiment 1.

Results

Exploration phase

Axial translations between explored locations shows a significant difference between males and females searching strategies ($F[1,178]=372.95$; $p=<.001$).

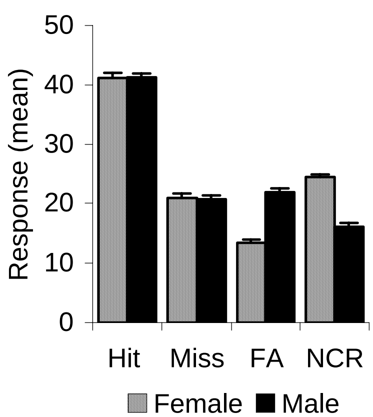
Men adopted a global strategy in which pictures were randomly chosen from an approximately uniform distribution over spatial locations. In contrast, women used a local searching strategy in which the probability of selecting a card was a function of its distance from a cluster of visited locations



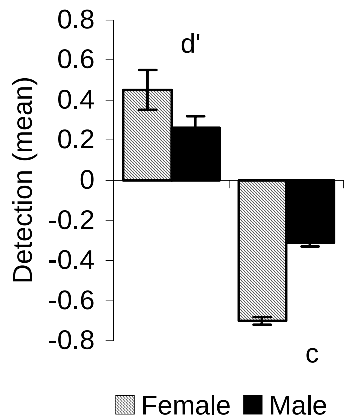
Discrimination phase

The model generally used in SDT assumes that the theoretical distributions of signal and noise are normal and have equal variance. The probability of correct and incorrect signal detection can be calculated from the ratio of the subject's acceptation and rejection responses. This probability is then used to determine the probit transformations aimed at estimating *d'* and *c* (Green and Swets, 1966).

More "present" responses in males and more "absent" responses in females (sex: F[1,178]=2.14; ns; answers: F[1,178]=217.7; p=<.001; sex X answers: F[1,178]=49.1; p=<.001) are shown.
This sex effect is not due to a difference in the identification of the design of the image on the cards.



No effect of sensitivity *d'* between sex (F[1,178]=2.53; ns), but a significant effect of the subjective criterion *c* (F[1,178]=77.69; p=<.001) are shown



Comments

By comparison with males, females use a local searching strategy in which the metric distance between what is already known and what is unknown is reduced. These disparities in exploratory behavior appear not to be associated with sex differences in sensitivity to visual stimuli, but with differences in confidence in judgment under uncertainty. Clearly, SDT analysis reveals that decisions were more circumspect and based on conservatism in females, while they were more risky in males. Consequently, sex differences might be related to variations in sense data processing modifying expectations based on environmental cues. Thus, male and female brains could be considered as two models of information encoder providing different representations. This speculative interpretation cannot be firmly validated by these experiments. However, it suggests that risk evaluation influences strategies' selection.

DIMORPHIC TURNING BIAS IN SPONTANEOUS ROTATIONAL MOVEMENT

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Introduction

Keeping track of position and orientation during travel relies on two main mechanisms: 1/ landmark-based navigation that provides direct sensory information about current position and orientation allowing the updating of a spatial representation; 2/ path integration where self-motion is used to update current position and orientation relative to some starting point. This last basic mechanism provides also a homing vector allowing subjects to directly return to the origin even in the absence of vision.

Understanding the evolution of an effective navigation system depends on the development of basic researches concerning spatial perception and spatial cognition. Among them, quite complex experiments are often designed to assess path integration abilities through distance and direction errors encoding. It is less common to evaluate how variations in cognitive profile related to biological characteristics, such as sex, could modulate this ability.

This experiment was designed to estimate sex differences in spontaneous body-turn following a most simple linear displacement in the absence of vision. This idea was based on several data provided by both animal and human researches showing that 1/ turning biases could be associated with unbalanced hemispheric dopaminergic activity; 2/ sexual differentiation in hippocampal dopaminergic receptors could be observed following spatial learning; 3/ dopaminergic activity could be correlated with cue-directed behaviors; 4/ sex-related differences may have more to do with disparities in preferred strategy than with differences in hemispheric asymmetry.

Materials and method

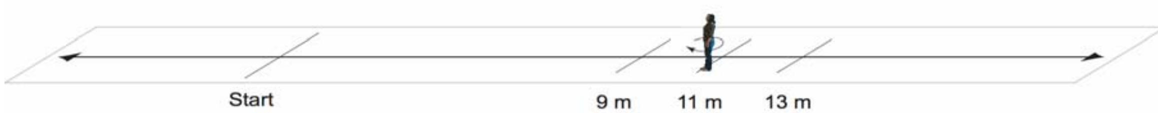
Participants

91 young volunteers (44 males, 22.9±1.4, 46 females 26.4±2.8) recruited from the University of Lausanne campus served as subjects.

41 females showed right-sided preference for handedness and 5 for left-sided. The same preference was observed in males (40 right-sided, 4 left-sided).

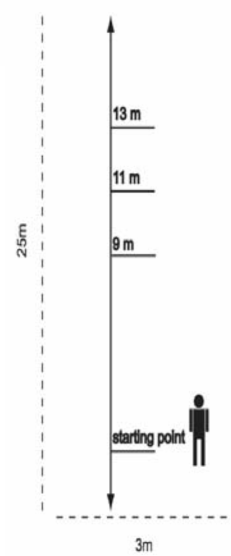
Apparatus

Our experiment was conducted in a large corridor of a University of Lausanne building. On the floor in the middle of the section, a 25-m line of white adhesive tape ran parallel to the walls. The starting point was marked by a 50-cm line of white adhesive tape perpendicular to the 25-m line. Actual traveling distances were limited to 9, 11 and 13 m.



Procedure of testing

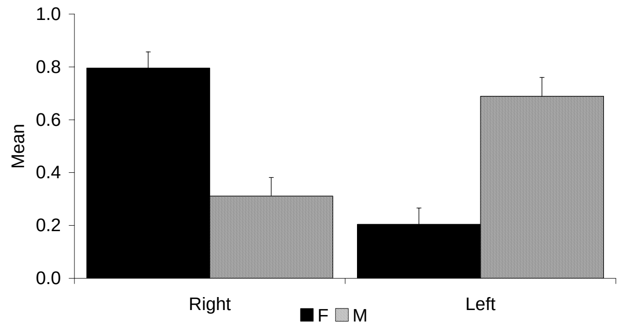
Blindfolded subjects were led on foot by the experimenter over one of the three fixed distances. The traveling distance was chosen randomly at the beginning of the experiment. The experimenter led the subjects by the arm. Once the pair stopped, the experimenter let go of the subject's arm and asked him/her to turn so as to face the starting point.



Results

Males and females differed in their spontaneous body turn preference (F[1,88]=27.58; p=0.000).

Females showed a right turn preference (t[45]=-4.1; p=.0002), while males showed a left turn preference (t[43]=-3.35; p=.0017).



Comments

The result of this single experiment is quite astonishing since it was never observed before. With no doubt, females turn spontaneously to the right, while males turn left. By contrast, turn biases studies in humans typically show a left turn bias for right-handed normal subjects, when a moderated bias toward the hemisphere with decreased DA is observed in subjects with dopaminergic abnormalities. In view of the task, this obvious behavioral asymmetry cannot be explained differently than by sex-related differences. The discrepancy with previous results might be associated with the design of the exercise. Indeed, blindfolded subjects are just linearly led by their arm to a point, and asked to turn alone towards the origin. There are no challenges like problem solving or complex devices that might bias spontaneous behavior through changes in brain activation. Thus, this observation gives a cue concerning a possible sex-related difference in dopaminergic activity in human brain. This difference might be associated with disparities in preferred strategies used for solving navigation tasks. Moreover, it emphasizes the fact that behavior is particularly sensitive to situation. Thus, it cannot be assessed without careful consideration of the effects of experimental design.

On the Assessment of Landmark Salience for Wayfinding Tasks

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1 Landmarks and Landmarkedness

In modern usage, the term landmark refers to anything that is easily recognizable, such as a building, river, specific districts or even idiosyncratic objects, and that supports reasoning when wayfindig. The property of being a landmark has so far been attributed to distinct objects [1]. We argue that *landmarkedness* is not an inherent property of some object, but rather is a unique property of the trilateral relation between the object itself, the surrounding environment, and the observer's point of view, both, cognitively and physically. In this work, we propose a framework for the assessment of the *landmarkedness* of potential landmarks, which is based on this tri-lateral relationship.

2 Related Work

Sorrows and Hirtle's [1] characterization of landmarks provides the foundation for various computational approaches for the determination of the salience of landmarks. Raubal and Winter [2] propose a model of landmark salience, which was further refined and tested by Nothenegger [3]. Elias [4] proposes an approach for the determination of landmarks that is based on Raubal and Winter's salience model [2]. Klippel et al. [5] introduce a model of structural salience that complements landmark research with an approach to formalize the structural salience of objects along routes.

3 Conceptualizing Salience for Wayfinding Tasks

The central assumption of our approach to the assessment of landmark salience is that in a wayfinding context, landmarkedness is a unique property of the trilateral relationship between *Observer*, *Environment*, and *Geographic Feature* and thus, cannot be attributed to a geographic feature per se. We assume that during wayfinding, the observer is located in the environment, which is perceived through sensory input. Based on this sensory input and on the task at hand, wayfinders are able to discriminate salient objects and refer to them as landmarks.

Our framework for the assessment of the salience of landmarks for wayfinding tasks is based on models of attention [6] and theories of human information processing [7]. In terms of human information processing, three different types of salience contribute to the landmarkedness of geographic features, namely *Perceptual Salience*, *Cognitive Salience*, and *Contextual Salience*.

3.1 Perceptual Salience

Perceptual salience is derived from the part of the environment that is perceived by the observer during the wayfinding process from one specific position. The identification of potential landmarks is based on a snapshot of the visual stream of stimuli and three criteria of analysis, which are: 1) *Location-based Attention*, 2) *Object-based Attention*, and 3) *Scene-based Attention*.

Location-based Salience assesses the potential for attraction of attention of regions across the spatial scene. This type of salience is analogous to space-based attention, which states that attention primarily selects salient regions in the visual field. Object-based Salience defines the salience of objects contained in the visual field. In terms of attention theory, the object-based view suggests that attention is directed to objects based on their structure, instead of particular locations of the visual scene [8]. Our framework considers both types of attentional capture in an integrative way. Scene-based Salience focuses on the global configuration of a visual scene, rather than on single objects. Location-based Salience and Object-based Salience ignore contextual information provided by the correlation between environment and objects, while Scene-based Salience captures this correlation.

3.2 Cognitive Salience

Cognitive Salience is dependent on the observer's experience and knowledge. We abstract the mental processes to the degree that the mind has internal states and that the assessment of saliency is understood as the assimilation of perceived input into existing knowledge. This abstraction allows the definition of two types of salience, namely 1) the *Degree of Concept Recognition*, and 2)the *Idiosyncratic Relevance* of the object.

The Degree of Concept Recognition assesses to what degree objects in a spatial scene are recognized. This measure sets the current environment in relation to the beliefs and knowledge of the observer. Idiosyncratic Relevance characterizes the relation individual observers have to specific objects in their environment. In the context of wayfinding, we define this relation as the individual familiarity of an observer with respect to an object.

3.3 Contextual Salience

Context during wayfinding tasks plays an important role, as it defines how much attention can be allocated to the identification and assessment of potential landmarks. We distinguish between two types of context: 1) *Task-based Context*, which includes the type of task to be performed in the assessment, and 2) *Modality-based Context*, which describes the mode of transportation and the amount of resources that need to be allocated.

Task-based Salience is based on the goal of wayfinding, namely to find a route from start to destination. This includes the identification of possible paths based on landmarks and an assessment of the relevance of these paths for achieving the goal. Modality-based Salience refers to the amount of attention required for moving along a route. Locomotion may be achieved through different modes, such as walking, riding, or driving. Eeach of these modalities has its own requirements in terms of allocation of attention and will force the wayfinder to adapt the selection process of spatial objects.

4 Conclusions and Future Work

The framework presented in this paper forms the basis of a computational model for the assessment of the salience of landmarks for wayfinding tasks. Future work includes the definition of the computational model, including the integration of the single components, as well as the evaluation of the model.

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Urban Form Shapes Spatial Knowledge

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Spatial cognition studies the interaction of people and their surroundings from a theoretical perspective, whereas urban design focuses on creating those surroundings and ensuring that they are liveable. This study bridges the two disciplinary worlds by evaluating undergraduates' spatial knowledge of their college campus and relating that to the urban form of the campus. Participants' performance on two tasks of spatial judgment and memory reveal systematic distortions, presumably the result of mental simplification, i.e., the rotation and alignment heuristics identified by Tversky (1981).

To formally describe the campus, I use a set of computational techniques known as space syntax. Axial map analysis, the particular method used here, considers environments in terms of their sightlines and the topological interconnections of those sightlines (see Bafna, 2003). Integration is an important measure that judges the average number of steps required to reach each sightline from every other sightline in the environment. In this study I hypothesize—and find evidence—that integration predicts participants' performance on the pointing and map arrangement tasks.

1 Method

A total of 32 undergraduate students at Carleton College (an equal number of first-years and seniors, males and females) were recruited to complete four computer-based instruments: a demographics questionnaire, the Mental Rotation Test, a pointing task, and a map arrangement task.

In the pointing task, participants are asked to judge and record the relative angle between two buildings, given a pair of well-known buildings on the Carleton campus. Each question includes a schematic birds-eye diagram that conveys to participants their imagined location and heading. Participants select the desired angle by rotating a pointer dot around a compass rose until it indicates the appropriate direction.

To complete the map arrangement task, participants are given a blank screen, which has been scaled to the size of the standard campus map, as well as a set of

* This work was completed at Carleton College (Northfield, Minnesota) under the direction of Drs. Kathleen Galotti and Roy Elveton. Funding was provided by the Cognitive Studies Program and the Dean of the College. Thanks also go to Drs. Mary Hegarty and Daniel Montello, as well as the rest of the UCSB spatial cognition community. In Santa Barbara, funding was provided by NSF Interactive Digital Multimedia IGERT grant number DGE-0221713.

similarly scaled cutouts of the campus buildings. Participants place the cutouts in the scaled blank area by dragging and dropping so that the cutouts best approximate the actual orientations and locations of those buildings; participants are allowed to move and rotate the cutouts until they are satisfied with the final arrangement.

To prepare the space syntax analysis, I manually marked axial lines to represent walkways on a CAD (computer-aided design) plan of the campus. Axial map analysis was then used on the resulting map using the software package DepthMap to determine the integration values of the axes.

2 Key Results

Mean error in degrees (aggregated across all participants) for each pointing trial is significantly predicted by the global integration of the starting building, β = -13.855, $t(10)$ = -2.435, p = .035, and accounts for a significant proportion of variance in mean error, R^2 = .372, $F(1, 11)$ = 5.930, p = .035. The global integration of the destination building does not significantly predict the error.

The global integration value of the starting building significantly predicts the mean error in degrees on the angles between the same 12 building pairs as they were arranged in the map arrangement, β = -12.046, $t(10)$ = -2.718, p = .022, and accounts for a significant proportion of variance in mean error, R^2 = .425, $F(1, 11)$ = 7.386, p = .022. Again, mean error is not significantly predicted by the global integration value of the destination building.

3 Conclusions

These results demonstrate that space syntax analysis can be used to predict people's performance on spatial cognition tasks. In other words, the mechanical procedures of space syntax at least partially describe the "cognitive maps" and related spatial knowledge that people learn of an environment. It is the integration of the starting building that predicts participants' performance on the tasks, suggesting that participants' spatial knowledge of the place in which they are asked to imagine themselves is the key determiner of their performance.

This study is limited by the particulars of a single college campus, yet the methods and results used here demonstrates how our spatial knowledge is intimately linked with the design of our surroundings, which lends real-world support to spatial cognition research and suggests that that theoretical work can be of practical use to urban designers.

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Time-frequency analyses of oscillatory activity during

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Abstract. Spatial navigation can be based on different, i.e. the ego- and the allocentric reference frames. For successful orientation in real environments both frames of reference are active and can be used dependent on the requirements of the task. To separate brain electrical activity dependent on the use of the egocentric and the allocentric reference frame we investigated spatial navigation in a desktop-based virtual reality where subjects can be categorized with respect to the preferred use of an ego- or an allocentric frame of reference. Clustering on time/frequency transforms of components extracted by independent component analysis (ICA) revealed similar oscillation patterns in a wide spread cortical network associated with the use of both reference frames. However, differences in frequency modulations in parietal and prefrontal brain areas support the assumption that distinct brain areas subserve the computation of an egocentric and an allocentric reference frame during spatial navigation.

Keywords: Spatial navigation, reference frames, EEG, ICA

1 Introduction

Navigation in space can be based on different reference frames integrating information about the navigator's position, the path traversed and/or landmarks in the environment. Dependent on the reference frame used during navigation the resulting spatial representations differ with respect to the type of information conveyed. Several studies using imaging techniques investigated the neuroanatomical basis of the ego- and the allocentric frame of reference. However, only little is known about the ongoing electrical brain activity associated with the use of either one or the other frame of reference. The time course and pattern of brain activity during navigation might provide further insight in the processes associated with navigation and the functional differences of distinct reference frames.

2 Method

We recorded 128-channel EEG during a desktop based virtual navigation with subjects using either an ego- or an allocentric frame of reference [1], [2]. Subjects had to indicate their position relative to the starting point of the tunnel passages using a homing arrow. EEG-data was decomposed into independent components by means of independent component analysis (ICA) using the open source software EEGLAB [3].

Component power spectra were computed using a moving window average of wavelet spectra and subsequently normalized for between subject comparison by subtracting mean log power from single-trial log power at each analysis frequency between 3 Hz and 50 Hz. After the computation of component spectra, event-related potentials, scalp maps, dipole locations, event-related spectral perturbation, and inter-trial coherence for each subject and trial all components were clustered using a Kmeans cluster algorithm implemented in EEGLAB.

3 Results

Several frequency bands showed task dependent modulations as indicated by clustering on time/frequency transforms of the extracted components. Brain areas associated with the processing of visuo-spatial information revealed desynchronization in the upper and the lower alpha band common to both strategy groups. Superior parietal areas demonstrated stronger power decreases in the theta range when an allocentric reference frame was used. After the turn, the same parietal areas revealed an increase in the upper alpha band for the use of an allocentric reference frame. In addition, frontal brain areas demonstrated increases in theta power during and after the turn in the tunnel passage for the use of an allocentric reference frame. Finally, the retrosplenial area revealed alpha synchronization in subjects using an egocentric frame of reference.

4 Discussion

We identified clusters of time/frequency modulations common to the use of both, the ego- and the allocentric frame of reference. These activation patterns reflected increasing activity in brain areas associated with the processing of visuo-spatial information, increased navigational demands during critical stages in navigation, (imagined) motor processes in the virtual environment, and processes related to overt responses. In addition, we identified clusters revealing significant differences in event-related spectral perturbation dependent on the frame of reference used. Increases in theta power for the use of an allocentric as compared to the use of an egocentric reference frame were observed short before the onset of and during rotational changes. Dipole localization points to an origin of reference frame-dependent theta within in frontal brain areas. Overall, we were able to identify frequency bands associated with the use of distinct reference frames in spatial navigation. Above and beyond common spectral modulations for ego- and allocentric spatial navigation increased theta activity in frontal brain areas was observed when an allocentric frame of reference was used.

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Sex Differences in the Computation of Traveling Distance

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Sex-related differences in spatial cognition have been explored extensively in the literature, which shows that men and women have different spatial abilities. Men usually perform better in many of the spatial tasks carried out during experiments. Surprisingly, however, few investigations concerning sex differences in the computation of traveling distance have been done. In this context, this study explored sex differences in: 1/ Nonvisual reproduction of linear passive traveling; 2/ Nonvisual reproduction of linear active traveling; 3/ Nonvisual and visual distance estimation; 4/ Nonvisual direction estimation.

Participants: Thirty-seven adult men (mean age = 28.1 yrs, sd = 5.1 yrs) and thirty-seven adult women (mean age = 23.1 yrs, sd = 5.1 yrs) participated in the experiment.

Apparatus: On the floor, in the middle of the section in a large corridor, a 25-m white line ran parallel to the walls. The starting point was marked by a 50-cm white line perpendicular to the 25-m line. To the left of the main line, 7 vertical white marks, numbered from 1 to 7, placed from 8-m to 14-m, served as visual cues. All seven marks and numbers were visible from the starting point. Actual traveling distances were limited to 9, 11 and 13 m (i.e., marks 2, 4 and 6). Angles of direction estimation were measured using a plumb line and a graduated metal circle. A wheelchair was used for the passive transfer.

Testing procedure: All participants underwent a 3-phases testing. At the beginning of each phase, a traveling distance was randomly chosen. Both the guide and the blindfolded subject ignored the chosen traveling distance.

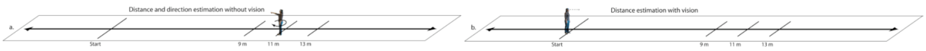
Phase 1: Reproduction of linear wheelchair distance

Blindfolded subjects were transported 3 times in a wheelchair to one of the marks (9, 11 or 13 m), which remained the same throughout testing. Then, subjects were turned around and led back towards the starting point. They were asked to say "stop" when they thought they had reached the starting point.

Phase 2: Distance and direction estimations

Blindfolded subjects were led on foot from the starting point to one of the marks and asked to estimate the traveling distance. Then, they turned around and pointed in the direction of the starting point (a).

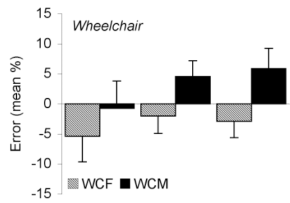
Next, subjects were guided to the starting point, the blindfold was removed, and they had to show which mark they have been led to and to re-estimate the distance that separated it from the starting point (b).



Phase 3: Reproduction of linear walking distance

Blindfolded subjects were guided on foot 3 times to one of the marks (9, 11 or 13 m) which remained the same throughout testing. Then, subjects were turned around and led back towards the starting point. They were asked to say "stop" when they thought they had reached the starting point.

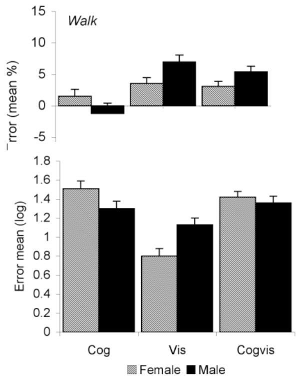
Reproduction of linear wheelchair distance



The performance did not vary throughout trial repetition (F[2,148]=1.25, ns), but comparatively to male, mean female's error was larger (F[1,74]=4.32, p=0.43). Moreover, the pattern's estimation showed that men overestimated traveling distance while female underestimated it.

Reproduction of linear walking distance

No significant sex difference was observed in terms of active distance reproduction (F[1,75]=1.02, ns), as well as in the pattern's estimation of traveling distance.



Distance estimation: Men were significantly more accurate without visual input (F[1,74]=4.06, p=0.048) while women were significantly more accurate in terms of visual-based distance estimation (F[1,74]=9.5, p=0.003).

No sex difference was observed when nonvisual- and visual-based distance estimation data were combined (F[1,74]=0.47, ns).

Direction estimation: Although angular dispersion was weak, Watson-Williams tests on direction estimation showed a significant left deviation in men and a slight right deviation in women. Moreover women were more accurate than men.

Mean arm angle was 355° for men and 2° for women (F[1,74]=7.01, p. < .05).

Body deviation as measured at the feet showed a mean angle of 354° for men and 0° for women (F[1,74]=4.98, p. < .05).

Comments: The results of this experiment showed that men and women differed in the reproduction of passive linear displacements while no sex difference was observed in active linear displacements. Indeed, in the absence of visual input, men were more accurate than women in reproducing linear passive wheelchair traveling distance. However, performance of both men and women did not differ during linear active walking traveling distance. This difference might rely on a variation in decision-making processes allowing selecting a response since consistent underestimation was observed in women when men overestimated the distance traveling.

When blindfolded participants had to mentally estimate the traveling distance, the female error was larger than the male one. But, when subjects were asked to indicate the visual cue corresponding to the traveling distance, the male error was larger than the female one. Finally, pointing to the starting point (0°) after a whole-body rotation showed a larger deviation from 0° in men than in women. Moreover, men showed a consistent left deviation and women showed a slight right deviation.

These results seem to indicate that sex differences in spatial abilities could be rooted in basic mechanisms involved in spatial navigation like path integration. Moreover, they support the hypothesis that men and women differ in information selection used for strategy choice. Our results also suggest that sex influences brain computation of linear distance and this may open some new avenues of research.

Title
WayTracer- A mobile assistant for logging navigation behaviour

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Abstract
Documenting navigation behaviour in real-world settings poses a challenge to experimenters: In addition to logging other task-related observation categories, they often have to mind the subject's position. Real-time logging of observation categories, positions and timestamps with paper and pencil is more than a single person can do reliably. That is why in many experiments, the subject's behaviour is videotaped – at the cost of time-consuming video transcriptions afterwards. For more efficient data logging and -evaluation we developed WayTracer – a software for logging observation data on tablet-PCs. WayTracer allows for real-time data entry by the experimenter who accompanies the subjects during navigation tasks. Both the map of an area and buttons for entering navigation-related observation categories are displayed in the software's graphical user interface. The subject's position is entered by marking the location with the PC's pencil on the displayed map. This method is particularly useful for areas where GPS data are not reliable or available. WayTracer writes the entered positions and other observations into a log file in combination with GPS position data in case they are provided by a connected GPS sensor. WayTracer allows for easy customization of the displayed observation categories. First tests confirmed the usability of the system.

Motivation for designing a mobile logging system
Documenting navigation behaviour in real-world settings poses a challenge to experimenters: In addition to logging task-related observation categories, they often have to mind the subject's position. The real-time logging of observation categories, positions and their timestamps with paper and pencil is more than a single person can do reliably. That is why in many experiments, the subject's behaviour is videotaped – at the cost of time-consuming video transcriptions afterwards. For more efficient data logging and -evaluation we developed WayTracer – a software for logging observation data on tablet-PCs. WayTracer's central innovation is that it combines all data (observations, positions, timestamps) in a single system which is highly mobile and easy to use.

General characteristics of WayTracer
WayTracer allows for real-time data entry by the experimenter who accompanies the subjects during navigation tasks. The whole system can be operated (without using the keyboard) by the PC's pencil with the screen heading upside. Both the map of an area and buttons for entering navigation-related observation categories are displayed. The subject's position is entered by marking the location with the tablet-PC's pencil on the displayed map. This method is particularly useful for areas where GPS data are not reliable or available (e.g., in buildings). WayTracer writes the entered positions and the other observations in a log file in combination with GPS position data in case they are provided by a connected GPS sensor. The subject's last position is shown on the map. In order to reduce cognitive load and errors, each button reminds the experimenter of missing entries. Completed entries are logged with the timestamp, which allows an efficient combination with synchronized video recording as a backup strategy: In case a button (e.g.: "check video") has been configured, the log file provides the exact timestamp of an observation that does not fit with one of the predefined observation categories. Thus, the videotape can be inspected selectively, just concentrating on the corresponding time interval. WayTracer's graphical user interface can be adapted easily within minutes: The displayed observation categories and maps are customized by editing the concise configuration files written in XML.

Exemplary configuration of WayTracer
Figure 1 below shows our configuration of WayTracer for the observation of human map usage while navigating on a campus area. One focus of the experiment is an exact measurement of total map inspection time and the related positions of our subjects. Accordingly, the second button on the left is a toggle button (studies map/map removed). This facilitates the handling while the experiment and the extraction of map inspection times from the log file. Other buttons log self-localisation-activities, the subject's status or whether the subject has really arrived at a given destination – or just wrongly believes so.

First testing of the WayTracer system
First tests with six subjects confirmed the stability and usability of the system.

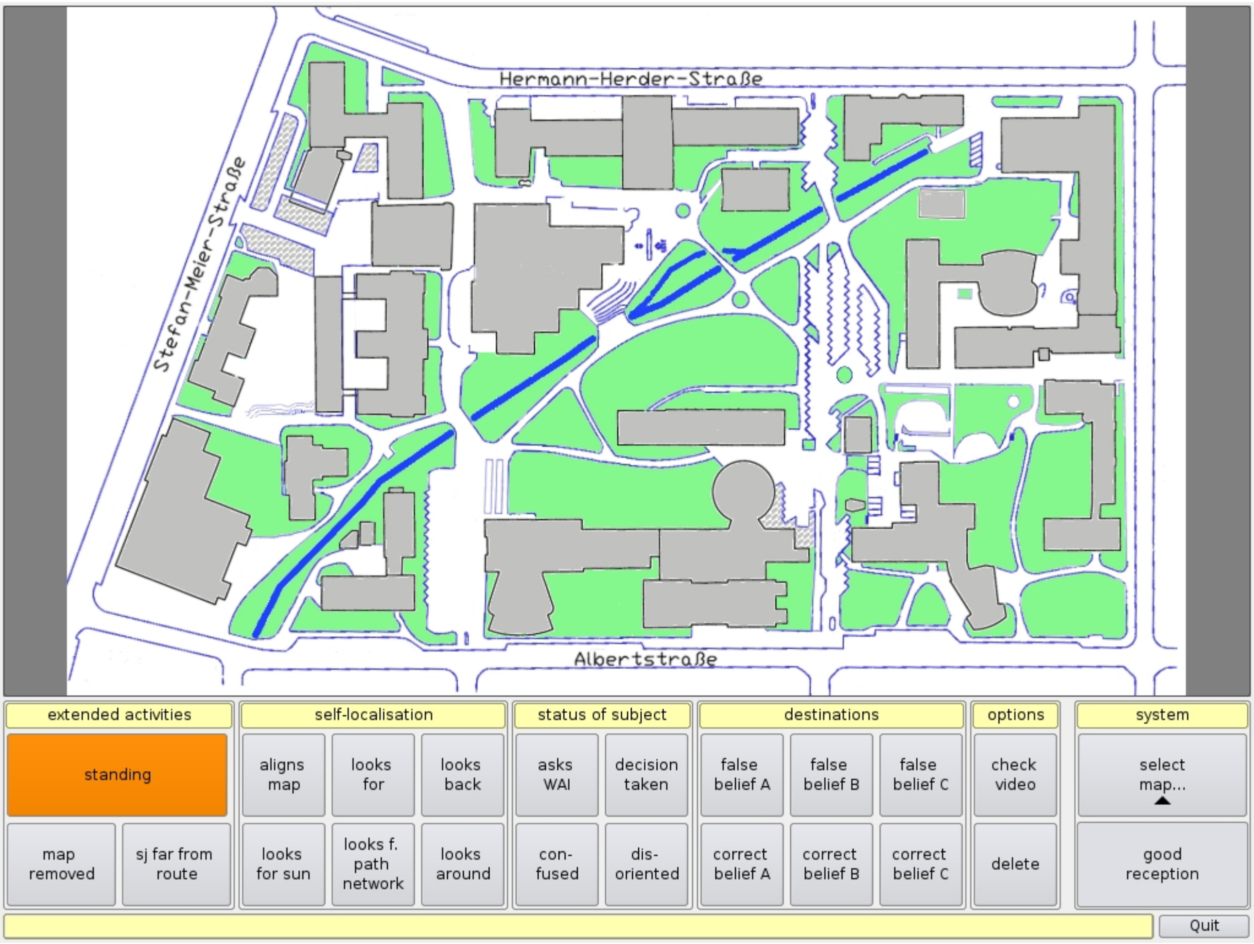
Future extensions of WayTracer

We are planning a replay mode to visualize the data of log files. Other modules will aggregate data across subjects and display frequencies of events (e.g., by a density graph) or prepare the data for statistical evaluation.

Selected technical details

- WayTracer was written using freeware/open source software and is independent of GIS data or GIS software
- WayTracer was programmed in C++, with a graphical QT™-extension. The configuration files are written in XML for easy customization by persons unexperienced in software programming
- Operating system: LINUX
- Tablet-PC: IBM X41 Thinkpad™ (screen: 12,1 inches)
- GPS sensor with 16-channel Nemerix chipset. C++ Nmea-parser with trigonometrical positioning algorithm

Figure 1: Screenshot of WayTracer's configuration for the observation of human map usage while navigating on a campus (upper part: simplified map of campus)



Dynamic Aspects of Interaction in Wayfinding Tasks

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1 Introduction

Wayfinding is a dynamic activity, and significant changes can occur during the course of a specific task. Wayfinding involves a sequence of plans and decisions as a dynamic process [1, 2]. During a task, wayfinding assistance can be provided in real-time via a mobile device. In order to understand how people carry out wayfinding tasks it is not only important to know specific aspects of the cognitive process but also how the cognitive task is managed as a series of interlinked or even simultaneous activities. In this paper we will focus on the dynamic interaction between the human wayfinder, the wayfinding environment and the different types of spatial information accessed via a mobile device. We outline a model which provides a framework for investigating the dynamic aspects of interaction and we then describe and discuss an empirical study which seeks to implement this framework.

2 Interaction Model

In order to study the dynamic aspect of interactions between environments, individuals and devices in wayfinding tasks, a model (Figure 1) is proposed as a framework for investigating such dynamic interaction. In this model, both environments and wayfinding assistance are regarded as dynamic sources of information during the interaction. Individuals, as another facet of the model, can access and acquire wayfinding assistance information in real-time from a mobile device; and they can also gain information directly from the environment.

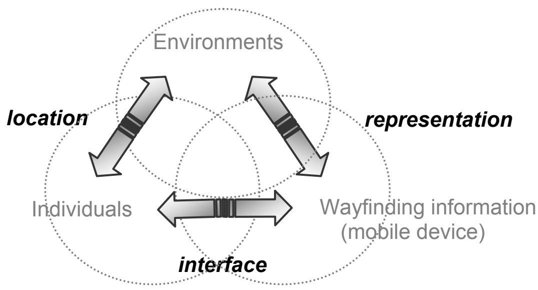

Figure 1. A Dynamic Interaction model

In this study, we have further identified three key dynamic aspects of the interaction (see Figure 1): location, interface and representation. ‘Location’ refers to the interaction between individuals and environments; ‘interface’ refers to the interaction between individuals and devices; and ‘representation’ is the interaction between device and environment. These three aspects are interlinked in wayfinding activities, and can be regarded as being dynamic in relation to one another.

3 Applying the Model

Methods: The three main elements in the model were implemented in a wayfinding experiment in order to study the three dynamic aspects. Virtual Reality urban models provided the wayfinding environment, wayfinding assistance was simulated using a mobile device (PDA) and there were 27 participants (15 male, 12 female). A task-based wayfinding experiment was set up, requiring the participants to find five destinations in sequence (see Figure 2), in an unfamiliar urban environmental setting. Participants could access wayfinding assistance information whenever and wherever they desired via the mobile device. They could freely choose between text or voice route instructions, schematized maps with landmarks and detailed localized maps.

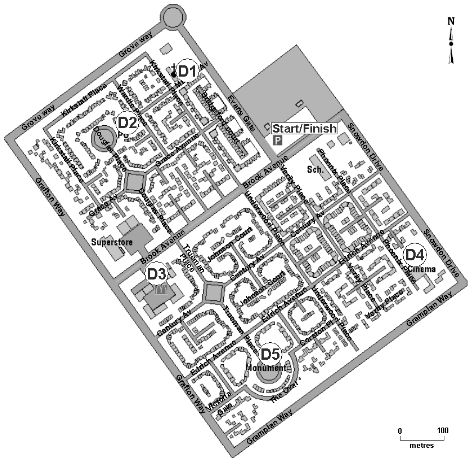

Figure 2. The test environment

Route	percent length
1 - Start to D1	12.04
2 - D1 to D2	17.17
3 - D2 to D3	17.07
4 - D3 to D4	34.11
5 - D4 to D5	19.60

a)

Route	info-route	info-Smap	info-Dmap
1 - Start to D1	38	78	26
2 - D1 to D2	63	96	50
3 - D2 to D3	34	91	29
4 - D3 to D4	54	150	47
5 - D4 to D5	32	71	32

b)

info-route: route instructions used
info-Smap: schematized map used
info-Dmap: detailed localized map used

Table 1. Types of information used

Results: In this task-based wayfinding experiment, the types of information participants required were recorded as: the type of information used, the number of times the information were accessed. The positions where the information was accessed were also recorded. In order to study the relationship between the environment and the information assessed, the position data and information access data were integrated. Table 1a) shows the percent length as each route’s proportion of the total distance from Start to D5.Table 1b) shows the total number of times each type of information was used for each of the five routes. Chi-Squared statistics were calculated for each type of information with null hypothesis of no significant difference between each of the five routes. Null hypothesis can be rejected ($p < 0.01$)

for all three types of information. These show that there are differences in the frequency of accessing information for the five wayfinding routes. Furthermore, individuals' wayfinding tracks were studied qualitatively. Two are presented here. Both had their own clear overall preference for one form of representation (Figure 3). However, during the wayfinding task, the participants' choice of information representation changed. This occurred mainly at key decision points such as road intersections and beginning of routes. The participant shown in Figure 3 (a) has route instructions preference and used route information for most of the journey but switched to the overview schematized map at a roundabout and at the start of two routes. Similarly the participant shown in Figure 3 (b) switched from the localized map preference to an overview schematized map at the start of most routes.

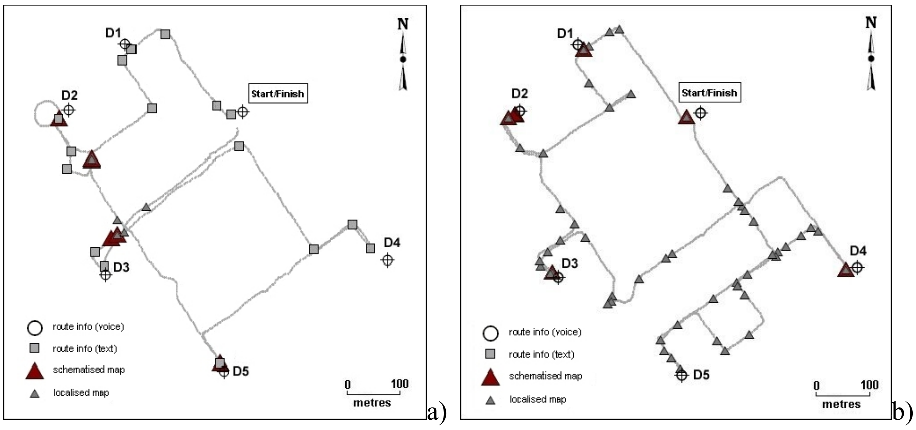

Figure 3. a) Participant with route instruction preference
b) Participant with localized map preference

4 Discussion

In this study, we have focused on the dynamic aspects of representation in the interaction, which are investigated through the types of information participants required and accessed in assisting wayfinding tasks. For each of the five routes, the frequency of individuals' interaction with wayfinding information significantly changed. The environmental differences in each route affect the number of times that individuals sought information for assistance in the wayfinding tasks. The changes in the environment also affect the type of information accessed. When the location aspect changed, such as when participants were at intersections or route start points, individuals switched between different forms of representation for more information to make decisions. The types of assistance information individuals select varies according to changes in the environment [see also 4, 5], which highlights the underlying link between the environmental structure and the requirement for spatial information. This interlinked relationship between individuals, devices and environments emphasizes the need for an integrated framework to study the dynamic aspect of interaction in wayfinding tasks.

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Remembering Object Position in the Absence of Vision: Egocentric, Allocentric and Egocentric Decentred Frames of reference

I. C. Mammarella, E. Coluccia, R. De Beni & C. Cornoldi

Introduction

According to Carlson-Radvansky and Irwin (1994), to represent the locations of objects in the environment, we can use different frames of reference. The frame of reference establishes a correspondence between the mental representation of space and the physical or perceived space. A reference frame is a coordinate system in which locations can be specified along different dimensions. Two main reference frames are the egocentric and the allocentric. In the former, the spatial relations are coded with reference to the self and to the observer's body, in the latter spatial relations are coded independently by the self, on the basis of coordinates external to the body. Even though the distinction between egocentric and allocentric is largely accepted, additional representations may also exist. Grush (2000) observed that the allocentric term can be used with different meanings and claimed that there are at least four different types of situations associated with "allocentric" representations: a) Egocentric space with a non-ego object reference point. b) Object-centred reference frames. c) Virtual points of view (i.e. Maps). d) 'Nemocentric' maps. From the perspective adopted in the present study the first two instances appear of particular interest.

A problem in these distinctions is that they are based on representations derived from visual experience and it is not clear if they are applicable to cases in which the body is not supported by vision. In this instance is the distinction between an egocentric and an allocentric representation still valid? What features critically define the allocentric representations?

To test for these effects in the present study, a non-visual test, named "Blind Exploration Test" (BET), was employed. 3 experiments test whether it is possible to distinguish among three reference frames (a) Object-centred reference frame (b) Egocentric space with a non-ego object reference point (i.e. Decentred Egocentric), as hypothesized by Grush (2000) and (c) allocentric representation.

Method

Participants. 16 participants in Experiment 1, 20 in Experiment 2 and 20 in Experiment 3

Material.

The participants were presented with a square 50x50 cm. cardboard with fixed reference points. In the middle of the lower perimeter of the 50x50 cardboard a small coin was glued. The coin represented the starting point for the exploration and for the *centred egocentric* test condition (Home). At the centre-left side of the cardboard another small coin was glued. This point was labelled School and was the starting point for the allocentric condition. In every trial the participants touched three objects of similar shape and dimension with their right hand, guided along the corresponding pathway by the experimenter. The first object to be explored was point A. The second object was point B. The third point was point C (see the Figure below).

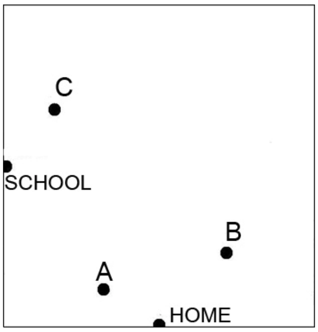
Procedure.

The participants (all right handed) were instructed outside the experimental room. After the instructions, they were blindfolded and were accompanied to the experimental room. Participants were required to remember the original positions of the three objects placed on the square cardboard. Because of the participants could not use external visual cues, as they were blindfolded, then we expected their reference points to be those given haptically by the experimenter.

Exploration phase. The participants were seated at the Home position and the experimenter guided their right hand along the perimeter of the cardboard so that they made a complete clockwise exploration. Then, starting from the Home point, the experimenter guided their right hand toward each object, moving it linearly from one location to the next, according to the following sequence: H-A-B-C-A-H. After the exploration phase, a retention interval followed. During this interval, the participant was asked to stand up, turn 90° and sit on the chair facing the H point (centred egocentric and decentred egocentric condition) or to stand up and sit on the chair facing the S point (allocentric condition). During this phase the experimenter removed the three objects (A, B, C) from the square cardboard on the table. Once seated, the test phase started.

Test Phase. Centred Egocentric condition: starting either from the H point participants were asked to indicate the original positions of the objects in B and in C (Exp. 1; Exp. 2).

Decentred Egocentric condition: participants remembered the positions of the objects in B and in C starting with their hand in the S location (Exp. 2; Exp. 3).
Allocentric condition: participants, turning their body 90 degrees to the S location, were asked to indicate with their finger the original positions of the objects in B and in C (Exp. 1; Exp 3).



Results

Experiment 1: comparison between Centred Egocentric and Allocentric conditions. A within subjects 2 (allocentric *vs*. centred egocentric) x 2 (point B vs. point C) ANOVA was computed, based on linear distance errors. Results revealed a significant difference between the Allocentric and the Centred Egocentric performance [$F_{(1,15)}$= 5.95, p< .05, η^2=.30]. As expected, the mean error was greater in the allocentric condition.
Experiment 2: comparison between Centred Egocentric and Decentred Egocentric conditions. Results showed a significant difference between the decentred egocentric and the egocentric performance [$F_{(1,19)}$= 13.20, p< .001, η^2=.42]. As expected, the number of errors was higher in the decentred egocentric condition. Also the main effect of type of point was significant ($F_{(1,19)}$= 7.03, p< .05, η^2=.28) with C errors higher than B errors.
Experiment 3: comparison between Decentred Egocentric and Allocentric conditions. Results revealed a main effect of condition ($F_{(1,19)}$= 16.22, p< .001, η^2=.47), demonstrating that the number of errors was higher in the allocentric condition.

Conclusions

Taken together, the results of the three experiments showed the possibility of a distinction between the Centred Egocentric, the Decentred Egocentric and the Allocentric frames of reference. The distinction between the Centred Egocentric and the Allocentric frames is well documented in the psychological literature (Klatzky, 1998; Holdstock, et al., 2000; Mou et al., 2004; Feigenbaum & Morris, 2004; Burgess, et al., 2004). However until now this distinction was generally studied with vision and in the context of large extrapersonal environments. The present study shows that a similar distinction also applies to the peripersonal space explored haptically.
A further finding in the study is the existence of a third representation that is the Decentred Egocentric. Such a representation matches with the notion of *Egocentric space with a non ego object reference point* proposed by Grush (2000), which, to this date, had no known empirical evidence. Consistent with Grush's theory, the present findings show that the Decentred Egocentric representation is neither egocentric nor allocentric but it is mid way between the egocentric and the allocentric representation.
The decentred Egocentric representation can be considered egocentric because the position of the body is the same both during the exploration and the test, but it is also in some respects similar to the allocentric, since the reference point is not centred on the body. The Decentred Egocentric representation could also be seen as a kind of "missing link", which directly connects the Centred Egocentric to the Allocentric frames of references.

Title

From description to spatial mental model: how change happens in mental model in function of text perspectives and individual differences.

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Introduction

An environment can be experienced by a person listening to verbal descriptions from different perspectives. Does the learning perspective influence the resultant spatial mental representation? Research has provided different, and sometimes contrasting, answers to this question. In fact, some studies have shown that learning text in different perspectives can produce a dependency from the learning perspective (e.g., Perrig & Kintsch, 1985; Pazzaglia, et al., 1994), but others have found that spatial representations derived from either route or survey descriptions are perspective-free (e.g., Taylor & Tversky, 1992). Thus, the role of perspective in determining the properties of a spatial mental model remains unclear. Maybe other factors – alone or interacting with perspective – may influence the properties of spatial mental representations. One could be individual differences. For example, some studies found that males (Perrig & Kintsch,1985) and subjects with high spatial-visualisation abilities (Bosco et al., 1996) are less dependent from the learning perspective.

Shelton and McNamara (2004, Exp. 1) investigated spatial memory of survey and route descriptions by the use of scene recognition task from different imagined heading. Results showed that participants tended to be best at the type of recognition consistent with their learning condition (i.e. best performance in survey test after learning of survey text). However, the authors used a recognition task based on picture images (visual modality) to test the spatial memory. This could have modified the spatial representation transforming the original mental model in several images dependent of the learning perspectives. If in using spatial measures (spatial pointing task) we find a dependency of text learning perspective, we may confirm that this effect it is not attributed to the visual input (see Shelton & McNamara; 2004) and the verbal modality (see Perrig & Kintsch, 1985) used in the test phase.

The purpose of present study is to compare spatial mental representations derived from survey and route descriptions using spatial pointing tasks. We expect to find more accurate and faster judgments in aligned than in misaligned condition. Furthermore, we suppose that the use of allocentric strategies permits to build up a good spatial mental model less dependent of the learning perspective, and less susceptible of alignment effect.

Method

Participants. Forty undergraduates from the University of Padua, 20 high-allocentric (HA) and 20 low-allocentric (LA) caracterised by high and low preference for allocentric strategies of spatial representation, respectively. The selections was based on the scores that participant assigned to the sub-scale “Cardinal Point” of the Questionnaire of Spatial Representation (Pazzaglia et al., 2000). The HA had greater performance in the Perspective Taking Task (Hegarty & Waller, 2004) and in a version of Road-Map test of direction sense (Money et al., 1965) than the LA, while they have the same reading comprehension ability.

Material.

Spatial Texts. Two spatial texts of an open environment (a Zoo), 10 sentences long, in survey and route perspectives were constructed. The order of landmark presentation in route description is presented in figure 1; the survey description presents the landmarks from south to north.

Spatial Pointing Task. 66 pointing task items were prepared following these criteria:

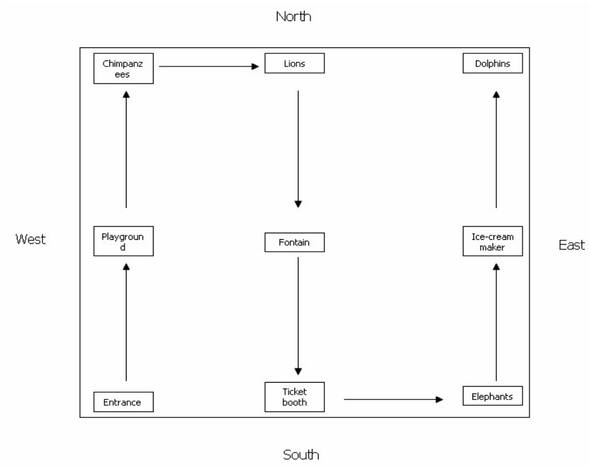
1. (1a) Pointing task aligned both with route and survey texts (0°) including the segments “Entrance-Playground-Chimpanzees” and “Elephants-Ice-cream maker-Dolphins”; (1b) Pointing task misaligned (180°) with survey and route texts including the same segments as in 1a, but in the opposite directions (“Chimpanzees- Playground-Entrance”, “Dolphins- Ice-cream maker-Elephants”);
2. (2a) Pointing task aligned with the survey (0°) and misaligned with the route (180°) texts, including the central segment “Ticket booth-Fountain-Lions”; (2b) Pointing task aligned with the route (0°) and misaligned with the survey text (180°), including the same central segment as in 2a, but in the opposite direction;

The landmarks to point could be at 0°, 45°, 90° and 180°.

Design. Spatial Text as *between-participants* factor (survey and route texts).

Procedure. Participant listened twice either to a survey or a route text. At the end of the second listening they performed the pointing tasks on a pencil-paper version.

Figure 1. Environment used for survey and route texts (the arrows showed the path of route text).



Results

It is performed two Analysis of Variance 2 (group: HA vs. LA) x 2 (text: survey vs. route) x 2 (Pointing task: 1st analysis: 1a vs. 1b; 2d analysis: 2a vs. 2b)

1) Pointing task aligned vs. pointing task misaligned with both route and survey texts.

Analysis of variance showed that participants were more accurate ($F=17.88$ $p \leq .001$) and faster ($F= 6.07$ $p = .019$) in aligned than in misaligned judgments. Furthermore, HA group was more accurate ($F= 17.88$ $p \leq .001$) and faster ($F= 5.43$ $p = .025$) than the LA group. In the accuracy, we found an interaction Pointing X Group ($F= 8,12$ $p \leq .01$), and a tendency of interaction Pointing x Text ($F= 3.66$ $p = .064$) and Pointing X Text X Group ($F = 2.11$ $p =.089$). Post hoc comparisons showed that LA group had a better performance in the aligned than in misaligned conditions $t =3.39$ $p \leq .01$ (particularly with the survey text), while HA group had a similar performance in both conditions $t < 1$.

2) Pointing task aligned with survey (0°) and misaligned with route (180°) texts vs. pointing task aligned with route (0°) and misaligned with survey text (180°).

The analysis of variance showed a better accuracy for the central segment "Ticket booth-Fountain-Lions" direction than "Lions- Fountain-Ticket booth" direction ($F = 15,87$ $p \leq .001$); furthermore, the HA group had a general better performance than the LA one. The analysis of response times showed a tendency of interaction Pointing X Group (.075) in which the HA group was faster in "Ticket booth-Fountain-Lions" direction rather than the opposite direction $t = 2.41$ $p= .026$, while LA did not differ ($t < 1$). No significant interactions with Texts were found.

Conclusions

Results confirmed that HA participants were in general faster and more accurate that LA participants. When spatial information are coherent between route and survey descriptions (point 1) LA were lesser accurate in misaligned than aligned spatial pointing task; while HA are equally accurate for both types of pointing tasks. When spatial information are incoherent between survey and route descriptions (point 2) HA participants were more accurate in both conditions than the LA but HA were slower in the imagined heading from north to south ("Lions-Fountain-Ticket booth") than the opposite one, while the LA were not. These results suggest that differences in spatial mental representations are less imputable to spatial text perspective and more to spatial orientation preference: the use of allocentric strategies permits to build up a good spatial mental model less susceptible of alignment effect

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An Implementation of the SRM-Model

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Abstract. Computational models for human spatial reasoning must be cognitively adequate, precise, applicable, and usable for and usable by psychologist. For that reason, a formally and theoretically well-founded model of spatial reasoning - like the SRM [Ragni *et al.*, 2005] - must be easy to handle in a clear user-friendly design. The purpose of this work is to present such an implementation. This implementation reflects all theoretical and empirical findings (from the spatial focus to the complexity measure which is able to explain many difficulties in spatial relational reasoning) but also offers a broad area of adjustable parameters (e.g. different cost units for cognitive operations). The aim of this implementation is to provide a computational working base to test theories and different possible approaches.

1 Cognitive Modelling

The human mind is one of the most fascinating and most complex research areas in cognitive science. Nonetheless, our ability to deal with complex spatial information in everyday life, like route descriptions etc. has not yet fully investigated. Different to most science areas where spatial information is normally represented quantitatively, e.g. by cartesian coordinates, humans mostly use a qualitative description together with a spatial mental representation for describing spatial entities. Take for instance the following set of premises: {'The computer is in front of the monitor', 'The monitor is on the table.'} and a question: 'Which relation holds between the computer and the table?'.

Although this description is less exact than a quantitative one, it may be useful to focus on essential details and to easily remember or reason about it. From cognitive science it is well known that human deduction on spatial information is a three phase process: mental model construction out of given information (premises), inspection of new relations, and model variation for conclusion checking. Many experiments have shown that individuals tend to construct similar models for a given problem. The construction of such *preferred models* follows economic principles as well as learned common practices [Rauh *et al.*, 2005]. The aim of our implementation is to build a theoretically plausible and empirically adequate software for reasoning with spatial mental models. It should correspond with human generated models as well as in intermediate steps of the model generation, to explain human errors in spatial reasoning.

2 Implementation

The implementation of the SRM machine is based on an improvement of the computational model proposed in [Ragni *et al.*, 2005]. Moreover the implementation had to face several design problems, which naturally effects the model. Questions about data structures, algorithmic complexity and parameters are of great importance to simulate the model construction by using a spatial focus, which performs read, write, move and annotation operations. For a full description see [Ragni *et al.*, 2005]. One of the most important parts, dealing with indeterminate information, is realized by storing the annotations in an (optionally) capacity-limited list data structure, which can be psychologically explained by the existence of the phonological loop. Different deletion strategies, e.g. FIFO, can be selected to provide a psychological research framework. The annotations are used to generate other possible models in the variation phase. Since the *processing* consists mainly of focus operations, the difficulty of tasks depends on the number of focus operations. It is possible to assign different costs to the focus operations, determining different complexities. The program has a graphical interface (GUI) which allows to setup new models and display the model generation using OpenGL. Model setup is done by specifying a set of premises in the GUI or by reading them out from a file. In the computational model, the spatial representation is done in an infinite 2-dimensional grid, where in the implementation objects are placed in a continuous structure (internally represented by a cartesian system). The object placement is done by applying different processing operations on the premises. It is also able to handle additional knowledge for already processed objects by applying model variation steps. The model variation itself consists of an algorithm that recursively exchanges neighbored objects.

3 Discussion

The SRM implementation is able to simulate the model processing of the computational SRM model. By assigning several parameters it is possible to select and test different approaches from focus operation costs and memory management strategies, which then can be compared to human results. The aim of our work is to provide a framework for testing different cognitive approaches before conducting experiments and predicting experimental results. Throughout the implementation process we figured out that the inheritance of annotations is a source for reasoning complexity. There are several other cognitive architectures which implement spatial reasoning, e.g. Casimir, ACT-R and Soar. ACT-R and Soar follow a rule-based approach. We are also able to simulate an implementation of ACT-R by assigning specific time costs for operations and to get the same predictions as in empirical experiments. Future work will include an integration of the model in the Casimir architecture to model reasoning in large-scale space and reasoning with mental images. This could allow to include human long-term memory where definitions of relations can be stored.

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Influence of Spatial Strategies on the Encoding of Spatial Information in a Virtual Navigation Task: an Electrophysiological Investigation.

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Abstract. The aim of the present investigation was to analyse information processing by means of behavioural and electrocortical parameters underlying spatial navigation. Subjects had to keep up orientation during desktop simulated passages through tunnels with straight and curved segments. After the passage subjects were asked to indicate their momentary position by adjusting one of two reaction formats: in the homing vector format subjects had to point a homing vector from the end-position to the starting point, in the start-end format subjects had to indicate the end-position with respect to the origin of the path. In a first experiment reaction formats were randomised and unpredictable on a trial, whereas in a second experiment the reaction formats were blocked. Even though identical visual flow information was given only one group of subjects, referred to as 'turners', adjusted the homing vector as if they updated their cognitive heading during the turns whereas the other group, 'non-turners', did not. In the start-end format an allocentric reference frame was induced and both strategy groups performed the task using identical coordinate systems with comparable accuracy. An FFT-analysis during the encoding of spatial information revealed distinct activation patterns for turners and non-turners at lower frequency ranges when reaction formats were blocked.

1. Introduction

In a desktop simulated passage through tunnels with one or two turns subjects had to maintain their orientation during the passages through the environment. After the passage subjects were asked to indicate their momentary position by adjusting one of two reaction formats: a) either adjusting an arrow from the end position to the starting point or, b) adjusting an arrow so that it pointed to the end-position with respect to the origin of the path. Both reactions were based on the identical reaction format, a homing arrow, which could be adjusted based on an ego- or an allocentric coordinate system. Even though identical visual flow information was given during the passages through virtual tunnels one group of subjects, referred to as 'turners', adjusted the homing vector as if they updated their cognitive heading during the turns [1]. The other group, referred to as 'non-turners', did not update their cognitive heading during stimulus turns and therefore overestimated the homing vector by the amount of the turning angle. When indicating the end-position with respect to the tunnel's starting point an allocentric reference frame was induced and both strategy groups reacted using the identical coordinate system. The pointing accuracy of both strategy groups was tested in two different conditions in subsequent experiments. In the first experiment, reaction formats were randomised and unpredictable on a trial. In the second experiment the reaction formats were blocked starting with the homing vector in the first experimental block and the start end-format in the second block. Performance differences between the strategy groups were expected only in the homing vector format. Furthermore, different patterns of electrocortical activation were expected for turners (preferring an egocentric reference frame) when the reaction formats were blocked as compared to the mixed presentation of both reaction formats in one experiment. In the latter condition both frames of reference should be active during virtual navigation whereas only one reference frame could be used for adjusting the homing vector in the blocked condition.

2. Method

Material. The first and the last segment of each tunnel were always straight. Tunnels were of constant length and included one or two turns of varying angledness. The same tunnels were used for both reaction formats.

FFT-Analysis. An FFT analysis with overlapping moving windows was calculated separately for each segment. An individual baseline calculated for a resting period was subtracted from the power spectrum of each segment.

3. Results and Discussion

Non-turners' performance was comparable for both reaction formats, whereas turners performed significantly better adjusting the homing vector. Pointing accuracy of both groups differed only in the homing vector format, with turners being more accurate. For the analysis of electrocortical activation desynchronisation in the alpha band was used [2]. Over occipital regions an effect of the subject's preferred strategy was present only in the second experiment, where the strategy interacted with the reaction format. Turners showed stronger right-hemispheric desynchronisation during blocks with the homing vector as compared to the start-end format. In contrast, non-turners revealed higher desynchronization for the homing vector task at midline and left occipital leads. As expected, the presentation of randomized vs. blocked reactions influenced the pattern of brain electrical activity which is attributable to differences in the underlying information processes. Furthermore, distinct oscillation patterns were found for turners when the reaction format was blocked. The results imply that turners compute and use only their preferred egocentric frame of reference when the reaction is to adjust a homing vector. In contrast, when the reaction format forces turners to react within an allocentric frame of reference both reference frames, the ego- and the allocentric one, are computed. Against the prediction, non-turners also showed different activation in the two reaction formats, even though they used the same frame of reference (allocentric) for both reaction formats.

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A Sensorimotor Representation used by Humans and Agents Navigating in Virtual Reality

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Introduction

We investigate the hypothesis that the main representation which underlies human navigation is not static and map-like, but is of an inherently sensorimotor nature, i.e. results from a combination of sensory features and motor actions. This hypothesis is already supported by recent results in psychology and neurobiology, which indicate that the traditional strict separation of sensory and motor systems is no longer tenable. Here we present further support from a behavioural study in a VR environment, in which we compared the navigation performance of human observers under two conditions. Either the VR environment is physically consistent and can hence be represented in a map-like fashion, or it is physically inconsistent and does not allow for such a representation, at least in an accurate manner. The performance is not influenced by this difference, suggesting that a map-like representation is not the major basis of human navigation. The alternative concept of a sensorimotor representation is currently tested in a simulated agent navigation system (Schill et al (2006) Cogn. Process , 7:90-92).

Methods

In order to pursue the idea of a sensorimotor basis of navigation, we must first rule out the null hypothesis that human representation of spatial configurations has essentially a static map-like characteristic and that people create an “image-like” mental map of the environment. Therefore, physically impossible environments in Virtual reality – environments that should not be able to be mentally envisioned correctly in a map-like fashion – are used. Experiments were conducted with human subjects in which navigation tests were performed including an additional forced choice phase (16 subjects). Subjects: 7 male, 9 female. Ages: 21 – 44 (all are randomly chosen). Nine environments were presented with one exploration cycle and three navigation tasks per environment (4 exploration/navigation tasks per environment, 36 total per session). The presentation order of the environments was random, but the same order was used for each subject. Environments were presented via a screen-projected perspective 2D image (screen: 2.5 meters and 3 meters; image: 1.5 meters by 2 meters). Subjects sat 2.2 meters back from the screen, navigating with a joystick.

Subjects explored each environment until they felt that they knew and understood the layout. There were then navigation tasks for the environment just explored in which the subjects' starting location was changed (first point *B*, then *C*, and finally *D*). They were asked to take the shortest path, in distance, from their starting location to the picture that was on a wall in the environment. The locations of these starting points were situated so that in inconsistent environments, subjects had to cross a metrically impossible section when taking the shortest path. There was only one picture in seven of the environments while two environments contained two pictures each. Note taking was allowed during the experiment as a memory aid for the forced choice experiment.

In the forced choice test, two images were shown side-by-side in a computer window; one image was of a metrically inconsistent environment and the other of a metrically consistent environment. There were also catch trials showing two images of consistent environments. The image pairs were presented in a random order. Subjects were asked to choose the inconsistent environments. Finally, subjects were given a short questionnaire to complete. An entire session required 1-1.5 hours.

Description of Environments

The layout for most environments was rectangular: four corners, four hallways, with a circular and continuous floor plan, with a set of landmarks (benches, stools, pillars, vents). All walls had a regular vertical stripe pattern textured onto them; the wall colours were different for each environment. The simplest consistent environments were rectangular, with two sets of equal length sides, respectively, and with 90º angles at each corner. Other consistent environments maintained the equality of side lengths, but their corner angles varied from the 90º.

Inconsistent environments diverged in two ways: lengths of halls and sizes of corner angles. Fig. 1a illustrates how hall length can vary in these environments. The environment depicted is completely enclosed and navigable, but notice that the angles of the corners are all 90º, yet the lengths of the respective halls do not match. This inconsistency was subtle in some cases, but often the lengths of the sides would differ to a significant degree.

Some environments were altered so that their angles were exaggerated to a physically impossible degree, illustrated in Fig. 1b. It was possible to have numerous obtuse or acute angles within a single environment so that the total of the angles either exceeded or fell short of the normal 360º. Most environments had a quadrilateral structure, but we also included a “triangular” environment (in the sense that there are three connected hallways). Fig. 1c shows an example with individual corner angles of 90º each (sum of angles = 270º).

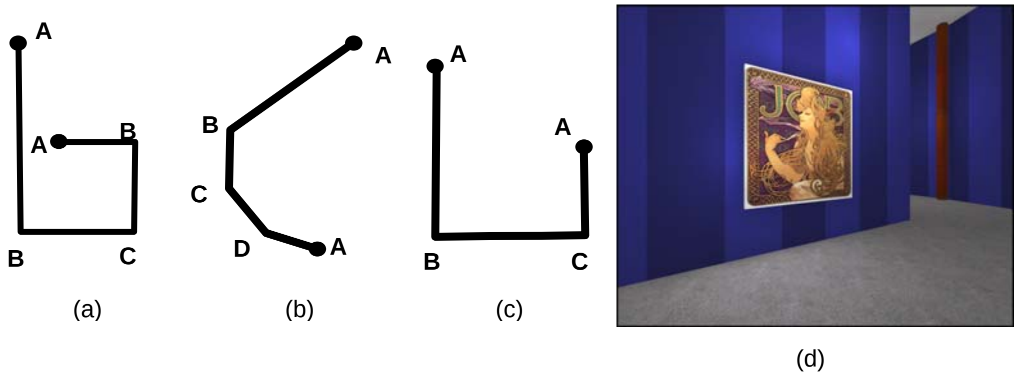

Fig. 1. It is impossible to draw these configurations as closed figures in a two-dimensional Euclidean space, but in virtual space they are closed and the two points labeled as A in each figure are identical to each other. Note that (a) and (b) have quadrilateral and (c) has triangular structure (d) VR environment.

Results

Initial examinations of results led us to believe that metric properties of an environment were not of a high order of importance. It seemed that the role of views, rough action, and landmarks all trumped the metric elements of environments in terms of importance.

For the navigation tasks, a vast and distinct majority of subjects navigated along the shortest route to the picture. As each environment had 3 navigation tasks, it was successfully navigated if 2/3 tasks were performed correctly. Of the 144 total environments encountered by subjects (9 environments, 16 subjects), 138 were navigated successfully and 6 unsuccessfully. Amongst consistent environments, 60 were successful and 4 unsuccessful; for inconsistent environments 78 were successful and 2 unsuccessful. There was no significant difference between navigation in consistent and inconsistent environments (Cochran's Q_ = 6.26, $p > 0.6$), illustrating that subjects were able to successfully navigate all environments equally well regardless of layout.

The forced choice results showed three clear tendencies amongst subjects: those not able to identify inconsistent environments, those able to identify some, and those who identified them consistently. Excluding catch trials (6 pairs), there were 6 subjects who identified less than 50% of inconsistent environments (10-45% correct), 5 subjects who identified between 55-65%, and 5 subjects who identified between 70-100%. While there is more information to be extracted from this test, it is clear that a majority of subjects while able to successfully navigate in all environments, were not able to identify which environments were metrically impossible.

Together, these results have provided initial evidence that map-like representations are neither used directly for navigation nor built-up for other purposes. What kind of representation is then established and how is it used for navigation? As mentioned sensorimotor features (features integrating actions and sensory information into a common framework) appear more suitable for a model of the human representation of the environment. We hence plan additional VR experiments to obtain more detailed information about the role of these sensorimotor features in human exploration and navigation. We also started with the design of a hybrid spatial exploration architecture for navigation based on sensorimotor representation. This architecture is implemented in a simulated mobile agent that operates in a virtual environment. From these simulations we expect not only hints for better understanding and testing of human navigation, but also ideas for the design of artefacts with human-like navigation skills.

Exploring the Experience of Path Networks

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1 Motivation and hypothesis

Despite individual distortions in the mental representations, people familiar with the environment can successfully communicate spatial knowledge in route directions. The hierarchical organization of this knowledge in mental representations is reflected in hierarchical route directions and place descriptions [1, 2]. Wayfinders—hearers are able to adapt the information received from direction givers—speakers, and match it to their own mental representation, grounded in a different hierarchy. This may be possible because the two hierarchies are created through similar processes, and thus have similar structure.

It seems that a part of the environmental knowledge is shared, at least at coarser levels of granularity, by the majority of locals. This shared knowledge is assumed by the speaker in a communication situation. As Schelling showed in his work on strategies in communication [3], prominent objects or locations are used as references in tacit communication. In order to create route directions with a variable level of granularity [2], prominent parts of the street network must be identified.

Our hypothesis is that we can quantify this prominence and hierarchically rank streets, reflecting the likelihood of the shared experience, through measures of network connectivity. Our goal is the identification of connectivity measures that will reflect the experience of space of the wayfinders, and thus will provide a plausible quantification of network elements' prominence.

2 Method

We use *named paths* [4, 5] as basic analytic elements of the street network, referred to in route directions. Degree, closeness and betweenness centrality were analyzed, starting from simple regular graphs, consecutively modified by the introduction of shortcuts and distortions. Global and local properties of the measures, as well as the change of their values after the introduction of irregular elements, were analyzed. The emergence of the hierarchy through experience driven by likelihood of usage was considered to assess the plausibility of the results.

Betweenness centrality was identified as a good candidate for explaining the experiential hierarchy of urban networks. It quantifies the proportion of shortest paths a graph element lies on. With the increasing number of trips performed by a wayfinder in city, the likelihood that betweenness approximates well the agent's experience of the urban environment increases. As the size and layout of the network influences the values of betweenness, it is the relative difference between the values within a network that reflects the variation of prominence.

3 Experiment

The analysis of the city of Melbourne, Australia was performed to test the path hierarchy revealed by betweenness centrality on a larger scale. Melbourne has a distinct regular grid pattern in its center and a system of streets which reach radially beyond the center. The paths identified by the analysis correspond to the most prominent streets of Melbourne, well known to virtually all inhabitants of Melbourne. Highest ranking Victoria Street is the major east-west street, and has a similar role as the second King Street, channeling most of the north-south traffic. Due to scale-free distribution, the few paths with high betweenness values are prominent and are likely to be experienced by any local or visitor of Melbourne.

4 Conclusion

This result illustrates the plausibility with which betweenness centrality reveals the experiential hierarchy in an urban network, and also points to the importance of named paths as a conceptual building block of the urban network. Urban datasets structured to match the experience of locals, instead of administrative hierarchies, are an important input for improved communication of spatial information in context aware applications, such as route direction generation for locals.

Acknowledgements

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Perspective selection in on-line navigation descriptions: the influence of Figure features, direction of motion, addressee feedback, and gender

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Abstract. Most studies on navigation descriptions have considered perspective use in relation to route and survey perspectives. Our study also considered gaze perspective. In an on-line task a speaker directed the experimenter through a maze, without landmarks, on a computer screen. The experimenter made no mistakes, one mistake, or two mistakes. An analysis of the participants' descriptions revealed that speakers mainly used route perspective, followed by gaze perspective, and finally survey perspective. There was no difference between perspective uses at direction change in the path. As predicted, a moving Figure with eye-and-nose features increased the use of route perspective compared to a featureless Figure, gender did not have an influence on perspective selection, mistakes by the experimenter increased the use of a survey perspective, and this effect was not sustained. These results fit Schober's [1] minimum effort hypothesis, and Pickering and Garrod's [2] alignment model in relation to perspective use.

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