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LONG PAPER

Gaining insight for the design, development, deployment and distribution of assistive navigation systems for blind and visually impaired people through a detailed user requirements elicitation

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Abstract
The autonomy, independence, productivity and, in general, quality of life of people with visual impairments often rely significantly on their ability to use new assistive technologies. In particular, their ability to navigate by foot, use means of transport and visit indoor spaces may be greatly enhanced by the use of assistive navigation systems. In this paper, a detailed analysis of user needs and requirements is presented concerning the design and development of assisting navigation systems for blind and visually impaired people (BVIs). To this end, the elicited user needs and requirements from interviews with the BVIs are processed and classified into seven main categories. Interestingly, one of the categories represents the requirements of the BVIs to be trained on the use of the mobile apps that would be included in an assistive navigation system. The need of the BVIs to be confident in their ability to safely use the apps revealed the requirement that training versions of the apps should be available. These versions would be able to simulate real-world conditions during the training process. The requirements elicitation and classification reported in this paper aim to offer insight into the design, development, deployment and distribution of assistive navigation systems for the BVIs.

Keywords Blind and visually impaired people · Assistive navigation system · Requirements' elicitation · Mobile apps design

1 Introduction

The twenty-first century has been characterized by the advance of smart devices, along with the development and extensive use of smart "apps" aiming to assist people to carry out a wide variety of tasks. The typical learning procedure on how these apps are used involves the reading of the basic instructions by the potential user, but most often is explorative through gestures on the touch screen, involving calls to a "help menu" or, more generally, a graphical user interface (GUI) when required [1]. The user's vision plays a significant role in this exploration, not only because the user directly observes how the app responds to the gestures, but also by observation on how the app interacts with the environment (when the interaction features exist, such as the use of a camera, or other sensors of the smartphone, etc.). It is, therefore, directly implied that the procedure of learning how to use a smart app is fundamentally different and more complex when the user is blind or visually impaired (BVI).

According to the World Health Organization [2], at least 285 million people globally have severe vision problems, of which 36 million are blind [3]. Furthermore, taking into account that the majority (82%) of people with visual impairment are over the age of 50 years [4], their experience with smart technology should be included throughout the design phase. The inability to visually observe the environment significantly affects the ability to use public spaces, including urban areas, transport systems and public buildings [5]. In particular, vision problems affect every activity of daily life, including mobility, orientation, education, employment and social interaction. Despite these limitations, BVI persons generally develop special abilities through other senses to partially offset the implications of vision loss [6–8]. For example, people with visual impairments sometimes develop

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a sense of space through sound (echolocation), a skill that involves the detection of objects and their distance through active sound generation [9]. Similarly, blind people tend to develop a very sensitive touch that allows them to read using Braille [10]. Other researchers introduce the use of vibration output or speech as input to assist BVIs [11, 12].

The acceptance of mobile services is a gradual process [13]. It involves understanding the benefits offered by these services before their acceptance and systematic use by the majority within a target group. In general, the development of smart apps does not take into account the particular requirements of people with special needs, and especially of BVI [14]. Even in the case that the app is designed especially for the BVI (see Csapo et al. [15], for a survey of assistive mobile apps for blind users), several features that facilitate the BVI to learn how to use the app are missing. Consequently, the learning procedure of the BVI relies on the availability of an instructor and, in the case of an app that interacts with the environment, the presence of the BVI at a location for which the app is designed. Assistive navigation apps for blind people are good examples where the familiarization process with the app depends on access to specific locations (see Meliones and Sampson [16], among others). This problem directly affects the rate of technology acceptance of BVI concerning smart app use. Interestingly, however, little or no research appears to have been undertaken on the inherent particularities in the take up of smart apps by the BVIs.

During our endeavor to explore this field in our previous work [17], we presented the development of training practices concerning the use of navigation applications based on the everyday practices and psychological features of the BVIs. Specifically, everyday practices (preferences, habits, facts) and psychological characteristics of the BVIs were identified and recorded from the interviews of 11 participants aiming to create an adequate framework for the development of training practices concerning the use of the proposed implementations. In this work, we proceed with adding questions and enriching the analysis of requirements and add more participants in the interviews to comply with works in the relevant literature using samples of similar sizes (see Sect. 3.1).

Furthermore, in this work, we have started running the interviews in the initial development phase of the assistive applications. Contrary to the former work [17], in which we presented only the plans of the proposed system to the interviewees, at this point we have demonstrated the preliminary design (beta version) of the two under development implementations.

Next, we proceed with the implementation phase which is an ongoing work with iterations. More specifically, various working versions of the envisaged applications are delivered to pilot users resulting in consecutive evaluations and suggestions for improvements. In this phase, a comparative study between the elicited requirements and the proposed technology that is under development follows.

The identification of the particularities of the BVI concerning assistive navigation apps relies on the threefold "user needs analysis," "requirements elicitation" and "engagement maximization." It is important that these apps not only augment user capabilities but also ensure the safety and well-being of the BVI [15]. User needs analysis and requirements elicitation are two fundamental stages within the user requirements analysis, along with information gathering, envisioning and evaluation [18]. Needs analysis focuses on the goals, aspirations or needs of the users. User needs can be elicited through various methods, e.g., task analysis, user surveys, focus groups or interviews. On the other hand, user requirements' elicitation, which is the process of seeking, uncovering, acquiring and elaborating requirements for computer-based systems [19], aims to discover and elucidate the requirements of a system from potential users (see Brown et al. [20], as an example of implementation of user requirements analysis in mobile services). Another example is the proposed micro-navigation system and the requirements classification that was included in Guerrero et al. [21].

Given the fact that assistive navigation apps for BVI are voluntary use systems, the degree of user's engagement with them is directly related to the perceived quality of experience and benefit of usage [22] and the existence of competitive alternatives [23]. User engagement can be considered as an assessment of the response of the BVI to the assistive app. Specifically, this involves a combination of interest, focus and enjoyment that "encompasses self-direction, interaction, emotion and choice naturally motivated by stimulating activities/actions" (see Noorhidawati et al. [24] and Marks et al. [25], among others).

This research presents a detailed analysis of the BVI needs and requirements concerning the design and development of assisting navigation systems. Specifically, this manuscript describes the processes of user needs analysis and requirement elicitation carried out by our team in connection to the development of two assistive navigation systems for blind and visually impaired people (Blind Route Vision and Blind Indoor Guide). For this purpose, seven main categories are identified for the classification of the user needs and requirements which are elicited from extensive interviews with the BVIs. To the best of our knowledge no previous work has so spherically examined and identified the perception and behavior of people with severe vision loss and blindness concerning Assistive Navigation Systems.

This is the first time that the needs and requirements of the BVI are presented in such a complete and structured way that outlines a useful framework for the development of assistive navigation systems. This framework aims to provide insights concerning features and approaches that will potentially increase the use rates of the navigation systems, along with the benefits offered to the BVIs. A very interesting example of such an approach that is emphasizing on integrated multipurpose assistive navigation systems is the combination of organized training offered to the BVIs with a training version of the corresponding navigation app in a simulation environment as well as in the field.

2 Related work

Over the last three decades, the design and development of location-based services for people with disabilities have been a central research topic of the accessibility literature (see, e.g., Loomis et al. [26] and Gleeson [27]). Concerning the case of assistive navigation systems for the BVIs, the elicitation and understanding of their needs, preferences and requirements, is necessary, not only prior but also throughout the development process. To this end, the main approach used in the relevant literature has been through interviews with members of the BVI to assess the importance of specific features or the accuracy of existing assistive navigation systems.

Azenkot et al. [28] conducted interviews with 13 blind and deaf–blind people to understand how they use public transit and what human values were important to them in this domain. They identified two key values, namely independence and safety.

Furthermore, essential literature that is eliciting user's navigation and safety requirements is listed below. First, Williams et al. [29] conducted interviews with BVIs and registered significant Personality and Scenario attributes describing their navigation behaviors. Additionally, Williams et al. [30] discovered during the interviews with BVIs remaining challenges concerning the navigation technology that come from the environment and the other sighted people. The researchers also identified what were the beneficial navigational cues for the participants, as well as what they wanted to know about their surroundings and the barriers they are confronted with.

Branham et al. [31] have distributed (conducted) an exploratory survey of 58 individuals with visual impairments and 10 interviews with blind people who discussed accessibility challenges relatively to physical safety imposed by other people. Moreover, they expressed the need to access visual cues that would allow them to better manage their safety. The ultimate goal is to design assistive tools based on ensuring a sense of interpersonal and physical safety.

Moreover, according to Ntakolia et al. [32], a set of user-centered design and system requirements concerning operational, functional, ergonomic, environmental and other optional features is defined after a series of interviews and questionnaires to the BVI. Specifically, they present the elicitation of requirements with the design of a novel system guiding the BVI to outdoor cultural spaces. The interviews were based on the BVI's difficulties, their ability to use smart technologies and their preferences on navigation. Consideration should be given to the fact that the particular requirements apply to every relevant assistive device.

To assess the quality of service provided by the assistive navigation system NavCog, Ahmetovic et al. [33] conducted interviews with BVI users. The interviews indicated that NavCog was still lacking some features they expected from a commercial navigation application, but they all expressed that the core turn-by-turn paradigm was something they would use.

Abdolrahmani et al. [34] used interviews to identify different levels of significance for the errors produced by imperfections of assistive navigation systems. Interestingly, they highlighted the importance of the context within which the error is produced. Specifically, some of the errors caused by imperfection of the technology may be classified as easy to ignore because their impact is minor or easily amended, while others may be classified as very significant, having implications on the safety and social status of the BVI user. However, because the same imperfection may cause errors of different impacts, the design and implementation of assistive navigation systems were tested.

Ahmetovic et al. [35] examined the interaction preferences of the BVI of various expertise and familiarity with a route with assistive navigation systems. Their conclusions provide useful information about the required adjustability features of the corresponding user interfaces.

Some more projects are focusing on user requirement analysis of navigational systems like Miao et al. [36] and Asakawa et al. [37] who report on a user requirement analysis for blind navigation in public buildings and museums, respectively. Moreover, Real and Araujo [38] reviewed the foundations and requirements of existing applications regarding the provision of environmental information. In their work, they focus on user-centered design for indoor and outdoor positioning taking into account their past experiences, technological state of the art, and user-related needs and constraints.

The aforementioned works and many of the works cited therein are excellent examples of how targeted interviews can provide valuable information for the design of assistive navigation systems for the BVI. However, these interviews, by construction, did not aim to cover most of the topics that characterize the needs, preferences and requirements of a BVI user. Our research, on the other hand, aims to elicit, classify and identify the broader set of prior needs and requirements of the BVI, thus allowing any design team of an assistive navigation system to efficiently set the desired aims, capabilities and features.

Because assistive navigation apps for BVI interact with the environment and auxiliary external devices as Bluetooth beacons and RFID transmitters (see, for example, Meliones and Sampson [16], Ghiani et al. [1], Guerriero et al. [39], etc.), it is not easy for BVI individuals to learn by themselves how to properly use the full set of the app's features. For example, learning how to use an app that aims to assist navigation in interior spaces (e.g., museums) may require that the BVI visits these locations. On the other hand, an outdoor navigation app may require that a sighted person (who knows how to use the app) escort and at the same time train the BVI on how to use the app. We argue that these requirements do not derive only from the user but also from the fact that the design of assistive navigation apps until now does not properly consider the required training framework within which a BVI can learn how to use them. Given the fact that a BVI user is usually not able to consider the factors on which a training framework depends, the corresponding user's elicited requirements are not analytical. This is verified by the discussions during our interviews with the BVI. Therefore, the degree to which the app is adjusted to the user's training requirements strongly relies on the ability of the app design team to include features that exclusively aim to assist in the training of the BVI. By the term "ease of learning" (EOL), we will refer to the degree to which these features facilitate the user to learn how to use the app. Based on the interview data and using abductive reasoning, we argue that these features play a significant role in the acceptance of the offered service.

Section 3 describes the BVIs who participated in the interviews and briefly outlines the whole procedure. Section 4 presents the classification of the elicited requirements of the BVIs after their responses being classified in these seven categories in the context of this research. This classification is then used in Sect. 5 to synthesize the elicited requirements and derive a framework within which the development of assistive navigation systems can optimally act as Gain Creators and Pain Relievers for the BVI, setting at the same time the foundations for the achievement of optimal adoption rates.

Special attention is given to the elicited demands raised by the BVI concerning the training approach on the use of these apps in Sect. 5.2. Following this, Sect. 6 describes the proposed assistive navigation system. Section 7 presents how user elicited requirements are met along with a discussion concerning the limitations and the future scope. Lastly, Finally, Sect. 8 concludes the paper.

3 Methodology

3.1 Description of the interview participants

The interviews were conducted at the premises of the Lighthouse for the Blind of Greece, which is the main non-profit organization for education and assistance of the BVI in Athens. Thirteen male and female members of the BVI community participated in semi-structured interviews. The number of participants not only appeared to be in line with the literature on qualitative research (Guest et al. [40] and Adu et al. [41], or, concerning people with visual impairments, Wolffe and Candela [42], Kane et al. [43] and Guerreiro et al. [44], among others) but also proved, in practice, adequate because data saturation appeared to be already reached before the last interview.

The impairment of the participants ranged from severely impaired vision to complete blindness. Generally, each interview lasted at least 45 min. Undoubtedly, handwriting and proctoring an interview simultaneously can be very challenging. For this reason, we carefully prepared the subjects and the questions before the first interview which lasted more than one hour. From the third interview, however, our performance was significantly improved, and the interview duration dropped to about 45 min. The descriptive characteristics of the interviewees are presented in Table 1.

3.2 A brief outline of the interviews

The general structure of the interviews was the following:

First, the participant introduced herself or himself. During this part of the interview, the BVI were asked about characteristics such as age, degree of vision loss, cause of vision loss and age at which this occurred. Then, they were asked about their employment status. They were also asked about how familiar they feel with digital apps. The next part of the interviews included a presentation of the features and capabilities of the apps as they were initially conceptualized by our research team. Finally, a detailed discussion followed, which included specific questions concerning the BVI's indoor and outdoor navigation habits. During this part of the interview, the BVIs were asked specific questions about their preferences and requirements that would ideally lead them to adopt and efficiently use the apps. These questions concerned requirements about the usefulness and capabilities, the functionality and the usability of the apps. The BVIs also had suggestions concerning the compatibility of the assistive navigation apps with other apps and services.

The discussion of each subject was separated into two sections. The first concerned the presentation of the apps and specifically the exhibition of the features that were initially included in the app to address the subject. The second section concerned the discussion on the subject and the recording of the answers of the interlocutor. Specifically, the interlocutor was asked about how he/she perceived the efficiency of the initial app design. Then, the BVI was urged to propose features for the app, which he/she believes are either necessary or that would significantly enhance the functionality of the app for the specific subject.

Table 1 Characteristics of the BVI who participated in the interviews

	Gender	Age	Degree of visual impairment	Cause of vision loss	Digital sophistication
P1	Male	55	Complete	By birth	High
P2	Female	35	Severe	By birth	Average
P3	Male	36	Complete	Diabetes	High
P4	Male	40	Almost complete (95%)	By birth	Low
P5	Male	40	Almost complete (95%)	By birth	Low
P6	Female	55	Complete	Retinopathy (23 years old)	Low
P7	Male	40	Almost complete (90–95%)	By birth	Low
P8	Male	40	Complete	Cancer (7 years old)	Low
P9	Male	35	Almost complete (> 95%)	Benign tumor (15 years old)	Low
P10	Male	60	Complete	By birth	High
P11	Male	30	Complete	By birth	High
P12	Male	40	Complete	By birth	High
P13	Male	38	Almost complete (90- 95%)	Craniocerebral injuries at 23	High

The questions and the overall discussion during the interviews were aiming to elicit user recommendations concerning not only desired characteristics of specific functions and the corresponding modules of the apps but also concerning specific factors that would facilitate the BVI to learn how to use them. It is worth noting that the term "ease of learning" is widely considered in the mobile applications' literature concerning learning through the app and not learning the app itself. The consideration of these factors during the design of the apps is expected to enhance both the interest and engagement of the prospective users.

Each interview lasted for at least 45 min. The interviews with the BVI were recorded on paper. During this time, a wide range of subjects were discussed. Their responses were classified to facilitate the derivation of useful conclusions. To retain parsimony, the primary material was classified in the seven categories of Table 2 and presented concisely.

The primary material gathered in the form of analytical notes corresponds to many pages. It is worthwhile mentioning that just the relevant part of the answers of the BVI participants (excluding the questions and the full dialogue that led to each answer) filled 29 typed pages. Moreover, similarities were often identified between the stated requirements

Table 2 Categories of interview responses

(1) Special characteristics of the BVI	a. Perception of the Environment
	b. Navigation (in general)
	c. Pedestrian navigation
	d. Use of smartphones and browsers
	e. General features and suggestion
(2) Requirements concerning usefulness and capabilities	a. Obstacle detection
	b. Navigation
	c. Additional characteristics
(3) Functionality requirements	a. External stimuli
	b. Audio/voice interaction between the BVI and the apps
	c. Tracking and positioning accuracy and auxiliary devices
(4) Usability Requirements	a. Characteristics/features of apps and devices
	b. Device handling
(5) Requirements concerning the learning process of the assistive apps and devices	
(6) Compatibility—parallel operation with other applications. Critique of applications, operating systems and infrastructures	a. Compatibility and parallel operation with other apps
	b. Critique on other apps, operating systems and infrastructure
7) Other desirable features and general remarks	

or described characteristics from different interviewees. The findings presented hereafter resulted from filtering the answers with respect to common content, as well as to references concerning location-specific (and other) particularities which may be considered as additional noise in the data. For example, when a BVI is not satisfied with the telematics system of a specific Mass Transit System, organization or company, we focus on the elements of an arbitrary telematics system, which would be required to offer a satisfactory service to the BVI. Finally, the classification of the requirements relied heavily on the basic principles of the Technology Acceptance Model [45] and its successor, the Unified Theory of Acceptance and Use of Technology [46].

4 Classification of the BVIs' elicited requirements

The answers, suggestions and comments of the BVI were classified into seven main categories. These categories correspond to a broader concept of a requirement (see Hickey and Davis [47]) and include special characteristics and needs of the BVIs, requirements about the usefulness and capabilities of the apps, functionality requirements, usability requirements, requirements about the learning process of the assistive apps and devices, requirements concerning the compatibility and parallel operation of the apps with other apps and services, and other desirable features and general remarks about the assistive apps and devices. These categories were further divided into subcategories as presented in Table 2.

The classification of the elicited requirements to the categories of Table 1 is presented in the following section. Each of the following subsections corresponds to one of these categories. The subsections begin with a paragraph describing the category and, when required, the corresponding subcategories. The paragraph also contains a sample of the primary interview material that corresponds to the category, where the participants are referred to as P# where # is replaced by the participant number as it is presented in Table 1. To highlight the rate at which data saturation was reached, the requirements presented after each of these paragraphs are also followed by the number of the particular participants who first mentioned them (in parenthesis). It is of great importance to note that all the statements concern the opinions and preferences of the particular interviewees and state it from their own experience and point of view. Nonetheless, their statements concern what they believe for the BVIs in general, and not specifically just for themselves.

Furthermore, after the parenthesis in every sentence is noted how many participants mentioned the same or closely related topics. Therefore, the degree of acceptance of the reported elicited requirements in relation to the whole sample of interviewees is ensured.

4.1 Special characteristics of the BVIs

The first category of the subjects and information, which was elicited during the interviews, corresponds to the particular characteristics and needs of the BVIs. This category was further divided into 5 sub-categories. Specifically, we have identified the subcategories of particular needs and characteristics of the BVIs concerning (a) the way they perceive the environment, (b) their navigation by using any means of transport, (c) pedestrian navigation, (d) the use of smartphones and web browsers and (e) the way they perceive navigation in exterior and interior spaces. The BVIs were very willing to talk about these subjects and provided us with valuable information about their special characteristics and needs, which directly or indirectly relate to navigation. For example, P3 mentioned that "I have a good ability to hear and perceive sounds from two different sources at the same time" (sub-category a), while P6 said about the use of buses, "… if I know the route, I will use a "smart stop". I ask the bus driver. Some of us are bashful and do not use the white cane when they get off the bus" (sub-category b). P2 states: "I do not do other things while walking. If I need to do something else, I will have to stop. I believe that other people with visual impairment do as I do" (sub-category c). P7 said that "the bone conduction headphone is excellent but expensive" (sub-category d), while P11 said that "the bad thing is that I am afraid that I will not be able to adapt to the new technology. I am used to real keyboards instead of touch screens" (sub-category e). The full set of characteristics elicited by the interviews is presented below.

(a) Perception of the environment. The BVIs in general:

- (i) have enhanced the ability to hear and perceive sounds from two different sources at the same time. (P3), mentioned by 10;
- (ii) can listen to reading at high speeds or pay attention to more than one sound source simultaneously. (P1), mentioned by 11;
- (iii) have a very good memory, as well as a sense of direction and time. (P3), mentioned by 8;
- (iv) can process sounds with increased speed and accuracy (e.g., in music, some are very good in dictation). (P2), mentioned by 8;
- (v) are orderly and well organized. (P11), mentioned by 3;
- (vi) When the BVIs do not have a complete loss of vision, they sense changes in the light (when

there are not too many dwellings). (P3), mentioned by 7;

(a) Navigation (general):

(i) The most preferable means of transportation for BVIs is Taxi. Most of the BVIs choose taxis for their journeys. (P2, P4), mentioned by 2;
(ii) The younger BVI use the internet for choosing a means of transport, while the older ones prefer to be accompanied. (P2), mentioned by 7;
(iii) When moving, a BVI relies much more on his/her memory than a sighted person does. (P1), mentioned by 8;
(iv) They prefer to arrange the call for taxis, as well as the payment, by phone, the internet or mobile apps (e.g. Taxi Beat with credit, prepaid or debit card). They do not trust taxis that are not connected to central reservation/call systems. They do not take a taxi randomly from the road. They always call a taxi by phone or the internet because this assures them that it will be a real one. (P4), mentioned by 7;
(v) Most of the BVIs choose (and prefer) to have someone to escort them. (P5), mentioned by 8;
(vi) When they use the bus, the BVIs use "smart stops" when they take a route they already know. They ask the bus driver where to get off the bus. (P6), mentioned by 7;
(vii) When they follow a track for the first time, they memorize characteristics of their route (step counting, direction, sounds, odours). They also often ask people they meet on their way. When they get off the bus, they rely on hearing, smell and finally touch, and count steps to move on the sidewalk. (P6), mentioned by 8;
(viii) They prefer using a taxi the first time they go to a destination. (P7), mentioned by 7;
(ix) Sometimes they are panicked when they go to unfamiliar places. They are often advised to visit only familiar places. (P8), mentioned by 5;
(x) In many countries, trucks may occupy the pavement in order to supply stores. This is considered by the BVI as a major danger. (P10), mentioned by 4;
(xi) Places, where special consideration should be given, are by priority the following: (P10), mentioned by 4;

(1) Subway Stations (English always with glass, no gap);
(2) Bus stop;
(3) Obstacles on the road;
(4) Stores;
(5) Public buildings, Ministries.

(a) Pedestrian navigation:

(i) The BVIs have to prepare a plan of the route before their departure. They believe that it is dangerous for them to walk and at the same time adjust the route. Any adjustment or change can only be done if the BVI stops, or as long as he/she is a passenger of any means of transport. (P1), mentioned by 6;
(ii) The BVIs move slower than the sighted people while walking. They do not simultaneously make other movements while walking. If they need to do something else, they will have to stop (e.g., checking the cell phone and listening to the sounds of the surroundings). (P2), mentioned by 7;
(iii) In some countries, the BVIs prefer to walk on the road instead of the sidewalks because laws are not respected concerning not occupying the sidewalk. They move side by side, right next to cars. (P3), mentioned by 9;
(iv) Elderly BVIs are moving on foot at a fast pace. Young BVIs have a much slower pace. (P3), mentioned by 4;
(v) The number and steepness of the stairs are very important for a BVI. (P9), mentioned by 4;
(vi) The white cane identifies the stairs by hitting their upper side (the edge). (P10), mentioned by 4;
(vii) Some are especially bashful about using the white cane after getting off the bus. (P6), mentioned by 6;
(viii) The BVIs use hearing to perceive when cars are moving or if a car is coming in their direction. (P6), 6 mentioned;
(ix) They cross wide streets (such as avenues) using their hearing. Electric cars, which make no noise at all, may be very dangerous. (P10), mentioned by 4;
(x) The narrow roads make BVIs confused. There, they use the smells they have memorized from previous visits (e.g., they recall smells by ovens, and the like). (P4), mentioned by 8;
(xi) When they go to new destinations, the BVIs put up signs (memorize sounds, smells, etc.) and do not hesitate to ask other people. (P6), mentioned by 6;
(xii) They always follow the special tactile paving on the sidewalk to avoid permanent obstacles. If they make a mistake (step counting, loss of

direction, etc.) and feel lost, they try to return to the sidewalk, and they start again from the beginning. (P2), mentioned by 5;

(a) Use of technology:

(i) The BVIs make extensive use of smartphone voice capabilities. (P2), mentioned by 6;
(ii) Overall, iPhone usage is around 75% (clearly over 60%) while the remaining 25% uses android devices. It is very rare for a BVI to have two devices with both operating systems. (P3), mentioned by 7;
(iii) The elder BVIs may not be interested in mobile applications. (P3), mentioned by 7;
(iv) The BVIs are usually open to try a new application or device, which they perceive as useful and accessible (e.g., designed so that it can be used by the BVI). (P5), mentioned by 7;
(v) They prefer bone conduction headphones. However, they are concerned about the cost. (P7), mentioned by 5.

(a) General features, psychological characteristics and suggestions:

(i) Often, the BVIs are afraid of the idea of having vision. (P2), mentioned by 6;
(ii) They are often employed in professions that require a particular ability to identify by touch (for example as physiotherapists). (P1), mentioned by 7;
(iii) The BVIs find very appealing the idea of a museum visit. They believe, however, that only the possibility to touch three-dimensional miniatures or sculptural representations of the exhibits would make them truly feel this experience. (P3), mentioned by 6;
(iv) While smartphones have voice capabilities, those who have at least minimal vision put the phone close to the eye probably because they do not want to accept their defective vision. (P7), mentioned by 5;
(v) The image that a BVI creates for something or someone is usually better than the real one. (P1), mentioned by 6;
(vi) The BVIs request a large variety of sculptures accessible to them at Tactile Museums. (P2), mentioned by 7;
(vii) They also use the white cane to avoid colliding with other people. The BVIs believe that sighted people care about them when they hold the white cane. (P10), mentioned by 4;
(viii) They learn mostly by word of mouth that an application is good and useful (e.g., e-radio, google translate, AMTS telematics). (P5), mentioned by 6;
(ix) The BVIs are often interested in visiting new destinations. (P1), mentioned by 7;
(x) For a BVI the order of importance of other senses is (P3), mentioned by 6:

(1) Hearing;
(2) Smell;
(3) Touch;

(xi) The BVIs who are blind by birth are better adapted to the lack of vision, not only in practice but also in terms of psychology. They do not know how it is to be able to see. On the other hand, the BVIs who could once see are psychologically burdened. (P2), mentioned by 7;
(xii) Mobile phones of the BVIs are often stolen. (P8), mentioned by 4;
(xiii) The BVIs are often familiar with having a wearable device. They believe it is a good solution to incorporate such a device on the white cane. (P12), mentioned by 2;
(xiv) Some of the BVIs are reluctant because they fear they will not be able to adapt to the new technology because of its complexity. (P11), mentioned by 3;
(xv) The BVIs fear that they will often block their smartphones when trying to make complex operations. (P11), mentioned by 6;
(xvi) It makes no sense to say "Do not Touch" to a BVI who visits a museum. This is because prohibiting the BVIs from feeling the objects through touch is equivalent to prohibiting a sighted person from looking at an exhibit. (P8, P12), mentioned by 2.

4.2 Requirements concerning the usefulness and capabilities of assistive navigation apps and devices

In this subsection, the requirements concerning the usefulness and capabilities of assistive navigation applications and devices are presented, as they were elicited from the interviews. These requirements have been classified into three sub-categories. These concern (a) obstacle detection, (b) navigation and (c) additional desired features of the apps. As P3 mentions, "… It is a problem to have obstacles at a different height at the same time…" (sub-category a), while P10 said that “it is important [the app] to announce the arrival of the means of transport” (sub-category b). Moreover, P3 stated that “I believe that it is also important to be able to inform a person of trust or the police about my position” (sub-category c). Next, all of the elicited requirements for this category are presented.

(a) Obstacle detection:

- (i) The sonar should be capable of scanning both horizontally and vertically. (P1), mentioned by 4;
- (ii) It should be possible to simultaneously detect multiple obstacles and report them appropriately, guiding the BVIs to manoeuvre with precision. (P3), mentioned by 5;
- (iii) The sonar should be able to detect obstacles that are relatively high and not only ground-based in front of the BVIs, such as low balconies, awnings, signs, etc. (P3), mentioned by 4.

(a) Navigation:

- (i) The app should be able to combine pedestrian navigation with the use of means of public transport. (P1), mentioned by 7;
- (ii) The app should be able to notify the BVIs about the arrival of a means of transport (bus, train, etc.), its type, its direction and destination. Smart stops are very important. (P1), mentioned by 4;
- (iii) There should be real-time information on public transport (e.g., connection to the AMTS telematics service). (P6), mentioned by 4;
- (iv) The app should be able to identify the traffic lights on the streets, as well as their status. (P3), mentioned by 7;
- (v) When the app notifies the BVIs about the status of a traffic light, it should be able to identify the danger that may arise from a driver who does not follow the signal of the traffic light. (P1), mentioned by 7;
- (vi) The app should be possible to detect a wrong route and to correct or adjust the route in case of deviation from the selected path. (P2), mentioned by 10;
- (vii) The apps should provide information about the entry or exit points from buildings or other restricted spaces such as parks, zoos, amusement parks, train stations etc. (P2), mentioned by 6;
- (viii) The apps should provide information about where the stations or stops are located and suggest a route that the BVIs would have to follow to arrive there. (P1), mentioned by 7;
- (ix) According to the BVIs, the app must inform them about the type and name of the shops that are located along the BVI’s route. (P3), mentioned by 7;
- (x) In interior spaces, such as museums, stores, etc., the app should be able to inform the BVIs about the location of points of interest, such as the WC, reception points, help desks or cashier facilities (depending on where the BVIs is located). (P3), mentioned by 7;
- (xi) When the BVIs are in a train or an underground railway station, the app should be able to inform them about where to find the ticket machines and the cashier, as well as how to reach the pier of the train they must take. (P10), mentioned by 5;
- (xii) It is desirable to be able to add multiple destinations or stops along a route. (P3), mentioned by 5;
- (xiii) Navigation priorities: (P2), mentioned by 7:
  - **(1) Obstacles on the road or the sidewalk;**
  - (2) Stores;
- xiv) There should be a brief routing report of the total route in the start of the navigation. (P1), mentioned by 7.

a) Additional features:

- (i) The data concerning internal spaces must be easily modifiable. For example, it must be easy to improve or modify a description of interior space (e.g., adding a museum exhibit, or changing its location). (P1), mentioned by 4;
- (ii) It is also important to have a trusted person, or the police informed of the BVI’s position. (P3), mentioned by 6;
- (iii) The BVIs must be able to request assistance from the staff of a museum at any time. (P3), mentioned by 5;
- (iv) It is very important to update and renew access information to stores as well as their name and type. (P3), mentioned by 5;
- (v) The apps should give weather information. (P3), mentioned by 5;
- (vi) The apps should display the battery’s status. (P1), mentioned by 5;
- (vii) The apps should have a lock function when it is in idle mode. (P1), mentioned by 6.

4.3 Functionality requirements

This subsection presents the elicited requirements concerning the functionality of the mobile assistive navigation apps. These requirements have been classified into three sub-categories. The first (sub-category a) concerns how the apps and the peripheral devices should behave concerning the external sounds, while the second (sub-category b) includes requirements concerning the interaction of the BVIs with the device through voice commands and directions, as well as through other types of sounds. Finally, the third (sub-category c) corresponds to requirements concerning the accuracy of tracking and positioning of the navigation system (app and auxiliary devices), as well as functionality requirements of the auxiliary devices. As P1 mentioned, "… it is very important that [the ambient sounds] are not covered by the sounds produced by the app because otherwise, it becomes for us very difficult to perceive the environment" (sub-category a). A very important issue that many BVIs mentioned was the identification and status of the traffic lights (sub-category b). Moreover, as P3 stated, any "GPS and sonar signal amplifiers should be discreet" (sub-category c). Of course, the elicited functionality requirements are much more, and are presented as follows.

a) External stimuli:

   i) The ambient sounds must not be covered by the sounds produced by the app, because the BVIs always use their hearing to perceive the surrounding space. Therefore, the use of a headset that covers both ears is excluded from the implementation of the assistive navigation system. One ear should be able to hear the sounds of the surroundings. (P1, P3), mentioned by 2;
   ii) Only important cell phone information should be reported phonetically, and ambient sounds should not be depreciated or covered. (P1), mentioned by 5.

a) Audio/voice interaction between the BVIs and the apps:

   i) Voice guidance is preferable to audio. (P1), mentioned by 7;
   ii) It is necessary to have an audio signal on the traffic lights. (P1), mentioned by 7;
   iii) In case that both traffic lights and apps produce sounds simultaneously, these must be easily distinguishable. (P9), mentioned by 5;
   iv) The user interface must accommodate real-time updates about the means of Mass Public Transit (MPT). (P7), mentioned by 4;
   v) The app should provide voice reporting of key route identification options that may combine pedestrian navigation and MPT use. (P4), mentioned by 4;
   vi) The BVIs should be able to choose between sound alerts or vibration as a notification method by the app about obstacles along their route. Whichever the choice, it should be possible to turn the alert on or off. (P7), mentioned by 4;
   vii) It would be desirable that the apps notify the BVIs about the remaining time before a traffic light turns red. In particular, a countdown informing the BVIs about the remaining time would be useful. (P7), mentioned by 4;
   viii) As far as the colour of the light is concerned, the BVIs would prefer to be notified by voice (e.g., "red light") instead of a specific sound. (P10), mentioned by 4.

a) Tracking and positioning accuracy and auxiliary devices:

   i) Positioning accuracy should be as high as possible. (P1), mentioned by 7;
   ii) Concerning indoor navigation, it is essential to have a precision pedometer that would be able to report both the number of steps and the distance travelled. (P1), mentioned by 7;
   iii) External GPS and sonar devices should be discreet and not too apparent if they are placed on the clothes or the body of the BVIs. (P1, P3), mentioned by 4;
   iv) The female BVIs would prefer that the external GPS device is placed on a belt, bracelet, or neck strap. Some BVIs would prefer a ring adjusted on the white cane. On the other hand, wearing a vest or a hat with a GPS device would not be efficient. They believe that it is easy to lose a hat, while it is not so easy to lose the ring on the cane. (P2, P4), mentioned by 2;
   v) To have a watch that provides increased GPS accuracy would also be a good idea. (P7), mentioned by 5;
   vi) The sonar must refresh the information it provides at high frequency because some of the BVIs are moving at a fast pace. (P1), mentioned by 5;
   vii) Concerning the use of a device on a companion dog, a significant number of the BVIs consider that the dog restricts their freedom since it requires commitment. Therefore, the majority of the BVIs would not prefer such a solution. (P9), mentioned by 3.

4.4 Usability requirements

This subsection presents the elicited requirements concerning the usability of mobile assistive navigation apps. These requirements have been classified into two sub-categories. The first (sub-category a) refers to the special characteristics and features of the apps and the peripheral devices that the BVIs would wish to have, while the second (sub-category

b) concerns device handling requirements. The elicited requirements presented below represent the statements of the BVIs during the interviews, which concern this category. For example, P2 notes: “I believe that since many of us do consume a lot of memory, the implementation should not be particularly burdensome in this area” (sub-category a), while P12 states that “you will have stored in the [smartphone’s] memory a set of favorite routes” (sub-category b).

1) Characteristics/features of apps and devices:

   i) The user interface on the touch screen must operate with clear and simple gestures. Keyboards are also useful. (P1), mentioned by 6;
   ii) It would be highly functional for the BVIs to have textured keys, but the keyboard layout should be simple to learn. (P2), mentioned by 6;
   iii) Still, many of the BVIs would prefer small keyboards like those of former types of cell phones, but with special features like the keyboard of Blackberry. (P11), mentioned by 3;
   iv) Because the BVIs allocate more memory during their everyday activities, the apps should not be particularly demanding concerning human memory. (P2), mentioned by 5;
   v) Bluetooth headphones have the advantage that they do not have cables that may become entangled. On the other hand, they are more easily lost and they require to be charged often. (P1), (P3), mentioned by 2;
   vi) The apps should use a button of the cell phone as a button dedicated to emergency assistance calls. (P6), mentioned by 5;
   vii) The information that appears on the smartphone screen must be sequentially presented (column by column or row by row) because the VoiceOver app often has difficulty identifying separate lists or columns and present them one by one. (P7), 4 mentioned by 4;
   viii) The BVIs prefer swiping gestures rather than tapping on the smartphone’s screen. (P1), mentioned by 8.

1) Device handling:

   i) It would be desirable that the search menu includes voice navigation, and that the app has the capability of voice activation of commands. Thus, the BVI would be able to dictate the destination address to the app and phonetically use its capabilities. (P1), mentioned by 7;
   ii) The BVIs should be able to navigate within the configuration activity to find destinations either using voice commands or the keyboard. The existence of a destination verification signal or message is also important. (P1), mentioned by 7;
   iii) It would help the BVIs in the use of the app if the app used a keyboard similar to the keyboard of the operating system of the BVI’s smartphone. (P2), mentioned by 7;
   iv) It would be useful that the indoor navigation app provides a destination index on the touch screen, with features such as scroll up and scroll down and sorting destinations alphabetically. (P1), mentioned by 7;
   v) The BVIs prefer to use the touch screen through gestures instead of tapping on touch icons. They appreciate the usability of iPhone apps. (P3), mentioned by 5;
   vi) It is important concerning the usability of the apps that their collaboration with the screen reader is not complicated. (P2), mentioned by 7;
   vii) Screen readers should be able to fully read in detail the screen produced by the apps. Voice confirmation must be requested before performing each operation/action (e.g., after a gesture or an icon tap). (P1, P5), mentioned by 2;
   viii) Concerning outdoor navigation, it would be desirable that the app provides a list of "favourites" (or preferable) destinations that the BVIs would be able to edit. (P7, P12), mentioned by 2.

4.5 Requirements concerning the learning process of the assistive apps and devices

This subsection presents the elicited requirements concerning the learning (or training) process that the BVIs should follow to efficiently and safely use the assistive navigation mobile apps. It must be noted that during the interviews, it was identified that the BVIs are very concerned about the complexity of the apps and how they could be used properly. Therefore, part of the interviews focused on the conditions which are believed by the BVI to be appropriate for learning how to use the apps. For example, P3 mentioned that “I would prefer to start learning the [interior navigation] app in a familiar space and not directly in a museum”, while P6 stated that “otherwise I will be very anxious: Am I going to make it? would it be as I would like to?” These concerns along with other statements by the BVI about specific requirements led us to create this distinct category. These requirements are presented below:

1. Because the majority of the BVIs use either Android smartphones or iPhones, the apps should be offered for both operating systems. (P1, P3) mentioned by 5;

2. The training process of the BVIs on how to use the apps should take into account that the BVIs prefer to be educated in their familiar spaces (those they visit frequently), such as their schools or training rooms. The BVIs could also practice in-house navigation in their home or workplace. (P3), mentioned by 7;
3. The BVI's learning rates of the apps may vary significantly, as their familiarity with digital technologies ranges from zero to very high levels. Considering the increased complexity of the apps, given their full range of features, the training of the BVIs can take from half a day to even a week. That is, users are not a homogeneous group in adopting technologies. (P4), mentioned by 4;
4. The need for organised classes, in which the BVIs will be trained on how to use the navigation apps, was highlighted even by those BVIs who believe that they can learn the apps on their own. It should be noted, however, that some of the BVIs failed to assess the number, variety and complexity of the tasks covered by the apps. (P4), mentioned by 7;
5. Although complex enough, the benefits of the apps should be explained analytically in an easy-to-understand way, to motivate the BVIs to get involved in the training process. (P3), mentioned by 9;
6. When visiting a museum using the app, the BVIs must be confident that they will not fall and hurt themselves or cause damage to the exhibits. (P7), mentioned by 6;
7. Some of the BVIs may be hesitant to visit a museum using the app without being previously well trained on how to use the app in a museum. (P5), mentioned by 7;
8. Because many BVIs are initially hesitant to use anything that has increased complexity, any training class should be organised in such a way that the BVIs will be able to learn the apps step by step, so that they gain confidence in their abilities. (P4), mentioned by 7;
9. It was stated that it would be better if information about the museum is provided before the visit, such as audiobooks and recorded lessons which are very helpful, especially when given in short sections for very quick listening whilst on the road or at home. (P9), mentioned by 5;
10. It is of high importance that the BVIs should have already been trained using applications such as smartphones, i-pads, telematics, etc., before they visit museums or other similar places, so as to be capable to move and deal with any possible obstacles they could encounter. (P6), mentioned by 8;
11. The BVIs consider that part of their training on how to use the apps should take place at locations, indoor or outdoor, which the apps will be designed to be used for. (P4), mentioned by 7.

4.6 Compatibility—parallel operation with other applications. Critique of applications, operating systems and infrastructures

This subsection presents the elicited requirements concerning the compatibility and parallel operation of the assistive navigation mobile apps with other apps or services. These requirements have been classified into three sub-categories. The first (sub-category a) refers to the compatibility and parallel operation with other apps, while the second and third present a critique of the BVIs on other apps and operating systems (sub-category b) and infrastructure (sub-category c), respectively. Many of the BVIs are concerned about how screen readers will collaborate with the navigation apps. As P2 mentioned, "[the navigation apps should] allow screen readers to run in parallel" (sub-category a). Very useful was also the feedback provided by the BVIs about the current appeal of smartphone operating systems: As P10 stated: "On iPhones, we have the BlindSquare app which is fantastic and collaborates with Maps" (sub-category b). As far as the infrastructure review is concerned, one must consider that the BVIs in the interviews had the experience of living only in Greece. However, we were able to identify significant accessibility requirements. For example, P11 mentioned "I feel that when it's crowded, it's dangerous for me to be on the pier of the underground railway, and in particular when it rains and the shoes of other passengers bring water downstairs and it becomes slippery" (sub-category c).

a) Compatibility—parallel operation with other apps:

   i) Applications should be accessible to screen readers. (P1), mentioned by 7;
   ii) The use of the screen readers (such as iPhone's VoiceOver and Google's TalkBack) requires special attention as they create their own "conditions" on the screen, adding, for example, gestures that assist navigation through the smartphone's interface. (P1), mentioned by 7;
   iii) The apps must be compatible with these conditions and not require that the screen readers are switched off. (P1, P3), mentioned by 7;
   iv) In case a parallel operation with the screen reader is not possible, the screen reader should go into the background or switch off, and once the navigation app goes into the background, the screen reader must be reactivated. (P1, P2), mentioned by 5;
   v) The navigation apps should allow other applications to run in parallel with them. (P2, P3), mentioned by 2;

vi) It would be very useful if the navigation apps could cooperate with image recognition apps that describe images, such as Google Lens. (P4), mentioned by 4.

a) Use and critique of other apps, operating systems:

i) The BVIs believe that the navigation services offered by Android devices (Google maps) and iPhones (Maps) suffer from inaccuracies and do not provide good route optimization, nor do they have a good menu. (P1, P7), mentioned by 2;
ii) Although the Google maps navigation app has a "countdown" feature for the distance before a turn or a stop, the BVIs believe that the notification of arrival takes place at the last minute without taking into account the reaction time of a BVI, but only that of a sighted person. (P1), mentioned by 4;
iii) The BVIs are satisfied with the performance of the iPhone's VoiceOver. (P3), mentioned by 4;
iv) The BVIs use the BlindSquare app extensively. (P10), mentioned by 3
v) The iPhone has proven to be very functional in its use by the BVIs. (P3), mentioned by 4;
vi) Many of the BVIs believe that Apple's touch screen keyboard is very functional and, in fact, more functional than the keyboards of Android smartphones. (P3), mentioned by 4;
vii) iPhone touch screens respond to simpler and more efficient gestures than the touch screens of Android smartphones. (P1), mentioned by 5;
viii) A bias was identified towards iOS in comparison to Android, concerning the accessibility features. (P2), mentioned by 5;
ix) iOS is a more closed system than Android. As a result, it offers more efficient control and protection against viruses. (P4), mentioned by 4;
x) The BVIs find it important that smartwatches like Apple's iWatch offer a service that gives precise, on-time notification to relatives and people of trust in case of an emergency. (P4), mentioned by 4;
xi) Concerning voice interaction with the smartphone, the BVIs believe that the preset settings of iOS provide better usability than the corresponding settings in Android devices. (P10), mentioned by 3;
xii) In general, Apple is characterized by applications and services that are already configured and ready to use. Many of the BVIs believe that this fact offers increased autonomy when compared to the required installation and setup procedures of similar Android apps, which may require assistance from a sighted person (e.g., for the installation and configuration of Android's Talkback for the first time). (P10), mentioned by 3;
xiii) Many of the BVIs believe that the iOS operating system has more sophisticated automated features than Android. (P9), mentioned by 3;
xiv) It is also very useful for the BVIs that VoiceOver can collaborate with Netflix to read the subtitles. (P4), mentioned by 4;
xv) The BVIs use image recognition apps (or capabilities of apps) while shopping in the supermarket to see when a product expires and for recognition of coins and paper money. (P4), mentioned by 4;
xvi) Many of the BVIs who use an iPhone do not trust Google's Talkback. (P7), mentioned by 4;
xvii) Google does not usually support the use of different means of mass transport in a single journey. (P11), mentioned by 2;
xviii) The BVIs believe that it would be useful if the screen readers have an option to spell the letters of a word. (P11), mentioned by 2;
xix) Unfortunately, screen readers propagate the errors of automatic translation services or apps. The BVIs believe that such services make wrong translations quite often, mainly due to a lack of understanding of the context of the specific phrase. (P3), mentioned by 4;
xx) Many BVIs would prefer to buy a more expensive smartphone if it had better accessibility features, including the already installed and configured apps. (P7, P10), mentioned by 2;
xxi) Some of the BVIs believe that attaching a mini keyboard to the smartphone increases its usability because this way the BVIs can understand the letters. However, other BVI stated that they would never prefer such a keyboard over the functionality a touch screen offers since they consider mini keyboards as obsolete. (P12), mentioned by 2;
xxii) The BVIs who reside in Athens Metropolitan Area are satisfied with the operation of the AMTS telematics application. There is also significant dissatisfaction with the Moovit application. (P3), mentioned by 4.

a) Infrastructure review:

i) Malfunctions or damages of traffic lights or in the means of public transport are not quickly repaired. (P2), mentioned by 4;
ii) In general, the BVIs residing in Athens metropolitan area are satisfied with the operation of the telematics app of the local civil transport organisation. However, they are not satisfied with the information provided by the Moovit app. (P3), mentioned by 4;
iii) The speakers on the buses, which are used by a telematics system (as the one of AMTS) often, should

operate properly. Otherwise, the BVI may not be able to hear the messages informing them that they have arrived at the stop of their destination or the intermediate stops. So that such a system functions properly, regular maintenance of the communication systems must be provided. Moreover, appropriate control and information systems or processes should be used to promptly identify any hardware malfunction. (P11), mentioned by 2;

iv) If the BVIs are not notified early enough, the bus may pass the destination stop before they realise it. The information system or the process that will inform the BVI about where to get off the bus must be reliable. Otherwise, the BVI will not be able to get off the bus at the right stop. (P11), mentioned by 2;

v) The BVIs believe that the design of any underground railway system should take seriously into account accessibility and safety issues for visually impaired people. Specifically,

   (1) tactile paving should be used around the entry points of any station, as well as inside the stations,

   (2) special care should be given around benches or other obstacles that protrude beyond their bases, because the white cane can go under them and the BVIs are not informed as soon as they wish about their existence, or it's difficult to find and use them, and

   (3) before the rails, because they fear the gap between the pier and the trains. (P10), mentioned by 2;

vi) The BVIs find the escalators useful because they produce noise, which makes them easy to locate. (P10), mentioned by 2;

vii) The BVIs feel that it is dangerous for them to use the underground railway when the pier is crowded or when the floor is wet, which usually happens when it rains outside. (P11), mentioned by 2;

viii) The BVIs would appreciate any voice message informing them when the next train arrives. (P11), mentioned by 2;

ix) There is no integration or there is inefficient integration between the Telematic system of intercity and civil buses, as well as one of the railways. The BVIs would appreciate an integrated telematics system or a collaboration between separate systems. (P11), mentioned by 2.

4.7 Other desirable features and general remarks

Although the previous subsections presented a detailed classification of the elicited requirements of the BVIs, few of their ideas or opinions, which focused on desirable features of the navigation apps or concerned general remarks, could not be classified therein. These ideas, opinions and remarks are the following:

1. The use of Bluetooth beacons is very important for accurate indoor navigation. (P1), mentioned by 4;
2. Colour recognition is applied by the BVIs for the use of washing machines, but it may also have other applications such as identification of the colour of the traffic lights. (P4), mentioned by 4;
3. The BVIs often use clock position to understand the direction they have to follow. Therefore, it would be useful that the voice messages concerning direction description use the clock position system. (P4), mentioned by 4.

5 Induced general requirements

The previous sections presented the elicited requirements of the BVI, classified in a detailed set of categories and subcategories. This classification corresponds to the first treatment of the "raw material" provided by the interviews and should be considered during the Design, Development, Deployment and Distribution of any assistive navigation system for the BVI. Specifically, the information presented in Sect. 4 aims to assist the design and developing teams by providing a framework for the development of assistive navigation apps with potentially optimal adoption and use rates.

5.1 Synthesis

This subsection presents the main general results as they are induced by the detailed elicited requirements which were presented in Sect. 4. To this end, we will follow the order of classification presented in Sect. 4, with an exception concerning Subsection 4.5, which refers to the training of the BVI on how the navigation systems can be used. A special focus on this topic is given in the next subsection.

5.1.1 Requirements concerning the special characteristics of the BVI

As mentioned in Sect. 4, the broad concept of the term "requirement" was used, which includes their special characteristics and needs. Subsection 4.1 highlighted these particular characteristics of the BVIs, with a special focus on navigation. The particular way the BVIs use to perceive the environment was identified, as well as the fact that the rest of their senses and their memory are trained to cope with the difficulties that arise because of their visual impairment. The preferences and needs of the BVI concerning the use of means of transport or during pedestrian navigation were also presented. It can be induced that the BVIs have a particular need for as much as possible controlled conditions of travelling and that they believe that any deviation of the initially programmed travel may easily result in disproportionate consequences for them. It was also identified that the BVIs may adopt a mobile app and, in general, a technological solution, as long as they feel confident that they can use it and understand the benefit from its use. As far as the benefit is concerned, however, this does not depend only on the app itself, but also on how the app is integrated into a broader accessibility plan (as, for example, the existence of 3D miniatures of the sculptures in a museum, which would allow the BVIs to understand the exhibits through touch).

5.1.2 Requirements concerning the usefulness and capabilities of assistive navigation apps and devices

Subsection 4.2 presented the user requirements concerning the usefulness and capabilities of assistive navigation systems. In other words, it presented the direct benefits the BVIs would wish to have by adopting the use of these systems. The need for detection of multiple, possibly moving obstacles with different shapes and at different vertical positions, was identified, along with the requirement for sensor signal update at frequencies higher than once per second. The BVIs also require a navigation system that would be able to combine pedestrian navigation with the use of other means of transport (providing real-time information for departure or arrival times). The importance of identification of traffic lights was also highlighted, and of the condition of the road to be crossed (e.g., incoming vehicles), independently, to cover the case where a driver does not (or is not able to) conform to the traffic light. Moreover, the navigation system should provide directions to the location and entry points of places of interest. As far as indoor navigation is concerned, again, the navigation app should be able not only to guide the user but also to inform him about service points, exits, etc. The navigation system should also easily adapt to modifications concerning the topology or the information about any point of interest. The BVIs showed a particular interest in museums that offer a haptic experience. Touching is by far the most useful way for them to understand an exhibit. Interestingly, the BVIs find particularly important the existence of a feature that allows notification of a trusted person, or even the police, in case of emergency.

5.1.3 Functionality requirements

The functionality requirements of the navigation app are presented in Subsection 4.3. It was stressed that the interaction between the smartphone and the BVI user through sound should not cover ambient sounds. The importance of interaction with the smartphone through voice commands was also highlighted, in combination, however, with sound notifications and vibration, with the possibility to be customized by the user. The user requirement for a voice interface is compatible with the recent evidence about its superior effectiveness (see, e.g., Guerrón et al. [48]). This, should take into account the findings in Ahmetovic et al. [35] that link the verbosity level of interaction with the expertise of the BVI user (implying a requirement for adjustable verbosity level). Any additional device, such as a GPS amplifier, should combine discreet design and the possibility to be attached to the white cane or as a cloth accessory. Again, the importance of the traffic light information provided by the system was emphasized.

5.1.4 Usability requirements

Subsection 4.4 presented the usability requirements. The BVIs prefer swiping gestures rather than tapping the smartphone touchscreen, along with as simple and not memory demanding as the possible design of the user interface. The auxiliary devices should not use cables. Interestingly, the BVIs highlighted the importance of the fact that they process information sequentially, and this rule should be followed when information appears on the smartphone screen. Navigation on the apps' menus should be possible through voice commands, while a list of "favorite" destinations would be very useful.

5.1.5 Requirements concerning the learning process of the assistive apps and devices

Subsection 4.5 referred to the procedure the BVIs would have to follow to learn how to use an assistive navigation system efficiently and safely. Because of the importance of the corresponding findings, they are discussed along with ideas concerning this process in the following subsection.

5.1.6 Compatibility—parallel operation with other applications. Critique of applications, operating systems and infrastructures

Issues concerning the desired (by the BVIs) compatibility and parallel operation of the navigation system with other apps/software are discussed in subsection 4.6. Parallel operation and collaboration of the navigation app with screen readers, the navigation services of Google and Apple, or other services, such as telematics services of mass transit systems, or apps that provide information about places and points of interest, was identified to be very important for the BVIs. Interestingly, the BVIs do not prefer over-customizable systems, because this increases the setup complexity. They believe that this factor makes Apple's services more accessible than the corresponding ones offered by Google. They find weaknesses in the translation services which are currently offered. Moreover, it must be noted that the BVIs cannot understand the speed of the vehicle they are using. In addition, they have to be trained to perceive a distance that is larger than a few meters. Consequently, when navigation services, such as Google maps, inform them about the distance to a significant point of their route they cannot understand how long it would take to get to this point. The navigation service should take into account the speed of movement concerning the reaction time of a BVI, and not only concerning the reaction time of a sighted person. Moreover, the Google maps navigation service suffers from inaccuracies, mainly due to the reduced GPS accuracy of smartphones, and does not provide good route optimization, nor does it have a good menu.

The BVIs would prefer that information from mass transit telematics systems would be announced through voice messages of the smartphone. It was identified that it is very difficult for the BVIs to compare prices and departure times of trains or buses. The BVIs proposed that the corresponding e-ticketing services present multiple prices and departure times in a structured way to facilitate screen readers. Moreover, the BVIs would prefer a fully integrated system of means of mass transit.

Notably, the BVIs provided useful information about desirable accessibility features of (underground) railway stations. A general conclusion concerning the comments of the BVIs about accessibility infrastructure is that its maintenance should be frequent, while adequate control systems should report any malfunction in real time.

5.1.7 Other desirable features and general remarks

Other desirable characteristics of an assistive navigation system (Subsection 4.7) would include color or image recognition (or collaboration with apps that offer this service). Finally, as far as indoor navigation is concerned, the potential benefits of the use of Bluetooth beacons were appreciated by the BVIs. It must be noted that there is difficulty to implement or apply the full set of capabilities of a navigation system in indoor spaces such as supermarkets or malls where the GPS, 4G or 5G signal is extremely weak and the deployment of Bluetooth beacons seems to be unrealistic.

The following subsection focuses on the findings concerning the training of the BVIs on how to use a navigation system.

5.2 Training requirements

Before the first interview, the six requirements' categories, which were outlined in the previous subsection, had been identified. As early as the middle of the first interview, however, the plethora of the stated user requirements concerning indoor and outdoor navigation was leading the conversation toward the issue of the complexity of an adequate (concerning the requirements) assistive navigation system. Consequently (and naturally), this raised a concern about the ability of the BVIs to efficiently and safely use the assistive system. This concern was one of the main topics of conversation in all of the interviews and was expressed by the BVIs, mainly with statements concerning the need for training on the use of assistive navigation systems. It must be noted that concerning smartphone use by a BVI, such a need was identified by Rodriguez et al. [49]. However, in the case of assistive navigation systems, the complexity increases due to the interaction of the mobile apps with the environment, with external systems, as well as because the BVIs will be possible in motion while interacting with the corresponding apps. To summarize, this subsection highlights the fundamentally increased difficulty of use on an assistive navigation system, mainly because of its interaction with a dynamic environment. These remarks led us to include a new category of requirements in our analysis, namely, "requirements concerning the learning process of the assistive apps and devices," which was presented in Subsection 4.5.

It must be noted that the BVIs are divided between those who use iOS devices and those who prefer the Android operating system. Therefore, the "end-user" apps and interfaces should have versions for both operating systems. Second, the BVIs do not form a homogeneous group concerning technology adoption. Some of them require much more training time than others to feel confident to use an assistive device or app. All of them, however, require to first feel very confident about the safety offered by the correct and efficient use of an app, along with the benefit of its use, before deciding to devote time to learn how to operate it. This implies that the benefits that the assistive navigation system offers should be highlighted and explained in detail.

In addition to the presentation of the benefits, the training steps (or processes) that should be followed must be presented in such a way that will not avert the BVIs, but rather will motivate them to get involved. In other words, the involvement of the BVIs strongly depends on their confidence that they will be able to complete the training process, and, eventually, to efficiently use the app/system. That said, it is important that the way of communicating the benefits offered by the assistive system, as well as the communication during the whole training process, must be adapted to the age of the BVIs. For example, the trainer should consider the evidence that early and severe visual impairments can cause "irregular" language development during childhood such as echolalia and verbalisms [17], and significantly poorer use of language for social purposes, when compared with sighted children [50]. Moreover, the young BVIs and the sighted people may present difficulties in understanding each other's referents (see, e.g., Landau [51], for the case of BVIs children). These facts highlight the significance of detailed guidelines presenting the navigation system operation, while a step-by-step training process, with many examples, particularly when young BVIs attend the training session is also necessary. Another suggestion is to incorporate the aforementioned specific guidelines and other aspects of technology-featured O&M (Orientation and Mobility) training programs [52] with technologies specialized for navigation assistance. In other words, technology should be incorporated into O&M lessons so that BVI students can fully embrace technology in their daily lives for O&M purposes.

Concerning the training process, the interviews revealed that the BVIs range from those who believe that they would manage to learn by themselves how to operate the navigation apps, to those who would consider adopting and using the apps only if they first attended well-organized classes, which would increase their confidence level above a significantly high threshold. The complexity, however, entailed by the navigation process, raises the need to convince the "overconfident" BVIs to follow even a short training program with respect to the navigation system. Moreover, all participants stated that they would prefer to be trained in places familiar to them. Given the purpose of the assistive navigation system, any attempt to explore, demonstrate and teach its capabilities within a restricted environment seems very restrictive (or impossible). A possible solution to this problem could be offered by the use of simulated environments within a virtual reality framework. Virtual navigation has already proved useful. The use of virtual navigation tools before the beginning of the actual navigation allows the BVIs to mentally build a sequential representation of their route, which proves to be significantly assistive during the actual navigation [39]. However, the difficulty of the task increases when a navigation system must be simulated along with the environment (as well as their interaction). Another solution could be offered by the use of training versions of the apps, which could be easily parametrized by the instructor to simulate real conditions in places that are familiar to the BVIs.

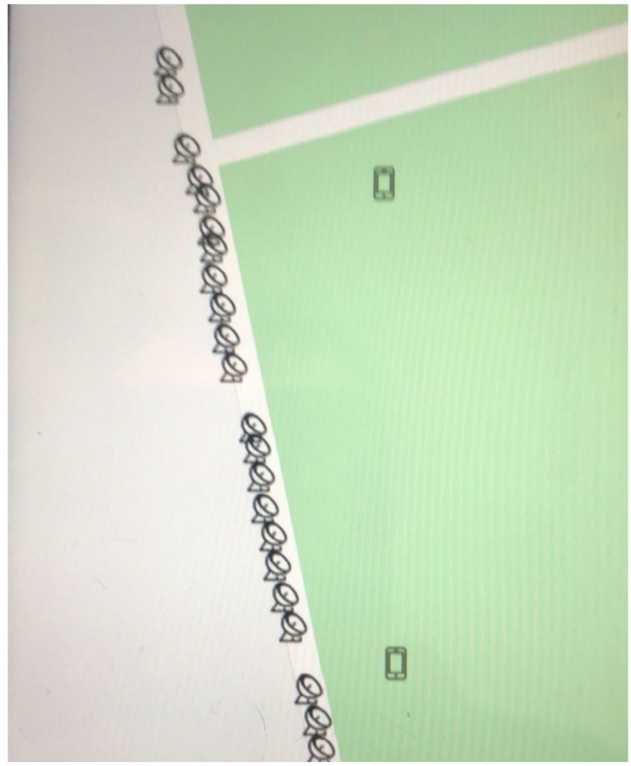

Fig. 1 Pedestrian route trials—localization accuracy comparison between mobile embedded position system and Blind RouteVision system

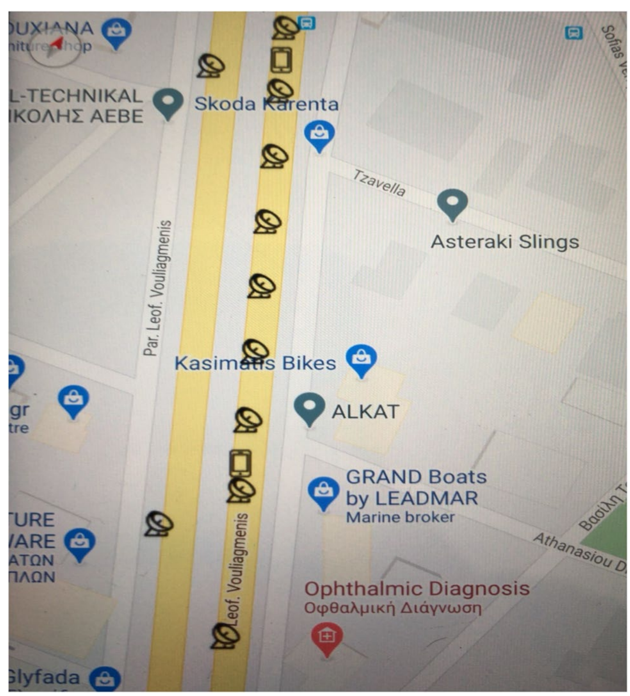

Fig. 2 Car route trials for simulating public transport—localization accuracy comparison between mobile embedded position system and Blind RouteVision system

6 System description and implementation details

The user needs and requirements analysis has been conducted during the initial phase of the development of two assistive mobile apps for autonomous navigation of the BVIs. These assistive apps are being developed in the context of the MANTO project (funded by the Greek RTDI State Aid Action RESEARCH-CREATE-INNOVATE of the National Operational Programme Competitiveness, Entrepreneurship and Innovation 2014–2020 in the framework of the T1RCI-00593 contract). The first mobile app (Blind RouteVision—see Figs. 1 and 2) aims to assist the BVIs during outdoor pedestrian navigation. The app's design includes enhanced GPS functionality and interconnectivity with other apps that may be useful during navigation, such as the corresponding service of Google Maps. The app is a part of an assistive navigation system that includes ultrasound sensors, synchronization with traffic lights and weather information, and utilization of information telematics of the Athens Mass Transit System (AMTS) for routes and urban transport stops. The initial version of the Blind RouteVision system is presented in the third section of [16].

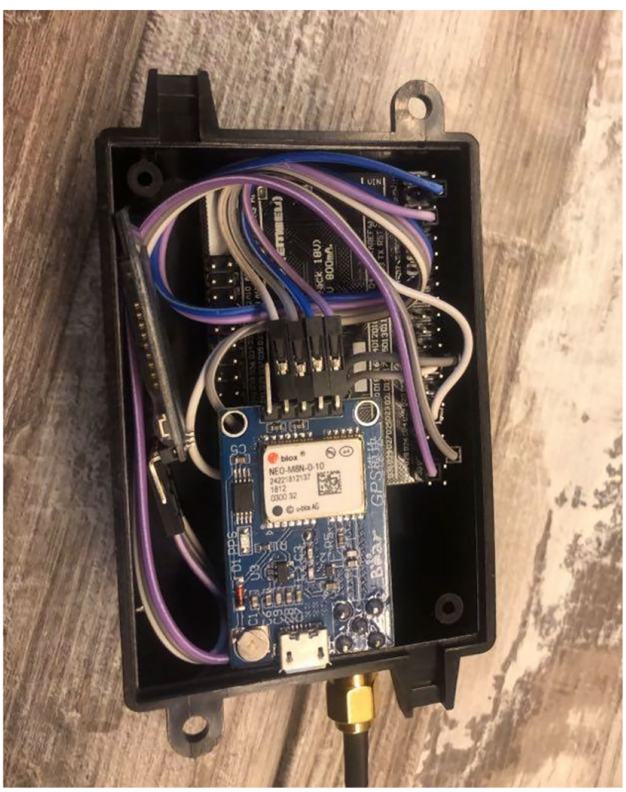

Fig. 3 Blind RouteVision outdoor navigation—advanced field navigation sensor

The mobile symbol is the positioning of the embedded receiver, while the antenna is the positioning of our application.

The smartphone application and its supportive external components consist of the aforementioned system for outdoor interactive autonomous navigation for the BVIs. Our developing system offers innovation in several fields. First, it has better user location accuracy over phone GPS (see Fig. 3). This new system can achieve centimeter position accuracy by using three parallel systems with a choice between GPS / QZSS, GLONASS, GALILEO, BEIDU and by using the large surface of the GPS receiver antenna that cannot be integrated on smartphone devices, producing much better accuracy in the actual position of the user [53].

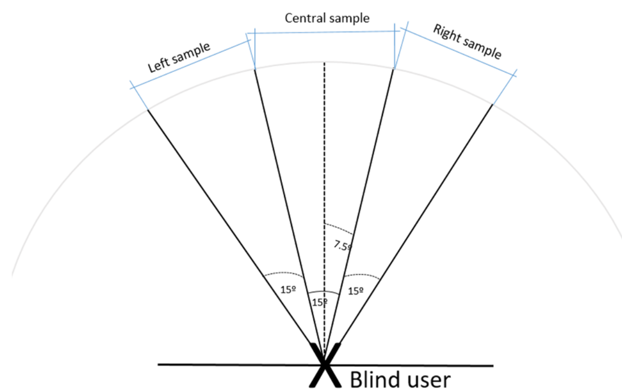

Fig. 4 Angle detection of the servo-sonar system

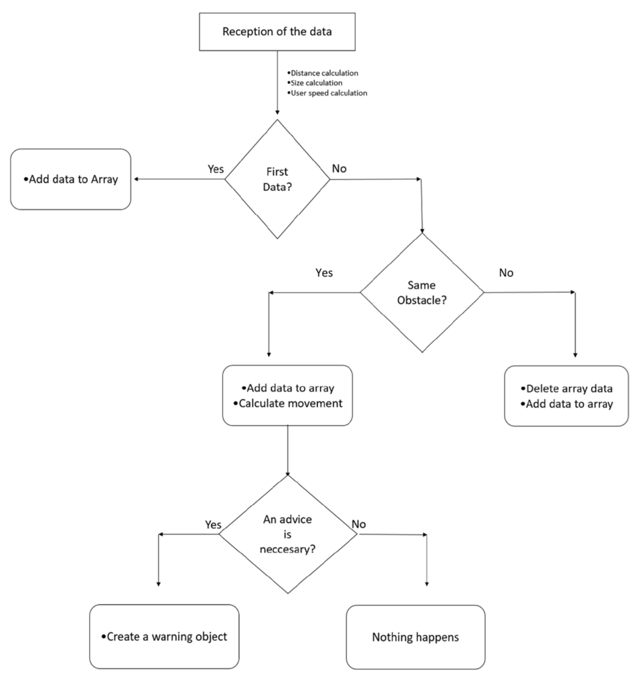

Fig. 5 Flowchart of the obstacle detection algorithm

The second advance of this application is the improved transformation of WGS84 coordinates to Cartesian with the usage of our Spherical Trigonometry function, in addition to the already commonly used Haversine Formula. This solves the problem in calculating the user motion vector, which is the transformation of the user position from geographic coordinates (WGS84 system) to Cartesian coordinates. Until now, most transformations have been undertaken using the Haversine Formula, which has a 0.5% error rate. The latter, in practice, reflects in positioning errors of several meters, which make classical navigation inappropriate or very dysfunctional for the BVIs. Additionally, a sonar-based scanner for nearby impediments recognition is used to identify user obstacles as well, in terms of calculating their (a) distance from user, (b) size, (c) optimal avoidance.

The angle of the sensor is increased to cover additional space (Fig. 4). Therefore, the sensor is mounted on a servo mechanism, which will allow the sonar to rotate in such a way that it covers 15 degrees to the left and 15 degrees to the right from the global position, that is, the view angle of the sonar will be 45 degrees.

The sonar data are continuously received by the application. These data are used to calculate the user's distance to the obstacle, the size of the obstacle and the speed of the user (Fig. 5).

In order to explain the procedure, the simplest case is assumed, i.e., the lateral samples not having detected any obstacle. The exact position in which the object is found is not known, because if the sensor covers an angle of 15 degrees, mathematically, there are infinite points at 1.86475 m (the example distance that we have already obtained) in which the obstacle can be found. It can be assumed that the object has a width of 0.48679 m., and that to the left and right of that distance there is no object, so the user could avoid that obstacle simply by moving that distance to the left or to the right (Fig. 6).

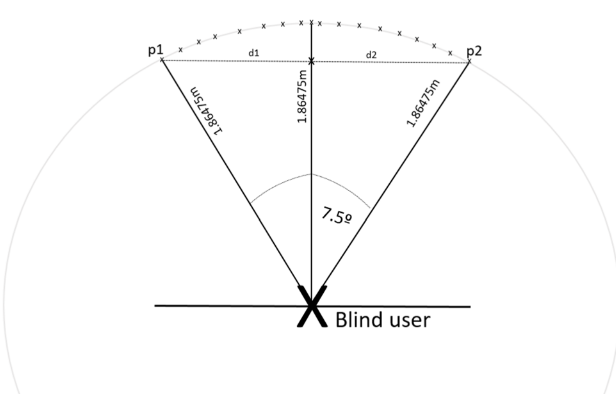

Fig. 6 Different frontal positions of the obstacle

Fig. 7 Traffic sensor

Next, this system also contains improved instructions based on patent-pending vector-oriented navigation [54]. For this, we use both a precise calculation for the position and a path of the user regarding the route of the navigation. The user's next possible position is calculated with the use of Markov chains. An additional characteristic of this system is that the navigational commands employ user-oriented and user-centered design (UCD) principles for the specific user-group of BVIs. Moreover, the application can guide with accuracy the BVIs to cross a traffic lights intersection equipped with the field sensor of the presented system [55, 56] (see Fig. 7). Practically there are three important results of our research for outdoor navigation that are summarized

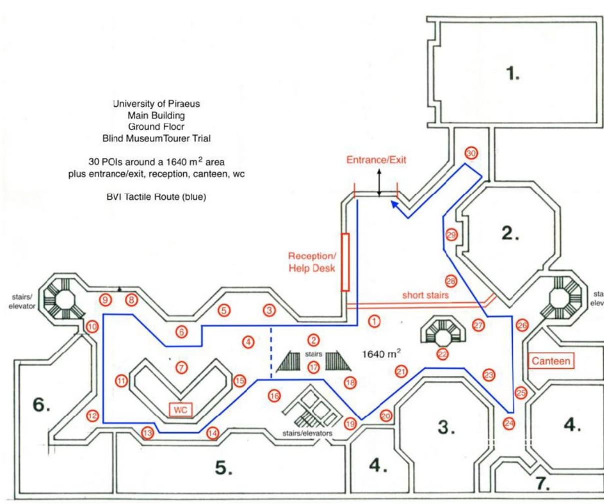

Fig. 8 Blind MuseumTourer indoor navigation and guidance system preliminary

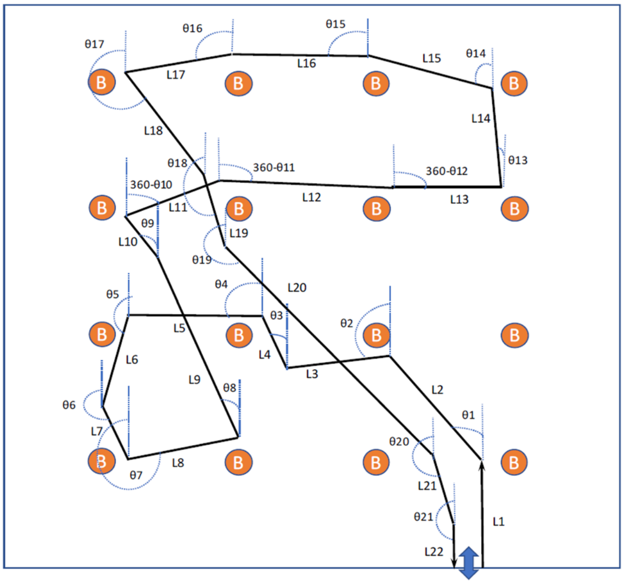

Fig. 9 Schematic depiction of the tracking capability of the proposed hybrid indoor positioning mechanism enhancing inertial dead reckoning with proximity processing of BLE beacons deployed in the indoor environment

in this section: precise tracking and navigation, the special voice guidance and the recognition of the status of the signals. All of these are possible with great guidance accuracy and due to the high tracking accuracy mentioned earlier.

Moreover, a smart visual information system is being developed with machine and deep learning techniques. It is an embedded system recognizing visual information in real time. The primary goal was to be used outdoors, where the locations of the objects of interest are not known in advance. The system of smart visual recognition can also function in indoor spaces like the museum, although it is not necessary as the place and the exhibits are mapped.

The second mobile app concerns autonomous blind navigation in indoor spaces. Due to the fact that the GPS is not reliable for indoor positioning, the app is supported by a highly accurate indoor location determination subsystem which includes accessibility mapping of indoor spaces with overlays of the positions of points of interest (POIs) (see Fig. 8). Moreover, Bluetooth beacons are used as proximity sensors and location indicators. Figure 9 demonstrates a BVI subject's independent movement inside an indoor space, from the entrance to exit, and the monitoring of the motion trajectory in real time, modeled on rectilinear signals and orientations, implemented through the proposed mechanism for indoor positioning. When the BVI approaches a beacon, its distance from it is determined with great accuracy. Thus, the system can correct the possible error of the estimated motion Trajectory and re-evaluate the calculation of inertial dead reckoning parameters to the subsequent tracking. The app will inform the BVIs about the relative to the BVI's position of POIs and will use dynamic issuing of voice navigation instructions toward POIs considering the current position of the BVI. Blind IndoorGuide inherits the features of the Blind MuseumTourer system, as presented in [16]. It aims to extend the functionality of the Blind MuseumTourer beyond the case of museums. The conceptualization of the Blind IndoorGuide is discussed in [16].

A reliable and highly accurate indoor positioning system is being developed, which succeeds in centimeter-level positioning. This is achieved because it combines Bluetooth proximity beacons and a linear tactile path with a highly competitive dead-reckoning algorithm (Inertial Measurement Unit), which perfectly correlates many of the accelerometer's variables with linear interpolation and rolling averages with great precision. It also calculates the length of the steps [A. Tsigris and A. Meliones, "Highly Accurate Step Length and Walking Distance Estimation using Smartphones". unpublished manuscript].

Another advance is a patent-pending floor mapping method implemented as a server-side application (featuring a web GUI), which allows complete and rapid mapping of a complex multi-level interior multi-space, defining each space dimension, entry and exit points, tactile routes and points of interest. The application automatically calculates all the relevant distances. The indoor blind navigation application receives mapping automatically, either off-line or by approaching space based on GPS location [57]. To elicit the requirements of the BVIs, interviews have been conducted concerning autonomous navigation but also psychological characteristics and practices that are related to their impaired vision.

7 Discussion—toward a training framework for the BVIs

Developing navigation applications for the BVIs is an ongoing important problem in the world at large. Our research set out to explore new navigation technology for the BVIs by first identifying current navigation challenges and requirements, then defining possible device features and incorporating them into our proposed implementation.

The need for training the BVIs in using navigation applications is also an important issue. The term "training" most often corresponds to the method followed within an educational framework to overcome the consequences of visual impairment [58]. More specifically, a training framework on mobile assistive apps by the BVIs should include the efforts to persuade the BVIs to accept the technology and is divided into two parts. The first part concerns the apps' presentation to the BVIs, which includes goals, rewards and features to increase motivation and to reduce the factors that lead to negative attitudes toward their adoption. The second part involves straightforward recommendations for the BVI's training methodology.

In the following, we discuss the most important user requirements of each category, which are indicated by the corresponding numbering in parenthesis, in relation to operations and features that are present in this phase of the development, while we compare them with our proposed implementation and methodology. Furthermore, unsatisfied requirements at the present stage are also reported.

The paper reports that one of the most important user needs is the ability of a smartphone app to train the user (4.5, x), except self-guiding him/her. Special emphasis should be given to the fact that the abilities and the learning rates of the involved subjects in using smartphones and available guidance apps differ to a great extent (4.5, iii). A major factor that influences this ability is their age. As it is clearly stated in subsection 5.2, the participating interviewers expressed their worries about their ability to use the assistive navigation technology effectively and securely. Moreover, it was highlighted that the fundamentally increased difficulty of the use of an assistive navigation system is caused mainly by its interaction with a dynamic environment.

For the above reasons, it has become clear how important it is to create a simulated environment that will function as a tool for the evaluation of the app and the user training simultaneously. This is achieved due to the fact that executed routes are being stored and rerun afterwards. In other words, simulated real data concerning user motion need to be more thoroughly detailed for training reasons than for evaluation and debugging reasons. Furthermore, the BVI's accurate position, where they tend to move and where is the final destination to fully understand the route and the application by extension are essential. The above details are not included in the simulation process of the evaluation.

In this light, regarding the implementation of outdoor navigation, our team developed a logger that stores and keeps track of the itineraries that have been taken and a simulation environment that helps the developers to test the application repeatedly, easier and safer than on the field. This results in the conduction of pilot tests that protect the BVIs from the dangers they must encounter on the streets and pavements. Moreover, they do not only show that the system is feasible, usable and functional, but also, they gather information useful in the design of the final system.

More specifically, with the use of the simulation process, we found and corrected a number of bugs. Examples of such bugs are the pronunciation of some wrong angles that influence even the combined transition or confusing instructions like the following one. While the app was saying "You are moving in the opposite direction," then it said, "Go straight ahead." Secondly, some mistakes in the GPS receiver have been identified. The weakening GPS signal under balconies or trees created problems in the calculations that were not treated well at the start but were dealt with afterwards.

Next, the user requirements that are exported from the interviews are discussed and related to operations and features that are present in this phase of the development. Furthermore, unsatisfied requirements are also reported.

At this point, it is important to highlight that the needs and the preferences of the BVIs are differentiated depending on many factors like their age, their culture and origin, their technological knowledge, their experience and finally their training in mobility with or without a guide. As a result, in our effort for better user satisfaction considering the wide variety of needs, our team includes in our implementation some alternative options to cover different needs of the BVIs.

Starting with the requirements concerning the perception of the environment (4.1a), our system supplies the users with induction headphones (4.1d, v) to be aware of the surrounding environment (4.3a, i, ii), which is a matter of great importance for their security. As a result, the auditory channel is not blocked, so both environmental stimuli and navigation instructions can be perceived and managed at the same time. Especially, if you take into account the fact that BVIs have an augmented ability to perceive and discriminate simultaneous sounds that stem from different sources (4.1a, i, ii). In our system concerning outdoor navigation, we support both guiding instructions depending on the hands of the clock (degrees) and simpler rectangular instructions (right, left, front, back and opposite) to cover the differentiated needs and preferences. Despite the BVI's good memory and sense of direction and time (4.1a, iii), the special navigational commands with the aid of the clock coordinates and the continuous provision of information for the accurate position of the user in relation to the map are very helpful.

The next subcategory's statements (4.1b) are also addressed with the combination of the application informing the status of conventional signals and traffic lights interoperability, route monitoring, high precision routing, real-time route correction, accurate real-time bus stop updates and near field obstacle detection with the aid of a continuously pendulum-like looking ahead ultrasonic sensor [59]. As a result, the need of having someone to escort them or visiting only familiar places can be omitted (v). Moreover, when using "smart stops" they do not have to ask the bus driver where to get off (vi) since all the stops, not only the next one and the destination, are announced from the app in advance. Regarding pedestrian navigation (4.1c), the application utilizes a sonar enabling positioning with high precision. For instance, it was reported by the participating interviewees that it was safer to cross the road instead of the sidewalks (4.1c, iii). Generally, with the advent of this navigation system that includes high-accuracy GPS tracking, routing of pedestrian mobility in real time and redefining of a route in case of an error in the navigation instructions or when there is user removal from the right route, the BVIs can be more independent as they are not obliged to ask for information from passers-by (4.1c, xi).

Another significant pillar concerning outdoor navigation is that our proposed system informs and prepares the BVIs regarding the local weather conditions (4.2c, v) to help them dress properly for walking outdoors. Additionally, a battery level button (4.2c, vi) is made after the requests from the expert users. The user is informed about the battery level of the external device through this button. There is also a lock button (4.2c, vii) that allows users to lock the curtain to prevent any accidental pressing on one of the other buttons. The lock curtain is deactivated by pressing three fingers on the screen at the same time.

In most existing apps, BVIs were obliged to plan and predefine their routes before their departure or between their stops (4.1c, i). On the other hand, in our system, this is improved since BVIs can adjust the route with voice instructions specific oriented to their needs and customs (4.1d, i). In case of a wrong selection of a road or route, or a deviation of a selected path, the app will restore the destination (4.2b, vi). Specifically, in case of wrong selection, the blind person will be asked if the destination the BVIs pronounced is the correct one, e.g., the application will ask to confirm that the application understood the selection well. In case the blind person deviates from the route, the application will recalculate the route to give him correct instructions. That seems to be one of the most persuasive arguments for the coverage of the BVI's requirements.

Concerning indoor navigation and specifically museum visiting, the BVI's interaction with the app concerns a single tap to hear an option or a double tap to confirm an option or speaking. The self-guided tour activity begins after the path selection. This activity manages real-time dynamic navigation within museum rooms, calculates the user's location during a self-guided tour and displays the exhibits along the tour. Complete user interaction with the application is achieved via a small number of simple voice commands but also distinct gestures, as the BVIs required in their statements.

Upon the entrance of a user into a museum room, the event is detected by the application, which loads the corresponding floor map and initiates the indoor navigation. The self-guided tour can be interrupted by the user at any time in case the user wants to dial a call or to proceed to the restroom or the exit. The guided tour is placed on hold until the user follows the voice instructions and returns to the interruption point.

The exhibits in the museum should primarily be perceived with the senses of touch (4.1e, iii) and hearing (4.1e, x) as BVIs consider that hearing, in particular, is the most important sense. They also require having instant contact with the helpdesk through an emergency button or making a call to the staff for asking help, or to a trusted person of their own in case of any need (4.2c, iii).

The BVIs, as they stated, need to have accessibility to as many sculptures as possible (4.1e, vi). Additionally, the users asked for easily customizable information, as it is likely that exhibits will be added or their position will be modified in the museum (4.2c, i). In these cases, the developers used a web application for importing cartographic data, managing to map the internal space [57]. The supervisor of the museum is putting detailed coordinates, dimensions and the required verbally descriptions of the exhibits. Finally, the application identifies available routes that it can follow with the use of special sensors of the system. This is a great solution as there is a great cost involved for the installation and the development team. All the above are feasible with our proposed design. Our team managed to simulate the role of a human museum guide or human escort of the BVIs through the creation of the presented application.

Moreover, our team's attempt to build a small, compact wearable device was driven by the need for easy device portability (4.1e, xiii). The latter is another significant aspect of the proposed system that concerns many requirements, and it is still under investigation. All the options of incorporating the GPS device in various preferable places according to the BVIs are being tested. In the beginning, the team gave priority to incorporate the device on the white cane, as the BVIs have declared in their requirements (4.1e, xiii). However, during the implementation, it became clear that it is not the best position to place the GPS device. Although the antenna of the receiver must be in an unobstructed position, placing the device on the white cane raises issues for the safety (possible damage) of the device. Conclusively, as the device is wireless, it can be attached to a pocket or in a case, whatever is more convenient for the user.

The requirements concerning obstacle detection (4.2a) are addressed with the utilization of the sonar sensor. As the latter itself has a limitation of a small viewing angle, the sensor is horizontally positioned higher than the middle height of an individual, for instance at chest height. This results in a simpler implementation. Otherwise, at a higher cost, the sensor can be accommodated with a more complex servo mechanism allowing the alternating movement of the sonar vertically and horizontally (4.2a, i). In this case, information on the height of the obstacle is more accurate, which is not possible only with horizontal scanning [59]. This results in the detection of obstacles that are in a higher position and not only on the ground (4.2a, iii). The evaluation of both solutions is ongoing.

Moreover, the obstacle detection algorithm detects continuous successive measurements and calculates relative velocities of objects in a collision course with the BVIs. The latter are being informed only of obstacles converging with their track to minimize the instructions issued by the sonar (4.3a, i). In this way, the safe transportation of the BVIs enforced with the reduction in unnecessary information is assured. In the case that the BVIs walks on the sidewalk, which may also have a bike path, the sonar will identify cyclists in a collision course with him and will inform him about these dangers and obstacles. Furthermore, when the BVI is moving on the side of the road, e.g., on the left, the sonar perceives the parked cars and selects not to unnecessarily inform the BVI who moves next to the parked cars about the "obstacles" to his left. Likewise, when the BVI moves on the side of the road and has the parked ones on the right.

The requirements (4.2b) are fulfilled by our proposed application exploiting the Public Transport Telematics REST API [60]. Specifically, the expert users asked for the combination of pedestrian navigation with the use of public transportation in real time (4.2b, i, iii), which is achieved with the real-time navigation modules and public transportation modules on the application.

Within our application for outdoor navigation, users can provide the desired destination verbally through speech recognition since the routes are not predefined. In this way, multiple destinations can be changed continuously depending on the user's wish (4.2b, xii). Moreover, information is vocally provided about the location of bus stations or stops that the BVIs want to use (4.2b, viii). Another task achieved by the developers after the demand of the expert team of users is a brief report of the total route and the intermediate stops before the user starts the navigation process (4.2b, xiv).

During the route, voice instructions guide the users and indicate the optimal route with the lowest cost following the Dijkstra algorithm (4.2b, viii). When the BVIs are less than 100 m away from a point of interest i.e., the bus station, they are informed about it. Finally, when they are located at the bus stop, they are informed about the estimated time of arrival, as well as its type, its direction and its destination (4.2b, ii). Similarly, on the bus, the BVIs are vocally informed about their current stop, the next stops and the distance to destination (4.2b, iii).

Currently, the system compares the speed of the BVIs and if the number has passed a threshold, that means that the BVI is on the bus. Otherwise, the BVI is moving on foot. Alternatively, in the case of slow-motion of the bus in traffic jams, there is a differentiated and simplified option in the way the system is being informed. To solve this problem, which was identified in the pilot tests, we have implemented a button for the relevant information about boarding and exiting the bus instead.

Concerning the security of the BVIs, during the interviews, it was found that they felt more comfortable if a trusted person or the police can automatically receive their location (4.2c, ii). For this purpose, among the basic functions of dialling/answering calls and notifying of an emergency, another function was added to the app, to directly send the coordinates of the location of the BVIs to the corresponding person through a button.

An equally significant aspect of the requirements for navigation that the authors should highlight is the ability to identify the traffic lights and their status on the streets. This is achieved due to traffic lights sensors, which inform the application for the level of the traffic lights (two different states, red and green) and the remaining time until the status of the traffic lights changes. Additionally, the system decides which is the traffic light that the BVI is interested in crossing the passage based on the user's movement (direction).

According to the responses of BVIs, it is of paramount importance to be informed about the movement of cars, bicycles and other obstacles in front of their path. For instance, it would raise great safety issues, in case a driver does not follow the signals of the traffic lights (4.2b, v). However, location-based systems are inefficient to find the real-time accurate position of a moving car due to 4G latency. Therefore, the incorporation of the innovative intelligent system for the real-time provision, along the path of the BVIs, of abstractive visual information is of fundamental importance. The specific module can recognize objects and patterns in still and moving images, also providing distance and motion-related information, which is communicated by the autonomous navigation application vocally (4.2b, i) to the user.

An additional user requirement, which will be included in a future version of the developed application is the provision of information regarding the entry or exit points of buildings or other designated areas such as parks or the type and name of shops along the BVI's route (4.2b, vii). Such features are included in separate applications in Blindsquare, which is widely used from the BVIs.

An equally significant aspect according to the BVIs is the capability of being informed about ticket machines, the pier of the train, the entrance and exit in an underground railway station or an above-ground station (4.2b, xi). In light of the recorded user needs, upgraded versions with more capabilities will be offered by the research team, for outdoor and indoor navigation.

Functionality requirements (4.3) are covered for the most part according to the pilot tests. The basic requirements concern the reduction in vocal information from the app, especially the irrelevant, non-essential or noisy repetition to perceive sounds from the surrounding environment (4.3a, i, ii). This has been achieved with the instructions scheduler and the bone conduction headphones. Specifically, via the timer, which is a processing distributor, the frequency that the voice instructions are repeated is set. In this way, the frequent repetition of instructions in a relatively short period that confuses the safe navigation of the user is avoided. In other words, only crucial information is transferred in an acceptable frequency for the BVIs accredited by evaluation tests.

The requirements described in (4.3c) are the primary goals of our team's implementation. Continuous monitoring of the user's geographical coordinates and high density and accuracy of reported locations are achieved by incorporating an external high-precision GPS antenna, which is the optimal cost–benefit solution for the desired accuracy. Moreover, the development of an algorithm that improves the calculation of the relative position of the BVI has also contributed to the efficiency of the app.

In case sound-enabled traffic lights are in the BVI's path then the produced by the app instructions and warnings should be distinguishable and serve as an additional confirmation. In this context, a feature for the self-management of the sound levels was embedded in the app for both traffic lights warnings and navigation instructions. As a result, sounds are not being produced simultaneously confusing the BVIs.

The requirements described in (4.4a) concerning the outdoor navigation are satisfied by the Talkback service, which is an Android component that enables text-to-speech functionality allowing the loud reading of instructions and general information. This works for the convenience of the users, as they are accustomed to this. More specifically, all the necessary functions, like swiping gestures (4.4a, viii) or serial display of options (4.4a, vii) are implemented in a way that is familiar with the BVIs. Furthermore, there is no issue about particular favorite keyboards and their features (4.4a, iii) as free text and speech recognition is utilized for the implementation.

The requirements described in (4.4b) concern the inclusion of a searchable menu with voice capabilities (4.4b, i). By exploiting this menu the user can navigate within the configuration activity, change settings, or select a destination very easily (4.4b, iv). Another important element is voice confirmation (4.4b, vii), which is also included in the museum navigation app. For example, as the name of the exhibits are addressed, the visitor has the opportunity to answer vocally (yes or no) if he wants to continue with analytical or with a short description for each sculpture.

Additionally, there is a destination index for indoor navigation in the museum (4.4b, iv), where the users can scroll up and down with their fingers. In the case of outdoor navigation, a list of "favorites" destinations (4.4b, viii) that the user can call and the app will guide him/her there, is not yet included. However, the specific functionality will be included in future versions.

Finally, the last set of requirements (4.6) comprises the integration of basic tools such as the screen reader and common in the field applications such as VoiceOver and Talkback with the described navigation apps in both platforms IOS and Android. It is of vital importance to integrate such functionality since without the screen reader, our app would be difficult to use (4.6a, ii, iii, v). In the same domain in order to avoid the errors of automatic translation services (4.6b, xix), our team embedded a button that states which commands (restricted number of acceptable words or phrases) can be recognized by the native Android app.

To summarize, although there is space for improvements according to the pilot tests, the user needs and requirements as stated in the interviews are covered to a great extent. Furthermore, the users are informed through the application about the status of the traffic lights that have real-time updates and monitoring through traffic light sensors (a patent-pending field sensor has been proposed by the project team), which is a significant positive result for traffic lights and high precision, real-time route monitoring. The users are then informed about the color of the traffic light (red, green) and the remaining time to change the current status of the color. The information update can be achieved rapidly with great precision even on the sidewalk toward the walkway.

A limitation of the initial design is that the special needs of blind and low vision users are not sufficiently distinguished. Although it is common to analyze the needs of BVI people, in our experience blind and low vision users can have substantially different needs for navigation assistance. A similar problem applies to people with congenital and late visual impairments.

Additionally, the subjects examined in this study are only Greek. Worldwide involvement of subjects recruited through web communities would result in more general conclusions. However, given the common impacts of vision loss to every BVI in the world, it is reasonable to assume that the preferences of the BVI, along with the solutions they are choosing to overcome them are to a certain degree invariant of location. As such, although the requirements express personal preferences, opinions and suggestions from that localized group, it can be considered as a useful basis for researchers in the field and developers of relevant applications. Nevertheless, it should be acknowledged that a different sample of users may have derived to different requirements in some per cent because some of the proposed features can be inconvenient or impractical during a user-based evaluation.

The aforementioned restrictions arise from the fact that there is difficulty in finding and recruiting a big amount of people with serious visual impairments for the interviews. That is why it is perceived that quantitative analysis concerning BVIs is a more time consuming and demanding task. Our future work includes continuing the research and reducing the above limitations.

We support the view that to adequately cover the topic, a quantitative study should take place and result in a forthcoming paper, which belongs to our plans for future work. However, we believe that the results of our detailed qualitative research are significant enough to be included in a paper devoted to them. Although we do not claim that all requirements are included, or every detail is addressed, we believe that the wealth of our findings is adequate for the description of a framework for the development of assistive navigation systems for the BVIs. Interestingly, we identified the important role that a training version of such a system, mainly a mobile app, could play in significantly improving adoption and use rates. We also identified that even the BVIs with good abilities in using mobile apps would prefer to test the navigation system in a controlled environment before trying it in real conditions.

Moreover, an expansion of the participant group including diversity in key areas of age, gender, technology usage and location will take place to provide an adequate basis on which to develop scenarios for future work. The latter will lead to the achievement of more user and Tam-centered design processes.

8 Conclusions

The purpose of this paper was to present in detail the elicited user needs and requirements for the design and development of assistive navigation systems for the BVIs. Such systems should aim to offer the BVIs enhanced autonomy, independence, productivity, opportunities for social inclusion and, consequently, quality of life. The paper presents the classification of user needs based on the raw interview data.

Thirteen members of the BVIs community participated in interviews, which resulted in a very rich primary dataset**.** The analysis of this dataset resulted in the identification of seven main categories of requirements and several subcategories. The outcomes of the interviews and the reported findings are analyzed to define a taxonomy of user needs that should be considered by designers and developers of assistive navigation systems.

Interestingly, a category emerged that includes requirements concerning how the BVIs should be trained on the use of assisting navigation apps (or, more generally, systems). The importance of this category was highlighted by all participants during the interviews. It was probably because they already knew how complicated and risky navigation can be for those who cannot visually perceive the environment. As a result, an assistive navigation system that aims to be adopted by the BVIs should be multi-purposed and able to interact with the environment and interconnect with other digital services.

The main tool that would allow such a system to meet the expectations of the BVIs regarding autonomous navigation is the smartphone, along with the necessary assistive navigation apps. In this research, it was proposed that training versions of the apps should be available to the instructors of the BVIs. These versions should be easily customized by the instructors to offer the BVIs the opportunity to be trained in familiar places before using the apps in real-world conditions. The importance of the training version was implied by the stated requirement by all the participants that they should be very confident about their safety and ability to use the assistive navigation apps before they finally depend on them.

The elicited requirements presented in this paper provide insight not only concerning the optimal user-oriented design of the apps but also about the auxiliary devices of an integrated assistive navigation system.

Considering the limitations presented in the previous section, this classification, along with its content and a corresponding evaluation method, aims to become a useful tool for the researcher or the developer involved in the development of digital services for the BVIs. It also aims to offer effective digital accessibility solutions to the BVIs. In conclusion, our goal in the future is to create metrics with which we can scientifically document and calibrate a system that supports the navigation of the BVIs.

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Declarations

Conflicts of interest The authors declare no conflict of interest.

Ethical approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed consent Informed consent was obtained from all individual participants included in the study.

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