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Human Visual Field and Navigational Strategies

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1. Introduction

Spatial navigation is an important cognitive ability which has contributed to the survival of animal species by allowing them to locate sources of the food, water and shelter (Epstein, 2008). In order to navigate, animals and humans use environmental landmarks as references to calculate their own position and the location of targets in the environment. In such cases, landmarks are used to estimate distances and directions of objects and targets (for a review of landmark navigation in vertebrates see Rozhok, 2008).

In a classic study, Morris (1981) demonstrated that rats could locate an object that they were unable to see, hear or touch by using spatial landmarks. In the test situation, rats learned to escape from the water by swimming to an invisible platform located under the water line. Subsequent tests done without the platform corroborated those findings. Further research using a virtual version of the Morris water maze showed that humans use landmarks in a similar way to locate a hidden goal (Astur, et al., 1998). Similarly, Chamizo et al. (2003) and Artigas et al. (2005) used virtual reality environments in order to study spatial navigation characteristics in humans.

Two experimental procedures have been commonly used to study human and animal spatial navigation based on landmarks. After a training period in which individuals learn to navigate to locate a target, the experimenter changes the experimental setting by 1) increasing the distance between landmarks (Tinbergen, 1972) or 2) removing one or more landmarks from the environment (Collett, et al., 1986).

Collett et al. (1986) studied spatial navigation in gerbils by training them to find hidden food in an arena. As shown in Figure 1A, food was located between two identical landmarks. After learning acquisition, trials were done without food. When tested in the presence of only one landmark (removing procedure), the gerbils searched for food on the left and right sides of the landmark, maintaining the corresponding distance and direction from it (Figure 1B). In a second test, the distance between landmarks was increased (expanding procedure) and the gerbils searched for food in two different locations but also maintained distance and direction with regard to the landmarks (Figure 1C). Collet et al. (1986) concluded that gerbils calculated the distance and direction of the food by using each landmark independently. In this case, search behaviour could be explained by a vectorial summation model in which gerbils use the learned vectors (between the goal and the landmarks) to calculate the direction and distance of the food. The vectors are added up and the resulting vector converges on a certain part of the space that corresponds to the location of the food.

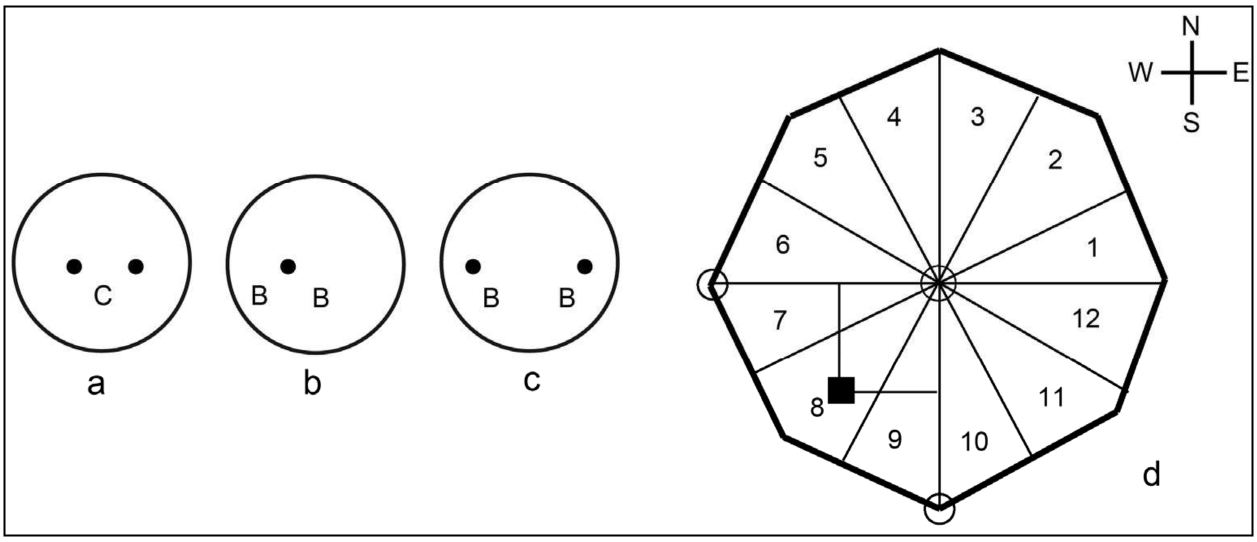


Fig. 1. Layout of the arena (left panel) and the virtual pool (right panel). In the left panel, landmarks are represented by black dots. The letter "a" shows the experimental setting in the training trials, "b" represents the situation in which one of the landmarks was removed, and "c" shows the condition in which the landmarks were separated. Capital letters "C" and "B" respectively represent the food and the regions where the animals search for the food during the test. The virtual pool used in this experiment is shown in the right panel ("d"). A black square represents the platform and the two empty circles represent the landmarks. The virtual pool was divided into 12 sectors. The central region of the pool was defined as the 0th sector.

Subsequent research, however, led to different results. Cheng (1988, 1989) trained pigeons in the presence of two landmarks. After acquisition, the pigeons were tested with the landmarks being moved further away and it was verified that they search for the food in midline between the new positions of the landmarks. Cheng assumed that pigeons navigate using an average vector that indicates the position of the food with regard to the animal.

MacDonald et al. (2004) applied the procedure of separating landmarks in a study with marmoset monkeys, children and adult humans. They concluded that a "middle rule" strategy is the common navigational strategy used by adults. However, children and primates used a different strategy, preferring to search near the landmarks. From these results, authors suggested that "among vertebrates, adult humans appear to be outliers" MacDonald et al. (2004) suggest that two strategies can be adopted by the participants in a virtual reality environment: a) encoding the goal location by means of its spatial relation with regard to the landmarks (configural strategy); and b) encoding a vector from each landmark to the goal (elemental strategy). Only the configural strategy elicits the use of the "middle rule", i.e. navigating using the resulting vector as a reference.

In this study we use a particular virtual reality environment to investigate spatial navigation in human adults in two viewing conditions. In the first, participants could simultaneously see both landmarks of the virtual environment which inform about the location of the goal (simultaneous vision). In the second, participants could see only one landmark at a time (sequential vision). Basically, conditions differed with regard to the amplitude of the visual fields, which might influence the strategy adopted by the participant to navigate in the virtual space and locate the goal. When people have visual access to both landmarks, they can use all relevant information to navigate. However, when people see only one landmark at a time, they need to integrate the partial viewings of the environment in order to reconstruct the visual space. Consequently, simultaneous and sequential vision tasks involve different cognitive demands.

In order to investigate the spatial learning in those visual conditions we used a virtual reality model of the Morris water maze (Morris, 1981) adapted for a human task (see Chamizo, et al., 2003 and Artigas, et al., 2005). Participants were trained to locate a hidden platform in the presence of two landmarks. In Experiment 1 one of the landmarks was removed (removing procedure), and in Experiment 2 the distance between landmarks was increased (increasing procedure). In both experiments participants were tested in simultaneous and sequential vision conditions. After the training period, the platform was removed and the time spent in each sector of the platform was registered.

We expected that the simultaneous vision of the two landmarks would promote a configural strategy so that participants would spend more time searching for the platform in the area between the landmarks (“middle rule”). The successive viewing task, on the other hand, would promote the use of an elemental strategy in which participants would spend more time searching in the adjacent regions, i.e. applying the “connecting cues rule” (from landmark to landmark). The results of these two experiments converge in the same direction, suggesting that different navigational strategies depend on visual conditions.

2. Experiment 1

2.1 Method

2.1.1 Participants

Forty-seven students of psychology at the University of Barcelona ranging in age from 22 to 24 years old took part in the experiment. Twenty-four participants were assigned to Group 1 (simultaneous vision) and performed the location task using a visual field of 90º, which allowed both landmarks to be viewed simultaneously. Twenty-three students were assigned to Group 2 (sequential vision) and performed the task using a visual field of 30º, which allowed only one landmark at a time to be viewed. The study was approved by the institutional ethical committee of the University of Barcelona in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki and students received course credits to take part in the experiment.

2.1.2 Materials and apparatus

The experiment was conducted in a room containing four individual soundproofed compartments equipped with a PC computer (Pentium IV 2.4 GHz) connected to a 15" monitor. Headphones were used to present sound in the experimental task. The computers were equipped with an ATI Radeon 9200 Graphics Card, which allows graphics acceleration and high resolution. Experiments were programmed in C++/Open GL, using a software interface for 3D graphics, with hardware developed by Silicon Graphics. The program controlled the virtual environment and the auditory information (background sound and positive and negative feedback) and registered the time taken to reach the platform. The positive feedback consisted of a brief three-second song ("That's all folks") and the negative auditory feedback consisted of an unpleasant melody (the sound of mournful bells). The auditory background sound was slightly unpleasant in order to generate some distress in the students and reproduce the conditions of an escape task. Participants used the keyboard arrow keys ("up", "down", "left" and "right") to navigate in the virtual environment.

The virtual space was an octagonal swimming pool (radius = 100 units) situated in the middle of the virtual space and surrounded by a pale blue surface (sky). Objects were placed hanging from an invisible ceiling. A circular platform (radius = 8 units) could be placed in the pool below the surface of the water (i.e. an invisible platform). Two spheres (pink and green) were used as landmarks (diameter = 20 units). The pool was divided into 12 sectors of 30°. The platform was placed in sector 8, perpendicular to the landmark (Figure 1d). The participants started the experiment in the centre of the pool (0th sector).

2.1.3 Procedure

Participants were tested in groups of four individuals and received the following instructions: "In this experiment you will be swimming for a long time in a circular pool from which you want to escape. You are very tired and you will only rest if you find the floating platform. You will see the platform only in the first trial. In the following trials, the platform will be hidden

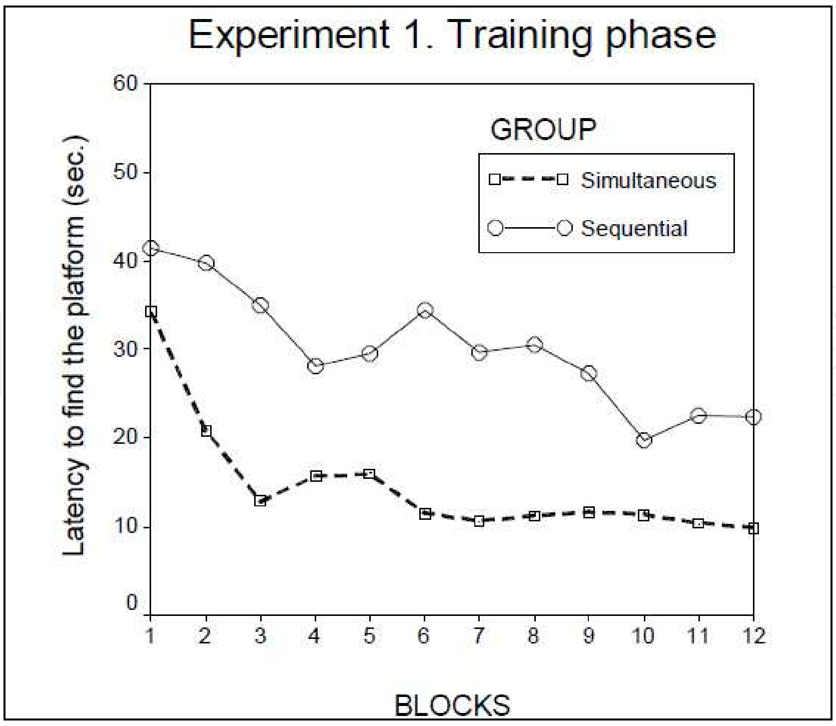


Fig. 2. Mean escape latencies of the groups of participants with simultaneous and sequential vision of the landmarks.

but located in the same position with regard to the other objects. Occasionally only one object will be presented. Your goal in the task consists of reaching the platform."

After the training period, participants find themselves in the middle of the pool (0th sector) facing a different direction each time (NE, SE, SW or NW). In the "escape trials" the platform was hidden and in the "final test trial" the platform was absent. Landmarks consisted of the two similar spheres of different colors, with an angular separation of 90^o. Participants performed 24 trials with an inter-trial interval of 10 sec. Participants had 60 s to find the platform. When they reached the goal a positive feedback was presented (song "That's all folks"). Otherwise, if they could not find the platform, a mournful sound was presented.

After acquisition, test trials were done. Half of the participants performed the search task with only one landmark. The other half did the task with both landmarks being presented in the virtual pool. A measure of interest was the time spent in the relevant sector of the pool (8th sector) which contained the platform. Participants had 60 s to search, but only the first 20 s were included in data analysis. The time spent in the different sectors of the pool was taken as a dependent variable.

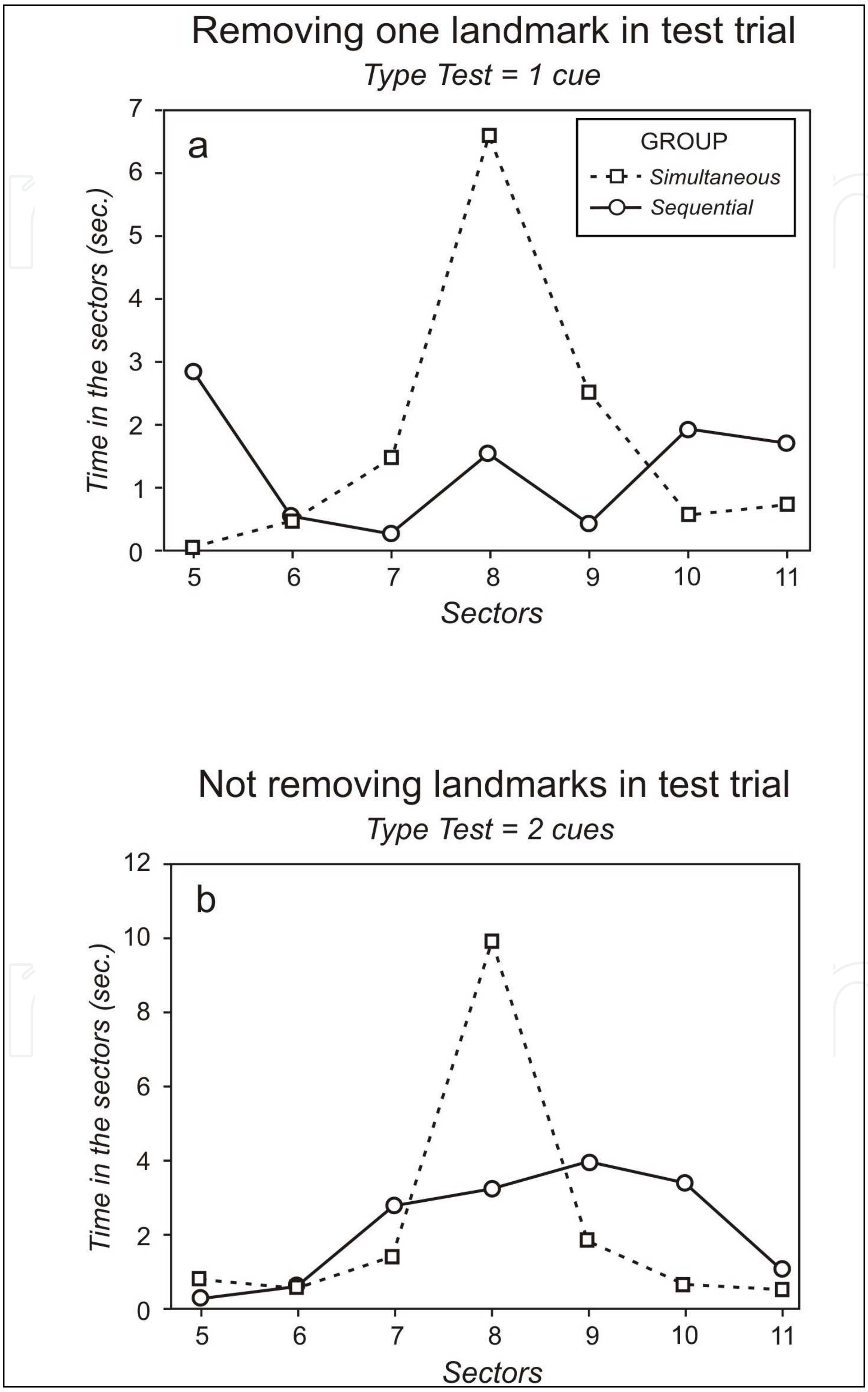
3. Results and discussion

An analysis of variance of escape latencies, with "groups" (simultaneous and sequential vision) and "blocks of trials" as factors, revealed a main effect for "groups" [$F(1,45) = 23.27$, $p < .001$] and "blocks of trials" [$F(11,495) = 13.99$; $p < .001$], and a statistically significant interaction between "groups" and "blocks of trials" [$F(11,495) = 2.28$ $p < .014$]. Figure 2 shows the mean escape latencies during acquisition. Although participants improved their performance in the course of the experiment, the group with simultaneous vision reached an asymptotic level after three blocks of trials. The group with sequential vision took more blocks to reach an asymptotic level. These data suggest that simultaneous access to both landmarks improves spatial navigation.

An additional analysis of variance was conducted with "groups" (simultaneous and sequential vision), and "types of test" (two landmarks or one landmark) as between factors, and "sectors" of the pool as a within factor. Figure 3A shows the time spent in sectors 5 to 11 for each group in the test trial with one landmark. Figure 3B shows the time spent in the test trial with the two landmarks.

This analysis showed a significant main effect of the variables "types of test" [$F(1,43) = 7.46$, $p < .009$] and sectors [$F(6,258)=16.17$, $p < .001$]. Data analysis also showed statistically significant interactions between "sectors" and "types of test" [$F(6,258)=2.19$, $p < .04$] and "sectors" and "groups" [$F(6,258)=10.53$, $p < .001$], and a second order interaction between "sectors", "groups" and "types of test" [$F(6,258)=2.58$, $p < .02$].

Post hoc tests indicated that the type of test (one or two landmarks) did not affect the time spent in sectors 7, 8 and 9 in the simultaneous ($p < .128$) and sequential ($p < .082$) viewing conditions. Results also showed that, in both types of test, participants with simultaneous vision spent more time in the relevant sector (8th) ($p < .007$). For the group with sequential vision, no differences were found between types of test (one or two landmarks) with regard to the time spent in the 8th sector.



Removing one landmark in test trial

Type Test = 1 cue

Not removing landmarks in test trial

Type Test = 2 cues

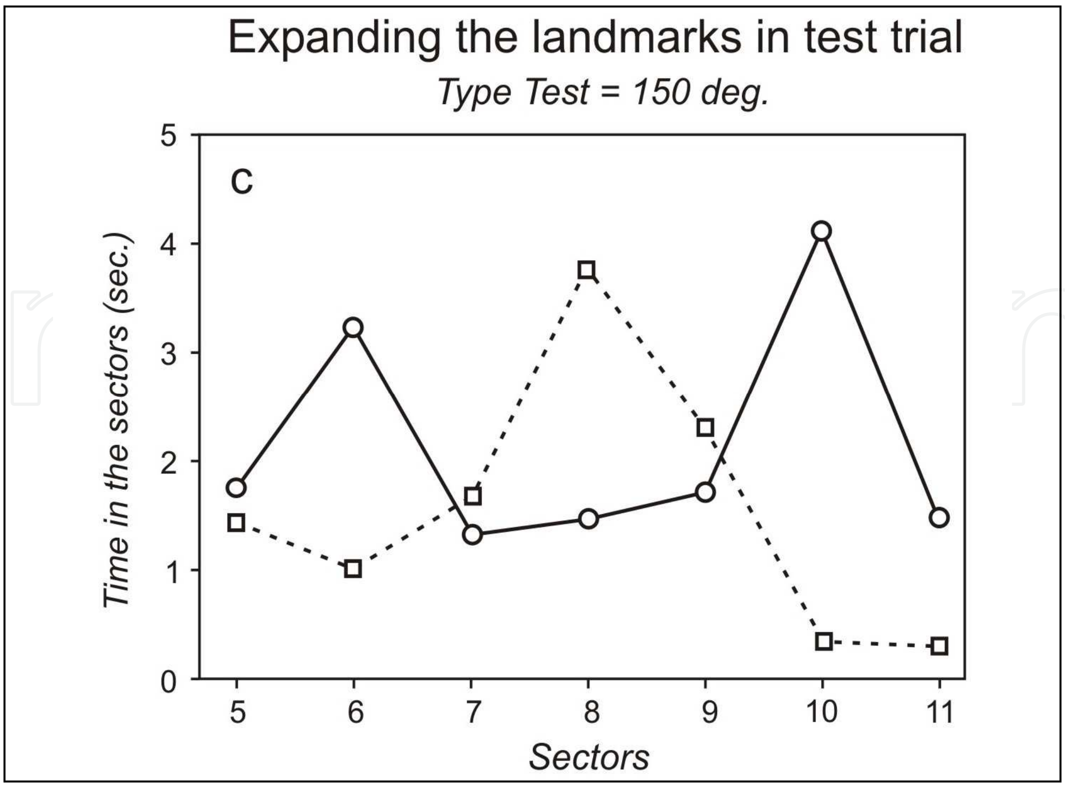


Fig. 3. Mean time spent in seven important sectors of the pool for the two groups with simultaneous and sequential vision of the landmarks. Panel “a” presents the results of Experiment 1, in which a landmark was removed during the test trial. Panel “b” represents the situation in which the test trial was identical to the training trial. Panel “c” corresponds to the results of Experiment 2, in which the distance between the landmarks was increased in the test trial.

Finally, *post hoc* tests revealed that in the simultaneous vision group for one landmark, participants differed only in the time spent between the 7th and 8th sectors [t(11)= 2.82; p < .017]. However, in the case of the same group with two landmarks, *post hoc* tests indicated differences between the 7th and 8th sectors [t(11)= 5.01; p < .001] and between the 8th and 9th sectors [t(11)= 4.51; p < .001]. With regard to the sequential vision group, no differences for the time spent in sectors 7, 8 and 9 were found.

Since no difference between escape and test trial was found, we considered it would be interesting to analyze the time spent at the starting point position as a function of the visual conditions. An ANOVA with “groups” (simultaneous and sequential vision) and “types of test” (one or two landmarks) as factors were conducted, using the time spent in the 0th sector (starting-point) as the dependent variable. Results revealed that only the factor “types of test” was significant [F(1,43)=7.33; p< .010]. Both groups spent more time at the starting point during the trial test (Figure 4).

In summary, a comparison of the viewing conditions, as we can see in Figure 3, clearly demonstrates that participants make use of two different strategies depending on whether they can see both landmarks simultaneously or just one at a time. In the test with one or two landmarks, the group with simultaneous vision spent more time looking for the goal in the 8th sector, while the subjects of the group with sequential vision spent their time in a different way, exploring the 8th but also the adjacent 7th and 9th sectors. As we predicted, participants of the sequential vision group seem to use an elemental strategy, applying the "connecting cues" rule (from landmark to landmark). In Experiment 2, we investigated the effect of the increasing procedure on the navigation strategies adopted in the task.

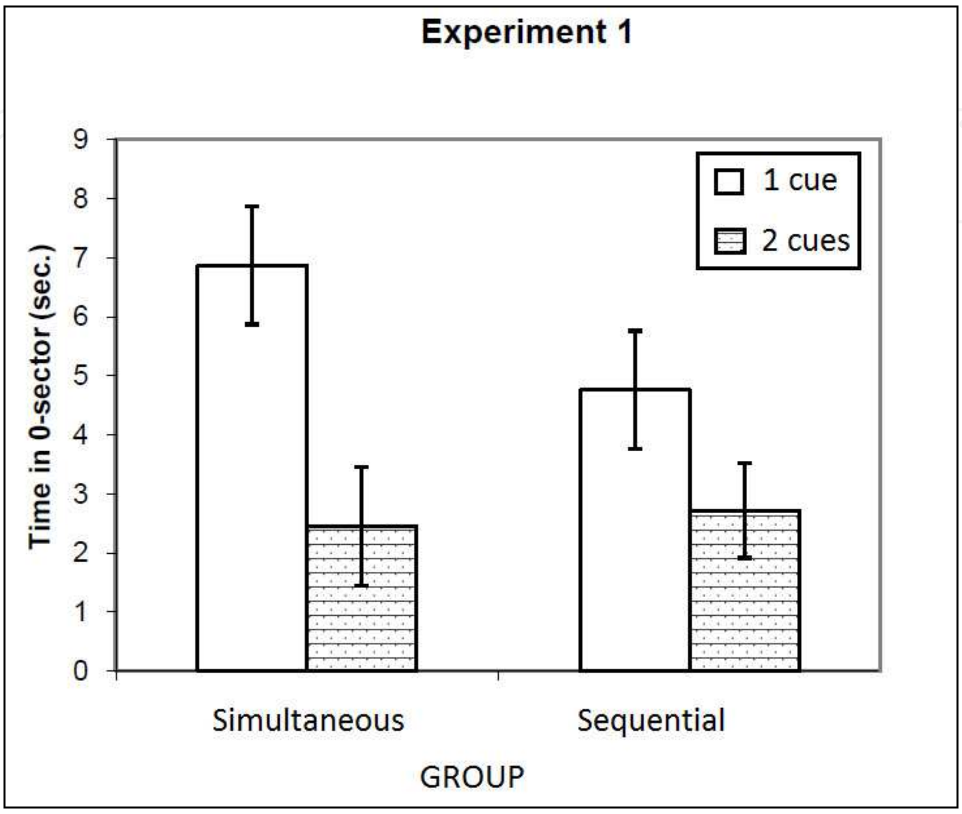


Fig. 4. Mean time spent in the 0th sector (starting point) for each group (simultaneous and sequential vision) as a function of the type of test trial (with one or two landmarks).

4. Experiment 2

In this experiment we tested human spatial navigation in a virtual environment by increasing the angular separation between the landmarks (expanding procedure). This procedure was important for analyzing whether navigational strategy depends on the kind of manipulation done in the test trial. As in the previous experiment, during the training trial the angular separation between the landmarks was kept constant (90º), while the visual field was manipulated: 1) Group 1 = 90º (simultaneous vision); Group 2 = 30º (sequential vision). In the test trial, half of the participants were submitted to the condition in which the distance between the landmarks was the same as in the training trials. For the other half we applied the expanding procedure, changing the angular separation between the landmarks from 90º to 150º. In the latter condition, we considered that if participants distributed the search time in sectors 7, 8 and 9, it would suggest that they had adopted a navigational strategy "from landmark to landmark". On the other hand, if participants spent more time in the 8th sector (platform) in comparison to the 7th and 9th sectors, it would suggest that they had adopted the "middle rule" strategy (following an egocentric vector from the starting point to the platform).

4.1 Method

4.1.1 Participants

Sixty-nine students of psychology at the University of Barcelona ranging in age from 22 to 24 years old were randomly assigned to two groups, differing with regard to the visual field condition. Thirty-three students took part in Group 1 and had visual access to both landmarks during the session (90º of visual field - simultaneous vision). Thirty-six students took part in Group 2 and had visual access to only one landmark at a time (30º of visual field - sequential vision). Volunteers were naive about the hypothesis of the experiment and received course credits to take part in the research. The experiment was conducted in the same room as the previous session.

4.1.2 Procedure

Experiment 2 was identical to Experiment 1 except for the use of the "expanding landmarks" procedure. In the test trial, half of the participants were submitted to the condition in which the distance between the landmarks was identical to the training trial (90º). For the other half of the participants, the expanding procedure was applied and the angular separation increased (150º). As in Experiment 1, we considered only the first 20 s of searching in the test trial for data analysis.

5. Results and discussion

An analysis of variance with "groups" (simultaneous and sequential vision) and "blocks of trials" (1-12) as factors revealed a statistically significant main effect of "groups" [F(1, 68) = 16.077, p < .001] and "blocks of trials" [F(11, 748) = 23.071, p < .001], as well as an interaction between "groups" and "blocks of trials" [F(11, 748) = 2.544, p < .004]. Although participants improved their performance in the course of the blocks, Group 1 (simultaneous vision) speeded up the latency time in finding the platform in comparison to Group 2 (sequential vision). Similarly to the previous experiment, analysis indicated that participants with simultaneous vision learned more quickly than participants with sequential vision (Fig. 5).

Afterwards a second analysis of variance was conducted with "groups" (simultaneous and sequential vision) and "types of test" [expanded landmarks (150º) and non-expanded landmarks (90º)] as between factors, and "sectors" of the pool as a within factor. This analysis showed no main effects for "groups" [F(1,66)=2.60, p < .15] or "types of test" [F(1,66)=0.56, p < .45]. We found a statistically significant effect for "sectors" [F(6,396)= 14.15, p < .001] and first order interactions between "sectors" and "types of test" [F(6,396)=7.09, p < .001] and "sectors" and "groups" [F(6,396)=12.17, p < .001]. A second order interaction between "sectors", "groups" and "types of test" [F(6,396)=3.06; p<.006] was significant. Figure 3 shows the time spent in the relevant sectors (5-11th) in the test trial with non-expanded landmarks (Fig.3b) and expanded landmarks (Fig.3c) .

In order to analyze the second order interaction ("groups" by "types of test" by "sectors") we conducted *post hoc* tests. For non-expanded landmarks (90º) we found differences between simultaneous and sequential groups in the 8th [t(22)= 4.07; p < .001] and 10th sectors [t(22)= 3.12; p < .005]. This implies that participants with simultaneous vision spent more search time in the 8th sector than the sequential vision group. Participants in the group with sequential vision spent more time in the 10th sector in comparison to the simultaneous group.

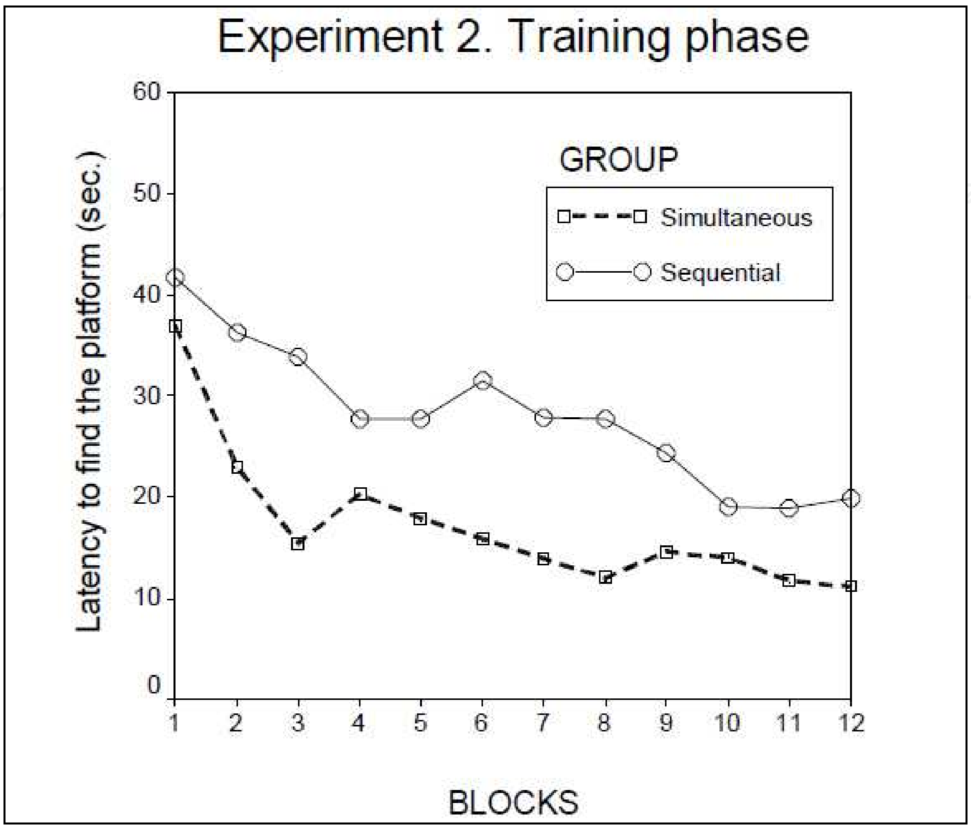


Fig. 5. Mean escape latencies of the two groups with simultaneous and sequential vision in Experiment 2.

In the expanded landmarks condition (150º) we found differences between simultaneous and sequential vision for the 6th [t(44)= 3.26; p < .002], 8th [t(44)= 2.21; p < .033] and 10th sectors [t(44)= 4.89; p < .001]. These data revealed that participants with simultaneous vision spent more time in the relevant sector (8th), suggesting that they adopted a strategy of advancing directly to the goal. However, participants with sequential vision and submitted to the "expanding procedure" spent more time in the 6th and 10th sectors, located adjacent to the landmarks. These results suggest that participants used a strategy of navigating from one landmark to another ("connecting cues" strategy).

As regards the participants in the group with simultaneous vision submitted to non-expanded landmarks, we verified that they spent more time in the 8th sector compared to the 6th, 7th, 9th and 10th sectors [t(11)= 4.51; p < .001]. Likewise, in the expanding procedure, participants spent more time in the 8th sector in comparison to the 6th and 10th sectors [t(21)= 2.91; p < .008]. A further analysis in the simultaneous group, comparing the two types of test (90º vs. 150º), only showed differences for the 8th sector [t(32)= 3.49; p < .001].

Our data showed that participants with simultaneous vision spent more time in the relevant sector (8th) than in the sectors adjacent to the landmarks. For the condition in which the distance between the landmarks was expanded, we could attribute the non-significant difference between the 7th, 8th and 9th sectors to a decrease in accuracy in finding the resulting vector that leads to the goal (platform).

For the group with sequential vision submitted to non-expanded landmarks, we found significant differences only between the 8th and 6th sectors [t(11)= 2.66; p < .022]. However, for the participants submitted to the expanding procedure (150º), the time spent in the 8th sector differed from that spent in sectors 6 and 10 [t(23)= 2.20; p < .038]. Additionally, we found that the time spent in the 6th sector differed from that spent in the 7th [t(23)= 2.41; p < .024] and that the time in the 10th sector differed from that in the 7th and 9th sectors [t_{min}(23)= 2.62; p < .015]. This showed that participants in the group with sequential vision predominantly searched for the platform in the 6th and 10th sectors rather than in the relevant sector (8th). A final analysis in the sequential group, comparing two types of test trials (90º vs. 150º), showed that only the time spent in the 6th sector differed [t(34)= 3.19; p < .003]. Generally speaking, these data indicate that participants with sequential vision submitted to non-expanded landmarks spent approximately the same time in the relevant (8th) and adjacent (7th and 9th) sectors. However, the group of participants with sequential vision submitted to the expanded landmarks (150º) spent more time in the sectors adjacent to the landmarks (6th and 10th) than in the relevant sector (8th). This pattern of results differs from that found in the group with simultaneous vision, suggesting the use of two navigational strategies. Analogously to Experiment 1, we predict that participants with sequential vision use an elemental strategy.

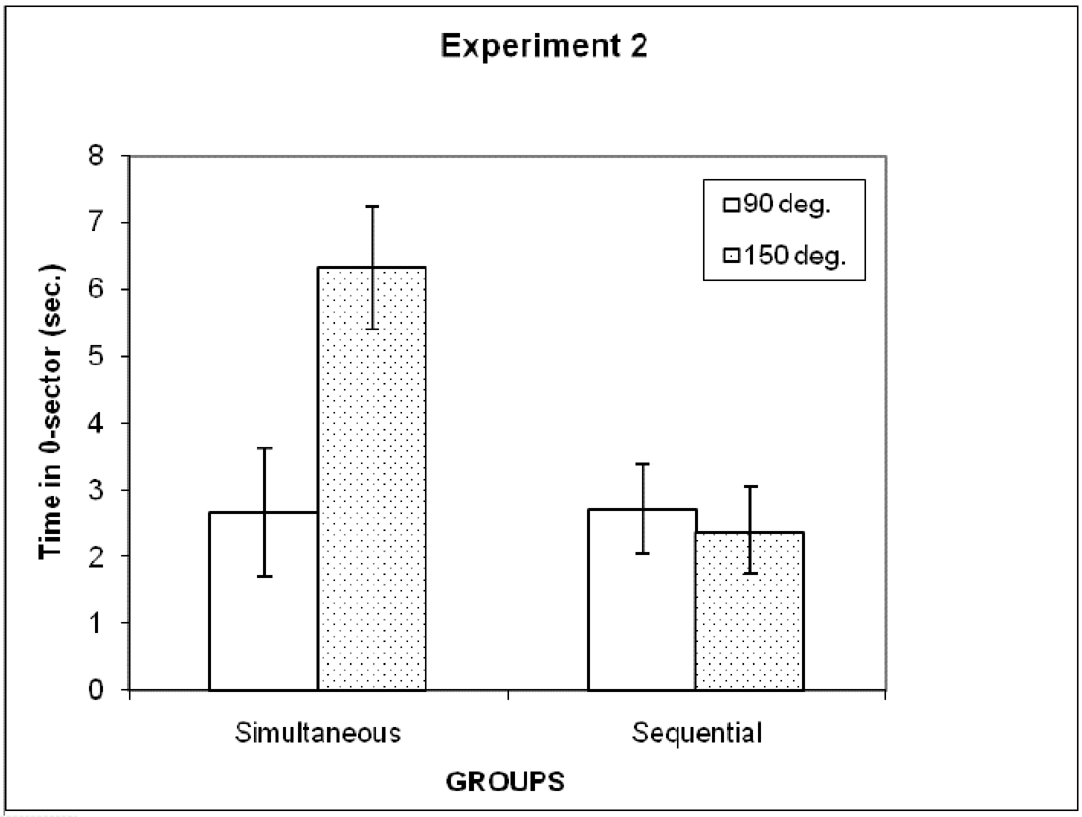


Fig. 6. Mean time spent in the 0th sector (starting point) for each group (simultaneous and sequential vision) as a function of the type of test trial (expanded and non-expanded landmarks).

Finally, an analysis of the variance with “groups” (simultaneous vs. sequential vision) and “types of test” (expanded vs. non-expanded landmarks) as factors was conducted. The time in the 0th sector (starting point) was taken as the dependent variable. Results revealed a statistically significant effect of “groups” [F(1,66)= 5.63; p < .021] and “types of test” [F(1,66)= 4.106; p < .047] as well as an interaction between them [F(1,66)= 5.879; p < .018].

A *post hoc* analysis of the interaction indicated that, only for the group with simultaneous vision, the distance between the landmarks affected the time spent at the starting point (Figure 6). In such cases, participants submitted to expanded landmarks (150º) spent more time (mean = 6.32 s) compared to those submitted to non-expanded landmarks (90º) (mean = 2.50 s). We can consider two possible explanations for these results. On the one hand, the change *per se* in the distance between landmarks promoted a decrease in the generalization of the response, and on the other, when the landmarks are further apart, the time to define the correct vector and direction increases.

6. General discussion

In this study we investigated the influences of simultaneous and sequential vision on human spatial navigation by using two classic procedures adapted from animal research. A virtual model of the Morris water maze (Morris, 1981) was used in the task, in which participants had to locate a hidden underwater platform in the pool. Experiments were designed in order to analyze in test trials the effect of the removal of one of the landmarks (Experiment 1) and the influence of increasing the distance between them (Experiment 2). The time spent by the participants in each sector of the pool was registered and taken as a dependent variable in data analysis.

In Experiment 1 we verify that participants with simultaneous vision spent more time in the relevant sector (8th) in comparison to other sectors of the pool. However, participants with sequential vision spent approximately the same time in the relevant and adjacent sectors. These results indicate that simultaneous vision compared to sequential vision improves spatial navigation in a virtual environment.

Similarly, in Experiment 2 participants with simultaneous vision also spent more time in the relevant sector (8th) compared to the other sectors in both conditions (expanded and non-expanded landmarks). But when participants with sequential vision were submitted to the condition of expanded landmarks they spent more time in the 10th and 6th in comparison to the 7th, 8th and 9th sectors. For the case in which participants with sequential vision were submitted to non-expanded landmarks (90o), they spent more time in the relevant (8th) and adjacent (7th and 9th) sectors.

As a whole, these results indicate that participants use different strategies depending on the visual condition. Participants submitted to simultaneous vision tended to navigate directly to the relevant sector (8th), indicating that they used a “middle rule” strategy based on a configural learning. However, participants with sequential vision submitted to the procedure of the removal of one landmark (Experiment 1) spent more time in the three sectors between the two landmarks (7th, 8th and 9th), suggesting that they navigate from one landmark to another based on an elemental learning. The latter finding is reinforced by the observation that when the distance between the landmarks was increased, participants with sequential vision spent more time in the sectors near the landmarks (6th and 10th). This pattern of results reveals that participants adopted two different strategies. The "middle rule" strategy takes into account the egocentric direction to determine the correct bisector between the starting point and the landmarks, while the "landmark to landmark" strategy takes into account the exocentric direction.

In the context of visual control of the action, Goodale and Humphrey (2001) state that perceptual tasks differ from motor tasks as a consequence of information processing in two independent neural pathways: the ventral (related to perception, e.g. object recognition) and the dorsal (related to directed action, e.g. blind walking). Dissociation between perception and action can be found in many studies (Goodale & Milner, 1992; Loomis et al., 1992; Smeets & Brenner, 1995; Philbeck et al., 1997; Fukusima et al., 1997; Kelly, Loomis & Beal, 2004; Kudoh, 2005). However, there is also evidence against this dissociation, with many papers trying to reconcile the pathways (Kugler & Turvey, 1987; Goodale & Humphrey, 2001, Norman, 2002). In this study, results might sustain the hypothesis of the dissociation between perception and action, with the "middle rule" being related to a perceptual strategy, while the navigation from "landmark to landmark" implies an action strategy.

We verified that the expanding landmarks test helped to clarify the strategies adopted by the participants with sequential vision. According to Sutherland & Rudy (1989), if the responses of the participants were based on an elemental learning, they should present a good performance in the test with two landmarks, but a worse performance in the test with one landmark. However, if the responses of the participants are based on configural learning, they should present a good performance in both types of test (removal and expanding procedure). If we apply those criteria to the data, we conclude that the group with sequential vision adopted an elemental strategy, whereas the group submitted to simultaneous vision adopted a configural one. However, we should note that these authors made this assertion in the context of discriminatory learning and it has not been applied to a spatial task until now.

These results differ from those obtained by MacDonald et al. (2004), who pointed out that human adults use a "middle rule" strategy, but that children and other primates do not. Our results suggest that only participants with simultaneous vision used a "middle rule" strategy, while participants with sequential vision employed a strategy of advancing from one landmark to another. In other words, navigation with simultaneous vision follows an egocentric vector directed to the middle of the landmarks, while sequential vision follows an exocentric vector that connects landmark to landmark.

The simultaneous visual access of the participants to the relevant information enables them to integrate the spatial relation easier and promotes a configural encoding which, in turn, allows the use of "middle rule" strategy. The visual access to only one landmark at a time makes the learning of global spatial relations difficult but promotes the elemental relationship between landmarks, enabling participants to apply the "connecting landmarks rule". However, more research is necessary in order to conclude whether these results could be attributed to general rules in spatial navigation or to the extensive training in the sequential condition.

7. Conclusion

In this work we have demonstrated that the amplitude of the visual field can affect the type of navigational strategy used by humans in a virtual environment. This study shows that simultaneous access to spatial cues in the training period improves the finding of routes and pathways which can be relevant when one of the landmarks is missing or when the distance between the landmarks is increased. Therefore, our study also emphasizes the importance of the amplitude of the visual field in the exploration of a virtual environment. Indeed, the area covered by the visual field may facilitate or hinder the integration of available information that is scattered in the environment. The results of this study can provide guidelines to the development of virtual environments more realistic and compatible with natural conditions of visual stimulation.

8. Acknowledgment

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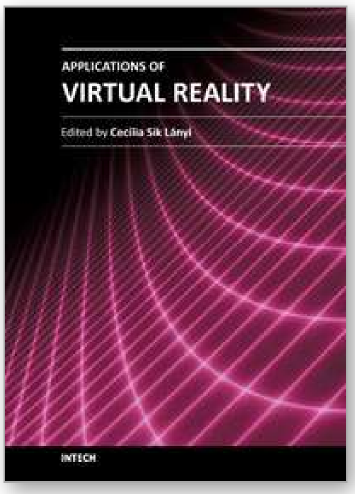

Applications of Virtual Reality
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Information Technology is growing rapidly. With the birth of high-resolution graphics, high-speed computing and user interaction devices Virtual Reality has emerged as a major new technology in the mid 90es, last century. Virtual Reality technology is currently used in a broad range of applications. The best known are games, movies, simulations, therapy. From a manufacturing standpoint, there are some attractive applications including training, education, collaborative work and learning. This book provides an up-to-date discussion of the current research in Virtual Reality and its applications. It describes the current Virtual Reality state-of-the-art and points out many areas where there is still work to be done. We have chosen certain areas to cover in this book, which we believe will have potential significant impact on Virtual Reality and its applications. This book provides a definitive resource for wide variety of people including academicians, designers, developers, educators, engineers, practitioners, researchers, and graduate students.

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