Differences in Spatial Knowledge of Individuals with Blindness when Using Audio-tactile maps, Tactile Maps, and Walking

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Abstract

Knowing that individuals with visual impairments understand space and the way they develop cognitive maps, we studied the differences in cognitive maps resulting from different methods and tools for spatial coding of large geographical spaces. We examined the ability of 21 blind individuals to create cognitive maps of routes in unfamiliar areas using (a) audio-tactile maps, (b) tactile maps, and (c) direct experience of movement along the routes. We also compared participants' cognitive maps created with the use of audio-tactile maps, tactile maps, and the independent movement along the routes with regard to their precision (i.e. the correctness or incorrectness of spatial information location) and inclusiveness (i.e. the amount of spatial information included correctly in the cognitive map). The results of the experimental trials demonstrated that becoming familiar with an area is easier for blind individuals when they use a tactile aide, such as an audio-tactile map, as compared to walking along the route"

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

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Cognitive mapping is 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 the environment (Downs & Stea, 1973). Although cognitive mapping of spaces is a prerequisite for developing adequate orientation and mobility skills (Lahav & Mioduser, 2008), most of the information required for cognitive mapping is gathered through the visual channel (Loomis et al., 1993). As a result, in the case of those with visual impairments, a large piece of spatial information is missing and cognitive mapping becomes a very difficult process, with the degree of difficulty depending on the degree of vision loss. Gathering information through compensatory sensorial channels is considered a fundamental way of dealing with cognitive mapping (Lahav & Mioduser, 2008). Knowing how individuals with visual impairments understand space, develop cognitive maps, and the methods that could aid the process of cognitive mapping may help individuals with visual impairments 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, and bus stops (Papadopoulos, 2004). Such features of an area that consequently comprise the cognitive map of an individual with visual impairment depend on the relative information the individual receives. When a tactile map constitutes the basic means for an individual to become acquainted with an area, the derived mental map should be modelled on the initial map's elements. On the other hand, when an individual with profound visual impairment or blindness walks in an area the cognitive mapping is directly dependent on environmental cues (i.e., olfactory, auditory, and haptic) (Koutsoklenis & Papadopoulos, 2011a, 2011b, 2014; Papadopoulos, Papadimitriou, & Koutsoklenis, 2012).

Moreover, the methods people use to acquire data for the spatial environment could influence their cognitive map. Individuals with visual impairments tend rely on egocentric strategies when they code a route (Tinti, Adenzato, Tamietto, & Cornoldi, 2006). In other words, they code space having an "egocenter" as a point of reference (i.e., egocentric) such as their whole body or a part of it, for instance their head or hand (Kappers, 2007). This means that they map locations or objects in the environment according to the positions of those objects in relation to their own body (Wang, 2003). As a result, the cognitive map arising from walking along a route should be presented egocentrically. On the other hand, providing a tactile map where there is an external frame of reference (e.g., the edges of the map) and the spatial relations of the elements' locations with each other and with the frame could lead participants to use allocentric cues (i.e., cues that emerge from objects' spatial relations with each other) and construct a corresponding representation (Nardini, Burgess, Breckenridge & Atkinson, 2006; Wang, 2003). Millar (1979) hypothesized that if external cues become available, then individuals with visual impairments could integrate them into mental representations. Indeed, research results have indicated that individuals with visual impairments rely on external spatial cues to code space when they are salient (Papadopoulos & Koustriava, 2011; Papadopoulos, Koustriava, & Kartasidou, 2011). Thinus-Blanc and Gaunet (1997) also stated that an individual with blindness reading a haptic map 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 et al., 2012; Papadopoulos & Koustriava, 2011).

Thus, using a tactile aid should result in better spatial performance. Although walking along a route leads to egocentric spatial coding, it provides ample information through the use of all other senses (touch, hearing, and smell) which further support the formation of a cognitive map. Therefore, the ways in which individuals with visual impairments have access to spatial knowledge affects the cognitive map they develop. By supporting the relative localization of objects, maps lead to the acquisition of survey knowledge, a knowledge that can be obtained more quickly and with less effort than direct experience either by sighted individuals (Thorndyke & Hayes-Roth, 1982) or by individuals with visual impairments (Caddeo, Fornara, Nenci, & Piroddi, 2006).

Furthermore, according to Lahav and Mioduser's (2008) review of orientation and mobility aids, tactile maps can support spatial learning before an individual makes contact with an area. As such, tactile maps are important for spatial awareness (Habel, Kerzel, & Lohmann, 2010) of close or distant places supporting wayfinding (Passini, Duprés, & Langlois, 1986) and orientation and mobility of individuals with profound visual impairments (Lawrence & Lobben, 2011), as well as for improving spatial cognition in the long-term (Ungar, 2000). Similarly, researchers have pointed out that raised-line graphics of the spatial environment prepare individuals with profound visual impairments to travel in unfamiliar spaces more safely and efficiently than working with a verbal description or a sighted guide (Espinosa, Ungar, Ochaita, Blades, & Spencer, 1998), demanding a smaller cognitive load than direct experience (Thinus-Blanc & Gaunet, 1997).

However, there are limitations accompanying tactile maps. According to Jacobson (1998) these limitations include: (a) the fact that fingertip resolution is lower than the eye's resolution; (b) the simplification problems that cartographers face; (c) issues of generalization, classification, and symbolization of the information included on a visual map; and (d) the extensive Braille labelling that is required, which leads to overload and is inaccessible to those who do not know Braille. The abundance of information and the complex graphics entail greater memory load (Ungar, Blades, & Spencer, 1993), but an increased amount of spatial information clearly influences spatial coding and representation (Papadopoulos et al., 2012). Moreover, separate legends restrict immediacy and interaction with a map (Hinton, 1993).

Verbal assistance can help to overcome many of the limitations catalogued by Jacobson (1998) by substituting Braille labels and legends, as well as by providing guiding information, such as spatial relations, descriptions of buildings (Habel et al., 2010) or significant landmarks (Wang, Li, Hedgpeth, & Haven, 2009). Information provided through speech in combination with touch can be helpful in overcoming the restrictions of touch in serial information gathering (Wang et al., 2009). Multimodal maps form the context for these solutions and specific audio-haptic devices, such as touchpad devices, represent the tools for using audio-tactile maps.

A touchpad device is a device that gives a user the opportunity to receive auditory information while simultaneously touching a tactile figure placed on the surface of the device. Thus, in the case of tactile maps, a touchpad device offers access to both the benefits of tactile maps and verbal aids at the same time. The combination of auditory and tactile information may result in a more complete concept (Landau, Russell, & Erin, 2006).

The touchpad device was originally presented by Parkes (1988) and research about the combination of auditory and tactile information on the device was reviewed later in the MICOLE project (2006), highlighting the benefits for individuals with visual impairments. Moreover, considering that touchpad devices provide the ability to use environmental auditory cues by incorporating the soundscape into the tactile map, they could promote an individual’s orientation because individuals with profound visual impairments are known to use auditory cues to determine and maintain orientation within an environment (Jansson, 2000; Koutsoklenis & Papadopoulos, 2011a) and to associate the soundscape with the structural and spatial configuration of the landscape and create cognitive maps (Papadopoulos et al., 2012). Landau and his colleagues (2006) found that individuals with visual impairments can enjoy control and independence in the ability to make choices between tactile and auditory information through a touchpad device.

Research pertaining to coding and representation of large geographical spaces has demonstrated that individuals with visual impairments can create effective and functional cognitive maps of familiar places (Casey, 1978). Moreover, they are able to learn an unfamiliar route by walking along it several times (Espinosa et al., 1998; Golledge, Jacobson, Kitchin, & Blades, 2000; Jacobson, Kitchin, Garling, Golledge, & Blades, 1998; Ochaita & Huertas, 1993), and can demonstrate complex spatial knowledge including orientation and estimating distances (Jacobson, Lippa, Golledge, Kitchin, & Blades, 2001).

Research has also provided evidence that individuals with visual impairments can develop a cognitive map using an audio-tactile map with a touchpad device (Papadopoulos & Barouti, 2015a), and that reading a tactile map to learn an area results in better knowledge compared to walking in the area (Espinosa & Ochaita, 1998). Moreover, a previous study (Papadopoulos, Barouti, & Koustriava, 2016) highlighted the contribution of audio-tactile maps to improve the existing spatial knowledge of individuals with visual impairments for a familiar city area. However, the specific differences in cognitive maps created from walking along a novel route of an unfamiliar area, using a tactile map of the same area, or using an audio-tactile map with a touchpad device where audio information and soundscape support spatial coding remain unclear.

The Present Study

In the present study we examined the ability of individuals with blindness to create cognitive maps of routes in an unfamiliar area through the use of (a) audio-tactile maps, (b) tactile maps, and (c) participants' direct experience of movement along the routes. Moreover, we compared the cognitive maps created using audio-tactile maps, tactile maps, and individuals' independent movement along the routes with regard to their precision (i.e., the correctness or incorrectness of spatial information location) and inclusiveness (i.e., the amount of spatial information included correctly in the cognitive map).

The present study is part of a larger project examining: (a) the spatial knowledge (cognitive maps) that individuals with blindness develop for city routes (familiar and unfamiliar) using different 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 aids. From this research, we have published five articles (Barouti & Papadopoulos, 2015; Papadopoulos & Barouti, 2015a; Papadopoulos & Barouti, 2015b; Papadopoulos, Barouti, & Koustriava, 2016; Papadopoulos, Koustriava, & Barouti, 2017). The experiments included in the studies of these four papers are similar to the studies presented in the present report; thus, there are similarities between the sections of all those papers. The aims of these studies were different to the aims of the current study. Two of the four previous studies (Papadopoulos & Barouti, 2015b; Papadopoulos, Barouti, & Koustriava, 2016) examined the developed spatial knowledge of a familiar city area, and as a result, the area under investigation and the aids used concerned a whole different area. The third study (Barouti & Papadopoulos, 2015) examined the participants' satisfaction after using a series of aids to develop spatial knowledge. The fourth one (Papadopoulos & Barouti, 2015a) was a pilot study examining the ability of individuals with blindness to create cognitive maps using audio-tactile maps. The fifth article (Papadopoulos et al., 2017) compares the cognitive maps of individuals with visual impairments formed with the use of audio-tactile maps to those formed after independent movement within a familiar and an unfamiliar area. This above mentioned study developed as a progressive step from the present study and the study of Papadopoulos and Barouti (2015a), and some of the participants took part in all these three studies.

Method

Participants

Twenty-one adults with blindness took part in this study. The sample consisted of 13 males and 8 females. The ages ranged from 20 years to 61 years (M = 35.8, SD = 12.34). All the participants had legal blindness. Specifically, 17 participants had total blindness or light perception, and four participants had profound visual impairments (their visual acuity was less than 1/40). Except for age (over 18), visual impairments, and unfamiliarity with the area examined in the research, an essential criterion for an individual to be included in the study was not having a hearing impairment or other disabilities. The visual impairment was congenital for 14 participants and acquired for the remaining seven participants. Two participants out of these seven lost their vision before the age of 3, two participants lost their vision at the age of 8, and the other three participants lost their vision at some point between the age of 12 and 25. Regarding the time the participants had been living as individuals with visual impairments: one participant lost his vision 7 years, one participant 12 years, one participant 14 years, and one participant 18 years before participating in the study; the other three participants had lost their vision 30 years before participating in the study.

We asked participants 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 independently (“by myself”) and sometimes with the assistance of a sighted guide, and (c) independently without any assistance. Moreover, the participants indicated 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 and mobility specialists, who were familiar with the participants and could assess the latter’s capacity for independent movement. Table 1 presents the participants’ and mobility specialists’ answers to interview questions.

Instruments and Procedures

Across all the studies, we followed the ethical principles of the Declaration of Helsinki and obtained informed consent from the participants. The participants were involved in three experimental trials. During the first trial the participants walked along a city route. In the second trial the procedure involved reading the audio-tactile map of a second city route, and in the third experimental trial the participants read a tactile map of a third city route. The area that contained the three routes was neither known nor ever walked previously by the participants.

The three different routes (itineraries; Figure 1) were carefully chosen. 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. To achieve the accessibility objective, researchers walked around the area and examined whether it was accessible for people with blindness. To assess accessibility, we avoided obstacles that would prevent individuals with blindness from passing through an area. We chose three different routes because of the experimental design.

This design ensures the variability of the degree of difficulty among the routes and reduces a learning effect that could affect participants' performance.

Researchers visited each route, recorded the spatial information (e.g., trees, parking positions, potholes in road surface, pillars, stores, ramps or stairs), with reference to the exact location of each piece of information, and selected 30 pieces to be mapped out on audio-tactile maps and tactile maps. The researchers selected 30 items because they calculated the mean number of pieces of spatial information that the participants had identified during the first experimental trial, when they walked along a city route (see First Experimental Trial). Moreover, the researchers recorded all the tactile, audio, and olfactory information. That is, we sought to reduce the possibility that a specific type of spatial information would be easier or more difficult to record and, therefore, would induce fewer or more errors in the cognitive map of individuals with blindness.

The experimental trials were conducted on different days to prevent the effect of fatigue impinging on the results. The sequence of the experimental trials 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 the three routes. For instance, the first participant walked down the first route during the first experimental trial, read the audio-tactile map of the second route during the second experimental trial, and read the tactile map of the third route during the third experimental trial. However, the second participant walked down the second route during the first experimental trial, used the audio-tactile map of the third route during the second experimental trial, and read the tactile map of the first route during the third experimental trial. 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 that the overall experiment (walking experience, tactile map, and audio-tactile map) was also balanced. This design was applied in order to avoid errors resulting either from differences in the degree of difficulty or from previous learning of the area structure.

At the end of their participation in each experimental trial, the participants created a haptic model representing their cognitive map of the route he or she had just completed. They constructed the haptic model using a variety of materials to symbolize the elements of an environment. The materials included a KAPA fix carton board (for the base) on which an A3 sheet was fastened. We provided a string so that the participants could indicate the position of roads and thumbtacks to fasten the strings and twist them when there were turns. We also provided different types of thumbtacks for them to indicate the position of different spatial information. There was no time limit for the creation of the haptic model. Each time a participant touched an item that he or she had added to the haptic model, the researchers named what this item stood for so that a review could be made.

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. We used these maps to record data for analysis. We followed methods of constructing participants' cognitive maps that have been employed by at least four other research teams (Afonso, Blum, Katz, & Tarroux, 2010; Casey, 1978; Lahav & Mioduser, 2011; Passini & Proulx, 1988).

The mean reading time of individual audio-tactile maps and tactile maps was 654 sec (*SD* = 244.0) and 808 sec (*SD* = 231.1), respectively. The mean time of the haptic model creation after using the audio-tactile map and tactile map was 382 s (*SD* = 176.9) and 356 s (*SD* = 120.6), respectively. The mean walking time of the route was 970 (*SD* = 384.9) s. The mean time of the haptic model creation after the independent movement in the unfamiliar area was 605 (*SD* = 260.2) s.

First Experimental Trial

In the first experimental trial, the participants moved along a route and afterwards they depicted the cognitive map resulting from their movement. Initially, we informed the participants about the procedure of the experimental trial and the haptic model they should create at the end. Next, each participant moved along the route independently using his or her white cane. The researcher moved with the participants, following at a short distance and providing guidance using verbal instructions (e.g., “at this point you should turn right”). In case a participant could be in danger, the researcher asked the participant to stop (stated “stop”). When the participant had finished walking down the route, along with the researcher, they moved to a quiet place to proceed with the next phase of the experimental trial–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 min on average.

We asked the first seven participants (the ones initiating the process by participating first) to describe all the spatial information they detected, while their examination continued. The spatial information detected was noted using an audio-recorder. The mean number of pieces of information was used to define the quantity of spatial information included in the audio-tactile maps and the tactile maps.

Second Experimental Trial

We used Adobe Illustrator CS6 to create digital tactile maps of the routes. We printed the maps on microcapsule paper and created the three tactile maps used to develop the audio-tactile maps, one for each route. On each tactile map, we placed dots on the locations with spatial information (30 pieces of spatial information) and short vertical lines on the locations where sounds were recorded. We provided no Braille labels because all the information was presented through synthetic speech.

We created sound recording for each route during evening hours. The recordings lasted for 20 s at each point along the routes. We recorded at the beginning and the end of each route, at all intersections, and at places with salient auditory information (e.g., school, café, car wash). For the recording, we used a Telinga Stereo Dat-Microphone with the recording system Zoom H4n-Handy Recorder. The software application Iveo Creator Pro 2.0 was used to develop the audio-tactile maps. The audio-tactile maps were read by the participants using the IVEO touchpad.

In the second experimental trial the examination consisted of reading the audio-tactile map through the use of a touchpad device. After completing the trial, the participants created a cognitive map, which might be their first, second, or third, depending on where the audio-tactile trial fell in any one participant's series. Participants were not familiar with the area represented by the audio-tactile map and, as a result, their first contact with the area was made through the audio-tactile map. The examination procedure was carried out individually in a quiet environment. 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 tactile map with the touchpad device took place. Then the audio-tactile map reading phase followed. Participants read the audio-tactile map using their touch. By tapping the streets they listened to the streets' name, by tapping the dots they listened to the spatial information the dots represented, and finally by tapping the small vertical lines they heard the sounds of the particular area.

The maximum time that was offered for the tactile map reading was 15 min, 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 min, and they could stop reading before 15 min was completed. A 5-min pause followed. Then the participants used the materials given by the researcher to depict their cognitive map.

Third Experimental Trial

We again used Adobe Illustrator CS6 to create the digital tactile maps of the routes. These maps were then printed on microcapsule paper, and consequently the three tactile maps for the third experimental trial were developed–one for each route. On each tactile map, we placed dots at the locations with spatial information (30 pieces of spatial information) and Braille labels indicated streets names and kind/names of spatial information. The tactile maps used in the third trial were differentiated from the audio-tactile maps used in the second experimental trial.

In the third experimental trial the examination consisted of reading the tactile map and then the participants depicted their cognitive map. As in the second experimental trial, the participants' first experience with the area at hand was through the tactile map. The examination procedure was completed individually in a quiet environment. Initially, participants were informed about the procedure of the experimental trial and the haptic model they would create at the end of the trial. The tactile map was placed on the table in front of them followed by the tactile map reading phase.

The maximum time that was offered for the audio-tactile map reading was 15 min. During this time, the 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 min, and they could stop reading before 15 min elapsed. A 5-min pause followed. Then the participants used the materials given by the researcher to depict their cognitive map.

Measures

During the processing of the cognitive maps (haptic models), researchers recorded and calculated the following variables: the number of streets, the names and length of the streets, the number and direction of turns, the street length, and the number of pieces of spatial information participants placed on the haptic model. Specifically, with respect to streets, researchers recorded how many streets participants placed properly and improperly (placed incorrectly, placed even though they did not exist, or omitted) and how many names of streets were identified correctly and incorrectly (named incorrectly, named even though they did not exist, or omitted). 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 omitted). It should be noted that correctly located information and mistakes were distinct measures, because correct and incorrect detection of the requested elements were not supplementary. In other words, a participant could have detected all the elements correctly and added one or more elements as well, which counted for an additional number of mistakes.

Regarding the amount of spatial information, the variable "correct information" was calculated. This variable concerned the pieces of spatial information that resulted from the total spatial information used by a participant on the cognitive map, having first subtracted the pieces of "wrong information." Wrong information included the following nine categories of errors: (1) information placed that 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, we adopted the following procedure for each participant: (1) We printed the actual map of the area; (2) we changed the scale on the cognitive map to the scale of the actual map; (3) we measured the absolute difference between the length of the actual road and the length of the road on the haptic model for each road on the participant's map; and (4) we calculated the average error length for all the roads included in the participant's cognitive map.

Two researchers scored participants' performance on the cognitive maps. Inter-rater reliability (Pearson product-moment correlation coefficient) was calculated based on those two researchers for seven variables: number of streets-correct, number of streets-wrong, street names-correct, streets names-wrong, turns-correct, turns-wrong, and information-correct. There correlations were as follows: $r = .96$, $r = .96$, $r = 1.00$, $r = 1.00$, $r = .96$, $r = .93$, and $r = .97$, respectively.

We found positive correlations between the variables number of streets-correct and turns-correct, indicating convergent validity. Moreover, there were also positive correlations between the variables number of streets-wrong and turns-wrong. The correlations between number of streets-correct and turns-correct for the audio-tactile map, the tactile map, and the walking experience were as follows: $r = .964$, $p < .01$, $r = .943$, $p < .01$, and $r = .957$, $p < .01$, respectively. The correlations between number of streets-wrong and turns-wrong for the audio-tactile map, the tactile map, and the walking experience were as follows: $r = .969$, $p < .01$, $r = .943$, $p < .01$, and $r = .955$, $p < .01$, respectively.

Statistical Analyses

Table 2 provides descriptive statistics for correct and wrong answers for the variables number of streets-correct, number of streets-wrong, street names-correct, street names-wrong, turns-correct, turns-wrong, information-correct, and street length-error. We analyzed these data using repeated-measures ANOVAs (and Bonferroni post-hoc test) to examine the differences among the cognitive maps created after (a) the independent movement, (b) the reading of audio-tactile map, and (c) the reading of tactile map.

We examined whether there was any correlation between the participants' performance in the experimental trials and the age at vision loss or the time they have been living as visually impaired individuals. Specifically, we calculated the Pearson's product-moment correlation coefficients between the age at vision loss and the eight outcome variables, as well as correlation coefficients between the years of visual impairment (the years since the vision loss happened) and the outcome variables.

Moreover, we calculated power using GPower 3.1 (Institut für Experimentelle Psychologie, Heinrich-Heine-Universitat, Düsseldorf) with effect size $f = 0.25$, α *error* = 0.05, *measurements* = 3, and *sample size* = 21. In addition, the experiment-wise error rate was calculated (8 independent comparisons were each to be done at the .05 level).

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 mean and standard deviation of scores are presented in Table 2. Each correct answer was scored as 1. If any participant placed all the streets and street names correctly, the score would be equal to eight. Regarding turns, if any participant placed all the turns correctly, the score would be equal to seven.

Furthermore, repeated-measures ANOVAs were conducted to answer the research questions. The repeated-measures ANOVAs revealed significant differences for the number of streets-correct [F (2, 40) = 4.741, $p < .05$], number of streets-wrong [F (1.557, 31.134) = 6.809, $p < .01$], street names-correct [F (1.390, 27.796) = 13.154, $p < .01$], street names-wrong [F (1.390, 27.796) = 13.154, $p < .01$], turns-correct [F (2, 40) = 5.569, $p < .01$], turns-wrong [F (1.509, 30.173) = 7.588, $p < .01$], information-correct [F (2, 40) = 3.480, $p < .05$], and street length-error [F (1.491, 29.822) = 7.654, $p < .01$].

For all the variables on which there were significant differences, with the exception of information-correct, the Bonferroni post-hoc test ($p < .05$) 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. Regarding the variable information-correct, participants gave fewer correct answers when they had read the tactile map than in the case of reading the audio-tactile map.

For the variables number of streets-wrong, street names-correct, and street names-wrong, the Bonferroni post-hoc test ($p < .05$) indicated that the participants gave significantly fewer correct responses and made more mistakes after having walked down the route than having read the tactile map. Furthermore, it revealed a nearly significant difference ($p = .060$) for the variable turns-wrong.

The results clearly support the superiority of tactile and audio-tactile maps over walking experience, with the audio-tactile map leading to a better performance in some cases.

The implementation of correlation analysis showed no statistically significant correlation between the age at vision loss and the participants' performance in the three experimental trials. Furthermore, we found no statistically significant correlation between the years of visual impairment and the participants' performance in the three experimental trials.

Furthermore, the power was equal to 0.68, and the experiment-wise error rate was equal to $1 - (1 - .05)^8 = 0.337$. Given the error rate of 0.337 (experiment-wise error rate) ≤ 0.40 (8*0.05), we consider the comparisons to be independent.

Conclusions

The present study presents a novel context of examining the quality of cognitive maps of individuals with visual impairments. It is the first time that the cognitive maps of individuals with visual impairments were examined in three different procedures, one of which relies on the use of a touchpad device as an orientation aid, and provides a qualitative comparison of these alternatives. This method was also strengthened by the targeted objectiveness which derived from two factors: conducting the research in a large geographical space instead of laboratory conditions, in combination with examining the cognitive map after one walking trial which reflects a real situation of becoming familiar with an area.

The results of the experimental trials reveal that becoming familiar with an area begins to be an easier and more effective process for individuals with blindness when they use a tactile aid such as the tactile or audio-tactile maps tested in this study. This result is consistent with the results of Espinosa and Ochaita (1998) who found that reading a tactile map promotes better spatial knowledge of an area than walking within the same area for individuals with visual impairments. Similarly, it has been suggested that reading a tactile map demands a smaller cognitive load than direct experience, but the individual has the ability to maintain a stable reference point, one that enables coding his or her physical surroundings (Thinus-Blanc & Gaunet, 1997). Additional research is needed to assess whether, in fact, cognitive load mediates the differences we observed.

The tactile map appeared to provide these participants with scant support as far as some variables were concerned. Although tactile maps aided participants in spatial coding more than the walking experience, there was a reverse contribution in remembering all the spatial information a participant encountered during the route coding. That means that the tactile map either inhibited the memorization of spatial information that exceeded a specific amount or that actually did not support the full coding of spatial information in abundance. It should be noted that in order to memorize the spatial information the participant, after having touched a symbol on the map, should turn to the map legend to get the explanatory information for the specific symbol. This delay could hinder memorization, especially when this process was repeated 30 times (30 pieces of spatial information). In the same way, it could be assumed that coding spatial information using all the other senses in combination with touch leads to a better result. The comparison of the variable "information-correct" between walking experience and reading the audio-tactile map showed that the participants' performance was comparable in each experimental trial, which could support this assumption.

Furthermore, this study shows that the use of an audio-tactile map supports the formation of a complete cognitive map, while it constitutes the most efficient method in comparison to a tactile map and walking in the real environment. This result may pertain to the fact that sound and soundscape have a supportive role for memory and, thus, enable storage and recall of spatial information. Moreover, theorists have already pointed out that combining tactile and auditory information may consequently lead to a more complete concept (Landau et al., 2006).

To conclude, the current study confirmed that tactile maps support the development of better spatial knowledge compared to direct experience with the environment. The addition of audio information to a tactile map seems to leverage new possibilities that compensate for the inherent limitations of tactile maps. In any case, tactile maps as aids that provide allocentric information and draw an allocentric spatial coding were a superior orientation-and-mobility tool, coinciding with what other researchers have previously suggested (Caddeo et al., 2006; Espinosa et al., 1998; Thorndyke & Hayes-Roth, 1982).

In addition, one more factor should be considered as far as the superiority of tactile aids is concerned. It is possible that the assessment method used in the procedure could have enabled the participants to perform better in the tactile aids conditions. Transferring the cognitive map created using a tactile map on a haptic model implies that the individual has no special scale adaptations to perform. On the contrary, transferring the cognitive map created by walking in the real environment on a haptic model could entail an inherent difficulty since the individuals have to adapt the scale and then model their cognitive map. Future research should try to examine the cognitive maps of individuals with visual impairments in both dimensions: cognitive map after walking experience in real environment examined through a haptic model, and cognitive map after reading a tactile/audio-tactile map examined through walking performance in the respective area. However, the overall aim of this study was to assess the power of audio-tactile aids as orientation and mobility aids for the real environment. For instance, Merabet, Connors, Halko, and Sánchez (2012), as well as Connors, Chrastil, Sánchez, and Merabet (2014a, 2014b) found that the ability of individuals with blindness to transfer their spatial knowledge emerged from a virtual environment to the respective physical environment.

The current research sheds light on new approaches for orientation and mobility training. Additional research should examine whether training a person with visual impairment to become an independent traveler within cities, campuses, or other large geographical spaces can be more easily accomplished by including tactile maps with a touchpad device. The present study supports using audio-tactile maps with a touchpad device as an orientation aid and as part of any relative training or large-scale space (for instance, a building or a campus) where spatial coding and orientation of individuals with visual impairments is implemented. Moreover, the present research supports the idea of using tactile aids to assist individuals with visual impairments to form cognitive maps and develop spatial knowledge of large geographical spaces. Such aids could become available through a web-based library where the prepared files would be stored so that individuals with visual impairments could secure them as needed. Thus, prior to their travel, they could download the file for the tactile map, print it on microcapsule paper, and in combination with the file for the audio-tactile map use it through a touchpad device to develop a supportive cognitive map and plan an efficient itinerary. In educational settings, complex figures presented in an audio-tactile form could probably support not only orientation and mobility training, but also subjects (for instance, geography) that require extended contact with graphical information.

In any case, the development of audio-tactile graphics is quite a simple process and does not require specific training and specialized knowledge. As a result, instructors, orientation and mobility trainers, and rehabilitation specialists could easily produce such aids or educational material. In addition, the cost of the device at the time of this research is approximately €600 ($650), which is not an amount that should deter most educational centers from purchasing them.

It should be noted that the basic limitation of the present research derives from the instruments used both to develop spatial knowledge and to assess the cognitive maps. Tactile and audio-tactile maps as well as haptic models appear to lack reliability and validity (Kitchin & Jacobson, 1997; Lahav & Mioduser, 2008). Kitchin and Jacobson (1997) emphasize that the research techniques based on such instruments need to be cautiously used since the possibility to produce consistent and reliable results is weak, even when they are punctually repeated. They explicitly suggest that validity issues should only entail a careful interpretation and generalization of results.

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Table 1

Ability and Frequency of Independent Movement According to Participants and Orientation and Mobility Specialists (the score represents 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	9	10	0	2	16	3
Specialists	4	2	15	3	4	10	4

Table 2

Means (M) and Standard Deviations (SD) of Correct and Wrong Answers regarding the Number of Streets, Street Names, Turns, and Spatial Information

	Independent move		Tactile map		Audio-tactile map	
	M	*SD*	*M*	*SD*	*M*	*SD*
Number of streets-correct	6.86	1.15	7.48	1.03	7.48	.81
Number of streets-wrong	1.33	1.11	.57	1.03	.57	.87
Street names-correct	2.95	3.03	5.62	2.46	6.29	2.43
Street names-wrong	5.05	3.03	2.38	2.46	1.71	2.43
Turns-correct	5.71	1.23	6.38	1.24	6.52	.75
Turns-wrong	1.52	1.29	.67	1.24	.52	.81
Information-correct	6.19	5.27	3.57	5.46	6.19	6.83
Street length-error	3.45	1.32	2.55	1.16	2.14	.679

Figure 1

The routes in the physical environment as they were presented on the audio-tactile maps (second experimental trial). The bold lines represent the course and the dots represent the spatial information; the short lines show the points where the recorded sounds were placed.