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Augmented Reality Based Assistive Technologies for the Safety of People with Dementia and Related Mild Cognitive Impairment: A Systematic Review

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Abstract

Dementia is a neurodegenerative condition affecting 55 million people globally, with nearly 10 million new cases each year. The societal and economic impacts of dementia are significant and are steadily increasing for caregivers and the healthcare systems. Assistive Technologies (AT), including Augmented Reality (AR), have significantly improved independence, safety, and Quality of Life (QoL) for People with Dementia (PwD) and Mild Cognitive Impairment (MCI). This study, therefore, investigates the state-of-the-art applications of AR-based AT focusing on improving the safety of PwD and MCI. It aimed at exploring areas of safety where AR-based AT have been applied, the interaction modalities employed to facilitate user engagement and situation awareness the systems are capable of drawing the attention of users or caregivers to in order to avoid danger. The study followed the Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) guidelines to identify 31 relevant studies for the review. The quality of the included studies was assessed with Mixed Methods Appraisal Tool (MMAT). The findings from the review shows that AR-based AT for the safety of individual with cognitive impairments is still limited. The few available studies can be categorised into three safety support types: mobility, medication management, and home safety and control. While most research focuses on mobility and medication management, there is a notable gap in addressing home safety and control, with interventions often targeting specific concerns. Most AR-based AT rely on smartphones, though prolonged use may cause fatigue. While wearable smart glasses are still developing and face ergonomic challenges, emerging lightweight designs show promise for wider adoption among older adults. Although AR-based AT demonstrate considerable potential to improve safety for PwD and those with MCI, the existing evidence is largely confined to small pilot and feasibility studies. There is a clear need for large, rigorous Randomised Controlled Trial (RCT) to evaluate their effectiveness in safety support in these target populations.

Keywords

Assistive Technologies, Augmented Reality, Dementia, Mild Cognitive Impairment, Old Adult, Cognitive Aging, Safety Intervention, Situation Awareness

1 Introduction

Dementia is a neurodegenerative condition affecting 55 million people globally, with nearly 10 million new cases each year (World Health Organization, 2023; Alzheimer's Society, 2023a). Dementia is a group of conditions that causes cognitive decline and it is characterised by symptoms such as memory loss, difficulty with thinking, trouble identifying and avoiding objects on the floor, impaired ability to perform daily tasks etc. (Rose et al., 2018; Kahya et al., 2020; Javeed et al., 2023). It is a cognitive impairment that varies from mild to severe condition (Rossi et al., 2020) and the progression of its severity depends on the quality of care received (Varghese et al., 2021). Dementia care is costly, with global expenses reaching $1.3 trillion in 2019 (Wimo et al., 2023). Informal carers, such as family members and friends, account for about 50% of these costs, providing an average of 5 hours of daily care (World Health Organization, 2023). The societal and economic impacts of dementia are significant and are steadily increasing for caregivers and the healthcare systems (Spalla et al., 2022). Family members bear significant burdens and personal costs in providing support (World Health Organization, 2023; Reisinho et al., 2022; Spalla et al., 2022;). One way to alleviate this burden is by promoting their independence at home (Spalla et al., 2022). However, dementia becomes more pronounced when individuals live alone (Hervas et al., 2014).

Despite this, people have continually expressed a preference to remain at home as long as possible if diagnosed with dementia (Alzheimer's Society, 2019).

In 2019, there were 120,000 People with Dementia (PwD) living alone and this number is predicted to double to around 240,000 by 2039 (Alzheimer's Society, 2019). Age is the strongest known risk factor for dementia however, dementia is not an inevitable consequence of ageing (Alzheimer's Society, 2021; World Health Organization, 2023). Age-related cognitive decline has been linked to reductions in processing speed, executive control, and response inhibition (Eckert et al., 2010). Research consistently shows that even among healthy older adults, several cognitive functions including processing speed, reaction time, task performance, and low vision tend to decline with age (Kirk, 2024; Yeverino-Castro et al., 2023; Parent et al., 2023; Ball et al., 2023). Mild Cognitive Impairment (MCI) is widely recognised as an intermediate stage between normal cognitive aging and dementia, characterised by measurable cognitive decline that does not yet substantially interfere with daily functioning (Morris et al., 2001; Langa and Levine, 2014). Understanding MCI is critical, as individuals at this stage are at increased risk of progression to dementia, highlighting the importance of early detection and intervention (Lopez et al., 2007; Solfrizzi et al., 2004). Home modifications are a key non-pharmacological intervention for supporting aging in place. The National Institutes of Health (2017) and Alzheimer's Association (2023b) traditionally, recommend home modification intervention to guarantee the independence and safety of old adults and PwD. Home modification interventions refer to the alterations made to living spaces using concepts of barrier-free design, architectural accessibility, and related principles (McCullagh et al., 2006). The goal is to eliminate identified hazards by making minor adjustments to the home environment, such as removing rugs or mats, enhancing lighting (including sensor lighting) and step edge contrast, installing grab bars and step/stair rails, and widening doorways (Taylor et al., 2021; Georlee et al., 2020; National Institutes of Health, 2017). However, it is not easy for older adults to grasp the necessity and criteria for installing such interventions (Miura et al., 2023).

Assistive Technologies (AT) have shown positive outcomes in enhancing independence, safety, and QoL for old adults, PwD and MCI (Peterson et al., 2012; Hayhurst, 2018; Ghorbani et al., 2023). AT refers to devices and systems that help people maintain or improve their independence, safety, and wellbeing in the cause of their Activities of Daily Living (ADL) (Social Care Institute for Excellence, 2019). It encompasses a spectrum of tools, extending from simple aids like walking canes to advanced technological interventions (Garçon et al., 2016) that can help both health old adults and people with cognitive impairment stay well and safe at home (Peterson et al., 2012; Bennett et al., 2017; Hayhurst, 2018; Sriram et al., 2020). AT supports individuals in the early stages of dementia by helping them maintain independence at home, while simultaneously reducing the burden on caregivers and the healthcare system (Ienca et al., 2017; Berrett et al., 2022).

In recent times, Augmented Reality (AR) have contributed immensely to the development of AT for old adults, PwD and MCI (Kanno et al., 2018; Su et al., 2024; Ball et al., 2023; Mettouris et al., 2021). AR, which overlays computer-generated objects to the real world, is gaining interest in dementia continuum for its ability to offer intuitive interactions and reduce caregivers' workload (Zhao et al, 2019a; Achilleos et al., 2023). AR enables users to stay connected to their real-world environment, integrating augmented experiences into their daily routines and lifestyles (Hauger et al., 2019). By leveraging AR technology, the AT system can deliver real-time warnings and safety alerts in a more intuitive and context-aware manner, making it easier for users to stay informed and make safer decisions while navigating their environment (Połap et al., 2017; Li, 2024). AR surpass traditional visual centric interfaces in unlocking new forms of interaction and engagement (Li, 2024). This capability enables cognitively impaired individuals to maintain their independence for a longer period before having the need to move into an assisted living facility (Mirko Rossi et al., 2020; Dickinson et al., 2023).

Although both traditional and technology-enabled safety intervention strategies have the potential to improve the independence and safety of older adults (Nguyen et al., 2021; Rose et al., 2018; Kahya et al., 2020; Chen et al., 2020), its effectiveness is only as strong as the level of adherence to its recommendations (Rose et al., 2018). Adherence to the intervention strategies can be an issue as older adults who could find it challenging to follow and comply with safety measures (Nishchyk et al., 2021; Orobor et al., 2025). The ability of older adults to comprehend safety interventions is critical to achieving empowering outcomes. However, existing design methods limit older individuals' ability to see their goals reflected in safety practices and services. This inhibits compliance with interventions and disempowerment (Bianco et al., 2016).

The preference of older adults to live at home, especially those with cognitive impairment living alone, raises concerns for relatives and caregivers. While home interventions often focus on fall prevention, other hazards, monitoring, and reporting dangerous events are not catered for hence, leaving significant safety needs unmet. AR-based AT have proven effective in addressing safety needs by providing timely hazard alerts to individuals with cognitive impairments and their caregivers to prevent or mitigate accidents. This review, therefore, investigates the state-of-the-art applications of AR-based AT focusing at improving the safety of PwD and individuals with

MCI. While some studies have investigated the use of AR to enhance safety for the target population, none have systematically explored the full range of potential hazards it can address or the risks it can mitigate. This review aimed to explore areas of safety where AR-based AT have been applied. The interaction modalities employed to facilitate user engagement with the systems and situation awareness the systems are capable of drawing the attention of vulnerable users to in order to avoid danger. Since the cognitive decline can further make the use of technology difficult (Hervas et al., 2014; Rossi et al., 2023), knowing the mode of interaction that works best for this target population is important to enhance interaction and engagement with the technology. Most existing research often overlooks the unique preferences of older adults, particularly those with cognitive impairments in terms of interaction modalities. Finally, the review highlights limitations in existing AR-based AT and provides insights for developing more effective interventions.

The remainder of this review is structured as follows: Section 2 details the research methodology, Section 3 presents the results, Section 4 discusses the findings along with the study's strengths and limitations, and Section 5 outlines future directions and concludes the review.

2 Research Methodology

A preliminary review was conducted to assess the need for a systematic literature review, leading to the development of research questions outlined in Table 1. The review investigates recent studies on AR-based AT aimed at improving the safety of PwD and related MCI. It followed the Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) guidelines (Page et al., 2021) to identify relevant studies for the review. Figure 1, below describes the PRISMA flow diagram for the systemic review.

2.1 Research Questions

The research questions of this systematic review are shown in Table 1.

Table 1. Research Questions

#	Research Question	Motivation
RQ1	What safety support does AR-based AT provide for PwD and related MCI?	To investigate studies that apply AR-based AT for the safety of PwD and MCI and categorise them into various support types to identify the most effectively addressed safety needs.
RQ2	What interaction modalities in AR-based AT could enhance user engagement in safety context?	To identify the most suitable interaction modalities to improve user engagement when designing AR-based AT safety intervention age-related cognitive impairment.
RQ3	What situation awareness that enhances user safety does AR-based AT provide for PwD and MCI?	To identify potential hazards that AR-based AT is capable of bringing to the knowledge of PwD and MCI and possible risks that can be alleviated.

2.2 Search Strategy

A systematic search using IEEE Xplore, PubMed, and Scopus databases was conducted. In addition, a random search was also performed on other database sources for relevant studies. The studies searched were from year January 2014 to December 2024. Only English language studies indexed in the above databases were considered for inclusion in the review. The full search strategy was formulated as (Set1) AND (Set2) AND (Set3), as shown in Table 2.

Table 2. Search Keywords

Search Set	Keywords
Set1	Augmented Reality OR Mixed Reality OR Assistive Technology OR Ambient Assisted Living
Set2	Alzheimer OR Old Adults OR Dementia OR Mild Cognitive Impairment
Set3	Mobile Phone OR Smartphones OR Tools OR Systems OR Smart Glasses OR Head Mounted Display

2.3. Selection Criteria

Studies satisfying the criteria outlined in Table 3 were either included or excluded from the systematic review.

Table 3. Inclusion and Exclusion Criteria

Inclusion criteria	Exclusion criteria
Studies including some or all participants who are older adults with dementia, MCI, or age-related cognitive decline	Studies that did not undergo peer-review
Written in the English language	Addressing conditions that are not dementia, MCI or age-related cognitive decline
Published in journals and conferences between the year January 2014 to December 2024	Whose methodology are not based on AR
Utilising qualitative, quantitative or mixed method study design	Addressing outcomes that are not safety related

2.4 Study Screening

All published academic journals and conference proceedings references retrieved from the search databases were downloaded into Zotero software for initial screening. Duplicates references where removed. The remaining titles and abstracts were screened by one author (IAO) and independently reviewed by two authors (RH and MK) using the inclusion and exclusion criteria outlined in Table 3. The references and full text of the remaining studies was assessed for eligibility independently by one author (IAO), reviewed by two authors (RM and MK). A fourth author (FD) resolved disputes.

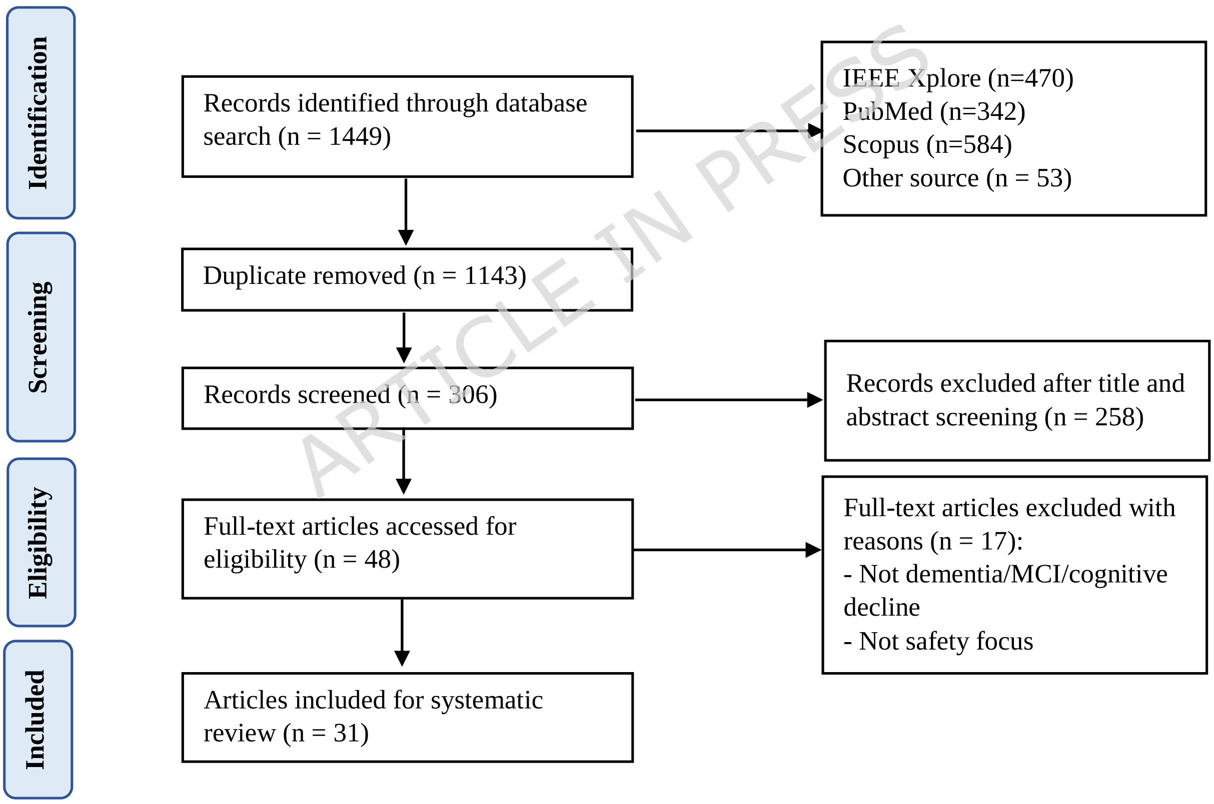


Figure 1. PRISMA Flowchart for Systematic Review

2.5 Quality Assessment

To ensure accurate and unbiased conclusions in this review, the Mixed Methods Appraisal Tool (MMAT) (Hong et al., 2018) was used to assess quality of the 31 included studies. MMAT is a critical appraisal tool used assess the methodological quality of empirical studies involving qualitative, quantitative, or mixed methods study design (Hong et al., 2018). One author (IAO) conducted the quality appraisal, two authors (RH and MK) independently review the outcome of the appraisal. Each authors answered five screening questions and rated the five MMAT criteria per study. Further quality assessment outcomes were cross-checked, and any disagreements were resolved through consultation with the fourth author (FD) to achieve consensus on all included studies. Responses agreed upon were compiled and presented in Appendix I.

2.6 Classification Analysis of AR-based AT for the Safety of PwD and MCI

The classification process involved gathering relevant data within the research scope. Five key elements were identified by reviewing and analysing the AR-based AT interventions discussed in eligible full-text studies. These elements are summarised in Table 4 with a focus on addressing the systematic review research questions in Table 1. The elements are: (1.) Safety Support - Methods used by AR-based AT to help individuals with cognitive impairments maintain safety and independence. (2.) Features - Specific safety functions provided by the interventions. (3.) Interaction Modalities - Input/output methods that enable user interaction and feedback. (4.) Situation Awareness - Situational information provided to keep cognitively impaired individuals and caregivers informed about the context. (5.) Risk Mitigated - Potential risks that the interventions aim to reduce for individuals with cognitive impairments. These elements are crucial in creating comprehensive safety interventions for PwD and MCI. They guide the development of AR-based safety interventions by helping in identifying suitable features, interaction modes, feedback mechanisms, and awareness strategies tailored to cognitive challenges, while addressing potential risks to enhance user safety.

The review broadly categorised the AR-based interventions discussed in the various studies included into three types of safety support (See Figure 2), these are: (1.) Mobility, (2.) Medication Management, and (3.) Home Safety and Control. Safety in this context refers to any function that directly prevents hazards, such as medication reminders, user monitoring, and fall prevention (Gross et al., 2011).

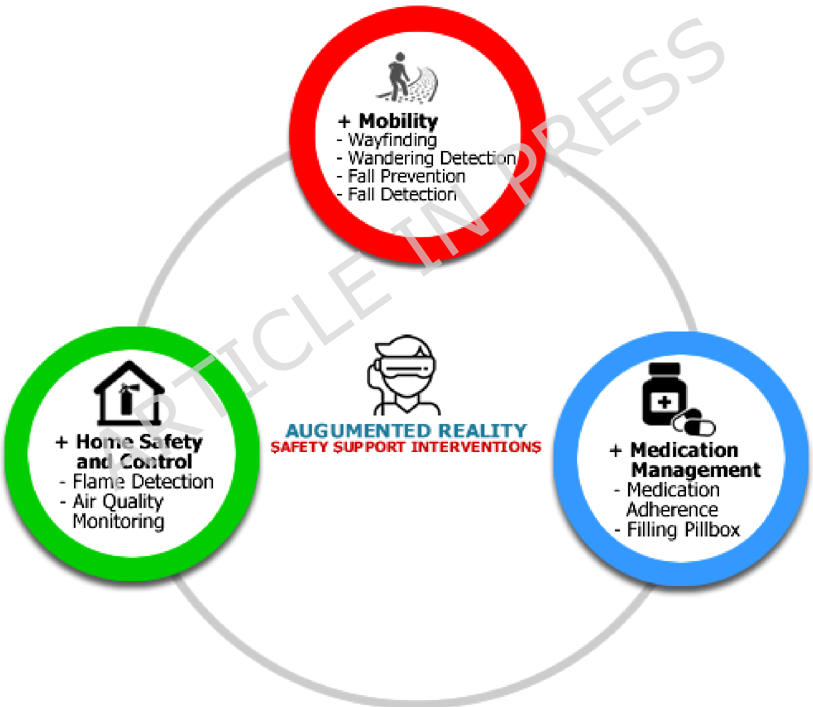


Figure 2. Categories of AR-based AT for the Safety of PwD and Related MCI

The safety support categories are mainly based on the features provided by the AR-based AT interventions to enhance the safety of PwD and related MCI. First, interventions that target fall prevention, fall detection, wandering detection and wayfinding were categorised as offering mobility safety support because these features emanate from user mobility activities. Mobility refers to the ability to move between positions, including sitting, standing, walking, and transitioning between postures (Tyson and Connell, 2009). Maintaining independent mobility for PwD is crucial, as mobility loss can lead to increased fall risk, reduced participation in meaningful activities, and other negative effects (Hauger et al., 2019; Ooteghem et al., 2019).

Secondly, AR-based AT interventions that focus on medication management were also considered to offer safety related outcome. This is because more complex medical issues or life-threatening situations might result from missed medications or improper dosage administration (Taghian et al., 2023). For PwD, their health condition might deteriorate unprecedentedly, hence, medication management becomes a significant safety issue, especially for vulnerable populations living alone. Poor medication management can lead to serious risks such as overdosing or underdosing, drug interactions, insufficient health outcomes, and missed doses etc (Yadav and Kirit, 2024; Taghia et al., 2023). Effective medication management is vital for maintaining safety and wellbeing; as such, AR-based tools that function as medication reminders, manage regimens, and assist with filling pillboxes (Guerrero et al., 2019; Blusi and Nieves, 2019; Franzén, 2023; Yadav and Kirit, 2024) were categorised as offering medication management safety support.

The third safety-related support is categorised as home safety and control. This category includes AR-based AT that connects with smart home embedded devices to provide safety information to cognitively impaired users by monitoring hazardous situations, atmospheric conditions, and controlling smart home devices (Mettouris, et al. 2021; Ghorbani et al., 2023). Monitoring the homes of individuals with PwD and MCI is essential, as they may need reminders to complete critical tasks, like turning off the stove, avoiding hazardous areas or need for ventilation in the home (Ghorbani et al., 2022; Ghorbani et al., 2023). AR-based AT with the capability of connecting with smart home device can be beneficial in providing real-time and precise information to cognitively impaired users.

Table 4. Five Key Elements of AR-based AT Safety Interventions

Authors	**Safety Support**	**Features**	**Interaction Modalities**	**Situation Awareness**	**Risk Mitigated**
Hervas et al. (2014)	Mobility	Wayfinding	IM: Visual (Touch) OM: Visual (Text)	User Location	Getting Lost
Lera et al., (2014)	Medication Management	Medication Adherence	IM: * OM: Visual	- Medication Time - Medication Regimen	- Missing/Delayed Medication - Incorrect Medication Dosage
Saracchini et al., (2015)	Home Safety and Control	Flame Detection	IM: * OM: Visual (Text, Sign)	Presence of Fire	Burn and Scald
Bianco et al., (2016)	Mobility	Fall Prevention	IM: * OM: Visual	Object on Pathway	Falling
Połap et al., (2017)	Mobility	Fall Prevention	IM: * OM: Visual (Sign)	- Object on Pathway	Falling
Kanno et al., (2018)	- Mobility - Medication Management	- Wayfinding - Medication Adherence	IM: Auditory (Voice) OM: Auditory (Voice), Visual (Text), Tactile (Vibration)	- User Location - Medication Time - Medication Regimen	- Getting Lost - Missing/Delayed Medication - Incorrect Medication Dosage
Ingeson et al., (2018)	Medication Management	- Medication Adherence - Filling Pillbox	IM: Auditory (Voice), Gesture OM: Visual (Text), Auditory (Voice)	- Medication Time - Medication Regimen - Medication Distribution	- Missing/Delayed Medication - Incorrect Medication Dosage - Mixing Medication
Liang (2018)	Medication Management	Pillbox	IM: Visual (Touch) OM: Visual (Text, Image, Audio)	Medication Regimen	- Incorrect Medication Dosage
Gacem et al., (2019)	Mobility	Wandering Detection	IM: Visual (Touch), Auditory (Voice) OM: Visual (Text, Image), Auditory (Voice)	User Location	Getting Lost
Ro et al., (2019)	- Mobility - Medication Management	- Fall Detection - Medication Adherence	IM: Visual (Touch), Auditory (Voice) OM: Visual (Text) and Auditory (Sound)	- User Position - Medication Time - Medication Regimen	- Falling - Missing/Delayed Medication - Incorrect Medication Dosage
Park et al., (2019)	- Mobility - Medication Management - Home Safety and Control	- Fall Detection - Medication Adherence - Air Quality Detection	IM: Visual (Touch), Auditory (Voice) OM: Visual (Text) and Auditory (Sound)	- User Location - Medication Time - Environment Condition	- Getting Lost - Falling - Incorrect Medication Dosage

					- Missing/Delayed Medication - Poor Ventilation - Respiration Issue
Liu et al., (2019)	Mobility	- Wayfinding - Wandering Detection	IM: * OM: Visual (Text, Arrow), Auditory (Sound)	User Location	Getting Lost
Guerrero et al., (2019)	Medication Management	- Medication Adherence - Filling Pillbox	IM: Gesture (Hand) OM: Visual (Text)	- Medication Time - Medication Distribution	- Missing/Delayed Medication - Mixing Medication
Zhao et al., (2019b)	Mobility	Fall Prevention	IM: * OM: Auditory (Sound, Voice)	Uneven Surface	Falling
Blusi and Nieves (2019)	Medication Management	Filling Pillbox	IM: Auditory (Voice), Gesture (Body) OM: Visual (Text), Auditory (Voice)	Medication Distribution	Mixing Medication
Younis et al., (2019)	Mobility	Fall Prevention	IM: * OM: Visual (Arrow), Tactile (Vibration)	Object on Pathway	Falling
Rossi et al., (2020)	Home Safety and Control	Flame Detection	IM: * OM: Visual (Text, Image) - Auditory (Voice)	Presence of Fire	Burn and Scald
Yang et al. (2021)	Medication Management	Medication Adherence	IM: Visual (Touch) OM: Visual (Text)	Medication Time	Missing/Delayed Medication
Mettouris et al., (2021)	Home Safety and Control	Air Quality Monitoring	IM: Visual (Touch) OM: Visual (Text), Auditory (Sound)	Environment Condition	Respiratory Issue
Varghese et al., (2021)	Mobility	- Wandering Detection - Fall Detection	IM: Visual (Touch) OM: Visual (Text)	- User Location - User Position	- Getting Lost - Falling
Ghorbani et al., (2022)	- Home Safety and Control - Medication Management	- Flame Detection - Medication Adherence	IM: * OM: Visual (Image) and Auditory (Voice)	- Presence of Fire - Medication Time	- Burn and Scald - Missing/Delayed Medication
Htike et al., (2023)	Mobility	Fall Prevention	IM: Gesture (hand), Auditory (Voice) OM: Visual (Line, Color, Comic overlay)	Object on Pathway	Falling
Taghian et al., (2023)	- Medication Management - Mobility	- Medication Adherence - Wayfinding	IM: Visual (Touch) OM: Visual (Text), Auditory (Voice)	- Medication Time - User Location	- Missing/Delayed Medication - Getting Lost
Miura et al. (2023)	Mobility	Fall Prevention	IM: * OM: Visual (Text)	Absence of Safety Intervention	Falling
Ball et al., (2023)	Mobility	Fall Prevention	IM: * OM: Visual (Arrow)	- Object on Pathway - User Position	Falling
Franzén (2023)	Medication Management	- Medication Adherence - Filling Pillbox	IM: Visual (Touch) OM: Visual (Text) Auditory (Voice)	- Medication Regimen - Medication Distribution	- Incorrect Medication Dosage - Mixing Medication
Achilleos et al., (2023)	- Mobility - Medication Management - Home Safety and Control	- Wayfinding - Medication Adherence - Air Quality Monitoring	IM: Visual (Touch) OM: Visual (Text, Arrow)	- Medication Time - Presence of Smoke/Gases	- Getting Lost - Missing/Delayed Medication - Respiratory Issue - Poor Ventilation
Dylan et al., (2023)	Mobility	Fall Prevention	IM: * OM: Visual (Arrow)	Object on Pathway	Falling

Ghorbani et al., (2023)	- Mobility - Home Safety and Control	- Fall Prevention - Flame Detection	IM: * OM: Visual (Text, Image) and Auditory (Voice)	- User Position - Presence of Fire	- Falling - Burn and Scald
Su et al., (2024)	Mobility	Fall Prevention	IM: * OM: Visual (Text)	- Absence of Safety Intervention - Object on Pathway	Falling
Yadav and Kirit (2024)	Medication Management	- Medication Adherence - Filling Pillbox	IM: * OM: Auditory	- Medication Time - Medication Regimen - Medication Distribution	- Missing/Delayed Medication - Mixing Medications

Table Acronym/Symbols: IM: Input Modalities; OM: Output Modalities; *: Not reported by author in the study

Based on the analysis of Table 4, findings resulted in the development of an AR-based AT conceptual framework shown in Figure 3. The framework highlights key elements from existing AR-based AT safety intervention systems, with a focus on dementia and related MCI. While not comprehensive, it serves as a guide to understanding some key elements of AR-based safety interventions for these target populations.

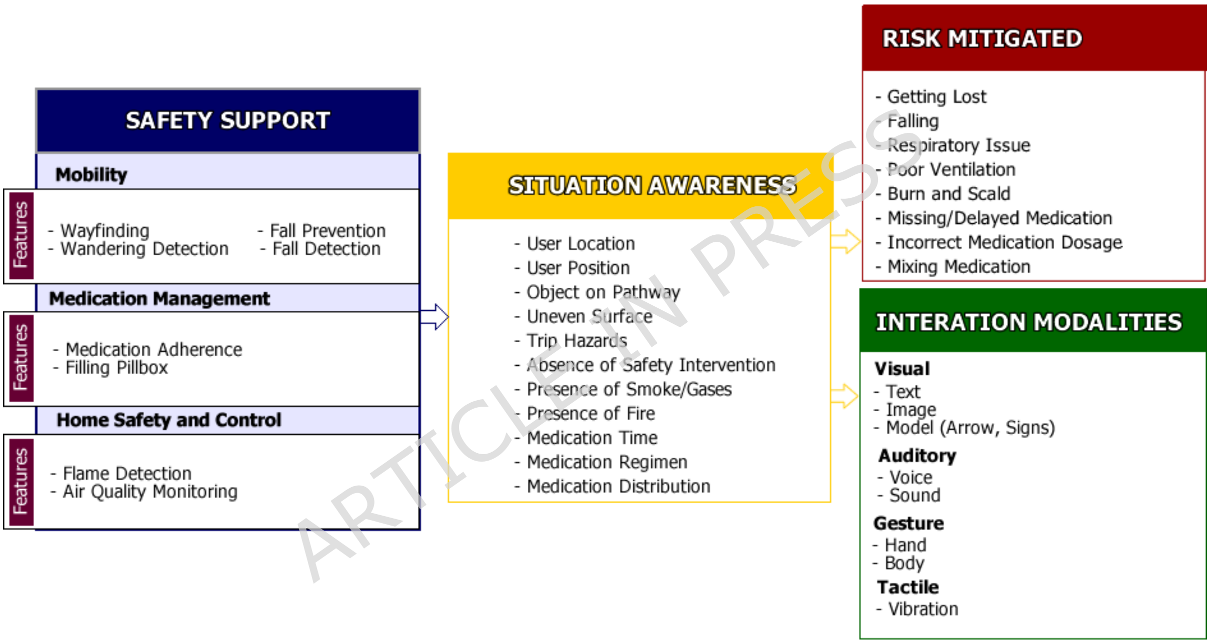


Figure 3. AR-based AT Applications Framework for the Safety of People with Dementia (PwD) and Mild Cognitive Impairment (MCI).

2.7 Summary of Existing AR-based AT for the Safety of PwD and MCI

Studies reviewed have shown great potential in the use of AR-based AT in ensuring the safety of PwD and MCI. This review attempts to highlight the limitations in existing solutions, as shown in Table 5, in order to provide insight for the development of improved future solutions. The limitations highlighted are based on some key elements identified in Table 4 in addition to a general analysis of the interventions.

Table 5. Summary of Existing AR-based AT for the Safety of PwD and Related MCI

Studies	**Study Design**	**Target Population / Condition**	**Benefits**	**Display Devices**	**Limitations**
Hervas et al., (2014)	Qualitative Study	10 participants including old adults / Alzheimer, MCI, Asperger syndrome	A navigation system that utilises well-known locations and monitors user activities to identify potentially risky situations	Smartphone	- Raises privacy concern - Requires activation of navigation mode, which might be difficult for the cognitive impaired individual

Lera et al., (2014)	Qualitative Study	Old adults / Needing help with medications	A general assistance system and drug dosage management system for the elderly	Robot	- Expensive - Indoor use only
Saracchini et al., (2015)	Qualitative Study	35 participants including 9 old adults / Cognitive impairment	Alert user of potential hazards, such as fire from the stove	- Tablet - DCPAR	- Devices is bulky and uncomfortable to use - Willingness to wear device
Bianco et al., (2016)	Qualitative Study	10 old adults who may need home modification/fall prevention.	Recommends suitable position for the installation of safety bar	Smartphone	- Only recommendation made
Połap et al., (2017)	Qualitative Study	Adults / / Low vision impairment	AR obstacle detection system based on deep learning methods that can helps older people to walk in the city and cross streets.	Smartphone	- Use of smartphone on busy environment could be a distraction.
Kanno et al., (2018)	Qualitative Study	2 old adults / MCI	- Reminds users to take their medications - Helps locate and identify the correct medication - Assists in tracking the location of user	Smartphone	- Raises privacy concern - The need to wear a tracker may make users uncomfortable
Ingeson et al., (2018)	Qualitative Study	15 participants including 11 old adults / Age-related cognitive decline	Medication coach intelligent system that enables users to maintain self-management and medication adherence	HMD	- Unclear how gesture can be used - Could be stigmatising - Bulky and uncomfortable to use
Liang (2018)	Mixed Method	50 participants including old adults / Memory deficits	Provide additional information to user on medication regimens	Smartphone	- User might not remember to scan medication.
Gacem et al., (2019)	Qualitative Study	Old adults / Alzheimer	Monitor if the user has lost their way, displaying directions home on the AR interface while simultaneously sending the user's location to the caregiver	Smart glass Smartphone	- Raises privacy concern - Text output can be unclear under certain lighting conditions - False alert user location - Depending on a smartphone to operate may cause inconvenience
Younis et al., (2019)	Qualitative Study	5 participants/ Low vision impairment	An egocentric indoor and outdoor hazard recognition dataset is created using a wearable camera and classified using DL object detector and Kalman Filter tracker to be used in the hazard detection and classification for people with vision defects	Smart glass	Difficulty detecting small objects.
Liu et al., (2019)	Qualitative Study	5 participants / MCI	POF based navigation system for PMCI based on wandering detection	Smartphone	- Raises privacy concern - False alert user location
Zhao et al., (2019b)	Qualitative Study	12 participants including old adults / Low vision impairment	Facilitate stair navigation by leveraging PLV's residual vision	HMD	- No input modality - Could be stigmatising - Bulky and uncomfortable to use
Blusi and Nieves (2019)	Qualitative Study	15 participants including 8 old adult / Needing help with medications	Helps in organising medications in a pillbox	HMD	- Tested only in lab settings - Device is inconveniencing. - Text only output - Could be stigmatising
Ro et al., (2019)	Descriptive Study	Old adults / Dementia	A projection-based AR system robot that can cover 360 degrees of space of the user environment	PAR	- Requires hardware - Expensive - Less interactive - Can only monitor indoor
Park et al., (2019)	Qualitative Study	Old adults / Age-related cognitive decline, MCI	- 3D space reconstruction of a pervasive PAR space for elderly support - Prevent accidents using DL pose estimation in detecting abnormal conditions, such as falling and tripping	PAR	- Requires hardware - Expensive - Less interactive - Can only monitor indoor - Fall related activities could trigger false alerts (Abbate et al., 2012) - No cue to environmental hazards
Guerrero et al., (2019)	Qualitative Study	5 old adults / Needing help with medications	Helps older adults manage their medications through a smart medicine cabinet	PAR	- Expensive - Limited ecological validity
Rossi et al., (2020)	Qualitative Study	Old adults / Age-related cognitive decline, Cognitive Impairment	Notify users about potentially dangerous situations such as stove flame, by providing cues in real time	HMD	- Did not mention the situation detected. - No input interaction - Could be stigmatising

					- Bulky and uncomfortable to use
Yang et al., (2021)	Qualitative Study	Old adults / Dementia, Needing help with medications	Recognises medication pack and track Medication Management	Smartphone	- Requires user to interact by pressing buttons - Adherence feature only shows medication details.
Mettouris et al., (2021)	Qualitative Study	39 old adults / Age-related cognitive decline	AR app that allows users to control their home environment and detect the presence of smoke or carbon monoxide using smart home service	Smartphone	Usability and user experience was not evaluated
Varghese et al., (2021)	Qualitative Study	Older adults / Dementia	Ensure the safety of the PwD through wandering and fall detection	Smartphone	False alarm when user genuinely enter dangerous zone
Ghorbani et al., (2022)	Quantitative RCT	37 older adults / MCI	Monitors user location and identifies dangerous areas such as near a fireplace in AR serious game simulation environment	Smartphone	- Tested in laboratory setting which might not be realistic - Wearable localisation tag. - False alert in dangerous place
Htike et al., (2023)	Quantitative Study	18 participants including old adults / Low vision impairment	Mobility aid for PLV in avoiding the obstacle	HMD	- Device is bulky and uncomfortable to use - Could be stigmatising - Bulky and uncomfortable to use
Taghian et al., (2023)	Qualitative Study	Old adults / Age-related cognitive aging, Needing help with medications	- Medication reminder - Helps users navigate back home if they get lost	Smart glass Smartphone	- Depends on smartphone - Required user to confirm medication taken
Miura et al., (2023)	Qualitative Study	Old adult / Age-related cognitive aging	Identifies indoor areas in a home where falls are likely to occur, and overlays fall prevention measures. Check for the need of fall prevention measures	Smartphone	- Only text output - No input interaction - Lower detection accuracy in some home settings
Ball et al., (2023)	Quantitative Non-Randomised Studies	170 participants including old adults / Vision Acuity and Colour Vision	Obstacle detection during navigation in pseudo-natural environments	Laptop	Experimented only in lab settings
Franzén (2023)	Qualitative Study	4 older adults / Needing help with medications	Provided an augmented way of accessing and consuming medication information	Smartphone	Does not remind the user when to take medication
Achilleos et al., (2023)	Qualitative Study	22 old adults / Age-related cognitive aging, Needing help with medications	Enables user in medication management, smart home device control and wayfinding	Smartphone	- Text only output - Required user to tick checkbox when medication is taken
Dylan et al., (2023)	Qualitative RCT	20 participants including old adults / Low vision impairment	Displaying multiple kinds of visual cues for obstacles on an optical see-through HMD	HMD	- No input modality shown - Could be stigmatising - Bulky and uncomfortable to use
Ghorbani, et al., (2023)	Qualitative Study	Old adult / MCI	Presents an IoT-based fuzzy decision-making system designed to manage user interactions and environmental factors	Smartphone	- False alarm when user genuinely enters dangerous zone - Interaction with dangerous zone was based on laboratory settings - No primary input modality - The need to wear a localisation tag may make users uncomfortable.
Su et al., (2024)	Qualitative Study	18 participants including old adults / Accessibility and safety issues	Helps identify, localise, and visualise indoor accessibility and safety issues such as throw rug	Smartphone	Misclassification due to several similar indoor objects
Yadav and Kirit (2024)	Qualitative Study	Dataset of old adults / Needing help with medications	Assist patients in tracking their medications and promoting adherence to prescriptions.	Smart glasses	No implementation

Table Acronyms: HMD: Head Mounted Display; DCPAR: Device with Pico Projector for Augmented Reality); PLV: People with Low Vision; POF: Point of Familiarity; IoT: Internet of Things; DL: Deep Learning; 3D: Three Dimensional; PMCI: People with Mild Cognitive Impairment; PAR: Projection Augmented Reality; RCT: Randomised Controlled Trial

3 Results

In this section, the results of the systematic review are reported according to the research questions outlined in Table 1, and the findings are illustrated through multiple visual representations. Figure 1 shows the number of records retrieved from each database and the screening process used to select relevant studies. Initially, 1449 records were retrieved, and after removing duplicates, 306 records remained. Applying the exclusion criteria eliminated 258 records, leaving 48 for further screening using the inclusion criteria. The inclusion criteria then removed 17 records, leaving 31 articles that were used to address he research questions of the systematic review. A variety of study designs were employed in the included studies which includes qualitative studies (n = 26), quantitative RCT (n = 2), non-RCT (n = 1); descriptive studies (n = 1), and mixed methods (n = 1).

3.1 AR-based AT Safety Support for PwD and MCI

As shown in Figures 4, AR-based AT interventions presented in 31 studies were classified into three types of safety support as shown in Figure 2. 46% of the studies applied AR for mobility-related safety support. 39% focused on medication management. Only 15% used AR for home safety and control.

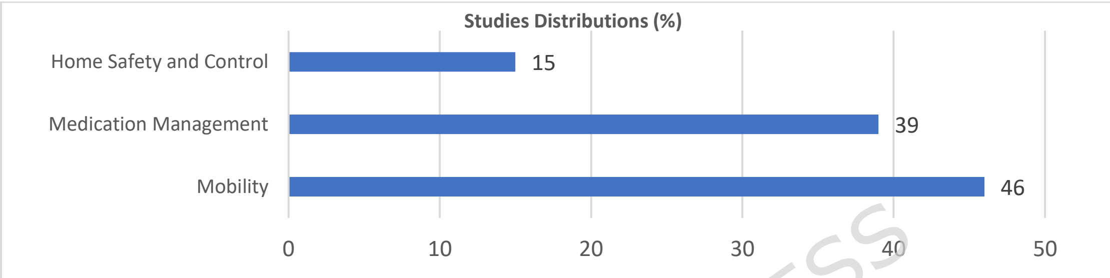


Figure 4. Bar Chart with Percentages Showing Studies Distributions Based on Safety Supports Categories.

The findings indicate that significant attention is directed toward mobility-related support, emphasising the integration of features such as wayfinding assistance, wandering detection, fall prevention, and fall detection to promote user safety and independence. Mobility is vital for PwD and individuals MCI as it enhances autonomy, facilitates social engagement, and helps mitigate the risk of falls and further cognitive decline. Additionally, medication management also emerged as a key area of focus, given that cognitive impairments pose substantial challenges to consistent medication adherence among older adults. PwD and individuals with MCI frequently experience memory lapses and executive function deficits, which hinder their ability to manage complex medication routines effectively. Such non-adherence can lead to adverse health outcomes; however, evidence from the reviewed studies highlights that digital reminders, structured regimens, and organisational aids can significantly improve adherence, reduce medication errors, and enhance overall user safety. Home safety and control received the least attention, despite being crucial for individuals with cognitive impairments due to the increased risk of accidents and threats to independence. Most interventions are implemented as smart home systems rather than AR-based AT.

Figure 5 illustrates the distribution of features across safety supports. Mobility-related safety focuses on wayfinding (11%), wandering detection (6%), fall prevention (22%), and fall detection (6%). Medication management emphasises adherence (28%) and pillbox filling (11%), while home safety and control includes air quality monitoring (7%) and flame detection (9%). Medication adherence and fall prevention are the most prominent features in medication management and mobility-related safety support, respectively.

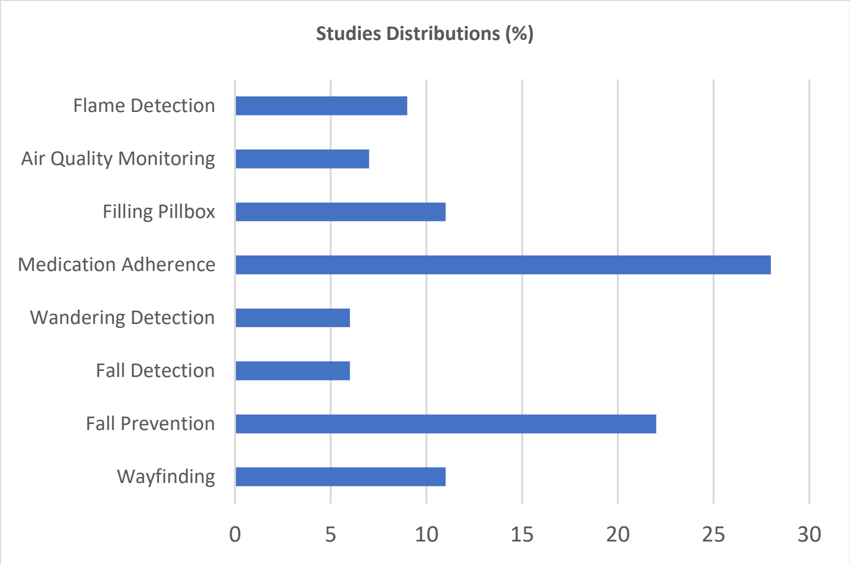


Figure 5. Bar Chart with Percentages Showing Studies Distributions Based on Safety Features.

Furthermore, Figure 6 shows that 77% of the studies interventions targeted specific safety support such as, mobility (Hervas et al., 2014; Bianco et al., 2016; Połap et al., 2017; Liang 2018; Gacem et al., 2019; Liu et al., 2019; Zhao et al., 2019b; Younis et al., 2019; Varghese et al., 2021; Htike et al., 2023; Miura et al., 2023; Ball et al., 2023; Franzén, 2023; Dylan et al., 2023; Su et al., 2024), medication management (Lera et al., 2014; Ingeson et al., 2018; Guerrero et al., 2019; Blusi and Nieves 2019; Yang et al., 2021; Yadav and Kirit 2024) and home safety and control (Saracchini et al., 2015; Rossi et al., 2020; Mettouris et al., 2021). While only 23% targets two or more safety support combined (Kanno et al., 2018; Ro et al., 2019; Park et al., 2019; Ghorbani et al., 2022; Taghian et al., 2023; Achilleos et al., 2023; Ghorbani et al., 2023) to address the safety concerns of cognitive impaired individuals as shown in Table 4.

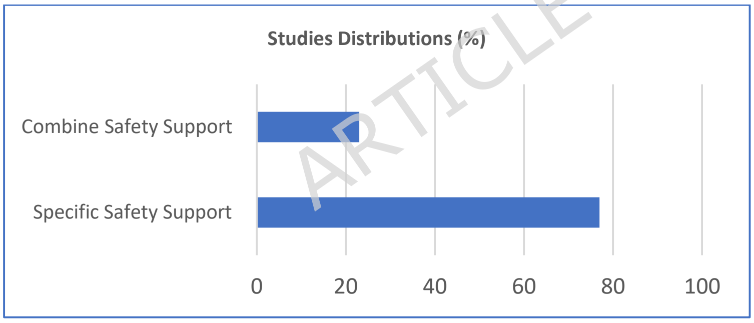
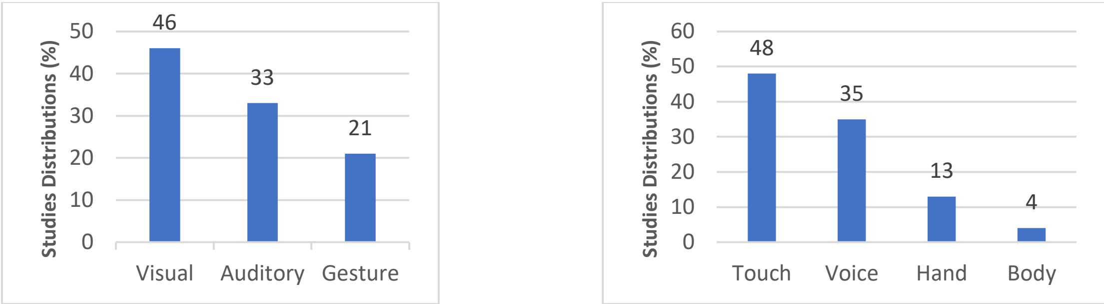


Figure 6. Bar Chart with Percentages Showing Studies Distributions Based on Safety Support Targets.

3.2. AR-Based AT Interaction Modalities for User Engagement

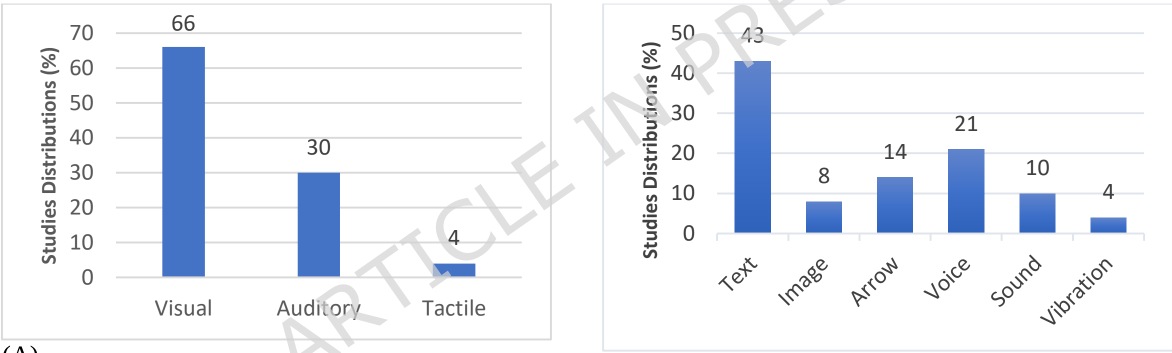
Interaction modalities enable users to interact and receive feedback from a system. While interaction modalities have the potential to boost user engagement with AT, their effectiveness varies depending on the context. This review results in Figure 7A show that input modalities used by AR-based AT for PwD and related MCI are categorised into visual, auditory, and gesture-based, with visual being the most used (46%), followed by auditory (33%), and gesture-based (21%) being the least used. Touch-based input (48%) is the most commonly used visual modality, followed by voice input (35%), while gesture-based inputs like hand (13%) and body (4%) are less utilised as shown in Figure 7B. Despite the popularity of touch input, PwD and older adults often face difficulties with technology and menu navigation (Hervas et al., 2014; Rossi et al., 2020). To address these challenges, Rossi et al., (2020) removed input modalities from their intervention, but this could reduce user engagement. Instead, prioritising usability, intuitive interaction, and ease of learning is essential to enhance engagement and meet users' specific preferences (Hervas et al., 2014).



(A) (B)

Figure 7. Pie Chart with Percentages Showing Studies Distributions Based on Input Modalities. A) Modalities Categories B) Modalities Forms

Conversely, output modalities were categorised into visual (66%), auditory (30%), and tactile (4%) as shown in Figure 8A. Among these, text (43%) is the most frequently used visual output modality, followed by voice (21%), while vibration is the least used (4%) as shown in Figure 8B. Some studies used text-only output (Miura et al., 2023), which may not be sufficient for PwD due to low vision. Older adults often struggle with small text on smartphones (Park et al., 2019), and text may become illegible in certain lighting conditions (Taghian et al., 2023). Voice and sound are gaining prominence in interactive technologies. Old adults prefer voice feedback to avoid constantly watching the screen while walking (Achilleos et al., 2023). Ghorbani's (2023) study suggests that using voice messages for feedback rather than images may reduce battery consumption and improve performance. Although this claim lacks sufficient evidence, it calls for further research into the resource utilisation and performance of different input and output modalities presentation forms.



(A) (B)

Figure 8. Pie Chart with Percentages Showing Studies Distributions Based on Output Modalities. A) Modalities Categories B) Modalities Forms

The review suggests that AR-based interventions employ diverse interaction modalities to promote safety while addressing the needs of individuals with cognitive impairments. However, reliance on dominant modalities such as visual and text in providing feedback may not match individual preferences. Although many studies employed multiple modalities, none integrated all output options. A broader multimodal approach could enhance personalisation, flexibility, and user choice while preventing cognitive overload.

3.3 Situation Awareness Provided by AR-based AT

Understanding how old adults perceive and interact with their surroundings can help create solutions that enhance safety, reduce confusion, and promote independence. This could involve investigating how AR can provide contextual cues, alert users to hazards, or guide them in navigating both familiar and unfamiliar environments. The studies reviewed provide clear evidence that AR-based AT significantly enhances the safety and independence of individuals with PwD and MCI by mitigating risks in both indoor and outdoor environments. Table 4 outlines the types of situational awareness AR-based AT are capable of providing the users and the potential risks these systems can help mitigate. However, the lack of detailed information about the physical environment of the target population presents a major challenge in designing effective solutions (Miura et al 2023). This review suggests the need for further research to explore the types of hazards and situation awareness that AR-based AT can provide for PwD and MCI. While some studies (e.g., Mettouris et al., 2021; Taghian et al.,

2023) offer multiple contextual cues or hazard detection, there is a need for broader situation awareness to develop robust AT for the dementia continuum. Developing applications that provide risk prevention feedback based on assessments of the user's physical characteristics and living environment could improve user autonomy and independence.

4 Discussion

This section discusses the review findings in relation to existing literature, highlight ethical concerns associated with AR-based AT for PwD and MCI, and outlines the strengths and limitations of the review.

4.1 AR-based AT Intervention for PwD and MCI

AR-based AT interventions for PwD and MCI are designed to enhance daily functioning, improve safety, and foster independence by delivering real-time, context-aware cues and guidance that mitigate challenges associated with memory loss, attentional deficits, and executive dysfunction. The review categorises safety-focused interventions into three areas: mobility, medication management, and home safety and control.

The results reveal that mobility support is the most commonly implemented safety-related feature, with fall prevention being the most frequently utilised mobility-related function. This is likely due to the significantly higher fall risk among PwD, who are twice as likely to experience falls compared to cognitively healthy older adults (Shaw, 2007; Panel on Prevention of Falls in Older Persons, 2011). Safety-related accidents occur most often at home and old adults living alone experience considerable anxiety associated with falling accidents (Kim 2015). Fall risk factors is associated with ageing, dementia, depression, dizziness, and low visual and balance issues etc. (Al-Aama, 2011; Gazibara et al., 2014; Htike et al., 2023). The risk of falls increases due to a complex combination of physical and environmental factors (Tinetti, 2003; Ambrose et al., 2013). This makes it crucial to assess both the physical characteristics of individuals and the environments they interact with. While safety features like handrails are commonly installed for older adults, understanding the specific needs and criteria for such installations, especially for those with cognitive impairments, is essential (Miura et al., 2023). AR-based AT shows strong potential for enhancing safety for individuals with cognitive impairments. It can superimpose fall prevention measures within real environments (Miura et al., 2023), provide virtual guidance to help users avoid dangers when disoriented (Yordanova et al., 2017), and improve orientation skills to support navigation and mobility (Htike et al., 2023).

Most studies reviewed for wayfinding and wandering detection involve tracking and sharing the user's location with caregivers or family members. A common method employed in identifying wandering behaviour is establishing a safety zone and detecting when the individual leaves this boundary (Ko et al., 2014; Liu et al., 2019). However, this approach may often trigger false alerts, as the individual may genuinely leave the zone while cognitively stable (Ko et al., 2014; Gacem et al., 2019; Liu et al., 2019). Wandering behaviours are complex and varied (Hammoud et al., 2018), making it crucial to model mobility patterns in a more adaptive manner (Yordanova et al., 2017). The system must be able to learn and detect states of disorientation (Yordanova et al., 2017; Taghian et al., 2023). Monitoring vulnerable people's movement and location can give essential information regarding safety (Yusif et al., 2020; Valeriu and Florentina-Magda, 2022) as this reassures caregivers and family members about the safety and security of the individual; however, this presents privacy concerns. Most wayfinding and wandering detection features reviewed have this limitation. These findings are consistent with the studies of Wangmo et al., 2019; Bhargava and Baths, 2022; Ong et al., 2023 as concerns commonly cited when it comes to AT. Hence, future AR-based safety interventions must be designed with a focus on addressing these privacy concerns. Fall detection is one of the least commonly implemented mobility support safety features. Although this approach is capable of alerting caregivers or family members by sending the user's location in case of a fall (Park et al., 2019; Ro et al., 2019; Varghese et al., 2021), it is a reactive safety measure rather than preventive. This means a fall would have already occurred, potentially leading to greater risk before assistance can be provided. Additionally, fall detection systems are prone to false alerts triggered by fall-like activities (e.g., sitting, lying down, walking, or running), as these actions can produce acceleration patterns similar to a fall. To address this, Abbate et al. (2012) used machine learning techniques to better differentiate real falls from similar events.

Interaction modalities for AR-based assistive technologies must be designed to accommodate and compensate for the cognitive impairments of the target users, ensuring usability, intuitiveness, and reduced cognitive load. Hayhurst, (2018), noted that as PwD conditions deteriorate, their capacity to engage with certain AT may also decline. An approach that offers users with alternatives that require no previous knowledge nor training to use is therefore encourage when designing AT for old adult (Avilés-López, et al., 2010). Hence, the need for the implementation of more natural mode of interaction with the system as much as possible. Avilés-López, et al., (2010) affirmed that voice commands are a very natural way of interaction as user effort is minimised. Kanno et al., (2018) posit that older people are more likely to interact with voice commands than other forms of interactions. Li (2024) noted a strong preference for auditory interactions compared to traditional touchscreen interfaces, highlighting that user perceive audio cues as more intuitive and engaging, a finding previously mentioned in Yang et al., (2022). Speech and gesture interactions can enable more natural user engagement, but they may appear awkward to observers, as users might seem to be talking or gesturing to no one (Lazaro et al., 2022). Gesture based input enables users to interact without wearing devices (Chen et al., 2020); however, these systems are only operational in specific indoor locations.

Furthermore, many studies fail to report the input modalities of proposed interventions, leaving uncertainty about how users interact with these systems. To enhance user engagement in AR-based AT, attention must be given to interaction modalities, prioritising intuitive design. Despite the benefits of AT, low adherence to digital prompts remains a major barrier to the effectiveness of technology interventions (Leslie et al., 2005; Glasgow, 2007; Trompetter et al. 2015). Kassinopoulos et al., (2023) attributed the reason for low adherence to AT interventions to a lack of user engagement and interaction with the systems. In this context, adherence is the extent to which users of a technological intervention follow or engage with the recommendations provided by the intervention. Accumulating evidence supports that almost twice as many users drop out from technological interventions compared to traditional face-to-face interventions, possibly as a result of feeling less engaged with the interventions (MacEa et al., 2010). A system lacks user engagement when it does not provide sufficient opportunities for users to actively participate, provide input, or engage in meaningful interactions.

Some studies combined input modalities to achieve better interaction and feedback (Ingeson et al., 2018; Gacem et al., 2019; Ro et al., 2019; Park et al., 2019; Blusi and Nieves, 2019; Htike et al., 2023). Lazaro et al., 2022 affirmed that combining modalities could lead to better user interaction and engagement. This review concludes that employing a combination of interaction modalities, customised to user preferences, can improve user engagement with the system. Such engagement may be further enhanced by adopting more natural forms of input and output interactions. The findings indicate that voice commands are particularly well-suited for this approach and can be effectively implemented in applications designed for both indoor and outdoor use.

Majority of the review interventions targeted specific safety support like fall mobility, medication management, and home safety and control etc. while only few targets two or more safety support combined to address the safety concerns of cognitive impaired individuals. This finding is consistent with Guthrie et al. (2018) studies which noted that addressing safety concerns for PwD and MCI may require multiple technologies, which will increase both cost and complexity.

4.2 Preferred Intervention Devices for AR-based AT for PwD and MCI

The suitability of AR intervention devices varies depending on the goal of the intervention (such as communication, safety, or social support) and the characteristics of the target users (for example, older adults or individuals with cognitive impairments). Notably, the reviewed studies show that AR is more commonly deployed on smartphones (55%) than on HMDs (19%) or smart glasses (13%) in safety related support. However, prolonged use of smartphone AR applications can lead to fatigue and discomfort caused by sustained visual attention, postural strain, and cognitive load especially in older adults (Liang, 2018; Farshid et al., 2018; Park et al., 2019; Gacem et al., 2019; Ko et al., 2021; López et al., 2024). While most study has focused on a single device type, direct comparisons between smartphones and HMD/smart glasses preference in this target population are not available. Wearable AR headsets are still an emerging technology particularly in the context of enhancing safety for older adults and individuals with cognitive impairment. Current HMDs and smart glasses are often perceived as bulky, heavy, expensive, and ergonomically uncomfortable, which can limit prolonged use and overall acceptability among older adults (Juan et al., 2018; Liang, 2018; Lee et al., 2019; Dickinson et al., 2023; Mikhailova et al., 2024). Consequently, smartphone remains more widely adopted due to its familiarity, ease of use (Liang, 2018), fairly inexpensive and commercially available (Lancioni et al., 2019), and non-stigmatising alternatives to traditional AT devices (Wilson et al., 2022).

This review posits that spatial aspect of mobility-related safety support cannot be adequately represented through conventional smartphone interfaces. Although smartphones can provide reminders, alerts, and location data (Achilleos et al., 2023; Taghian et al., 2023; Yadav & Kirit, 2024; Liu et al., 2019; Gacem et al., 2019; Varghese et al., 2021), they are limited in offering intuitive, embodied, and context-aware spatial support for real-world mobility tasks such as fall prevention especially for users with cognitive impairments. They can be distracting and unsafe, as they lack hands-free, gaze-aligned guidance needed for safe walking.

Nonetheless, some studies have reported good acceptance rates for smart glasses among older users (Gacem et al., 2019; Hellec et al., 2023). Smart glasses provide hands-free and more immersive experiences compared to smartphones. These advantages position smart glasses as a promising option in the future. The emergence of lightweight and more affordable AR smart glasses, such as the Vuzix Blade (Vuzix, 2024), increases the feasibility and accessibility of AR-based AT. Further miniaturisation into traditional eyeglass designs may enhance user acceptance, especially among older adults accustomed to wearing spectacles.

Finally, this review focuses on AR-based AT, despite the use of other technologies, such as sensors (Weizman et al., 2021; Tiersen et al., 2021), robotics (Lera et al., 2014; Ro et al., 2019), and Virtual Reality (VR) (Afifi et al., 2021; Flynn et al., 2022) in developing AT for older adults and individuals with cognitive impairment. AR is preferred in this context because of its unique capacity to enhance real-world experiences and its adaptability across diverse platforms and devices (Zhao et al., 2019a; Achilleos et al., 2023; Li, 2024; Oun et al., 2024). AR-based AT deliver real-time, context-aware safety cues that support users in making safer decisions within their environments. In contrast to the conventional visual interfaces offered by other technologies, AR enables more intuitive, engaging, and immersive forms of interaction (Połap et al., 2017; Li, 2024). It helps uncover the hidden aspects of reality within our actual environment. Through the overlay of contextual information, data visualisations, or virtual objects onto real-world environments, AR enhances human perception and understanding beyond what is immediately visible.

While there is promising evidence that old adults with age-related cognitive decline, PwD and those with MCI accepting the use AR-based AT (Saracchini et al., 2015; Bianco et al., 2016; Kanno et al., 2018; Ingeson et al., 2018; Blusi and Nieves, 2019), the technology acceptance levels were not consistently measured or reported across the included studies. However, studies including Su et al., (2024), Guerrero et al., (2019), Achilleos et al., (2023) showed that participants provided high rating for indicators such as usefulness, ease of use, performance and interactivity. This points towards a generally positive attitude and willingness among older adults and individuals with cognitive impairments to adopt AR-based AT, provided that these systems are properly design to their needs.

4.3 Ethical Concerns

Ethical considerations appear to be a major concern in the design of AR-based AT for old adult and individual with cognitive impairment, as the majority of reviewed studies overlook one or more ethical issues. This concern has been widely acknowledged in both academic literature and clinical practice hence, emphasising the importance of a human-centered approach in the development and application of these technologies (Wolff et al., 2021). Proactively identifying and addressing ethical concerns early could have averted certain problems and encouraged wider acceptance of the technology. Key ethical considerations in AR based AT include privacy and confidentiality (Bennett et al. 2017; Sombilon et al. 2024), independence and autonomy (Bennett et al. 2017), informed consent (Sombilon et al. 2024), and other related concerns.

Privacy and confidentiality are important considerations, as it often involves handling personal data (Sombilon et al., 2024). This consideration extends to both users and nonusers (Denning et al. 2014; Jerome and Greenberg 2021). People value privacy and generally oppose the recording of conversations, reuse of collected data, and the use of facial recognition or intrusive analytics. However, assistive systems often rely on cameras and sensors to monitor user behaviour and environments, which raises significant privacy and security concerns. Users are concerned about their data being collected and shared without consent, while bystanders worried about privacy breaches, unwanted surveillance, and disturbances to social environments (Safavi and Shukur 2014). Although some of these technologies are designed to enhance safety and well-being through monitoring and surveillance, they can also infringe on privacy and restrict freedom of movement (Bennett et al., 2017). However, limited data collection and implementation of clear regulations on data access and storage are recommended (Wangmo et al., 2019). Data must be protected through secure storage and anonymised whenever possible (Sombilon et al., 2024). Default mode of AR based AT should include protection of the privacy of nonusers, including public collection.

Although AR based AT are promising, they must be designed to uphold the rights of users, particularly those who are vulnerable. Excessive automation may also reduce autonomy for PwD, potentially accelerating cognitive decline and fostering dependence (Köhler et al., 2024). Since autonomy involves maintaining control over one's own thoughts, goals, and decisions, it is essential that users retain the ability to decline assistance, ensuring that autonomy is prioritised over safety when appropriate (Köhler et al., 2024).

The lack of co-design with PwD and their caregivers or family members has also been recognised as an ethical issue in AT design. Björling et al. (2021) noted that excluding PwD from co-design processes compromises ethical principles of autonomy and inclusion. Although PwD often require care, they seek to maintain their independence and autonomy (Köhler et al., 2024). Consequently, involving users in the design of AT is not only methodologically advantageous but also ethically imperative to ensure fairness and inclusion (Span et al., 2013; Ienca et al., 2018). Excluding target users, regardless of cognitive status from the design process represents a clear ethical shortcoming. Ethical design should prioritise transparency, user control, and privacy-by-design to safeguard dignity and safety. Moreover, meaningful stakeholder involvement throughout development is essential, as co-design aligns technologies with real user needs, enhances usability, acceptance, and equity, and prevents paternalistic outcomes.

4.4 Promising and Less-Explored Directions in AR-Based Safety Interventions for PwD and MCI

The findings indicate that AR interventions for the safety of PwD and individuals with MCI exhibit varying levels of maturity and practical promise across different approaches. This variability provides an opportunity to identify which approaches appear most promising in enhancing safety target population and which areas remain underexplored or less effective. In particular, mobility-related interventions emerge as the most promising, as they align closely with AR's core strengths in providing spatially aligned, real-time guidance. Empirical evidence suggests that AR overlays can improve navigation, spatial orientation, and hazard avoidance in older adults, supporting independence and autonomy (Miura et al., 2023; Htike et al., 2023).

Medication management represents a moderately promising area. Cognitive impairments often disrupt adherence to complex medication regimens, which can lead to adverse health outcomes such as overdosing, underdosing, or drug interactions (Taghian et al., 2023; Yadav & Kirit, 2024). AR-based interventions in this category primarily provide reminder systems or visual and auditory guidance. While these functions can improve adherence, the majority rely on basic prompts rather than interactive, context-aware support, which limits AR's unique potential unless more immersive or personalised features are incorporated (Guerrero et al., 2019; Blusi & Nieves, 2019).

Home safety and control remains the least explored but holds high potential. This category involves AR applications integrated with smart home devices to monitor environmental hazards such as flame detection or air quality, and to provide context-aware feedback for safer decision-making. Although the evidence is limited and mostly confined to prototype or laboratory settings (Mettouris et al., 2021; Ghorbani et al., 2023), AR's ability to visualise invisible hazards and provide real-time guidance could substantially enhance independent living for PwD and MCI.

4.5 Strengths and limitations

This review is the first to assess AR-based AT aimed at enhancing the safety of PwD and MCI. It included a quality assessment of 31 articles, analysing different safety support, interaction modalities, and situation awareness provided by current interventions. Additionally, the study identified gaps in existing AR-based AT safety interventions, offering valuable insights for future research.

Despite following best practices for scoping reviews, the results may be affected by selection bias due to the inclusion and exclusion criteria. Additionally, some relevant sources may have been missed, even though multiple databases were used. This limitation was partially mitigated by manually checking reference lists and conducting forward searches, but some significant studies could still have been overlooked.

Furthermore, the evidence in the review may not fully capture the broader potential of AR-based AT for PwD and MCI, as most studies are qualitative and lack consistent measurement or reporting of technology acceptance levels by the target users.

5 Future Direction and Conclusion

This section highlights future directions for AR-based AT in meeting the safety needs of PwD and MCI, and presents the review's conclusions.

5.1 Future Direction

In this review, we focus on exploring approaches that leverage AR techniques in developing interventions for the safety of PwD and MCI. The findings show that AR-based AT for the safety of individual with cognitive impairments is still limited. Therefore, more research is needed to address unmet safety needs in the target population, such as preventing domestic hazards and monitoring, and reporting dangerous situations. Most AR-based AT currently use smartphones, which can cause fatigue with prolonged use. Wearable AR smart glasses remain emerging, often limited by discomfort and ergonomic issues, but the development of lightweight devices like the Vuzix Blade offers significant potential for expanding AR-based interventions for older adults. This aligns with Gacem et al., (2019) who found that old adults preferred smart glasses with AR. Thus, smart glasses that integrate key features found in smartphones are likely to become the preferred devices for AR-based AT in the future. While most studies have concentrated on mobility and medication management safety, there is limited research on home safety and control. Therefore, more research is needed in the area of home safety and control, as individual with cognitive impairments needs constant reminders to complete critical tasks to avoid domestic hazards. Most studies' interventions focus on specific safety concerns. This indicates that multiple technologies are required to address the unmet safety needs of PwD and MCI, potentially leading to increased purchase costs. Hence, this study suggests that future AR-based safety interventions should adopt a holistic design approach, like the framework proposed in Figure 2, which is aimed at consolidating multiple safety features into a single tool to address the safety needs of the target population. While existing studies have provided valuable insights into user experiences and the perceived benefits of AR-based AT, majority of the current evidence is derived from qualitative research. These studies have been instrumental in exploring feasibility, usability, and user acceptance; however, they offer limited generalisability and empirical validation of outcomes. Future research should therefore adopt RCT designs to strengthen the evidence base and assess the effectiveness of AR interventions more rigorously. Employing RCT would allow for systematic evaluation of causal relationships and provide stronger evidence to guide the development and implementation of AR-based assistive solutions for older adults and individuals with cognitive impairment.

5.2 Conclusion

This study conducted a systematic literature review to explore the current state of AR-based AT designed to enhance the safety of PwD and MCI. It focused on the types of safety support provided by these interventions, the interaction modalities used to engage users, and the situation awareness offered to ensure user safety. Despite an extensive search, only 31 articles met the strict eligibility criteria for inclusion, indicating limited research on the use of AR-based AT for the safety of PwD and MCI. Results showed that AR-based AT interventions for cognitive impairments can be classified into three categories: mobility, medication management, and home safety and control. Interventions primarily focus on mobility and medication management, while home safety and control remain underexplored. In addition, further research is needed to identify other possible safety supports and situational awareness for comprehensive AR-based AT in dementia care. The interaction modalities that facilitate unobtrusive user engagement are also critical, especially when considering the cognitive abilities of the user and their environment. Furthermore, the studies highlight the significant potential of AR-based AT in addressing safety concerns for PwD and MCI, helping individuals maintain independence longer before needing assisted living. However, most existing studies are still at early stages such as pilot, prototype, or feasibility trials with small sample sizes evaluation. A substantial research gap remains, as rigorously designed RCT assessing AR interventions for the safety of PwD and MCI populations are limited or unpublished.

Conflict of Interest

The authors declare no conflict of interest.

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Consent Statement

This study did not involve human participants, and informed consent was therefore not required.

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Appendix I

References	Qualitative					Quantitative RCT					Quantitative Non-RCT					Quantitative Descriptive					Mixed Methods				
	1.1	1.2	1.3	1.4	1.5	2.1	2.2	2.3	2.4	2.5	3.1	3.2	3.3	3.4	3.5	4.1	4.2	4.3	4.4	4.5	5.1	5.2	5.3	5.4	5.5
Hervas et al. (2014)	Y	Y	Y	Y	CT																				
Lera et al. (2014)	Y	Y	Y	Y	CT																				
Saracchini et al. (2015)	Y	Y	Y	Y	Y																				
Bianco et al. (2016)	Y	Y	Y	Y	Y																				
Połap et al., (2017)	Y	Y	Y	Y	Y																				
Kanno et al. (2018)	Y	Y	Y	CT	CT																				
Ingeson et al., (2018)	Y	Y	Y	Y	CT																				
Liang (2018)	Y	Y	Y	Y	Y											Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Gacem et al. (2019)	Y	Y	Y	Y	CT																				
Younis et al. (2019)	Y	Y	Y	Y	Y																				
Liu et al. (2019)	Y	Y	Y	Y	Y																				
Zhao et al. (2019b)	Y	Y	Y	Y	Y																				
Blusi and Nieves (2019)	Y	Y	Y	Y	Y																				
Ro et al. (2019)	CT	CT	CT	CT	CT																				
Park et al. (2019)	Y	Y	Y	Y	Y																				
Guerrero et al. (2019)	Y	Y	Y	Y	Y																				
Rossi et al. (2020)	CT	CT	Y	Y	CT																				
Yang et al. (2021)	Y	Y	Y	Y	CT																				
Mettouris et al. (2021)	Y	Y	Y	Y	Y																				
Varghese et al. (2021)	Y	Y	Y	CT	CT																				
Ghorbani et al. (2022)						Y	Y	Y	Y	Y															

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Htike et al. (2023)																Y	Y	Y	Y	Y					
Taghian et al. (2023)	Y	Y	Y	Y	Y																				
Miura et al. (2023)	Y	Y	Y	Y	CT																				
Ball et al. (2023)											Y	Y	Y	Y	Y										
Franzén (2023)	Y	Y	Y	Y	Y																				
Achilleos et al. (2023)	Y	Y	Y	Y	Y																				
Dylan et al. (2023)						Y	Y	Y	Y	Y															
Ghorbani, et al. (2023)	Y	Y	Y	Y	Y																				
Su et al. (2024)	Y	Y	Y	Y	Y																				
Yadav and Kirit (2024)	CT	CT	CT	Y	CT																				

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