# A Systematic Review of Navigation Assistance Systems for People with Dementia

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**Abstract**—Technological developments provide solutions to alleviate the tremendous impact on the health and autonomy due to the impact of dementia on navigation abilities. We systematically reviewed the literature on devices tested to provide assistance to people with dementia during indoor, outdoor and virtual navigation (PROSPERO ID number: 215585). Medline and Scopus databases were searched from inception. Our aim was to summarize the results from the literature to guide future developments. Twenty-three articles were included in our study. Three types of information were extracted from these studies. First, the types of navigation advice the devices provided were assessed through: (i) the sensorial modality of presentation, e.g., visual and tactile stimuli, (ii) the navigation content, e.g., landmarks, and (iii) the timing of presentation, e.g., systematically at intersections. Second, we analyzed the technology that the devices were based on, e.g., smartphone. Third, the experimental methodology used to assess the devices and the navigation outcome was evaluated. We report and discuss the results from the literature based on these three main characteristics. Finally, based on these considerations, recommendations are drawn, challenges are identified and potential solutions are suggested. Augmented reality-based devices, intelligent tutoring systems and social support should particularly further be explored.

**Index Terms**—Information Interfaces and Representation (HCI), Health care, Navigation, Dementia, Alzheimer, Augmented reality

## 1 Introduction

Different commercially available devices, digital or otherwise, can be used to provide navigation assistance, such as paper maps or smartphones/tablets applications. Nowadays, technological devices are the main source of navigation advice, i.e., help provided to improve navigation. Most of all, these devices vary depending on the advice they provide. Based on the literature on feedback [1], we argue that such advice can be described using three main characteristics (see Figure 1). First, the **modality of presentation of the advice** represents which sensory perception it relies on, e.g., visual, auditory and tactile modalities. Second, the **content of the advice** represents the information that it conveys. Based on the model of spatial knowledge proposed by Siegel and White, the content can be composed of three different an non-exclusive types of spatial knowledge-related information [2]. The *route type* corresponds to the information provided regarding the location of the user as well as direction regarding the way to follow to reach a destination. For example, arrows pointing toward the direction to take at intersections are a common type of route information. The *landmark type* of navigation information, i.e., information regarding a point of interest along the way, can also be provided. For instance, noticing that the user is passing by a famous bakery on the way does represent such a landmark information. Finally, the *survey type* of navigation information, i.e., information regarding the structure or layout of the environment, provides a more comprehensive view of the way, that enables complex tasks such as route planning or acquiring survey knowledge. For instance, maps do provide such type of survey information. Third, the **timing of presentation of the advice** refers to when and how often it is provided to the user. Navigation technological devices also vary depending on the hardware and software they are based on. Such choices imply different types of interaction and localization methods (the term localization refers to both the position and the orientation for the remainder of this manuscript), which in turn are decisive in the adaptability of the devices.

Spatial navigation refers to the ability to find and maintain a route from one place to another. Such an ability already vary greatly for neurotypical people, i.e., individuals with typical cognitive abilities [3] and even more for people with dementia. "Dementia" is an umbrella term which is used for clinical syndromes characterized by a progressive cognitive loss, e.g., memory, language or problem solving, that significantly interferes with daily life activities [4]. It is estimated that it affects 50 million people worldwide and this number is expected to triple by 2050 [4]. The most common type of dementia is Alzheimer's Disease (AD) that contributes to 60-70% of the cases [4]. Throughout the

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Fig. 1. Example of a commercially available navigation device and its characteristics in terms of technology and navigation advice.

stages of dementia the spatial navigation ability gradually decreases and can even be considered as a marker for dementia diagnosis [5]. More than a third of people with AD were diagnosed because of navigation-related issues, e.g., wandering or getting lost [6]. Spatial disorientation in AD is related to changes in medial and posterior temporal, parietal and frontal lobes and retrosplenial cortex [5]. Navigation abilities are necessary to perform activities of daily living (e.g., access commodities and public facilities, do physical activities or socialize) and to preserve autonomy. As a result, people with spatial disorientation require higher amount of supervision from their caregivers and are more likely to be institutionalized [6]. The impacts of a loss of wayfinding abilities on people with AD can be (i) medical, i.e., increase in immobilization and medication consumption, (ii) psychological, i.e., anxiety, depression, loss of personal esteem or suicide and (iii) social, i.e., loss of privacy, isolation and loss of self-control [7]. Thus, one key element in improving the quality of life and delaying the institutionalization is to enable people with dementia to maintain their navigation abilities.

People with dementia have shown interest in using navigation devices to support themselves in their daily activities [8]. Navigation assistance is one of the main applications for the development of technological devices for people with AD [9], [10]. The aim of this assistance is to improve the quality of life of the persons and caregivers but also to reduce the health care cost as well as premature institutional care. The navigational benefit of using such systems should be twofold. It should first show the way and enable to reach a destination, whether it is a familiar one or not. Second, it should enable people to remember the way and maximize the chances of reaching the same destination in the future. In their review from 2016, Teipel et al. provide a thorough overview of experts' recommendations regarding the functionalities, implementation and design guidelines of navigation assistance systems for people with dementia [11]. A review from D'Onofrio et al. on information and communication technologies developed for people with dementia does provide first elements of response regarding the technologies that were developed to help them navigate and support their caregivers [9]. The aim of the authors is to present a global overview of the different technologies developed for people with dementia and their caregivers. Thus, they do not make specific recommendations for navigation technologies and only include three technologies providing navigation advice [12], [13], [14]. Evans et al. [10] and Hayhurst et al. [15] did also review technologies used to support daily living of people with dementia, with a focus on augmented reality and virtual reality devices for Hayhurst et al. While both provide interesting insights on the benefits, limitations and potential opportunities of using assistive devices, none of them present any recommendations or results regarding navigation device. To the best of our knowledge, a state of the art regarding the devices that have been used to help people with dementia navigate indoor, outdoor or virtually had never been made.

The aim of our systematic review is twofold. First, it aims at providing a thematic synthesis of navigation assistance systems that were tested with people with dementia and the gaps in the literature that could and should be explored in future experiments. Second, it aims at providing guidance for the design, implementation and evaluation of future navigation assistance systems for people with dementia in particular, and to the population in general. Indeed, based on studies on universal access, finding new methods to adapt the devices to people with dementia could be beneficial to take into account the diversity in the population [16].

In this systematic review, we assess the literature while focusing on three main characteristics of the studies (i) the navigation advice that the devices provide, (ii) the technology on which the devices rely and (iii) the experimental methodology used to test the devices. Doing so, we aim at answering the following questions: (i) Which devices providing navigation assistance for people with dementia have been developed and tested? (ii) Do they improve navigation abilities and daily living? (iii) Which characteristics are the most beneficial? (iv) How were the devices assessed?

In the remainder of this article we present in Section 2 the methodology we used to search, select and extract data from the literature. Then, in Section 3 we present the results obtained from our analysis of the literature focusing on three main points: the navigation advice provided, the technology that provided the advice and the experimental methodology used to assess the device. In Section 4 we discuss our results, deduce recommendations, identify challenges and propose ideas for future research. The limitations of this systematic review are also presented at the end of this Section. In Section 4, we take a step back and assess the relevance for the whole population of the recommendations we made based on this review. Finally, Section 5 provides a conclusion to our systematic review.

# 2 METHOD

## 2.1 Study selection

To summarize the state of the art regarding navigation assistance systems tested with persons with dementia, a systematic literature search has been conducted in the Scopus and PUBMED databases as described in Figure 2. PRISMA and ENTREQ guidelines were followed for this comprehensive search that aimed at seeking all available studies, i.e., preplanned search (see Supplementary material Table named *Adequacy to ENTREQ statement*).

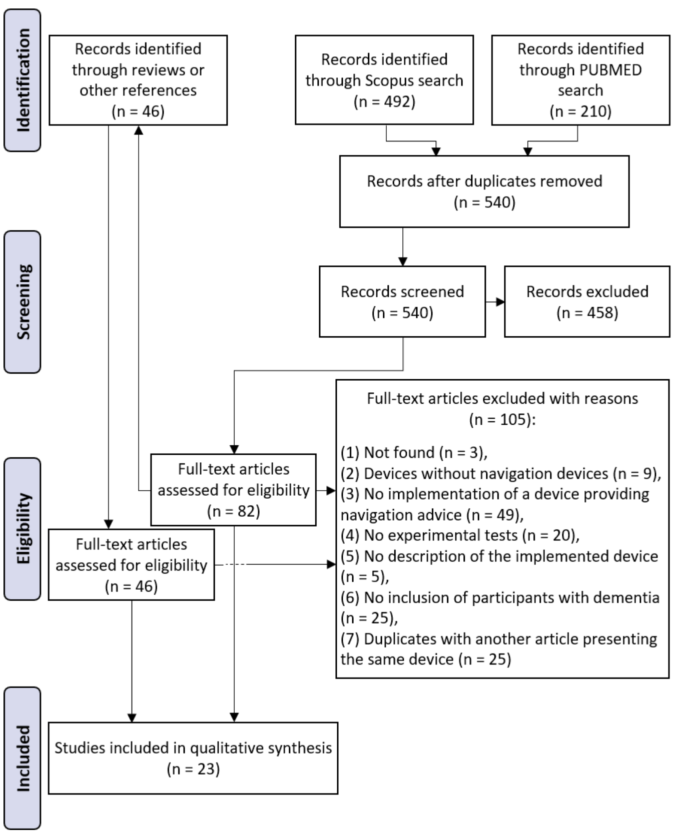


Fig. 2. PRISMA flow diagram for the inclusion of studies.

The following field-related terms connected by Boolean operators were used: (wayfinding OR guiding OR navigation OR indoor traveling OR outdoor traveling) AND (alzheimer OR dementia OR mild cognitive impairment) AND (device OR tool OR system OR instrument OR glasses OR smartphone OR gps OR virtual reality OR augmented reality OR mixed reality OR windshield). This search resulted in 540 non-duplicate citations.

Two independent reviewers (LP and GM) examined the titles, and abstracts if there was a doubt. Both reviewers agreed on the selection of the studies. Thus, no third reviewer was involved. Based on the inclusion/exclusion criteria, 82 articles were selected for the next step of the study. The inclusion criteria used were the following ones: (i) description of an implemented device providing navigational advice (ii) presentation of experimental results from navigation tests using the device with people identified as having dementia. The exclusion criteria were: (i) the use of a non-English language (as we lacked translation resources) (ii) the description of a wandering detection device without navigation advice (iii) studies including only healthy or with other non-dementia conditions participants (iv) interventions without the use of a technological navigation device (v) duplication in the experiments or devices presented. No restrictions were set with regards to study type or publication date.

The references provided in the included articles and relevant review articles [9], [10], [11], [15] were examined as a measure of precaution to identify the studies that might have been missed in our search. As a result, 46 supplementary articles were also selected for the next step of the study. After screening the 128 selected articles, 105 articles were rejected for the following reasons : 3 articles could not be found, 9 described wandering detection devices without navigation advice, 49 did not describe the implementation of a device providing navigational advice, 20 did not present experimental results from navigation tests, 5 did not include a description of the implemented device, 24 presented studies including only healthy or with other non-dementia conditions participants and 25 articles described a device that was already presented in another article. One article could have several of these rejection motives.

The review protocol is registered in PROSPERO (ID number: CRD42021215585).

## 2.2 Data extraction

This article does not aim at comparing the devices proposed in the different articles to one another. Such a comparison would not be possible currently due to the diverse assessment methods of the different devices presented in the articles included in this systematic review. Our aim is to summarize the outcomes and results from the literature to guide future developments. To do so, based on the literature, LP extracted information related to three main characteristics presented in the articles (GM verified the accuracy of the data extraction). First of all, we extracted information pertaining to the aim, results and potential bias of the experiments. All the articles were first read to extract the reported sources of bias, e.g., navigated routes of different difficulties. Based on this information, the articles were read once more to verify if potential sources of bias could be found. We also extracted the different characteristics of the navigation advice that was provided, i.e., modality of presentation, content and timing. Then, we extracted information regarding the technology that was implemented, i.e., tool (e.g., smartphone, eyeware, etc.), localization method, interaction method with the device, adaptability of the device (e.g., to the user's preferences, social context, environment, safety, cognitive abilities, needs, state, etc.) and adverse effects or default of the technology. Finally, we extracted information pertaining to the experimental methodology that was used to assess the devices, i.e., characteristics of participants included in the experiment, measures used, inclusion/exclusion criteria and wayfinding task. The different authors did not use the same norm to report the dementia stage of their participants. Thus, to be able to compare the results based on the dementia stage of the participants, when available, we extracted the results of the most reported cognitive test, i.e., Mini-Mental State Examination (MMSE, maximal score of 30), and mapped them into dementia stages using the norm proposed by Perneczky et al., i.e., no cognitive impairments: 30, questionable dementia: 26-29, mild dementia: 21-25, moderate dementia: 11-20, severe dementia: $\leq$10 [17]. The stages of dementia reported in the review are based on this mapping.

## 3 Results

The different navigation assistance for people with dementia identified in our systematic review are presented in the Supplementary material Table named *Extracted Data* which summarizes the data extracted from 23 published studies [8], [12], [13], [14], [18], [19], [20], [21], [22], [23], [24], [25], [26], [27], [28], [29], [30], [31], [32], [33], [34], [35], [36]. The table is divided into four sections respectively pertaining to (i) general information regarding the experiment, (ii) the advice provided by the device, (iii) the technology used and (iv) the experimental methodology. The following sections are based on the last three types of information, i.e., advice, technology and methodology. The general information regarding the experiment, i.e., aim, results and potential bias, are included in the results of these sections.

### 3.1 Which navigation advice was provided?

First of all, we studied the advice that was provided by the different technologies. As stated in the introduction, we argue that the advice can be defined using three main characteristics, i.e., (i) its modality of presentation, (ii) its content and (iii) its timing of presentation. In the following paragraphs, we present the results regarding each of these characteristics. Figure 3 summarizes the different types of advice that were used depending on the modality of presentation and the type of information that was provided. As there was not enough information regarding the association of modalities nor for the association of content types, in the following Subsections, we report the results and reported adverse effects associated with the different modalities and content types separately. Information pertaining to the association of these modalities or to the association of contents types are included in the paragraphs.

#### *3.1.1 Which modalities was the navigation advice relying on?*

The information was conveyed through the visual, auditory and/or tactile modalities. Some devices did convey information using several of these modalities (see Figure 4).

Almost every device (91%) provided information **visually**, most probably because vision is the sense on which daily life perception relies the most. Visual displays did present several issues related to low contrast (or luminosity) and small text-size [22], [27], [30]. As visual advice is often provided using a screen, variations in luminosity can cause visibility issues, particularly in outside settings [20]. As can be seen in Figure 3, the variety of advice is much more important for the visual modality than for the auditory and tactile modalities.

Photos were used to provide realistic visual advice [12], [28]. However, they can only be considered as realistic at the time of taking the photo due to changes in perspective [30] or potential changes occurring in the environment between the time when the photos is taken and the moment when the user receives it [28]. No adverse effect of using photos with differences in the environment were reported [28]. However, when the user's perspective does not contain distinctive visual features, matching the photo to the environment can become a cognitively high-effort task that takes attention away from the surroundings [30]. Also, photos can be insufficiently representative of actions to perform [12], [20]. They seem beneficial when depicting landmarks [23] but when used behind a direction arrow, photos did not provide further help [23]. Videos can be more representative than photos and lead to higher accuracy in the navigation [12]. However, videos require more time and concentration leading to longer navigation time and lower approval than photos [12].

Most of all, visual advice requires users to divide their attention between monitoring the environment and the advice displayed on the device. Thereby, it reduces their awareness of the environment [30]. Double visual monitoring tasks are not adapted for people with dementia [27]. When only visual advice was provided, 25% of participants forgot the presence of the commercial Global Navigation Satellite System (GNSS) (constellation of satellites transmitting positioning and timing data from space to receivers that use these data to determine their position, e.g., GPS) [34]. Two possibilities have been explored to directly provide visual information in the field of view and limit the impact of double tasking. First, three authors directly inserted the visual advice in the environment using either LED strips [19], strobe lights placed on the floor [13] and a laser to project arrows on the floor [22]. When light cues were used, participants took more time to decide which way to turn but made the correct decision 75% of the time compared to 50% when no light cue was provided [19]. Also, visual light advice was found just as efficient as localized auditory advice and psychology students rated it as more practical and socially preferable to the auditory advice [13]. Second, Google Glass [26] and eyeglasses with RGB LEDs on the frame [18] as forms of augmented reality devices were used. Some minor difficulties were found to perceive the surrounding environment [26].

The use of **auditory** information was also quite harnessed (48%). When auditory advice was not provided, some participants suggested its use [27]. More than half of the participants from [31] preferred speech-based audio prompts and found them easier to follow and more straightforward than visual ones. People with cognitive disabilities performed significantly better with speech-based audio prompts particularly compared to different types of visual advice, i.e., maps and text instructions [31], [34] but also compared to visual and auditory instructions [34]. However, a great majority of people with AD reported usually using GNSS with both visual and auditory settings [34]. Addressing the participants by their names [23] and using a familiar voice [29] could further help guiding them. However, some sounds, e.g. arrival ones, can be found too intrusive by participants [27].

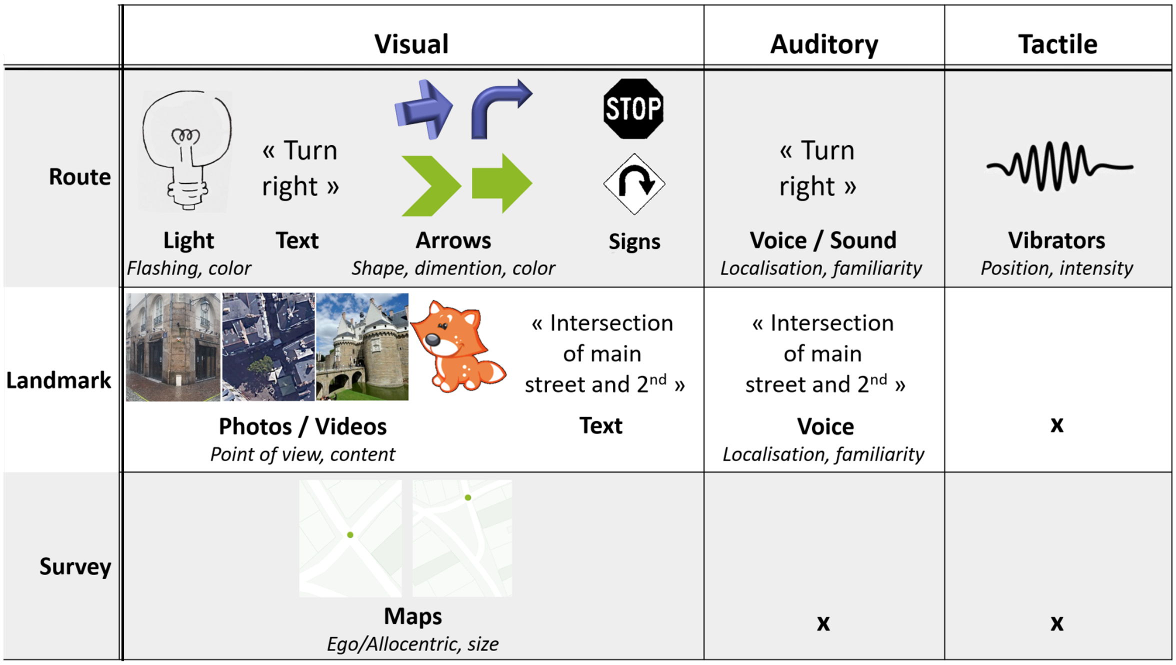


Fig. 3. Representation of the different types of advice that were used by the navigation devices reviewed in this article. Each type of advice is written in bold and located in the table depending on its modality of presentation and the type of information that it provides, e.g., lights, text and arrows. In italics below the names of the different types of advice are how the characteristics varied among the different devices presented in the review, e.g., light cues could be flashing or not and had different colours. The different types of advice can be combined. For instance, some devices displayed maps with overlaid arrows and landmarks and also provided auditory advice.

Finally, about 22% of the papers report providing information using **vibrotactile** stimuli. The perception [25] and the comprehension [23] of the tactile stimuli represent limitations for some participants. Errors made despite the tactile advice are related to a lack of attention toward the stimuli [14]. A learning curve was observed in using tactile advice to navigate [25]. While the wearable haptic belt of Grierson et al. was found easy to use, comfortable and useful for navigation [14]. The results from Rosalam et al. could indicate a poor acceptability of their wearable haptic belt [25]. Indeed, they report (i) unspecified wearability issues, (ii) the non acceptance of the device by one person and (iii) only half of the people that participated to the first navigation task did participate to the second one.

Regardless of the modality of presentation, sensory abilities of participants were often a prerequisite to benefit from the advice provided by the devices, which led to the non-inclusion of participants in several studies [18], [25], [31], [33], [35].

### 3.1.2 What was the content of the navigation advice?

As presented in the introduction, navigation-specific advice can be divided into three main categories, i.e., route, landmark and survey types.

Most devices (87%) provided information regarding the location of the user as well as direction regarding the way to follow to reach a destination, i.e., **route type** advice. Among them, 30% used light, sound and/or vibrotactile stimuli indicating which decision to make at decision points, e.g., turning right at an intersection [13], [14], [18], [19], [23], [25]. Moreover, most of the devices providing route type advice (75%) used arrows to indicate at decision points which direction to take [8], [12], [20], [21], [22], [23], [24], [26], [27], [28], [29], [30], [31], [32], [34]. They enabled people with AD or Mild Cognitive Impairments (MCI) to obtain comparable spatial navigation and memory performances to neurotypical people in a virtual setting [32]. Tervonen assessed the participants' preference for different shapes of 2D arrows and found that traditional ones are preferred to V shaped ones (see the green arrows in Figure 3, the left one is V shaped and the right one is traditionally shaped) [22]. An arrow was also used in a compass-like type of advice that differed from these traditional route advice and provided users with the direction and distance to their destination [27]. It was perceived as more demanding than a landmark-based application [27]. However, the freedom in choosing the route to take was appreciated by the participants. The acceptance of the compass-like type of advice was dependent on the usual strategy that the participants used to navigate [27]. For instance, one person with dementia that appreciated this device reported keeping track of the direction of his residence when navigating in his neighborhood [27].

A third of the devices (30%) provided information regarding points of interest along the way, i.e., **landmark type**. In virtual settings, both neurotypical people and people with AD/MCI reached the destination more often and faster when salient advice (colourful and familiar [33] or colourful and flashing [32]) was placed at key points [32], [33]. The presence of landmarks also improved spatial memory (free recall and landmark recognition and ordering) compared to a no visual advice condition [32]. However, landmarks did not enable people with AD/MCI to have comparable performance to neurotypical people [32], [33]. It was also reported that when presented with both landmarks and route advice, the participants did not pay attention to landmarks [27] and landmarks did not seem to be as successful as directional advice [23]. Placing non-familiar landmarks on a full-scale map increased navigation time and workload of people with AD/MCI, but mildly decreased the error rate [35]. Nearby landmarks that are present in the field of view of the user presented with a similar perspective are easier to find and the most useful [30]. Landmarks that are difficult to identify can cause stress and confusion, making the navigation task even more challenging [30].

Information regarding the structure or layout of the environment, i.e., **survey type**, was provided in 39% of cases. Two types of maps can be used to provide survey type of advice. Egocentric maps provide information based on the position of the users while allocentric maps do not [37]. People with AD are able to plan a route based on an allocentric or an egocentric map but are significantly impaired in the use of allocentric maps for navigation and in translating allo- to egocentric information compared to neurotypical people [36]. For instance, using an allocentric paper map, none of fourteen people with AD with moderate to no cognitive impairments left the starting zone [27]. In virtual settings, the presence of an allocentric map did not improve the performance (navigation time and number of errors) or spatial memory of people with AD/MCI [32]. When an allocentric did not enable people with AD/MCI to have comparable performance to neurotypical people [32], an egocentric map did enable so [35]. Conversely, Sohlberg et al. did not find any significant difference between the use of an egocentric and an allocentric map [31]. Though, around half of the participants rated the allocentric map the least helpful as it was hard to understand where the arrow was pointing and to locate oneself in the map. The characteristics of the map, i.e., scale, orientation, presence of landmarks, significantly influence the navigation time [35]. Small-scale, without landmarks and egocentric maps improved navigation time compared respectively to full-scale, with landmarks and allocentric maps [35]. The characteristics can influence one another [35]. For instance, a full-scale map without landmarks led to shorter navigation time than a full-scale map with landmarks but it was not the case for small-scale ones [35].

Finally, few studies (9%) explored the use of warnings before providing guidance [29], [30]. Their use seems to have a negative influence on the time needed to reach the destination, the number of errors and the number of times the participants asked for the instructions to be repeated [29]. However, the participants seemed to prefer the presence of warning sounds [29].

#### *3.1.3 What was the timing of presentation of the navigation advice?*

Almost every papers report providing navigational advice systematically at intersections or decision points (91%) (also called turn-by-turn or step-by-step advice). Systematically providing advice requires the constant users' attention to the detriment of their user awareness or safety [30]. Only two devices do not systematically provide advice. The device used by Sejunaite et al. provides navigation help on demand during 8 seconds after tapping on the right bracket of the glasses. Such a choice was made for technical reasons as the Google Glass used in this study did not have enough battery for the navigation advice to be displayed all the time [26]. Their results indicate that on demand help might not be used by users even though they need it [30]. Also, the device described by Tervonen et al. is meant to be controlled by an assistant or a caregiver (based on an image feed and various sensors from the device) when the person is in "complex and unknown areas" [22].

### 3.2 Which technology has been developed?

The navigation advice was presented on different technologies using different interaction, localisation and adaptation techniques. This section describes these various elements that influence the navigation outcome as well as the usability of the device.

A little bit more than half (56%) of the devices tested in real settings, i.e., indoor and/or outdoor, were based on existing technologies, i.e., smartphones or phones [24], [27], [28], [30], Google Glass [26], commercial GNSS [8] or PDAs [12], [20], [29], [31] (see Figure 4). The fact that smartphone applications can quit unexpectedly or their use be disturbed by other applications, e.g., messages or notifications displayed, created usability issues [24]. Limitations also arose from the physical characteristics of the devices, e.g., PDAs are fragile and not water proof [20]. Acceptance of smartphones (i.e., attitude towards using technology, perceived usefulness and perceived ease of use) was as high among participants with mild dementia as among neurotypical participants [24]. Acceptance of Google Glass was quite positive too (i.e., perceived ease of use) even though overall participants did not express the willingness to buy the glasses for daily use [26].

Custom-made devices consisted in wearable haptic belts [14], [25], eyeglasses [18], LED strips [19], laser pointer [22], green strobe and recording /playing device [13] or augmented walkers [21], [23] (see Figure 4). Common-shaped objects with advice that is only perceived by the users are particularly appreciated [18]. With the exception of the augmented walker developed by Kulyukin et al. that either provided visual and auditory or visual and tactile advice, all the custom-made devices that were developed provided unimodal visual, auditory or tactile advice (see Figure 4). No specific usability, acceptability or security issues were reported for eyeglasses, LED strips, green strobe and recording /playing device or augmented walkers. However, using lasers to display visual advice presents a major safety issue as it creates a high intensity of energy on a small area [22].

Virtual reality has been used to test different navigational helps for people with dementia with promising results [32], [33], [34], [35], [36]. However, some participants (24% in [34]) may experience VR sickness [33], [34]. Also, people with AD with mild to moderate cognitive impairments might not have sufficient proficiency in guiding themselves in a virtual environment [36].

#### *3.2.1 Which were the interaction methods?*

Half of the devices tested in real settings did not offer any interaction with the users. Almost every device that enabled interaction used tactile interactions [8], [12], [20], [23], [24], [26], [27], [30], [31]. The use of tactile screens or

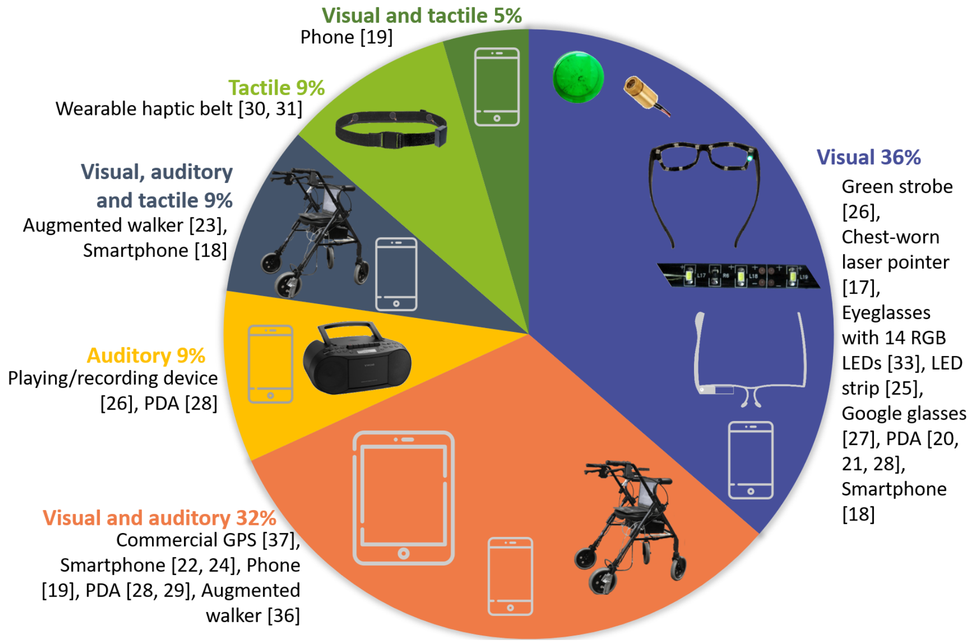


Fig. 4. Representation of the different technologies that were used to provide navigation advice to people with dementia depending on the modality of the advice that they provided, e.g., visual, auditory, or visual and tactile. The device represented using light gray graphics are commercially technologies. Only the augmented walker as well as the eyeglasses with LEDs in the frame correspond to devices that were actually used to provide navigation advice [18], [21].

buttons can be challenging for people with dementia that can have issues seeing and pressing them [23], [24], [27]. Sensory impairments affected the usability of the device, e.g., hearing the instructions [24]. Only one device enabled the users to send voice commands by using Apple's virtual assistant Siri [24]. In this study, all the participants were able to successfully initiate Siri by voice in their first attempt [24].

#### *3.2.2 Which were the localization methods used?*

Highly accurate localization and orientation are necessary to provide accurate navigation advice, particularly when photos are presented and require to be aligned with the user's perspective [30], [31]. Among the devices that were tested indoor and outdoor, respectively 67% and 33% were tested using a Wizard-of-Oz deception method, by which is meant that the experimenters controlled the navigational advice that was sent to the participants. Thus, no localization methods were used for these devices. All devices tested without a deception method for outdoor navigation were based on GNSS localization [8], [24], [25], [26], [27], [28], [29]. Smartphones and Google Glass-based devices were most probably also relying on networks and accelerometric data [24], [26], [27], [28] to localize the participants. A recent study, reported that the reliability of the GNSS signal affected the usability of the device [24]. Indoor devices tested without a deception method relied on Bluetooth beacons [12], QR-code tags [20] or RFID tags [21]. Bluetooth beacon and RFID tags (depending on the walking speed of participants) can be missed by the devices' sensors [12], [21] or by the user [20]. Cognitively impaired users report having difficulties using PDA cameras to scan visual codes and pay attention to find RFID tags [12].

#### *3.2.3 Were the devices adaptable to the user or context?*

A majority of the devices (65%) were not adaptable to either the user or the context. In the remaining devices, the instructions [20], wearing location [25], [29], routes chosen to reach destinations [12], proposed list of destinations [14], [27], modalities and presentation of the instructions [22], [23] could be adapted to the users' preferences [12], [14], [22], [23], [25], [27], [29] and/or sensory abilities [12], [23]. One smartphone application proposed by Rassmus-Gröhn et al. also changes its display depending on the GNSS precision [27].

### 3.3 Which was the experimental methodology used to assess the devices?

Finally, we investigated how the different devices were tested in terms of experimental methodology, i.e., people included in the experiments, navigation performance and influencing factors and measures used.

#### *3.3.1 Which were the experimental settings?*

The testing environments of the devices were for 39% indoor, 43% outdoor and 22% in virtual reality. All devices were tested in only one type of setting with the exception of Sorri et al. who tested their augmented walker both indoor and outdoor [23]. Oderud et al. are the only ones reporting results with people with dementia from a long-term (3 years) ecological study assessing the usability and acceptability of a navigation device, i.e., a commercial GNSS for outdoor navigation [8]. The remaining studies assessed their devices over one or a few sessions during navigation tasks in which participants were asked to reach a destination, follow a path that had previously been shown or find a direction at an intersection. Some of these navigation tasks took place in familiar places for the participants [13], [23], [24], [25], [30]. Lancioni et al. [13] and Ebert et al. [19] added non-navigational goals to their participants during the wayfinding task. Lancioni et al. were the only ones to add a social dimension to the task and goal by asking their participants to deliver and/or pick up small objects and meet a staff person.

#### 3.3.2 Which measures were used?

Every study reporting the evaluation of a device in real settings has used subjective measures, i.e., dependent of the personality, opinion and state of the participants, and objective ones to do so.

A majority of objective measures used were, expectedly, navigation-related. All the authors except Oderud et al. reported using at least one among the three following measures: number of trajectory errors (65%), time to complete the navigation task (61%), arrival at destination or not (35%). Twenty-two percent also reported measuring the number of times participants asked questions, were assisted or their navigation corrected. Three different papers (13%) also reported measures related to the walking or driving speed, i.e., average or difference between during navigation test and before [18], [25], [34]. It should however be noted that walking speed varies a lot particularly among older people. Such variability should be taken into account in the analysis to avoid any bias. For instance, by using the difference in walking speed prior and during the navigational task. Interestingly, Cogné et al. were the only ones to assess how the navigation advice impacted the spatial memory of their participants [32].

None of the studies reporting results of virtual navigation used subjective measures. In real settings, the subjective measures were assessed through experimenters, e.g., observed behavior, hesitation or difficulty to perform the task [19], [28], [30], [31], or a third party, e.g., social validation assessment by university psychology students [13] or participatory observation [22], [23]. Participants were also asked about their opinion on the device through interviews (39%) and questionnaires (30%). The questionnaires assessed the workload (NASA-TLX or modified versions) [12], [27], [29], acceptance (Senior Technology Acceptance Model questionnaire) [24] and user-experience (unvalidated questionnaires) [14], [20], [26].

#### 3.3.3 What was the profile of the people included?

Depending on the settings used to test the device, i.e., indoor, outdoor and virtual, the median number of people with dementia included varied. The median number of people with dementia included was much higher in virtual settings (*Med* = 23, *Min* = 20, *Max* = 28) than in real settings (*Med* = 7, *Min* = 1, *Max* = 208). The stage of the dementia and the cognitive evaluation were not always reported which limits the comparability and reproducibility of the results [8], [12], [18], [19], [20], [22], [27], [30], [31]. Even when the dementia stage is reported, authors use different norms to map the cognitive test results into dementia stages (see Section 2, for the method used in this paper to report dementia stages). The more severe the dementia, the less paper report including participants at such stage, i.e., respectively 88%, 47% and 24% of papers report testing their device with people in a mild, moderate and severe stage of dementia. All the studies including people with dementia in severe stage were testing a device in an indoor setting [13], [18], [19], [23], with the exception of Sorri et al. who tested their augmented walker both indoor and outdoor.

#### 3.3.4 Which were the navigation performance?

As expected, the experiment comparing the performance of people with dementia to neurotypical people confirm that people with dementia suffer from spatial disorientation starting at the mild stage of dementia. Yi et al. are the only ones reporting their participants' history of loss. Among people with AD with up to mild cognitive deficits, 29% reported getting lost once a month, 25% getting lost once every two weeks, and 18% getting lost once a week in an unfamiliar environment [34]. In a familiar environment among the same participants, 7% reported getting lost once a month, 4% reported getting lost once every two weeks and 7% got lost once a week [34]. During the navigation tasks, people with dementia reached the destination less often and required significantly more time to do so than neurotypical people [24], [33], [35].

Initial instructions on how to reach a destination [12] or current navigation help, e.g., map, written instructions or verbal guidance, [30] are not sufficient for people with cognitive impairments to reach their destination. In [30], all but one among 9 persons with cognitive impairments struggled to reach a destination during a navigation task using their usual guiding help. However, a great majority of people with dementia were able to control and follow the advice provided by the different devices. For instance, Liu et al. report that none of their participants with cognitive impairments had difficulty following guidance from their smartphone application. When using the device, their participants had less trouble making decisions and initiating actions [30]. Based on this review, the use of technological navigation devices seems to be secure, even for outdoor navigation where the risks are high [29]. Dementia, at least in mild to moderate stage, does not seem to preclude people from learning how to use a technology [25], [33]. However, neurotypical people have a better learning curve than people with dementia [33].

As stated previously, Oderud et al. are the only ones to provide long term and ecological results regarding the use of a navigation technology, i.e., commercial GNSS [8]. While half of the participants stopped using their GNSS during the three years project, the caregivers reported that the use of GNSS enabled the people with dementia, family and caregivers to feel safer. For people with dementia, the use of a GNSS was felt as a way to maintain their autonomy, enjoy their freedom and continue outdoor activities despite the progression of the disease. The administration of the GNSS, e.g., charging the device, was sometimes experienced to be a challenge, especially for people with dementia living alone in their personal homes.

Interestingly, our review reveals that the evaluation of the devices should take into account the number of time the users asked for assistance. Indeed, several papers (22%) report that users need intermittent assistance or reassurances, which are currently provided by the experimenters or nurses [12], [13], [23], [26], [28], [30]. For instance, people with AD with moderate to no cognitive impairments using a smartphone navigation application required assistance from the experimenters to reach a bit more than half (52%) of the routes [28]. Such assistance was particularly required "on longer paths without decisional requirement to turn or choose between options" [28] and to confirm that the participants were on the right route [23]. However, it could also be provided when participants reached a destination [13]. The percentage and frequency of people requiring assistance or reassurance while using navigation devices is difficult to estimate and most probably depends on the navigation technology. However, assistance or reassurances can be necessary from the early stages of dementia [26], [28]. Sejunaite et al. report that "All patients [with mild dementia] needed intermittent assists or reassurances" while using Google Glass [26].

#### 3.3.5 Which were the characteristics of people influencing the performance?

The severity of dementia seems to be an important factor that influences the usability of the devices [14], [18]. It was also reported that visuospatial (distinguishing right and left or assessing distances), divided attention (involving security issues regarding traffic lights), and memory (forgot where they were going) disturbances affected the usability of the device [24]. In long-term, the cognitive abilities of the people with dementia condition the duration of time using a GNSS [8]. However, there is only one paper reporting a correlation between cognitive tests, for working memory (assessed using the MMSE, Doors and People Test and Route-Finding Memory Test) and navigation performance (success of wayfinding) in real settings [34]. Grierson et al., Sorri et al. and Lanza et al. did not find any correlation between the navigation performance and cognitive tests scores (MMSE, Judgment of Line Orientation Test and Rey Visuospatial Immediate Copy) [14], [23], [28]. In virtual settings, visual memory and constructional abilities (assessed using the verbal memory span and the Rey-Osterreith complex figure copy and recall tests) [32], [35], complex visuospatial function (assessed using the clock drawing test) [35], memory and spatial memory (Corsi's span and supra-span test) [36], complex visual form discrimination (assessed using the visual form discrimination test) [35], executive function (assessed using the MMSE and Trail Making Test Part A and B) [32], [35], [36], body representation [36] and the useful field of view [35] significantly correlated with the number of errors and/or navigation time.

In real settings, the duration of use in long term of the device depends on the physical abilities and the level of support from the caregivers [8]. Along the experiments, the level of fatigue influenced if the participants reached the destination [26], [27]. Furthermore, people with cognitive impairments stressed out the importance for them to know the effort required to complete a route when choosing one to adapt it to their resources in energy, e.g., use longer routes instead of shorter ones but with stairs [30].

Attitude toward the technology was almost never assessed (either the Senior Technology Acceptance Model (STAM) questionnaire [38] or a question in a self-made questionnaire were used [24], [26]). Related to the attitude toward the technology, the computer skills were assessed [36] and few authors asked their participants if they had already used the technology they based their device on, i.e., smartphone [27], PDA [20] and GNSS [34], and with which settings [34]. Finally, Rosalam et al. report using the acceptance of the device observed in the behavior of the participants (method not reported) as an exclusion criterion in their navigation task [25]. However, none of the articles report the potential influence of such factors.

## 4 Discussion

In this section, we still base ourselves on the same three mains features, i.e., (i) advice, (ii) technology and (iii) experimental methodology to discuss and compare the former results based on the recommendations made in the literature.

### 4.1 Which navigation advice should be provided?

During navigation tasks, people must search, select, and process the information in their surroundings [39]. Regardless of the technology or modality of presentation of the navigational information, several guidelines should be followed when designing navigation advice. The advice provided should be salient, i.e., stand out in their environment and attract the attention of people [23]. The three components of salience, i.e., perceptual (e.g., use colourful objects), cognitive (e.g., calling people by their name) and contextual (e.g., take into count the current task and state of the person) should be leveraged [40]. The advice should also be congruent, i.e., consistent with the context and across the advice. Indeed, a redundancy in the perception of an information increases the degree of confidence associated with it [41] and compensates for the loss of spatial abilities and memory [7]. Also, people with AD have difficulties differentiating relevant from irrelevant information and would benefit from non competing information displays [7]. In the following paragraphs, we discuss the modality of presentation of the advice as well as its content and timing.

#### 4.1.1 Modalities of presentation

The literature recommends to use input modalities that are adapted to the preferences, environmental factors and cognitive and perceptual abilities of the users [11], [42]. For instance, the luminosity of a visual display should adapt to the ambient light. Providing multimodal advice is highly recommended as it is a way to fulfill the recommendations stated above. To be competitive with commercially available devices, future custom-made device should provide multimodal advice.

Healthy people heavily rely on visual information to find their way. The main limitation for visual displays arise from the necessity to pay attention to the device which is often at the expense of monitoring the surroundings. This is particularly true for elderly that are more likely to develop dementia and need more time to process information [43]. Also, people with dementia often have a decline of visual abilities affecting the perception, e.g., motion discrimination and contrast sensitivity [44], and process, e.g., difficulties in paying attention to several things at once [45], of visual information. Such deficits affect their ability to pay attention to wayfinding advice, especially if the advice is not salient [46]. Colour perception is relatively preserved for elderly people with and without dementia [47]. Using colours, and more specifically realistic ones (e.g., green for leaves) [48] and the yellow one [47], is beneficial as it enhance elderly's and people with dementia's ability to recognize, select and memorize environmental advice [47], [49]. Geometric information, i.e., layout of the environment, was also reported to be helpful for people with AD to find their room [49]. Regardless of the colour and layout, visual advice might benefit from being located on the floor as elderly and people with Alzheimer tend to look toward the ground [7]. Several types of visual information have been conveyed, i.e., text messages, photos and videos. Clear textual signs are recommended to improve wayfinding [50]. Though the ability to understand written text declines during the moderate stage of dementia, single words can still be used [51]. The use of pictograms should be better explored [7]. Photos and videos enable more realistic advice but should be considered carefully as difficulties matching the photos with the environment increase the workload associated with their use [30]. The beneficial effect of familiarity that was observed for voices [29] extends to visual advice. Indeed, placing a portrait-type photo of the person younger and a name tag in front of their room improved its finding [52].

The use of auditory advice is limited by the hearing loss that is often associated with cognitive decline of elderly people [53] and is not adapted in noisy environments [27]. However, it enables to reduce the cognitive load compared to visual advice [54] and leads to better navigation performances [31], [34]. The use of a natural (as opposed to synthetic) and familiar voice providing indications and addressing people by their name is recommended [23], [29]. Also, as auditory loss impacts mostly the ability to separate high frequencies, [23] recommended to use a low voice. Localized 3D sounds represent a useful indoor guiding advice but might be difficult to implement in a living facility were several people live. Indeed, it could generate noise and confusion in the intended recipient of a piece of advice [13].

Most navigational applications rely on visual and auditory modalities. However, age mostly affects these modalities [55]. In addition, the visual and auditory modalities are essential in the monitoring of the surroundings, e.g., vision and sound of cars indicating not to cross a street, while the tactile modality is not as taxed during navigation. Even though, tactile sensitivity diminishes with age [56], using a tactile feedback to provide navigation advice seems particularly suited. Only vibrotactile advice was tested to provide navigation advice, caregivers and experts felt that the best suited locations for such stimuli are on the waist or shoulder [57]. Based on the results from the articles included in our review, vibrotactile navigation advice could lead to poor acceptability and require to focus the attention on the tactile modality at the expense of the visual one [14], at least for some people. Further studies are required to assess the acceptability and usefulness of vibrotactile advice.

#### 4.1.2 Content of the navigation advice

Different wayfinding information suit differently people depending on their strategies, prior knowledge and/or preferences. Pieces of advice should co-exist and complement each other [27]. Currently, most of the advice provided correspond to guidance ones, i.e., they are provided before the persons make a decision regarding the route. However, it would be just as important to study how to provide advice to people regarding the choices that they made. Indeed, several articles report that their participants need reassurance regarding their choice [23], [26], [28]. Furthermore, the devices must be able to correct people when they make a choice that leads them astray or could even be dangerous [27]. Future research should investigate how to provide corrective navigation advice.

Most navigation advice included **Route** information. Such information can be presented in several forms: (i) visually through directional lights, text arrows or signs (ii) audibly though speech and spatialized sounds and (iii) through vibrotactile stimuli (see Figure 3). people with dementia have difficulties memorizing spatial route type representations [33]. Using route advice seems promising as in a virtual setting it improved spatial navigation and spatial memory and enabled people with AD/MCI to have comparable performances to neurotypical people [32]. However, directional information was found to impair spatial memory for neurotypical people compared to navigation without any advice [58]. Such impairment could be caused by a lack of attention dedicated to the surroundings because of the need to pay attention to the device, which in turn could limit the memorization of navigation information [58].

**Landmarks** represent a core advice enabling egocentric and allocentric representations. They can be presented in the form of text, speech, photographs and videos (see Figure 3) [42]. People with AD have difficulties remembering sequences of landmarks on a route [59] and linking landmark and route knowledge [60]. Adding landmarks has a better influence on wayfinding abilities than spatial layout or incidental items of the environment [61]. Based on our review and studies on elderly people, landmarks seem to improve spatial navigation and memory in virtual settings [32], [33], [42]. However, in real settings, when presented with route information, participants were paying less attention to the landmarks [27]. In general, the use of landmarks seems less efficient than route information in short-term [23], [32]. Landmarks have characteristics, i.e., size, colour, shape, location or familiarity, that modulate their salience and usefulness for navigation [39], [40]. Salient landmarks, e.g., colourful, flashing or familiar representation, were used in studies which found that landmarks improve the navigation performance and memory of people with dementia in virtual settings [32], [33], [40]. Controversially, landmarks placed at a decision point that were highly attended by people with AD were less remembered than the ones that people with AD paid less attention to [62]. It was hypothesised that paying attention to the salient landmarks use cognitive resources that are then not used to integrate the landmark to its location [62]. The location of the landmarks also makes a difference [33]. Their location needs to be invariable and not too high as people with dementia tend to look toward the ground [7], [33]. Also, landmarks are beneficial and better recalled by people with dementia when placed at decision points and at destination [61], [62]. The geometric information has also proven to interact with the usefulness of landmark for navigation [63]. The combination of specific geometry and landmarks seems to be more effective than landmarks alone in general for people to orient themselves, particularly for people with high level cognitive impairments when the landmarks cannot be seen simultaneously with the target [63]. Future advice could leverage such geometric information.

**Survey** information has been provided visually through the use of maps (see Figure 3). people with dementia have difficulties memorizing spatial survey type representations [33]. Maps enable the creation of topographic knowledge, i.e., spatial representation of an environment. The characteristics of the map, i.e., scale, orientation, presence of landmarks, has a significant influence on the navigation time [35]. It is recommended to use maps that are small-scaled, without landmarks and egocentric (first-person) instead of full-scaled, with landmarks and allocentric ones for people with dementia [31], [32], [35], [36]. Indeed, allocentric maps require their users to perform complex cognitive transformations and comparisons to locate and orient themselves in space, e.g., rotation, scale, number of dimensions or shape distortions [64]. The performance of such cognitive transformation causes decreased accuracy, increased response time and increased workload [65]. The greater the amount of cognitive transformation required to go from the allocentric representation to the egocentric representation, the greater the impact on the performance. The difficulty of using allocentric maps for people with dementia also seems related to deficits in associating landmark information to route knowledge [60]. Preferences regarding allocentric or egocentric navigation seems to depend on the stage of dementia [66]. It should be noted that a small-scaled map might however not enable people to make their own decisions regarding the path that they want to follow, change path when one is blocked or go back to the last familiar place that was reached [67].

When designing a system for people with dementia, one has to take into account that memory loss might result in people forgetting to bring the device with them, to ask for help or to pay attention to the advice. Thus, using **warnings** might be particularly useful to implement on navigation device for such population. Warnings were shown to diminish the response time and increase the accuracy in a decision making task [68]. The time between the warning and the advice should remain constant [68]. The use of warning sounds has been very little studied in our context. They are appreciated by people with dementia but could have a negative effect on navigation outcomes [29].

#### *4.1.3 Timing of presentation*

Using wayfinding abilities regularly could help elderly people preserve their cognitive functions [69]. Thus, navigation devices should provide advice while still soliciting the users' wayfinding abilities [70]. Continuously presenting navigation advice is likely to create a dependency to the system and thereby hinder people's ability to remember routes and recognize scenes [70].Instead of systematically providing advice, the participants might benefit from a system that gradually reduces the level of supervision and thereby promotes independence [67]. The use of geofencing, i.e., "virtual perimeter for a real-world geographic area that allows users to receive notifications whenever they enter or exit a specified area", could also limit the use of turn-by-turn advice [11], [71]. For instance, it can be used to send a warning message to people with dementia, or their caregivers, when they exceed a certain distance to their home. The use of geofencing is double-edged as it is easy to develop though it should not limit the area in which people perform their activities. While several papers state that the timing of presentation of the advice, i.e., when and how often to provide some, is really important [23], [30], it has not been much investigated. Navigation advice is particularly important at decision points. If the advice is presented too early, participants might forget about it. However, if the advice is presented too late, then participants might miss an intersection [23]. Also, people that utterly comply with the advice can be confused and frustrated when presented with a piece of advice at a wrong timing, e.g., turning against walls [23], [30].

#### *4.1.4 Recommendations, challenges and prospects - Augmented Reality*

Most of the devices that were developed relied entirely or partly on visual advice (see Figure 4). It is particularly recommended to use high contrasts, large text size and congruent or yellow colours for visual displays [27]. Providing contextualized advice, for instance through the use of photos with overlaid arrows, is promising [12], [28]. The realism of such advice, that conditions its relevance for navigation, is limited by the potential changes in the environment or the perspective between when the photo was taken and the moment when the user receives it. Augmented reality (AR) enables to enhance the real world by overlaying artificial visual, auditory or tactile elements that are co-located in the real and virtual space. AR applications have been developed for people with dementia (see the review of Hayhurst [15]), for instance to provide memory aids. AR represents an opportunity to provide a more contextualized, realistic and immersive navigation experience and its use, which should not be limited to visual display, has been recommended for people with dementia [32]. However, based on our review, the main limitation for visual displays arises from the necessity to pay attention to them on a separate device which is at the expense of monitoring the surroundings. Thus, the use of Head Mounted Displays (HMDs), i.e., helmets or glasses that enable adding information directly in the field of view of their users, seems particularly adapted as it enables hand-free navigation that would not force users to divide their attention by looking directly at a device [72]. As stated previously, Google Glass [26] and glasses with LEDs on the frame [18] were already tested. While the results are already promising, neither provide integrated visual navigation advice in the field of view of the user, i.e., separated egocentric map in Google Glass [26] and LEDs at cardinal locations in glasses frame [18]. Further research should be led to assess the efficiency of AR devices with integrated navigation advice. In the following paragraphs we present three main benefits that could arise from the use of AR.

First, AR enables the addition of new elements, e.g., directions or landmarks, directly in the environment of the person with the correct perspective and could reduce the ambiguity of instructions (see Figure 5) [72]. In automotive

Fig. 5. A person using a Microsoft HoloLens 2 Augmented Reality headset for navigation purpose.

applications, using AR-HMD displays has already enabled to improve navigation, user-experience and safety [72]. The challenge is to place the information, e.g., on the floor, so that it is easily seen and interpreted but it is does not occult the vision of important elements, e.g., cars. Second, AR would enable to modify the characteristics of existing navigational elements such as directional information and landmarks and make them more visible, e.g., changes in luminosity, colours and/or contrast, which is recommended in the literature to improve recognition and recall [48], [49], [73]. Third, AR could enable to attenuate the visibility of distracting elements from the surroundings, e.g., irrelevant navigation signs. Though, the use of such functionality should be weighted according to the potential negative influence that a system error could have on security, e.g., if the system inadvertently blurs a bicycle, or another source of accident.

The use of AR also has several potential limits that must be addressed before the large scale development of such device. First of all, the current AR HMDs have a narrow field of view, e.g., 52° diagonally for the Hololens 2, that may influence the perception, orientation and representation of the world (specific advice might counter the detrimental influence of AR [74]). Second, the augmented advice should be designed not to block or distract from the perception of crucial or relevant safety of navigation information (see [75] for an example of dedicated navigation advice for elderly people). Finally, the influence on cognitive abilities, acceptability and safety of a potential confusion between the real and virtual world that may arise while using augmented reality should be assessed. The literature lacks information on the matter. These potential limitations should not discourage future research on the use of AR for people with dementia but encourage researchers to further explore equally both the potential benefits and drawbacks of this technology.

## 4.2 Which technology should be developed?

Some design guidelines, that are not specific to the type of technology used, can be drawn from the literature. The system must be safe, unobtrusive, discreet, comfortable, not stigmatizing, easy to use for caregivers and patients, not require too much time to set up, involve the minimum amount of learning from the patients, not increase the cognitive load associated with the task and not require any programming knowledge [57].

Integrating the device inside a daily used object, such as a walker [21], [23] or a watch might decrease the risk of people forgetting about the device and favor its use. In the same vein, it is also recommended to avoid using medical looking objects to avoid stereotypes, offer to personalize the object and offer non-medical applications to the assistive device [76]. The navigation device can also be integrated directly in the environment, particularly for indoor navigation [13], [19].

The interaction, localisation and adaptation method to implement of the devices are discussed in the following sections.

### *4.2.1 Interaction method*

Our results indicate a necessity to improve the modalities of interaction with the navigation device developed. Indeed, half of the studies do not report any possible interaction with the device. The other half mostly consists of hand-held devices, e.g., PDA or smartphone, that enable tactile interactions. Touchscreens are intuitive and easy to use (particularly large ones) even for people with dementia [77]. However, the use of tactile interaction while navigating is particularly challenging. It requires users to divide their attention, which is particularly difficult for people with dementia [45]. Hand-held devices also often place demand on working memory and require holding on to information viewed in an earlier screen display to know how to proceed in a subsequent screen view. Using voice commands depending on the users' preferences and cognitive abilities might be better adapted [11].

### *4.2.2 Localization method*

Several limitations arise from the methods of localization. A reliable localization method is a prerequisite to the usability and security of the device. Precise localization implies detailed maps to contextualize this information. However, there is still a lack of detailed map with information relevant for pedestrians. Future projects, particularly for outdoor navigation, could rely on participatory maps, such as OpenStreetMap [78].

Reliable and acceptable indoor localization methods are still lacking. Most of the devices tested indoor did not implement a localization method and used a deception method instead. New developments in indoor positioning methods, such as the ones proposed in the comprehensive review of Yassin et al., could promote the development of indoor navigation devices [79]. For instance, ultra-wideband based localisation, i.e., method based on radio signal with frequency greater than 500 MHz, is described as a highly accurate, scalable, low cost and low energy consumption solution and has never been tested in this context.

Finally, the use of localization methods does raise ethical questions. Based on the long-term study of Oderud et al., a majority of people with dementia and their caregivers did not feel that the person with dementia using a device with a GNSS localization method was being under surveillance or monitored [8]. The ability to locate the person or to be located in case of loss was experienced as a safety measure that enabled more freedom and peace of mind [8].

#### 4.2.3 Adapted and adaptive devices

Devices developed to provide navigation advice should be adapted, i.e., initial adaptation to the traits (i.e., stable personal characteristics), abilities, preferences, previous knowledge of the user and the context of use. For instance, the sensory impairments could be taken into account to adapt the type of interaction to favor [57]. As importantly, the devices should be adaptive, i.e., continuously adapting to the user and context. As dementia inexorably progresses [4], the device should adapt over time to the progressive loss of cognitive abilities of the user. In a shorter range of time, the device should adapt to the modification in the environment, e.g., adapt the luminosity of the screen to the ambient luminosity. It should also adapt to the state (i.e., temporary personal characteristics) of the user, e.g., adapt the content of the advice to the attentional state of the user. As the attention of people with dementia can easily be disrupted by external factors that are not related to the task at end, e.g., surrounding people, such type of adaptation could be particularly useful [23].

#### 4.2.4 Recommendations, challenges and prospects - Intelligent Tutoring Systems

Most of the devices that were developed were not adapted nor adaptive to the stakeholders or the environment despite the recommendations from the literature [11]. Based on the literature, the device should be adapted to (i) the characteristics of the stakeholders, (ii) the characteristics of the environment and (iii) the interactions between the three (see Figure 6). It is expected that adapting the device would improve its usability and acceptability. To adapt the device, a comprehensive model of how the characteristics of the stakeholders, the environment and the advice impact the navigation is lacking. In addition to enabling adapted and adaptive devices, such a model could also be useful to better understand the mechanisms underlying navigation in the context of deterioration of cognitive functions and to better comprehend the inter-participants and inter-study variability we observed in the literature. Most importantly, the device should adapt to the needs of each person and provide advice only when requested. Such adaptation would enable the users to keep soliciting their wayfinding abilities and learn routes in order to remain autonomous as long as possible, including the autonomy toward the device. Elderly people that use their wayfinding skills on a regular basis have an increased amount of gray matter in the hippocampus and are more likely to be healthy [69].

The use of an Intelligent Tutoring System (ITS) has recently been recommended in the literature for people with memory problems [80]. Such systems use computational tools to tutor a person while learning a task and/or a skill. Figure 6 provides an example of how an ITS could be implemented in a navigation device and which characteristics of the navigation device it could modify depending on the characteristics of the environment and the stakeholders. ITS can be based on a predefined model or framework [81], though they could also base themselves on the previous experience to automatically generate and optimize the advice, e.g., path location and timing of wayfinding advice [82].

### 4.3 Which experimental methodology should be used to assess the devices?

Finally, we discuss the experimental methodology that was used to assess the devices and offer leads for future experimentation.

#### 4.3.1 Experimental settings

Among the studies presented in this review, only Oderud et al. [8] provide a long-term and ecological assessment. Most of the remaining studies consist in proof of concepts or assess characteristics of devices that have been developed specifically for people with dementia. Such studies are essential but represent only the first steps toward the availability of such devices outside research laboratories. Rigorous long-term ecological studies assessing among others how these devices or advice influence the autonomy, security, sociability and cognitive abilities of people with dementia and the burden of caregivers are needed before doing so. Until such long-term and ecological experiments can be performed, navigation tasks used during the experiments could be made more ecological and motivating by using non navigational goals and by adding a social context. Also assessing the influence of navigation devices across several days would enable to test the recall of the different routes as well as to provide users time for learning to occur, which is particularly important for elderly people [83].

#### 4.3.2 Measures used

With the exception of experiments performed in virtual settings, all the experiments were performed using both objectives and subjective measures. Objective measures are not subject to bias from the cognitive disorders of people. All the experiments performed in non-ecological settings assess the efficiency of the device by reporting either the number of trajectory errors, time to complete the navigation task and/or arrival at destination or not. Assessing the amount of assistance required to use the device is also an important marker of the long-term usability of the devices [8].

The end goal of the navigation device is not to supersede the participants' navigation abilities but to improve or at least not deteriorate them. The participants should not be dependent on the device. The influence of the device on spatial memory was only reported by one author [32]. Though, it is of utmost importance.

Using behavioral or biophysiological measures could be of interest to assess and improve the systems in real time. It is recommended to automatically assess disorientation, cognitive load as well as stress and to generate automatic prompts for people with dementia [11]. Indeed, when stressed, they tend to ignore the indications that they are provided with [11]. Thus, it would be necessary to anticipate such a situation and react rapidly enough by offering guidance and support.To do so, biofeedback e.g., based on heart rate, eye-tracking or gait measures could be used. For instance, previous research has shown that accelerometric data and GNSS records processed using machine learning

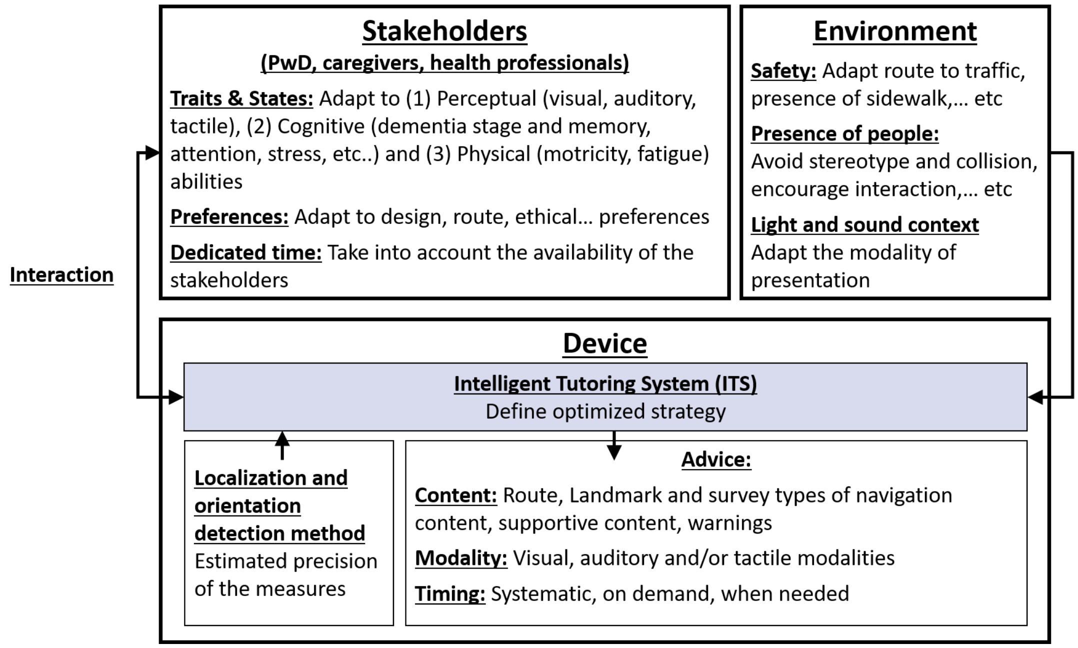


Fig. 6. Representation of the main influences on the navigation in the context of using a navigation device. An example of how an Intelligent Tutoring System could be integrated into the navigation device to adapt the latter to the stakeholders and the environment is included.

algorithms (i.e., linear discriminant analysis) can detect 65% of spatial disorientation events [84]. Physiological variables have already been used to assess usability of navigation advice [39], track emergency situations and health issues. Prosodic features, i.e., nonverbal aspects of human speech such as the speaking rate, might also provide information regarding the cognitive burden that is induced by navigation guidance [85].

In addition, subjective measures enable the assessment of the opinions and preferences of the stakeholders. The comprehension and communication skills of people should be taken into account when designing and choosing the subjective measures as well as their method of evaluation. For instance, mid-task interviews, such as in [27], might be best suited as the participants might have increasing issues recalling their experience with time. It should also be noted that traditionally used interviews or questionnaires, such as the NASA-RTLX, are not usable for some people [12], [23], [27]. Furthermore, the opinion of all the stakeholders, i.e., people with dementia, their caretakers and the health professionals, should be acquired [15].

#### *4.3.3 Participants' profiles*

Results from current studies, particularly the ones with experiments in real settings, are limited by the number of participants included. The fact that most studies included participants in the early stages of dementia is probably related to the increasing complexity in including such participants in experimental protocols. However, it could also indicate that the devices are mostly suitable during the early stages of dementia. Given the variety of dementia sub-types [4], more people should be included to assess the usefulness of the devices on such a population. The participants' cognitive traits, i.e., their stable personal cognitive characteristics, should be more reported and/or assessed as well. Very few papers report a diagnosis of dementia based on standard guidelines, such as the National Institute on Aging-Alzheimer's Association criteria [86], which would be necessary. Also, a more precise assessment of their loss behavior history, traditional navigation assistance used on a daily basis, cognitive and sensorimotor impairments, quality of life using widely accepted clinical measures and/or validated questionnaires would provide key elements for the adaptation of the devices. Future studies evaluating the influence of a navigation device would benefit from the assessment of the everyday navigational ability of their participants. The Questionnaire of Everyday Navigational Ability (QuENA) was made to assess the navigation abilities of people with AD [87].

#### *4.3.4 Navigation performance*

Non-technological navigation assistance, e.g., initial instructions, maps, written instructions or verbal guidance, do not seem to be sufficient for people with dementia to navigate. The long-term use of commercially available devices seem promising for at least some people and were shown to improve the feeling of safety of both caregivers and the people with dementia [8]. GNSS devices were perceived as a mean to preserve autonomy, enjoy freedom and continue outdoor activities despite the progression of the disease [8]. Other studies including less people with dementia over a few sessions also demonstrated that most instructions are followed and most people succeed in their navigation task using a commercially available device, i.e., a regular smartphone application, Google Glass, or a GNSS [24], [26], [34]. However, the navigation outcomes vary depending on the participants and the trials.

Comparing new navigation technologies such as the ones presented in this review to traditional and commercially available ones is important as well. Indeed, the ratio benefit (usability, security during navigation), cost (price, learning time, cost of deployment) of a new device for navigation should exceed the one of existing devices. A comparison between neurotypical people and people with dementia navigation performance with the device is also more revealing of its efficiency. For instance, if neurotypical people and people with dementia have comparable issues when navigating with a device, then the cognitive impairments caused by the dementia are not sufficient to explain these issues.

Many articles report having a support person beside the participants to help them when they require help. The presence of experimenters and/or caregivers might have affected the participants' behavior, performance and responses. Formalizing their role and the context and content of their interaction with the participants is not always done. However, formally assessing it would provide relevant information regarding the supportive feedback that the device could provide and limit the bias that could arise from the presence of experimenters.

#### *4.3.5 Characteristics of people influencing their performance*

As stated in the previous section, navigation outcomes vary intra-participant as well as inter-participants. In the following paragraphs, we argue that some characteristics of people with dementia reported in the articles reviewed, e.g., stage of dementia or physical fatigue, could provide first leads to explain such variability.

First, the stage of the dementia is most probably a predictor of the usability of navigation devices. However, most studies in real settings that tested this hypothesis did not find a correlation between cognitive tests scores and the navigation outcomes [14], [23], [28]. Such correlations were mostly found in virtual settings [32], [35], [36]. It is recommended to provide the people with the device during the early stages of the disease so that they can familiarize themselves with it, which is expected to improve the usability of the device [11], [14].

Second, our results indicate an influence of the level of physical fatigue on navigation abilities and preferences [26], [27]. Future research might benefit from assessing and taking into account the physical fatigue in their analysis [14], [26], [27], [30].

Third, we argue that the attitude toward the technology should also be evaluated as it could influence the navigation outcomes. Indeed, a previous research has found that the attitude toward the technology (assessed using the senior technology acceptance model) could explain 68% of the variance in the self-reported use of 16 different technologies by elderly people [38].

Finally, AD is associated with a range of behavioral abnormalities [88]. Around half of people with AD have abnormal levels of anxiety [88]. As anxiety was shown to influence the subjective perception of navigation abilities of neurotypical people [89], it would be worth assessing and reporting such information.

#### *4.3.6 Recommendations, challenges and prospects - Learning companions*

Several papers reported that their participants required support during navigation, for instance to confirm that they are on the correct path. Currently, the experimenters or caretakers did provide such support [26], [28]. Navigation represents a source of stress for people with dementia and their caregivers. Such anxiety toward the task, and maybe also toward the use of new technology, could partly this need for support. Providing social support could increase the overall level of enjoyment and self-fulfillment [13] and is supported by both the educational and neurophysiological literature [90]. Learning companions (a type of ITS) are computer-simulated, human-like, non-authoritative and social characters meant to foster learning [91]. In other fields of research, such as distant learning or neurofeedback (protocols which aim at training people to self-regulate neurophysiological measures, often for a medical purpose), learning companions were successfully used to compensate for the lack of social presence and emotional support [92], [93]. A learning companion could provide supportive advice to reassure people, provide them with social presence and emotional support as well as navigation advice and might diminish the stress induced by navigation and the use of a new technology. Such a companion could be presented visually, for instance as a virtual character that could be displayed through the use of AR (see Figure 7). Its behavior, i.e., gaze, gait, locomotion and gesture, could be based on the friendliness model described in [94] to increase the perception of a social presence or on the modular framework from [95], a comprehensive platform to design and author virtual characters. Based on the literature, ITS and more specifically learning companions need to adapt to the users [93]. Biophysiological and behavioral data from the users could be used to adapt the behavior of the learning companion. Developing a learning companion in AR would be beneficial. Indeed, the numerous sensors present in AR headsets, e.g., head tracking, eye tracking, depth sensors and cameras, could provide highly relevant information regarding the user and the environment to the ITS. In return, the ITS could adapt the information provided to the user (see Figure 6). Such adaptation could rely on the research led in pervasive and context-aware AR (see the comprehensive review on the matter from Grubert et al. [96]). However, the accuracy in the detection of the state of a person based on physiological and behavioral measures remains a challenge. One solution could be to couple these measures to improve the reliability of the ITS.

### 4.4 Limitations

As stated in the previous section, many of the papers included in this review report including few people with dementia, which does not enable to account for the variety of types of dementia and limits the reliability of the information that is reported in this paper. The limited number of participants most probably arises from the difficulty to have people with dementia participate into the experiments, the difficulty in obtaining ethical agreements for such studies and the variety of symptoms that people with dementia can express such as behavioral issues [10]. Also, most of

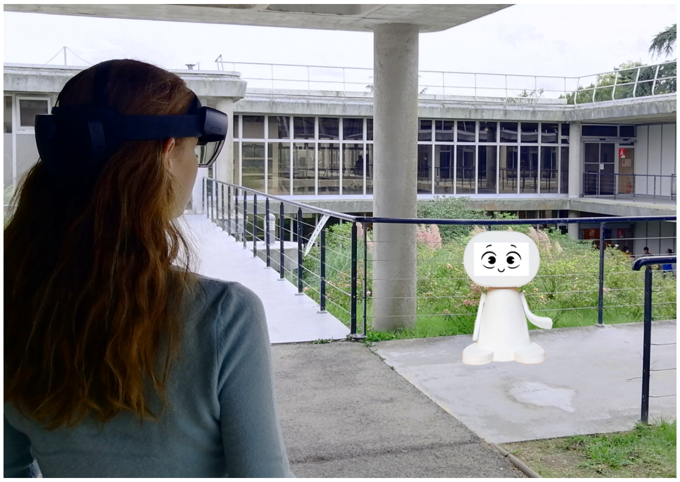

Fig. 7. A person visualizing a learning companion through the use of a Microsoft HoloLens 2 Augmented Reality headset for navigation purpose.

the articles did not report important information that we discuss in this paper. For example, several studies did not report which stage of dementia their participants were in or how it impacted their cognitive abilities. Such information is important to report as it could contribute to the development of a first model to adapt the navigation advice and would enable to compare the results of the different articles.

Our review also presents its own limitations. The keywords used for our search in the Scopus and PubMed databases could have led to the omission of relevant articles. The study of the titles and abstracts from the articles that were included in the review based on outer sources (i.e., relevant reviews of the field or articles found in our databases search) provides more information on the matter. Indeed, [30] and [31] were not found in our database searches because the keyword "mild cognitive impairment" (used along the keywords "Alzheimer" and "dementia") was too restricting and should have been replaced by "cognitive impairment". Also, even if we did include many nouns that could be used to describe a navigation device, i.e., "device OR tool OR system OR instrument OR glasses OR smartphone OR gps OR virtual reality OR augmented reality OR mixed reality OR windshield", the keywords "rollator" and/or "walker" should have been added as evidenced by the absence of [21] in our research. The omission of [8] by the databases search was due to the fact that it did not include any keyword in the title or abstract indicating that the device aimed at helping people navigate (nor any related keywords) which made it difficult to find through a database search. Finally, the article [35] was not referenced in the Scopus or PUBMED databases. Based on the authors' experience working either with AR/VR and/or medical applications and on the fact that 46 articles were retrieved and read in precaution following our reading of the relevant reviews of the field or articles found in our databases searches, we are confident that the vast majority of the relevant articles corresponding to our topic were included in this review. Also, the assessment of the potential bias of the articles is based on the biases reported in every articles. Such method of bias analysis presents the benefit of reporting biases that are specific to a given topic of research. However, it could have led to the omission of some bias that were not reported by any authors of the included articles. In addition, in this article we discuss the different characteristics of the navigation advice separately from one another because of a lack on information on the interaction between the types of advice. For instance, we discussed the use of a tactile advice separately from the use of an auditory one. In the future, a better understanding of how these characteristics interact with one another is important. Despite these limitations, we believe that this review still provides relevant guidelines for future developments in the field.

## 5 Global recommendations

Previous reviews in the literature indicate that there are substantial gaps in the literature regarding (1) spatial knowledge acquisition in real-world settings involving complex wayfinding tasks [97] and (2) how traditional, e.g., maps or signs, and digital, e.g., GPS or smartphones, navigation advice and their particular types of advice influences the acquisition of spatial knowledge and complement one another [97], [98].

Universal design approach could provide first leads to bridge these gaps. As stated in the introduction, a better understanding of why the current navigation devices are not adapted to people with dementia also provides very relevant information regarding how to adapt these devices to the diversity of the general public. There are many matches between the navigation difficulties presented by people with dementia and the ones presented by the general population. For instance, many adults, whether they have dementia or not, are not competent nor confident in using maps [97]. Also, wayfinding difficulties among neurotypical people are associated with underdeveloped decision-making and problem-solving abilities, which are frequent cognitive impairments among people with dementia [99]. Strategies used to develop spatial knowledge is similar among people with and without dementia (see the literature on backward chaining procedures that consist of learning each part of a path by starting to learn the last part and progressively proceed to the first part until the whole path is learnt and no navigation assistance is needed anymore) [98].

Based on recent reviews on wayfinding [97], [98], [99], many of the recommendations that we make can be generalized to the design of devices for the general population. Among the recommendations that we make several can be found in the literature on neurotypical people: (1) landmarks and wayfinding information should be salient and colorful [98], [99], (2) standardized spatial cues and specifically symbols, pictograms and photographs are recommended [97], [99] (3) the use of an egocentric map limits the risk of mistakes [97]. In the following paragraphs, we go through the different main recommendations for future research we made and elaborate on if they can be generalized for future research on the global population.

In Section 4.1.4, we recommend to assess the potential benefice and disadvantage of using augmented reality for navigation. The importance of using advice with realistic context and perspective is also stressed out in the literature

TABLE 1
Summary of recommendation, challenges and potential solutions that can be drawn from our systematic review of the literature on the navigation devices developed for people with dementia (PwD).

| | Recommendations | Challenges associated | Potential solutions |
|---|---|---|---|
| **Advice** | Using realistic advice limits the amount of cognitive resources necessary to locate and process it<br><br>PwD's attention should not be divided between monitoring the environment and the device | Changes occur in the environment limiting the realism of photos/videos<br><br>Encompassing the device directly in the environment requires time and resources and is particularly challenging outdoor | Augmented reality (AR) to co-locate the virtual advice in the environment |
| **Technology** | Adapt the technology and the advice to the characteristics of the stakeholders and the environment<br><br>PwD should keep soliciting their wayfinding abilities | A comprehensive model of how the characteristics of the stakeholders, the environment and the advice impacts the navigation is lacking | Intelligent Tutoring System (ITS) based on the previous experience |
| **Methodology** | Provide adapted support during navigation<br><br>Use biophysiological measures to assess PwD's state, e.g., stress or disorientation | Infering PwD's state from biophysiological data can be unreliable | Augmented learning companion (type of ITS) providing social presence and emotional support<br><br>Combining biophysiological measures |

on wayfinding for neurotypical people [98], [99] and the ability to divide attention between the monitoring of device and the surroundings varies among the population. Thus, the potential benefits of using AR and HMDs should be assessed among people with and without dementia. It should also be stated that the limitations associated with the use of AR, e.g., potential confusion between the real and virtual world, should be assess among the whole population too.

In Section 4.2.4, we recommend to develop future research to adapt the technology and the advice to the characteristics of the stakeholders and the environment. This recommendation is not only valid to develop devices for people with dementia but for the whole population. Indeed, it was shown that wayfinding abilities greatly vary among people and are influenced by individual differences (e.g., age, gender, cognitive development, perceptual capability, spatial ability, mental and physical conditions and culture) and characteristics of the environment (e.g., complexity, type of landscape) [3], [97], [99]. The type of advice that should be provided to the users also depends on their profiles. More specifically, the type of map used should depend on the user's characteristics, e.g., age and skills [97]. For instance, a symbolic map can be very difficult to use of beginners [97].

In Section 4.3.6, we advocate for further research using learning companions that provide emotional and social support during navigation. Wayfinding abilities can be improved through training [97], [99] and navigation devices should support the creating of such spatial knowledge regardless of them having dementia or not. As several theories and methods have shown that learning can be strengthened by a social feedback [90], [91], a learning companion could be beneficial to the whole population.

For the community working on devices for a specific population, encouraging the use of their device by the general population could first increase the acceptability of their device as the risk of stigmatisation for using the device would be reduced or removed. Second, by increasing the target population, the economic sustainability of such device could be improved. Such universal design scientific approach was already used to provide new recommendations for navigation devices based on the ones made for people with visual impairments [100]. For instance, the democratisation of 3D maps that enables to create a survey type of representation of the environment, originally created for visually impaired people could be useful to the general population [100]. We strongly encourage researchers to contribute to this universal design endeavour.

## 6 Conclusion

Few research is led on navigation devices. This article shows that navigation devices are promising for enabling people with dementia to (i) navigate in familiar and unfamiliar locations as well as (ii) increase or maintain their abilities to navigate in these locations. These devices are also expected to reduce the burden of caregivers (or at least not increase it) as well as to improve the quality of life of people with dementia. However, such influence of the devices remains under-evaluated. This gap in the literature should be fulfilled by future research on the matter among which long-term and ecological one will be decisive. Also, a universal design approach would enable to expend the results obtained for people with dementia to the global population. In this context, we particularly recommend to further experiment the use of augmented reality while initiating the use of intelligent tutoring systems that provides not only navigation advice but also social support (see the summary Table 1).

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