Cognitive maps of individuals with blindness for familiar and unfamiliar spaces: construction through audio-tactile maps and walked experience

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Abstract

Though individuals with visual impairments are able to form mental representations of space, it is critical to investigate the way they develop or update their cognitive maps taking a closer look at quantitative and qualitative data on them. The aims of the present study were to examine the ability of individuals with blindness to create cognitive maps of routes in familiar and unfamiliar areas through the use of audio-tactile maps, and to compare these cognitive maps with those created after independent movement in the real environment regarding their precision and inclusiveness. Thirty adults with blindness participated in this study. The findings of the present study reflect the positive effect of audio-tactile maps on cognitive map creation and, thus, their effect on the spatial knowledge of people with blindness. Moreover, the findings featured the dominance of the audio-tactile map over walking experience, since the participants formed more complete cognitive maps after having explored the audio-tactile map than walking along the route in the unfamiliar area.

Keywords: blindness, spatial knowledge, cognitive maps, audio-tactile maps

1 Introduction

The theory concerning the cognitive mapping of individuals with visual impairments has evolved around three basic axes – three distinct theories – structured upon the question of the ability or inability of individuals with visual impairments to form mental representations of space. The first axis – the deficiency theory – supports the belief that individuals with congenital blindness are incapable of coding space because of the lack of visual experience necessary to process spatial concepts and relations. The second axis – the inefficiency theory – supports the notion that individuals with visual impairments understand and code space but at a more germinal stage. The third and dominant theory is the difference theory based on which individuals with visual impairments are as capable as sighted individuals of understanding and coding space; and any differences in mental representations result from the different conditions of the spatial processing, i.e. the available data (Kitchin, Blades, & Golledge, 1997; Kitchin & Jacobson, 1997; Ungar, Blades, & Spencer, 1996).

Taking for granted that individuals with visual impairments are able to form mental representations of space, it is critical to investigate the way they develop cognitive maps, the processes they follow for cognitive mapping under different circumstances and the elements of their cognitive maps. It should be noted that cognitive mapping is in effect a process of mental representation of spatial knowledge (Kitchin, 1994), during which an individual acquires, stores, recalls, and decodes information about the relative locations and attributes of the phenomena in his/her environment (Downs & Stea, 1973, p.7). Knowing how individuals with visual impairments understand space and what are the features that their cognitive maps contain could help to plan the environment appropriately, make the right information available to them and improve their wayfinding (Jacobson & Kitchin, 1995).

Cognitive maps of individuals with visual impairments appear to contain basic environmental features such as streets, buildings, parks, fixed obstacles, bus stops etc. (Papadopoulos, 2004). The objects of an area that consequently form the cognitive map of a subject with visual impairments depend on the relative information the subject receives. When a tactile map constitutes the basic mean for a subject to become acquainted with an area, his/her mental map should be modelled on the initial map's objects. On the other hand, when an individual with visual impairments walks in an area the cognitive mapping is directly dependent on environmental cues, i.e. olfactory, auditory and haptic (Koutsoklenis & Papadopoulos, 2011a; Koutsoklenis & Papadopoulos, 2011b; Koutsoklenis & Papadopoulos, 2014; Papadopoulos, Papadimitriou, & Koutsoklenis, 2012).

Much more complex appears to be the process under which a spatial representation is cognitively constructed. Individuals with visual impairments seem to rely more on egocentric strategies to code and represent space than on allocentric ones (Morsley, Spencer, & Baybutt, 1991; Warren, 1994, p.107). Allocentric strategies result in mental representations where objects of the environment are spatially defined according either to each other's location or to an external frame of reference (Nardini, Burgess, Breckenridge, & Atkinson, 2006) Egocentric strategies – where an individual uses the relation between his or her body and an object to code space (Wang, 2003) – are considered inferior to allocentric since the latter induce representation that better support the movement within an area as well as the duration of spatial knowledge (Nardini et al., 2006; Pick, 2004) than egocentric representations.

Although it is preferable that these two systems are used complementarily and interchangeably (Nadel & Hardt, 2004; Simons & Wang, 1998; Wang & Simons, 1999), individuals with visual impairments maintain egocentric strategies when spatial coding is required. Millar suggested that external cues are not accessible and that is why individuals with visual impairments rely on egocentric cues (Millar, 1979). Therefore, Millar (1979) implied that if external cues become available, then individuals with visual impairments could integrate them into mental representations. Indeed, research results indicate that individuals with visual impairments rely on external spatial cues to code space when these are salient (Papadopoulos & Koustriava, 2011; Papadopoulos, Koustriava, & Kartasidou, 2011).

Thus, the type of information provided to participants during a spatial task could modulate their behavior through the process and, therefore, their performance. Thinus-Blanc and Gaunet (1997) stated, also, that when an individual with blindness reads a haptic map he or she has the ability to maintain a stable reference point. Using points of reference during spatial learning enables allocentric coding which leads to better spatial performance and knowledge (Papadopoulos & Koustriava, 2011; Papadopoulos, Koustriava, & Kartasidou, 2012).

Tactile maps present, however, a series of limitations. The main challenge a tactile map entails seems to be the need for extended Braille labelling (see Jacobson, 1998 for a review), while the abundance of information and complex graphics require greater memory load (Ungar, Blades, & Spencer, 1993), which influences spatial coding and representation (Papadopoulos et al., 2012). Verbal assistance provided as audio information can help to overcome many of the challenges of tactile maps by providing audio information instead of Braille labels and legends. Information provided through speech in combination with touch can be quite helpful, overcoming the restrictions of touch to serial information gathering (Wang, Li, Hedgpeth, & Haven, 2009).

A touchpad offers access to the benefits of tactile maps and verbal aids at the same time. The combination of auditory and tactile information with the use of a respective device in research studies has been reviewed in the MICOLE project (2006) highlighting the benefits for individuals with visual impairments. Specifically, combining auditory and tactile information may present information in a more efficient way (MICOLE, 2006) resulting in a more complete concept (Landau, Russell, & Erin, 2006).

Different types of audio-tactile cartographic representations have been used in various researches. The audio-tactile maps with the use of a touchpad device have been examined in a series of researches (Holmes & Jansson, 1997; Holmes, Jansson & Jansson, 1996; Holmes, Jansson & Olsson, 1996; Papadopoulos, Barouti & Charitakis, 2014), while other kind of audio-tactile maps have been created in an experimental context. Zeng and Weber (2010) have developed a system which permits access to GIS using a tactile device of pins; Talbot (2011) introduced audio-tactile maps through a digitalized tablet with which the user received auditory information as he/she moved a stylus on the display. Other researchers focused on virtual audio-tactile maps where the user interacted with the interface using a force-feedback joystick (Lahav & Mioduser, 2008), a gamepad (Schmitz & Ertl, 2010) or a force feedback device such as Phantom and Novint Falcon (Kaklanis, Votis, Moschonas & Tzovaras, 2011).

However, a basic distinction should be made between cognitive mapping of an unknown area and processing the cognitive map of a familiar space. During the latter, an existent cognitive map can be updated or transformed relative to a task’s requirements. Golledge and her colleagues (1985) suggested that combining knowledge structures and information via cognitive processes relative to spatial perception and management lead to task-specific cognitive maps, which in turn means that cognitive maps are dynamic (Kitchin, 1994).

The main body of research examining cognitive maps of individuals with visual impairments in large geographic spaces took place in familiar areas. There are three basic reasons explaining this fact; in large geographic spaces it becomes difficult to control environmental conditions (e.g. traffic), while the design of the experiment requires enough time in the environment in order for a subject to present knowledge of the environment. Furthermore, research results in small geographic spaces proved that individuals with visual impairments performed worse than sighted individuals, which makes studies in large spaces worthless (Kitchin et al., 1997).

Research in familiar areas reveals that individuals with visual impairments form effective cognitive maps (Rieser, Lockman, & Pick, 1980; Ungar et al., 2006). Similarly, research in novel environments proved that individuals with visual impairments are capable of forming mental representations of space and, specifically, that repeated trials of walking down a route results in an effective mental representation of the route (Blades, Lippa, Golledge, Jacobson, & Kitchin, 2002; Espinosa, Ungar, Ochaita, Blades, & Spencer, 1998; Ochaita & Huertas, 1993).

Ochaita and Huertas (1993) examined the cognitive map of individuals with visual impairments after they had learned a route between seven landmarks in a novel area. Results showed that the participants, after several trials, were able to represent an accurate map and estimate sufficiently the distances between the landmarks. Similar results were obtained in the study of Espinosa and her colleagues (1998) where participants with visual impairments learned adequately a 2 km distance, as well as the studies of Jacobson, Kitchin, Garling, Golledge, and Blades (1998) and of Golledge, Jacobson, Kitchin, and Blades (2000) where participants with visual impairments performed similarly to sighted individuals learning a route after a series of trials.

All these studies support the conclusion that individuals with visual impairments do form a mental representation of an unfamiliar route within a novel area. Learning a route while walking along it constitutes a process of egocentric coding and results in route knowledge that is suggested to lack plasticity (Tinti, Adenzato, Tamietto, & Cornoldi, 2006).

Thus, the question that may arise is whether individuals with visual impairments are able to present configurational knowledge or whether they continue to present egocentric representation such as route knowledge. Configurational knowledge is considered the highest level of cognitive maps entailing spatial knowledge that includes among others angles, directions, orientation, and relative positions of objects/landmarks (Golledge, Gale, & Richardson, 1987).

Casey (1978) asked 10 individuals with blindness and 10 individuals with residual vision to represent their cognitive map of the school campus by creating a relative model using cubes and strips for the buildings and the roads respectively. Subjects from both groups performed well, but participants with residual vision performed comparatively better than most participants with blindness. This study made it apparent that individuals with visual impairments, even blindness, can present configurational knowledge in a familiar large-scale space.

Jacobson, Lippa, Golledge, Kitchin, and Blades (2001) proved that individuals with visual impairments are able to develop complex spatial knowledge when asked to learn a novel route. Participants in the study at hand could understand orientation and relative positions of landmarks (pointing task), estimate distances and construct a representative cognitive map using a model with magnetic pieces.

Though the research above proved that individuals with visual impairments could demonstrate evidences of configurational knowledge after several trials, it would be critical to examine the quality of cognitive maps when participants have only one trial walking along the route. Moreover, it should be examined whether providing the necessary information in a context enables the creation of a complete cognitive map. Incorporating spatial information of a large geographic space is difficult in an external context of reference, which normally would support configurational knowledge (Tinti et al., 2006). Thus, it would be significant to examine the cognitive map created after receiving spatial information within an external frame of reference and to compare it with a cognitive map developed after walking in the area where all information is received using an internal frame of reference, i.e. the subject's body. Espinosa and Ochaita (1998) found that reading a tactile map to learn an area results in better knowledge compared to walking in the area. Similarly, Papadopoulos and Barouti (2015a) proved that individuals with blindness may well be supported in the formation of cognitive maps by using audio-tactile maps. Moreover, previous researches suggest both the improvement of spatial knowledge of individuals with blindness regarding a familiar area through the use of an audio-tactile map (Papadopoulos, Barouti, & Koustriava, 2016), and their preference of audio-tactile maps as means spatial knowledge development (Barouti & Papadopoulos, 2015).

The present study is part of an extended research which aims at examining: a) the spatial knowledge (cognitive maps) that individuals with blindness develop for city routes (familiar and unfamiliar) through the use of different means/ aids (audio-tactile maps, tactile maps, and participants' direct experience of movement along the routes), and b) their satisfaction deriving from the use of these means/ aids. From this research 4 published articles have emerged (Barouti & Papadopoulos, 2015; Papadopoulos & Barouti, 2015a; Papadopoulos & Barouti, 2015b; Papadopoulos, Barouti, & Koustriava, 2016). The experiments included in the studies of these 4 papers are the same to the ones presented in the present study, and thus there are similarities between the sections of all those papers. However, the present study developed as a progressive step from these studies, while the aims of the studies above were different from the aim of the present study.

The paper of Papadopoulos and Barouti (2015b) concerns the spatial knowledge (cognitive maps) that individuals with blindness develop for familiar city routes through the use of tactile maps, and participants' direct experience of movement along the routes. Papadopoulos, Barouti, and Koustriava (2016) examined the improvement of spatial knowledge of individuals with blindness regarding a familiar area through the use of an audio-tactile map. The existent spatial knowledge of individuals with blindness was compared the knowledge formed after the use of an audio-tactile map. The study of Barouti and Papadopoulos (2015) examined the participants satisfaction after using a series means/ aids (audio-tactile maps, tactile maps and walking experience) to develop spatial knowledge, while the study of Papadopoulos and Barouti (2015a) was a pilot study examining the ability of individuals with blindness to create cognitive maps through the use of audio-tactile maps. The present study developed as a progressive step from the study of Papadopoulos and Barouti (2015a).

The aim of the present study was to examine the ability of individuals with blindness to create cognitive maps of routes in familiar and unfamiliar areas through the use of audio-tactile maps and through participants' direct experience of movement along the routes. The degree of precision of the created cognitive maps was also under investigation. Moreover, the study aimed at comparing the cognitive maps created through the use of audio-tactile maps and those created by the independent movement along the routes with regard to their precision and inclusiveness.

2 Material and Methods

2.1 Participants

Thirty adults with blindness took part in this study. The sample consisted of 20 males and 10 females. The ages ranged from 20 years to 61 years (*M* = 35.9, *SD* = 11.01). Twenty five participants were blind or had severe visual impairments and 5 had the ability to detect very large objects. An essential criterion to be included in the study was not having a hearing impairment or other disabilities, apart from visual impairments. The visual impairment was congenital for 17 participants and acquired for the remaining 13 participants. With respect to their level of education, 12 participants were university graduates, 7 were university students, 6 had graduated from high school, and 5 had graduated from junior high school.

The participants were asked to indicate the main reading media they used (i.e., Braille, TtS systems, recorded material), and how many years (overall) they had been using TtS systems. Twenty three out of 30 participants used TtS systems as the basic reading medium. In addition, 11 participants declared that they have at least a ten-year experience in using TtS systems, 17 participants stated that they had been using TtS systems for 2 to 10 years, while two participants stated that they started using TtS systems two years ago.

The participants were asked to identify how they moved about daily in outdoor places, by choosing one of the following: a) with the assistance of a sighted guide, b) sometimes myself and sometimes with the assistance of a sighted guide, and c) myself, without any assistance. Moreover, the participants were asked to indicate the frequency of their independent movement using a 5-point Likert scale: always, usually, sometimes, seldom, or never. In addition, these two questions were answered by orientation & mobility (O&M) specialists, who were familiar with the participants and could assess the latter's ability of independent movement. Table 1 present the answers of the participants and O&M specialists.

<Insert Table 1 about here>

2.2 Instruments

The main research instruments were audio-tactile maps of one unfamiliar and one familiar area in Thessaloniki. The unfamiliar area was neither known nor walked by the participants in the past. On the other hand, the familiar area is extended around the special school for individuals with blindness in Thessaloniki, which means that the chosen familiar area was a well known place for the vast majority of people with blindness in Thessaloniki. All the participants presented experience of frequent movement in this area.

The software application Iveo Creator pro 2.0 together with the touchpad device, were used to develop the audio-tactile maps. Both of them are products of "ViewPlus® Technologies" company. The Iveo Creator pro 2.0 is a WYSIWYG editor (Kanahori, Naka & Suzuki, 2008) and has the potential to create and/or edit any type of image format. The files produced by the software are saved in Scalable Vector Graphics (SVG) format. The touchpad device is a pointing device consisting of a specialized surface that can translate the position of a user's fingers to a relative position on the computer screen. When used in combination with a tactile image, this device has the potential to offer tactile, kinesthetic and auditory information at the same time (Jansson & Juhasz, 2007).

Six audio-tactile maps were created to represent six different routes (itineraries), three for each area (familiar and unfamiliar). The choice of the routes was based on the following criteria: a) they had approximately the same length b) they all had the same number of turns, c) they had different shapes and d) they were suitable or accessible for people with visual impairments. In order to achieve the accessibility objective, researchers walked around the areas and examined whether they were accessible for blind people. The main concern was to avoid obstacles which would prevent blind people from passing through. The decision to choose three different routes for each area (familiar and unfamiliar) was taken because of the experimental design. This design ensures the variability of the degree of difficulty between the routes, while at the same time eradicating a learning effect that could possibly affect participants' performance (see Procedures section).

Researchers visited each route, recorded the spatial information (e.g., trees, parking position, chuckhole, pillar, stores, ramp or stairs), as far as absolute location of information was concerned and selected 30 pieces to be mapped out. The number (30) was not random. The researchers calculated the mean number of pieces of spatial information that the participants (see Procedures section) had identified during the first and the third experiment – walked along a familiar and a unfamiliar city route, respectively. Moreover, the researchers carefully recorded all the tactile, audio and olfactory information. Thus, an attempt was made to exclude the possibility of error in case a specific type of spatial information was stored more easily or greater difficulty in the cognitive map of individuals with blindness.

Moreover, sound recording for each route was made at a certain time, during evening hours and for 20 seconds at each point. Sound was recorded at the beginning and the end of each route, at all intersections and at some places with special auditory information, such as school, café, car wash etc. For the recording a Telinga Stereo Dat-Microphone was used with the recording system Zoom H4n-Handy Recorder.

Adobe Illustrator CS6 was used for the creation of digital tactile maps. These maps were then printed on microcapsule paper, and consequently six tactile maps were developed. On each tactile map dots were placed at the locations with spatial information (e.g. trees, pillars, stores) and short length vertical lines were placed at the locations where sounds was recorded.

In the next phase the digital tactile maps were installed on the touchpad and all audio information (street names, information, and sounds) were added to them. A speech synthesizer was used for the presentation of spatial information and street names.

A laptop, a touchpad device and headphones through which participants listened to audio information (street names, spatial information and sounds) were used to read the audio-tactile maps. In the phase where their cognitive map was depicted, a range of different materials were used by the participants. The materials included a kappa fix carton on which an A3 sheet was fastened. Moreover, a string was placed in the position of roads, thumbtacks to fasten the laces and twist them when there were turns were used, and different types of thumbtacks were used to indicate the position of spatial information.

2.3 Procedures

The subjects participated in four experiments: the independent movement within the familiar area (first experiment), the use of an audio-tactile map into the familiar area (second experiment), the independent movement within the unfamiliar area (third experiment), and the use of an audio-tactile map into the unfamiliar area (fourth experiment).

The experiments were conducted in different days to avoid the negative impact of fatigue on their performance. The sequence of the experiments was not the same for every participant. A circular design of implementation was applied for the purpose of eliminating a possible learning effect. Moreover, a circular design of implementation was applied with reference to routes. For instance, the first participant walked down the first route during the first experiment, while he/she used the audio-tactile map of the second route during the second experiment. In the same way, the second participant walked down the second route during the first experiment, and he/she used the audio-tactile map of the third route during the second experiment, and so on. It should be noted that not only the route to be studied each time was addressed in a cyclic way from one participant to the other but also the experiment. This design was applied in order to avoid any error resulting either from differences in the degree of difficulty or from previous learning of the area structure.

Ten participants (those who initiated the procedure by participating in the first or the third experiment) had been asked to verbally point out all the spatial information they would detect during the first and the third experiment, while their examination continued. The spatial information detected was noted using a recorder. The mean number of spatial information was used to define the quantity of spatial information to be consequently mapped on the audio-tactile maps.

Both in the first and the third experiment, the participants moved along a route and afterwards they depicted the cognitive map resulting from their movement. Initially, the participants were informed about the procedure of the experiment and the haptic model they should create at the end. Next, the participants moved along the route independently using their white cane. Each time the researcher moved with the participant maintaining a short following distance from him/her and guiding him/her using verbal instructions (e.g. “at this point you should turn right”). Furthermore, the researcher mentioned the name of the street and the walking duration each time a participant was walking along a street.

In case of emergency where a participant could place him-/herself in danger, the researcher asked him/her to stop (uttering “stop”). When the participant had finished walking down the route, he/she and the researcher moved to a quiet place in order to proceed with the next phase of the experiment – the representation of the participant’s cognitive map by creating a haptic model of the route previously walked. The elapsed time from the completion of walking the route until the beginning of haptic-model-creation phase was 5 minutes on average.

Both in the second and the forth experiment the examination consisted of reading the audio-tactile maps through the touchpad device and then the participants depicted their cognitive map. The examination procedure was carried out individually in a quiet place. Initially, participants were informed about the procedure of the experiment and the haptic model they should create at the end. The tactile map was placed on the touchpad device and a familiarization process using the audio-tactile map with the touchpad device took place. Then the audio-tactile map reading phase followed. Each participant read the tactile map that was placed on the surface of the touchpad device using his/her touch, and by tapping the streets he/she listened to their name, by tapping the dots he/she listened to the information they represent, and finally by tapping the small vertical lines he/she heard the sounds of the particular area. The maximum time that was offered for the map reading was 15 minutes, in which participants had to learn the route, street names and 30 pieces of spatial information. They could refer to the map and listen to the information as many times as they wished during the 15 minutes, and they could stop reading before 15 minutes elapsed. A five-minute pause followed. Then the participants used the materials given by the researcher to depict their cognitive map.

At the end of each experiment, the participants created a haptic model representing their cognitive map. There was no time limit for the creation of the haptic model. With the aid of the researchers, the participants placed the laces to represent the streets forming the route. The researchers helped the participants in placing and stabilizing the laces on the base whenever it was necessary. While placing a lace, the participant mentioned the name of the respective street, and the researcher noted down on the surface. Consequently, the participant placed the respective thumbtacks to represent the spatial information naming the type of information and the researcher noted down the name/ type of information on the surface of the model. Each time a participant touched an item on the haptic model, the researchers pointed out what this item stood for so that he/she could make a review. In many cases, participants corrected the initial haptic model after this review. Times of audio-tactile map reading and creation of the haptic model were recorded.

After the completion of the haptic model, the researchers drew the maps by drafting an outline of the materials of the haptic model on the A3 sheet. The recording of data on the cognitive maps and their analysis followed.

During the processing of the cognitive maps (haptic models), the following variables were recorded and calculated by the researchers regarding their accuracy: the number of streets, the names and length of the streets, the number and direction of turns and the number of pieces of spatial information participants placed on the haptic model. Specifically, with respect to streets, variables that were examined included how many streets participants placed properly and how many mistakes (placed incorrectly, placed in abundance or were missed). How many names of streets were identified correctly and how many incorrectly (identified incorrectly, placed in abundance or were missed) were also recorded. Regarding the road turns, two variables were measured: one for the number of turns placed correctly and one for the number of turns that were placed incorrectly (placed incorrectly, placed additionally or forgotten).

Regarding the amount of spatial information, the variable "correct information" was calculated. This variable concerns the pieces of spatial information that result from the total spatial information used by a participant on his/her cognitive map, having firstly subtracted the pieces of "wrong information". Wrong information included the following nine categories of errors: 1) information placed did not actually exist, 2) wrong position on the same road, 3) the wrong position on the opposite road, 4) the combination of wrong position and opposite road, 5) error placement, i.e. in the correct position some other information was used, 6) a combination of error location and replacement, 7) combination of replacement and placement on the opposite side of the street, 8) combination of wrong position, replacement and placement across the street, and 9) could not remember the kind of information but only its existence in that location.

Regarding the street length, the average error of the length of the roads placed in the haptic model was measured. To make this measurement, the following procedure was followed for each participant: 1) the actual map of the area was printed, 2) a change of scale on the cognitive map from the scale of the actual map was implemented, 3) for each road the participant placed, the error length was measured; this is the divergence between the length of the actual and the length of the cognitive road (after scaling), and 4) the average error length for all the roads included in the participants' cognitive map was calculated.

The mean reading time of audio-tactile maps of the familiar and unfamiliar area was 717 (*SD* = 204.7) and 646 (*SD* = 245.4) seconds, respectively. Moreover, the mean time of the haptic model creation after using the audio-tactile maps for the familiar and unfamiliar area was 485 (*SD* = 200.0) and 380 (*SD* = 169.6) seconds, respectively.

The mean walking time of the routes in the familiar and unfamiliar area was 855 (*SD* = 386.4) and 988 (*SD* = 408.4) seconds, respectively. Moreover, the mean time of the haptic model creation after the independent movement in the familiar and unfamiliar area was 607 (*SD* = 300.0) and 660 (*SD* = 315.9) seconds, respectively.

3 Results

Initially, the scores for the following eight variables were calculated: "number of streets-correct," "number of streets-wrong," "street names-correct," "street names-wrong," "turns-correct," "turns-wrong," "information-correct," and "street length-error." The minimum, maximum, mean, and standard deviation (*SD*) of scores for the familiar and unfamiliar area are presented in Tables 2 and 3, respectively. Each correct answer was scored as 1 with reference to the variables "number of streets-correct," "street names-correct," "turns-correct," and "information-correct." Moreover, each wrong answer was scored as 1 with reference to the variables "number of streets-wrong," "street names-wrong," and "turns-wrong." Concerning the number of streets and streets names, if any participant placed all the streets and street names correctly, his/her score would be equal to 8. Regarding turns if any participant placed all the turns correctly, his/her score would be equal to 7.

<Insert Table 2 about here>

<Insert Table 3 about here>

Furthermore, repeated-measures ANOVAs were conducted to examine the differences between the cognitive maps created after the independent movement and the cognitive maps created after reading the audio-tactile maps (independent movement vs. audio-tactile map) in both cases of familiar and unfamiliar area. The repeated-measures ANOVAs were conducted for the eight variables presented in Table 2 and 3 (number of streets-correct, number of streets-wrong, street names-correct, street names-wrong, turns-correct, turns-wrong, information-correct, and street length- error).

Regarding the cognitive maps of familiar area, the repeated-measures ANOVAs revealed no significant differences for the variables: number of streets-correct, number of streets-wrong, turns-correct, turns-wrong, and street length-error. Moreover, the implementation of the repeated-measures ANOVAs indicated that the participants gave significantly fewer correct responses and made more mistakes after having walked down the route than having read the audio-tactile map, with reference to the following variables: street names-correct [F (1, 29) = 5.715, p < .05], street names-wrong [F (1, 29) = 5.394, p < .05]. On the other hand, participants gave fewer correct responses after having read the audio-tactile map rather than having walked down the route, with reference to the variable “information-correct”. However, this difference was not statistically significant but close to significant [F (1, 29) = 3.930, p = .057].

Concerning the cognitive maps of the unfamiliar area, the repeated-measures ANOVA revealed no significant differences for the variable "information-correct". Moreover, the repeated-measures ANOVAs indicated that the participants gave significantly fewer correct responses and made more mistakes after having walked down the route than reading the audio-tactile map, with reference to the following variables: number of streets-correct [F (1, 29) = 6.843, $p < .05$], number of streets-wrong [F (1, 29) = 4.721, $p < .05$], street names-correct [F (1, 29) = 28.475, $p < .01$], street names-wrong [F (1, 29) = 28.475, $p < .01$], turns-correct [F (1, 29) = 11.764, $p < .01$], turns-wrong [F (1, 29) = 9.386, $p < .01$], street length- error [F (1, 29) = 25.421, $p < .01$].

In order to examine if there is any correlation between the participants' performance in the experiments and the age at onset of visual impairment, a correlation analysis was implemented. Specifically, it was calculated the Pearson's product-moment correlation coefficients between the age at onset of visual impairment and the 8 variables (the scores of each one of the 8 variables for each of the four experiments). The analysis showed statistically significant correlation between the age at onset of visual impairment and the participants' performance in the experiment of independent movement within the unfamiliar area. Specifically, a significant correlation between the age at onset and the score on the variables "number of streets-correct" (r = -.478, $p < .01$) and "number of streets-wrong" (r = .440, $p < .05$) was ascertained. The participants who lost their vision in greater age presented a worse performance compared to those who lost their vision earlier in their life.

4 Discussion

The present study aimed at comparing the quality of cognitive maps developed through different methods – walking within an area and exploring an audio-tactile map – in two cases: familiar and unfamiliar areas.

The findings of the study concerning independent movement in familiar and unfamiliar area were to a degree expected. The participants presented a well-formed cognitive map of the familiar area and, of course, a better cognitive map of the same area compared to the cognitive map of the unfamiliar area. Repeated experience of coming into contact with an area seems to be an important factor for the formation and updating of cognitive maps. Other research studies that have tested the ability of individuals with visual impairments to learn a novel geographic space proved that repetition leads to increasing knowledge of this space (Blades et al., 2002; Espinosa et al., 1998; Ochaita & Huertas, 1993).

As far as the use of an audio-tactile map to create a cognitive map is concerned, the findings of the present study reflect the positive effect of audio-tactile maps on the creation of cognitive maps, and thus, their effect on the spatial knowledge of people with blindness. The contribution of the audio-tactile maps appeared both in familiar and unfamiliar areas, though the positive effect of audio-tactile maps became more obvious in the unfamiliar area, which all the participants were visiting for the first time. This means that their cognitive map was then created, unlike the familiar area for which participants possessed an already formed cognitive map. More than half of the participants presented their cognitive maps with precision, while the other participants performed well in all the variables that were examined. Previous research has also proved that audio-tactile maps result in adequate spatial knowledge (Papadopoulos & Barouti, 2015a).

The only exception was the poor identification of the information in participants' cognitive maps. However, this should not be accounted a disadvantage of the aid, considering the large amount of information that a participant had to memorize (30 pieces of information) in the relatively short time span available for studying the audio-tactile map. Probably, the repeated use of the aid i.e. the usage experience could result in the better performance of individuals with blindness regarding the coding of information in cognitive maps. This should constitute a future research objective.

The most striking result of the present study appeared to be the dominance of the audio-tactile map over walking experience. The participants formed more complete cognitive maps after having explored the audio-tactile map than walking along the route in an unfamiliar area, where a previous cognitive map did not exist, with the spatial knowledge being developed as a whole from scratch. Thus, in this case, when the participants used the audio-tactile map, 18 (60%) of them did not make any mistakes in the number of streets and turns, whereas 14 (46.7%) participants did not make any mistakes in street names. On the contrary, when the participants moved independently along the route, only 9 (30%) of them did not make any mistakes in the number of streets and turns, whereas only 5 (16.7%) participants did not made any mistakes in street names. Previous research studies comparing walking experience with exploration of audio-tactile maps have not been encountered. However, comparison of walking experience with reading a tactile map leads to the finding that audio-tactile maps entail a better spatial knowledge than walking experience in novel environments (Espinosa & Ochaita, 1998).

The only case where the performance of the participants was better after independent movement compared to the use of the audio-tactile map, was the identification of the correct spatial information of the familiar area. The main hypothesis that could explain this result is that the objects of the area had been repeatedly used as points of reference or landmarks in the past by the participants. This may have resulted in a well established knowledge. In this case, the representation of these objects through tactile symbols could not only entail an inferior knowledge but also a distorting factor of this well established knowledge. Moreover, the performance in the same variable was slightly better – though not statistically significant – after walking experience than after reading the audio-tactile map in the case of the unfamiliar area as well. Taking this result into consideration it could be additionally assumed that using all the other senses in combination with touch to memorize objects of the environment leads to better knowledge relative to this variable.

The findings of the present study contribute to the understanding of issues concerning the development of cognitive maps in individuals with blindness both through the use of audio-tactile maps and the experience of independent movement. These findings are specifically significant in the case of familiarization with a novel area and the consequent creation of a new cognitive map. Thus, the results of the study have implications for both educators and orientation and mobility specialists. Proving the dominance of audio-tactile maps, touchpads are suggested to be included in orientation and mobility training as a main tool, while large-scale spaces (for instance, a campus) should be equipped with audio-tactile maps to support and guide first-time visitors with visual impairments.

The current research appears to be a significant contribution on the field of spatial knowledge development in individuals with visual impairments. It provides solid evidence on the support that an audio-tactile map could provide especially when an individual with visual impairment come into an unfamiliar environment. The audio-tactile map enables the development of a functional and effective cognitive map in the case of an unfamiliar area, while it contributes to the improvement of an existent cognitive in the case of a familiar area. The combination of tactile and auditory stimuli within a map display leads to better understand and encode space than walking in the real environment, where tactile and auditory stimuli are also available, but the borders or other critical points of reference are vague. The contribution of audio-tactile maps in cognitive mapping versus walking experience in the real environment has never been studied. Thus, the results clearly enrich the existent knowledge and give new directions for research concerning the abilities of spatial awareness as a result of an audio-tactile map use. Specifically, future research should focus on which specific attributes of the audio-tactile interaction provide the greatest support, and how these attributes are connected to the user's spatial behaviour in the physical environment.

A limitation of the present study could be the relation between the methods used to code space and the methods used to assess the result of the coding process. Transferring the knowledge developed through walking experience in the real environment on a haptic model requires scale adaptations, while transferring spatial knowledge acquired using an audio-tactile map on a haptic model does not entail such cognitive processes. That means that after walking in the real environment (great scale) participants are required to transform the spatial knowledge in order to provide a tactile model (small scale). This is not the case for the audio-tactile map, since the scale of the map and the scale of the tactile model were approximately the same. However, such an influence should be expected only for the variables "street length-error" and "information-correct", and not for the variables "number of streets-correct", "number of streets-wrong”, “street names-correct”, “street names-wrong”, “turns-correct”, and “turns-wrong”, since these were independent of the scale alteration. The variable “street length-error” was possibly influenced since the participant had to assess the length of the street usually based on the duration of his/her movement along the street. Moreover, the variable “information-correct” was possibly influenced since the placement of the thumbtack on the correct location depended on distance assessments. To further examine the issue of the results’ influence because of scale adaptations, a repetition of the research including a verbal description as a method to assess the participants’ cognitive maps (instead of the haptic model), could help. However, such a method presents a series of weaknesses. For instance, the participants have no tactile access to the cognitive map they represent and, thus, they would not be able to make corrections and modifications easily.

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Table 1

Ability and frequency of independent movement according to the answers of participants and O&M specialists - the score represent the number of participants in each group

	With or without sighted guide			Frequency of independent movement			
	with	with & without	without	seldom	sometimes	usually	always
Participants	2	10	18	0	2	18	10
Specialists	4	4	22	3	7	14	6

Table 2

Minimum (Min), maximum (Max), mean (M), and standard deviation (SD), of correct and wrong answers regarding the number of streets, streets names, turns, and spatial information (familiar area)

	Independent Movement				Audio-tactile map			
	Min	Max	M	SD	Min	Max	M	SD
number of streets-correct	4	8	7.57	.94	4	8	7.50	1.01
number of streets-wrong	0	4	.43	.94	0	5	.67	1.24
streets names-correct	0	8	4.80	3.16	0	8	6.27	2.26
streets names-wrong	0	8	3.20	3.16	0	9	1.77	2.36
turns-correct	3	7	6.57	.94	3	7	6.50	1.01
turns-wrong	0	4	.50	1.01	0	4	.67	1.18
information-correct	2	22	9.30	5.77	0	23	6.80	6.18
streets length-error	.98	10.6	3.19	1.79	.68	7.50	2.66	1.51

Table 3

Minimum (Min), maximum (Max), mean (M), and standard deviation (SD), of correct and wrong answers regarding the number of streets, streets names, turns, and spatial information (unfamiliar area)

	Independent Movement				Audio-tactile map			
	Min	Max	M	SD	Min	Max	M	SD
number of streets-correct	4	8	6.60	1.35	4	8	7.30	1.02
number of streets-wrong	0	4	1.60	1.28	0	6	.90	1.49
streets names-correct	0	8	2.80	2.95	1	8	6.20	2.31
streets names-wrong	0	8	5.20	2.95	0	7	1.80	2.31
turns-correct	2	7	5.30	1.60	3	7	6.33	.99
turns-wrong	0	7	1.97	1.79	0	5	.80	1.27
information-correct	0	23	6.37	5.59	0	25	5.80	7.04
streets length-error	2.03	7.63	3.69	1.48	.80	4.08	2.21	.72

Figure 1

The touchpad device with the audio-tactile map of the route 3 of the unfamiliar area, connected to a computer and a headset

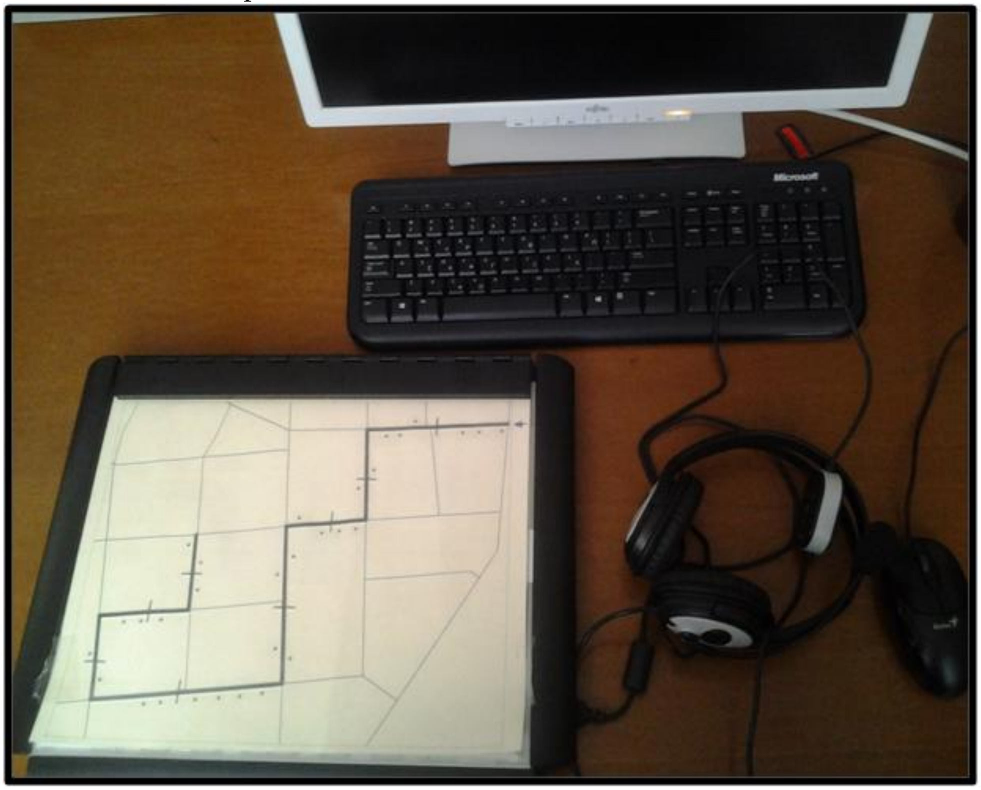

Figure 2

The haptic model created by a participant to represent the route 3 of the unfamiliar area after his walking experience in the real environment. The laces represent the streets, and the thumbtacks with the small circular head the location of the spatial information. The thumbtacks with the bigger head were used only to stabilize the laces. On the surface of the model, the name of the streets and the name/ type of spatial information were noted after the participant had mentioned them.