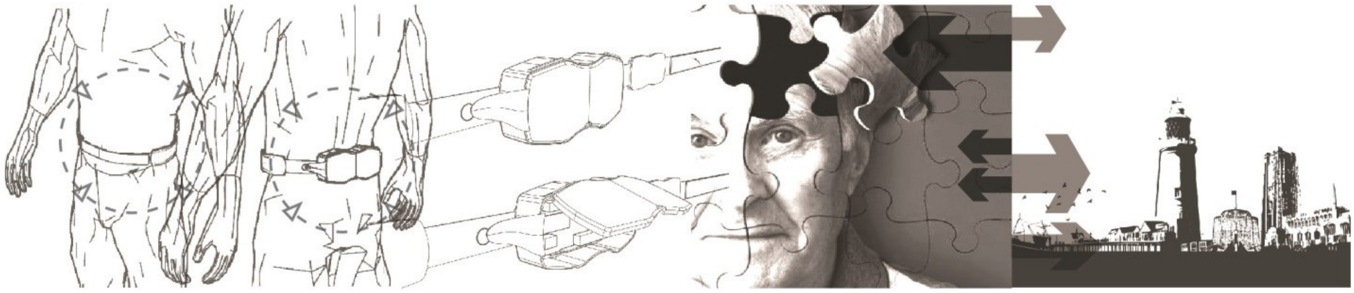
ASSISTIVE [WAYFINDING] DESIGN AND TECHNOLOGY

Development of a Wearable Haptic-Feedback Navigational Assistance for Elderly with Dementia



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To my beloved parents, Che Me Bin Awang Cha and Che Sam Binti Omar

My beloved brothers and sisters

All my family members

My loving friends

Thanks for your patience, encouragement and loving support.

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ABSTRACT

In today's new media age, there are constant discoveries in the field of design and technology. While this is indeed an expedient progress, rarely is the attention given on the debilitated multitude. Anyone is likely to undergo functional limitations at some time in our life, due to biological and non-biological causes. Discounting the mortality factor, the most common ban is ageing. Aside from physical and sensory changes, age is typically affiliated with the decline of cognitive function. This increases the inclination for elderly to suffer from Alzheimer disease or dementia.

Demographic trends on the constant grow of ageing population and dementia cases is a worrying depiction , as the disease induces destructive implications to both patients' life and everybody around them. One of the most obvious deficits that we highlight in this study is on their wayfinding/navigation problem. The decline in spatial navigation skill is interrelated with the mobility, autonomy, caregiving burden and eventually institutionalization.

In providing better or optional acquisitions, designers should contemplate the inadequacies of a specific design, so that the decisions for preponderance do not disregard individual's abilities and disabilities, as the non-inclusive designs worsen their limitations. Hence, from the viewpoint of design and technology, the study aims to understand the decline of wayfinding ability in elderly with dementia in order to find the possible ways to assist or improve it. The theoretical construct was fortified with series of literature reviews on: (1) the stressed issues on mobility-related disabilities and (2) related works on wayfinding strategies, assistive and wearable technologies.

Discoveries from the theoretical requirements initiated the design project as an intervention to alleviate the difficulties of elderly with dementia during the outdoor wayfinding, grounded on User-Centered Design and Inclusive Design philosophies. Unlike common approach of using visual and audio interactions as conventional navigation systems the proposed innovative elements in the concept are: (1) the integration of haptic signals, and (2) the wearability aspect.

The design project went through three main phases of developments with each phase featuring its individual strategy of assessments: (1) a survey aimed to investigate the perception and acceptance of dementia experts and caregivers towards the proposed design concept, (2) a usability test with target users (subjects in diverse dementia severity) aimed to evaluate the utility of the first developed device prototype, and (3) second usability test with the target users from different groups, focusing on the wearability aspect of the prototype's refined version. Collective results demonstrate that the straightforward–yet-intuitive plus wearable features of the device are appreciated, and in some way augment the sensing of haptic signals. This suggests that haptic stimulus can be a useful form of navigational signal. However, user familiarization is highly essential and influences the success of the intervention.

Improving the wayfinding ability is about prolonging mobility, preserving the performance of daily activities, and ultimately leading a good quality of life which is an important survival factor for the patients. In a broader view, the study caters to the critical issues by means of developing the design project that is utilized as a platform to validate the hypotheses and research questions emerging from the intensive analyses of previous works. Despite the disclosures of promising findings from the theoretical constructs until the series of evaluations, comprehensive analysis of market research and planning are also essential before this intervention could be commercially implemented.

The study encourages further interdisciplinary researches that merge the investigations on related topics such as disability, health and aging, while from the design and technological perspective, design for disability, assistive technology and wearable technology themes are looked up so that the beneficial outcomes of interventions are extendable to wider and diverse applications.

Keywords: Assistive Technology; Design for Disability; Cognitive Impairment; Older Adults; Navigation/Wayfinding; Wearable Technology

SOMMARIO

Ai nostri giorni, emergono continue scoperte nel campo del design e della tecnologia. Mentre ciò rappresenta un grande progresso per la maggioranza della popolazione, raramente l'attenzione è focalizzata verso le persone con disabilità. Chiunque, durante la propria vita, può incorrere in limitazioni funzionali sia per cause biologiche che non biologiche. Analizzando i fattori di mortalità, il più comune è l'invecchiamento. Oltre a cambiamenti fisici e sensoriali, l'avanzare dell'età è in genere associato al declino della funzione cognitiva. Questo aumenta la possibilità per gli anziani di sviluppare il morbo di Alzheimer o più in generale varie tipologie di demenza.

Il costante invecchiamento della popolazione e l'aumento dei casi di demenza delineano un quadro preoccupante, in quanto la malattia comporta implicazioni distruttive per la vita del paziente e di tutti coloro che lo circondano. Uno dei deficit più evidenti che il ricercatore ha evidenziato in questo studio sono le difficoltà che si incontrano nella navigazione (o wayfinding). La diminuzione delle capacità di orientarsi nello spazio sono direttamente correlate con la mobilità, l'autonomia, la necessità di cure da parte dei caregiver e, infine, l'istituzionalizzazione degli anziani.

Nel proporre strumenti o soluzioni migliori e alternative, i progettisti dovrebbero tenere conto delle abilità e delle disabilità dei singoli individui, per evitare di proporre soluzioni non inclusive che ne limitano l'efficacia. Quindi, dal punto di vista del design e della tecnologia, lo studio mira a comprendere il declino della capacità di orientamento negli anziani con demenza al fine di trovare i possibili modi per assisterli o migliorarne queste capacità compromesse. Il framework teorico è supportato da un'attenta analisi della letteratura su: (1) le problematiche legate a compromissioni della mobilità dovute a deficit cognitivi (2) studi sulle strategie di supporto all'orientamento e nel campo delle wearable technologies.

Il quadro delineato nei requisiti teorici della ricerca ha fatto si che il progetto di design sia iniziato come un intervento per alleviare le difficoltà degli anziani con demenza ad orientarsi nel contest urbano, basato su un approccio User-Centered e Inclusivo. A differenza degli interventi già realizzati che utilizzano interazioni visive e uditive come sistemi di navigazione convenzionali, gli elementi innovativi proposti nel progetto sono: (1) l'integrazione dei segnali tattili, e (2) l'aspetto della vestibilità.

Lo sviluppo del progetto ha attraversato tre fasi principali di sviluppo, ognuna con una specifica strategia di valutazione: (1) un sondaggio proposto a operatori sanitari e geriatri volto a indagare la percezione e l'accettazione del design proposto, (2) un test di usabilità con dei potenziali pazienti (soggetti con diverso grado di demenza) volti a valutare l'utilità del primo prototipo del dispositivo sviluppato, e (3) secondo test di usabilità con i pazienti, con particolare attenzione verso l'aspetto della vestibilità ed effettuato tramite una seconda versione del prototipo. I risultati ottenuti dimostrano che il funzionamento semplice e al

tempo stesso intuitivo, associato all'indossabilità del dispositivo, sono stati apprezzati. Nello specifico, questa peculiarità ha in qualche modo aumentato la percezione dei segnali tattili. Ciò suggerisce che lo stimolo tattile può essere considerate un segnale utile al fine di supportare le capacità di navigazione nelle persone con demenza. Tuttavia, la familiarizzazione dell'utente con il dispositivo ne influenza l'efficacia.

Migliorare le capacità di orientamento può prolungare la mobilità, preservando lo svolgimento delle attività quotidiane, e in ultima analisi, aumentare la qualità della vita, che è un importante fattore di sopravvivenza per i pazienti. In una visione più ampia, lo studio affronta le criticità mediante lo sviluppo di un progetto di design che è stato utilizzato come uno strumento attraverso cui convalidare le ipotesi e le domande della ricerca che sono emerse a seguito dell'analisi di studi precedenti. Nonostante i risultati promettenti provenienti dall'analisi teorica e dai successivi test di valutazione, un'analisi completa delle inerenti ricerche di mercato risulta essenziale affinché questo strumento possa essere commercializzato.

Lo studio incoraggia ulteriori ricerche interdisciplinari che indaghino argomenti correlati quali la disabilità, la salute e l'invecchiamento, mentre dal punto di vista del design e delle tecnologie, il design per le disabilità, le " assistive technologies" e le "wearable technologies" in modo che i risultati possano essere estesi ad applicazioni più ampie e diversificate.

Parola chiave: Tecnologia Assistiva; Design per Disabilità; Decadimento Cognitivo; Adulti più Vecchi; Navigazione; Tecnologia Indossabile

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CHAPTER ONE

1 Introduction

1.1 General Introduction

It is without doubt that one of the most fundamental requirements in designing and developing new product, system or services is to place users as the centre of attention. In fact, this is what User-Centered Design (UCD) is defined as design processes in which end-users influence how a design takes shape [1]. By bearing in mind the users' demands, needs and problems, the tasks for designers to assure products' practicality, functionality, aesthetic and even preference towards the users are certainly achievable. For example, by understanding the limits of physically disabled people, the designed products should be able to be used by these users with minimum physical effort.

Over the past two decades, there are significant changes for both negative and positive impacts: in politics, social, economic and legal spheres that open the vast opportunities for design and technological interventions to serve the community. This is indicated by the increase in awareness and knowledge on the importance of human-computer interaction, information and communication technologies, internet-of-things and other technology-related platforms such as the media to bridge the issues between the community levels and the possible solutions. Utilizing technology in the appropriate manner could certainly be very beneficial to every level of ages in these diverse communities.

However, as users are often considered as the main consumers, users with special needs and unique incapability as well as the senior citizens have always been neglected in view of the design of commonly used or everyday products. Then again, the pressing need to design with respect to older and physically disabled people should be further encouraged and addressed. This is principally due to the fact that the population is continuously ageing.

Ageing population is not uncommon; it exists in almost all the countries in the world. According to the report by the United Nations on World Population Ageing 2013 [2], the segment of older people aged 60 years or over has globally increased from 9.2 % in 1990 to 11.7 % in 2013. This rate will continue to grow as a proportion of the world population, reaching 21.1 % by 2050. Ageing which is caused by decreasing mortality and declining fertility [3] as well as with the improved medical care contributes to significant increases in the number of disabled people [4].

In parallel, older adults are typically experiencing the age-related changes such as slower cognitive functions as well as the decline of sensory acuity and physiological capacities. What makes it worse is that this deterioration of basic needs increases as they grow older [5]. The increasing number of people with disabilities influences the perspective of a growing body of research on technological solutions or assistive technology for these specific needs. In addition, it may lead to a significant impact on the design and development of assistive technology systems, while at the same time demonstrates the potential and niche markets for products designed for older and disabled people.

It is therefore apparent that the decisions for the design mainstream and production of everyday products, systems or services should appropriately meet the necessities and not neglecting the disabilities shown by this group of population. One of the reliable strategies is to understand what kind of difficulties that limit the performance of their everyday task, or Activities of Daily Life (ADL). The highlight should be given on the difficulties related to mobility of older people and the intersected issues in performing the ADL, in particular the wayfinding.

The key question raised in this research is on the possible ways to improve or at least maintain the wayfinding ability (or capability to navigate) of older adults mainly with dementia due to Alzheimer's disease (AD) from the design and technological perspective. Wayfinding disabilities lead to many negative implications on these individuals, their informal caregivers and society in general. The mentioned problem is further discussed in the next chapter. Thus, as to answer the key question, the research in general aims to understand the decline of wayfinding ability of this segment of population in order to find possible ways of assisting them.

Existing and common wayfinding or navigation systems mostly use visual and/or sound modalities as interface. Based on the consideration of previous works and the emergence of needs for alternative wayfinding strategies envisioned for the specific target users, a design concept of assistive navigation device that integrates the haptic modality is proposed. At the time of this thesis writing, there is a growing number of researches on the use of haptic/tactile stimulus as a cue for wayfinding. This shows the potential of this alternative and uncommonly used sensory device for navigational purpose. More importantly, many of the existing studies focus on mainly people with visual impairment.

In its initial stage, the proposed design project is preliminary to assess and comprehend the perception of dementia experts and caregivers. The feedbacks of primary assessment are taken into accounts for improvement purposes. After that, the working principle of the device is designed and developed as a working prototype. This prototype is used as an apparatus to be tested on actual users. The Usability Testing (UT) demonstrates positive results mainly on the acceptance of the intervention and promising possibilities for the working principle of the device to work on target users.

Nevertheless, introducing a new form of intervention is not an easy and straightforward task; it should be followed by continuous practices, constant uses, and proper training to get the users familiarized with the device system. Then again, the effect of learning process by the people with dementia is indicated after several sessions with the device. This shows the potential for this intervention to be further explored and commercialized. In the next section, brief description on the contents of each chapter in this thesis is presented.

1.1.1 Structure of the thesis

This thesis is structured as follows:

Chapter One introduces the research in general in terms of the theme, emphasized issues, motivation and the questions to be answered by the end of the research.

Chapter Two and Three are the contributing parts of the theoretical requirement of the research. They contain the main related works concerning the issues raised in the previous chapter. Chapter Two highlights the common problems, difficulties, and even disabilities manifested by the elderly with cognitive impairment due to dementia and in particular on mobility-related issues. On the contrary, Chapter Three reviews mainly on the previous related works on technological interventions and the potential of using alternative modality for wayfinding.

Chapter Four focuses on the design project for the study. The proposal is based on the consideration of the previous works as discussed before and provides the possible solution for the wayfinding problems. A preliminary assessment was conducted to assess the proposed design solution in its initial stage.

Chapter Five is the main methodological part of the research. It is the first report on phases involved to complete the functioning prototype. This prototype development is important as it is used to further assess the proposed design intervention. The chapter then presents a Usability Test (UT) result which was conducted using the functioning prototype on the subjects with dementia who represent the real users of the intervention.

Chapter Six presents the improvement in the design project based on the results of the first usability assessment. Further development is essential especially for the commercialization purposes as a good design project comes both with its practicality and marketability. The chapter also reports on the second Usability Testing conducted after the second prototype development.

Chapter Seven contains the conclusions and describes several aspects of the future works that can be performed, including further investigations and improvements of the device. Eventually the analysis of its potential market is discussed.

1.2 Increasing Dementia cases among Elderly

In the past two decades, the segment of the older population (65 years and above) increased by 3.6% in the European Union (EU) [6]. In contrast, the segment of the population aged less than 15 years old decreased by 3.7% [6], and the number of older population is projected to exceed the number of children for the first time in 2047 [2]. Likewise, the worldwide number of older persons is expected to more than double, from 841 million people in 2013 to more than 2 billion in 2050 [2]. At the moment, about two thirds of the global older people live in developing countries since the older populations in less developed regions are growing faster. In addition, nearly 8 in 10 of the world's older population will live in the less developed regions by 2050 [2]. Consequently, as the world population ages, the worldwide prevalence of dementia of AD type was 26.6 million in 2006, and it is estimated to increase to 106.2 million by 2050 [7].

The worldwide ageing of the population will more than triple the projected number of demented persons between 2010 and 2050 [8][9]. Although there are some indications that dementia incidences may be decreasing, current data are scarce and inconclusive [10]. Dementia is an important cause of disability and dependence among older people. AD and other dementias rank as the fourth most important disorder in high income countries after depression, hearing loss, and alcohol abuse, for all age-groups [11]. Among older people in countries with low and middle incomes, dementia is the most important independent contributor to disability.

The cognitive and behavioural impairments together with the physical and sensory changes due to ageing really add to the factors that cause them to be vulnerable to numerous risks, including personal injury. Hence, the fulltime supervision is required such as the high level of care with round-the-clock supervision as equivalent to nursing homes or similar health institutions. Most of the cost incur is due to this careful and intensive supervision which increases the burden of their caregivers, either they live at home or institutionalized.

Accordingly, the worldwide costs of dementia care were estimated to be US$ 604 billion in 2010, and this may increase by 85% by 2030 [12]. For instance, a report from the United Kingdom estimated that the annual societal cost of dementia was at £23 billion, £12 billion for cancer, £8 billion for heart disease, and £5 billion for stroke. The societal costs of dementia almost matched those of cancer, heart disease, and stroke combined [13] making it an important area to be further investigated.

Therapeutic interventions and preventive approaches which lead to even slight delays in the onset and progression of AD significantly may reduce the global burden, in terms of expenditure and caregiving cost of this disease. In the same way, delaying the onset and progression of AD by only one year may reduce nearly 9.2 million AD cases of disease in 2050 [7], which also decrease the need for highly intensive care. Cognitive impairment is more likely to develop AD over time if it is not prevented in the earlier stage [14] [15], as referred to full-blown dementia. Many therapies have intervened to help individuals with cognitive impairments to live their life and do the daily activities with less dependency. AD is not curable but the progression of cognitive decline can be delayed in some appropriate ways.

1.3 Cognitive Dysfunction of Dementia of Alzheimer type

Dementia is an umbrella term describing a variety of diseases and conditions that develop when nerve cells in the brain (called neurons) die or no longer function normally [16]. Apparently, there are several types of commonly reported dementia which include Dementia with Lewy bodies, Frontotemporal lobar degeneration, Parkinson's disease, Creutzfeldt-Jakob disease, normal pressure hydrocephalus, Vascular dementia, mixed dementia and Alzheimer's disease (AD) [17].

Yet, there are numerous established causes of dementia, of which AD is the most common type of dementia, as it accounts for about 60% to 70% of all dementias [17]. Other than that, vascular dementia represents 20% and dementia with Lewy bodies represents 10% to 15% of total cases. Then again, frontotemporal dementia could be as common as AD for individuals below 60 years old. Due to this, many researchers refer dementia as AD and vice versa, in their studies [18]. Like the other types of dementia, AD affects individuals differently. AD patients experience the changes in their memory, behaviour and ability to think clearly due to neurons failure. The decay of brain function impairs the ability to perform even the simplest everyday tasks. In addition, one of the earliest and common symptoms of AD is depicted by the worsening deteriorating ability to remember new information, let alone learn new things [19] [20].

The symptoms emerge when the neurons usually found in the brain region for developing new memories fail to function normally. AD typically develops slowly and gradually gets worse over the course of several years [21]. Thus, the common symptoms that indicate the diagnosis of AD can be categorized as: (1) the worsening of memory loss that interrupts daily life, such as forgetting and misplacing things, (2) difficulties in problems solving, judgment and decision making, and performing the familiar tasks, (3) confusion of time or place, (4) problems with visual images and spatial representation, and (5) communication issues, like overlooking or omitting words to write or speak [22][23].

Due to systemic brain damage, it is unlikely for any opportunity to reverse the damage. Thus, it has been said that there are no current treatments to cure or completely stop AD from progressing. What is likely to be done is to improve or sustain the quality of life of AD patients. A new paradigm is needed that focuses on minimizing the symptoms of AD rather than focusing only on a search for a cure.

Ageing is the greatest known risk factor for AD, apart from genetic mutations, genetic factors and family history, as highlighted by [18] in Table 1.1. What makes it even worse is most of them not only suffer from this severely progressive neurologic disease but also other health problems common for older people. More often, they are prescribed with many medications which may result in even worse health condition, due to drugs complication. Moreover, drug treatment can be very costly due to high cost of developing the medicine [24]. This health-related and economical issue has initiated the effort to find alternative for not using drugs or medication to treat these AD patients. This approach is often referred to as non-drugs treatments or non-pharmacological therapies (NPT)[25][26].

Table 1.1: Risk factors for AD [18]

WELL ESTABLISHED	LIKELY	LESS LIKELY
Old age Genetic mutations (rare) Other genetic factors: • Down syndrome • Apolipoprotein E status Family history of AD	Head injury (especially more severe) Head size (smaller) Vascular risk factors including smoking and hypertension Fatty diet	Depression Elevated homocysteine / low B12 and folate Hormone Replacement Therapy / Oestrogen Sleep disorders Female gender Exposure to very strong electromagnetic radiation Aluminium

Equally important, the viable treatments to slow down the progression or to delay the onset of AD will be most appropriate to be conducted during the early stage of the disease [27]. This is because, there is still the possibility to preserve the brain function before the neurons worsen or malfunction during these initial stages. Furthermore, the ability to perform ADL among individuals in the early stage of AD is not much effected as compared to those in later stages or severe cognitive disability. In fact, individuals with more severe cognitive impairment demonstrate a faster decline in functional ability [28], while the degree of deterioration towards the performance of even the basic activities of daily living (BADL) is higher for those in later stages of AD [29].

Therefore, the effort to seek for more prospective interventions to enable and support the individuals in retaining the normal functional ability is ultimately crucial as an important therapeutic target. This could be done in the early stages before the disease rapidly progresses, whilst sustaining their sense of autonomy. Then again, understanding the progression of the disease according to the stages may also help in designing the appropriate treatments for the intended level of cognitive decline.

1.3.1 Stages of Dementia due to AD

There are several versions to describe the stages and progression of AD. Some medical experts categorize them in seven stages: from no impairment (normal function), very mild cognitive decline, moderate cognitive decline (mild or early-stage AD), moderately severe cognitive decline, severe cognitive decline and the final stage is very severe cognitive decline[30][15] [31]. The very severe cognitive decline is indicated when individuals lose the ability to respond to their environment, to carry on a conversation and, eventually, to control movement. On the other hand, the other version labels five stages associated with Alzheimer's disease: preclinical AD, mild cognitive impairment (MCI), mild dementia due to Alzheimer's, moderate dementia due to Alzheimer's and severe dementia due to AD.

Nevertheless, the progression of AD is commonly categorized into three main stages, as described in Alzheimer’s Association Report in 2013 Alzheimer’s disease facts and figures [17]. In this version, there are three stages of AD proposed with the new criteria and guidelines which are preclinical AD, mild cognitive impairment (MCI) due to AD, and dementia due to AD. Dementia due to AD or as refer to a full-blown dementia is categorized into three more stages; namely mild, moderate and severe AD.

For the preliminary level, or the preclinical AD, individuals have measurable changes in the brain, cerebrospinal fluid (CSF) assays, and/or blood (biomarkers) that indicate the earliest signs of disease [32]. At this stage however, individuals still have not developed symptoms such as memory loss [30]. According to [31], in defining the conceptual phase of the disease process at this stage, the term ‘preclinical’ is most appropriately used. Here, the preclinical AD does not necessarily denote all individuals who demonstrate the evidence of early AD pathology, but will end up to be clinically diagnosed as dementia due to AD.

This preclinical stage reflects the current thinking that AD related brain changes may begin 20 years or more before symptoms occur [17]. As mentioned by [33] in their reviewed article, there is a series of preclinical deficits within multiple cognitive domains observed in individuals at this stage. This includes episodic memory, executive functioning, verbal ability, visuospatial skill, attention and perceptual speed. Having said that, although the new criteria and guidelines have been documented in [17] to identify preclinical disease as a stage of AD, they do not established diagnostic criteria that doctors can now use .

Next, the second established stage for degenerative progress of cognitive change is MCI. So, individuals with MCI have mild measurable changes in thinking abilities that are noticeable to the person affected (and to family members and friends), but it does not affect the individual’s ability to carry out everyday activities [15]. As defined by [34], MCI is “a syndrome defined as cognitive decline greater than that expected for an individual's age and education level but that does not interfere notably with activities of daily life”. Hence, it concurs with [34] findings, who claimed that this stage of cognitive change is indeed used to hypothesize as a boundary or transitional state between ageing and dementia. Also, the usual complaints of memory deficits in MCI are similar with the basic feature of AD. A person is detected to have MCI when they are observed with the evidence of memory impairment, absence of diagnosed dementia, but general cognitive and functional abilities are preserved [35].

In addition to this, MCI with memory complaints and deficits (amnestic MCI) stand a good chance to progress or convert into dementia, in particular the Alzheimer type [34]. Yet, as reported by [17], nearly half of those patients who have visited a doctor due to their concerns about MCI symptoms will develop dementia in 3 or 4 years. Over 1 year, most individuals with MCI who are identified through community sampling remain cognitively stable. Primarily for those without memory problems, they experience an improvement in cognition or revert to normal cognitive status.

Dementia due to AD is the stage where the disease is fully-blown or matured. It is characterized by memory, thinking, and behavioral symptoms that impair a person's ability to function in daily life and that are caused by AD-related brain changes. As reported by [31] in their recommendations of diagnostic guidelines of dementia due to AD, this stage is diagnosed when the patients demonstrate at least two of these impairments: ability to acquire and remember new information, reasoning and handling of complex tasks, visuospatial abilities, language functions and changes in personality, behaviour, or comportment.

This stage of AD progression has been previously discussed in detail in the former section. It is the level of severity of this stage to be highlighted here instead. In the early stage or Mild AD, a person may function independently. The AD or medical experts may be able to detect problems in memory or concentration, such as remembering names, coming up with correct words, losing or misplacing a valuable object, and increasing trouble with planning or organizing.

In the middle stage, i.e. Moderate AD, apart from the existing symptoms of the former stage, the said persons start to get frustrated or angry and act in unexpected ways, such as refusing to eat or taking a shower. It is the damage in the nerve cells of the brain which makes them difficult to express thoughts and perform routine tasks. Individuals at this stage typically show personality and behavioral changes like suspiciousness, delusions, compulsiveness, wandering, repetitive behaviour, as well as getting lost in time and space. In fact, it is the longest stage and can last for many years.

The latter stage is severe AD; the almost total failure or dysfunction in cognitive domain. Here, individuals are incapable to even respond to their environment, carry on a conversation and control movement. Since the memory and cognitive skills are progressively degrading, they experience degeneration in personality, awareness of the current event, communication, as well as physical abilities. When this happens, persons with severe AD definitely need extensive help even with their daily personal care and undertaking the simplest tasks.

The differentiation of dementia from MCI rests on the determination of whether or not there is significant interference in the ability to function at work or in usual daily activities. Equally important, the chance of the conversion from ACI to AD is certainly high, despite a number of studies documenting vice-versa on the unlikeliness [36][37] [38]. But then again, the occurrence rate of dementia in general is based on the age groups, and it is constantly increasing when they grow older. For instance, the prevalence rate in Europe is: (1) 65 to 74 years old, 2.1/100 cases, (2) 75 to 84 years old, 6.9/100 cases, while (3) above 84 years old, 27/100 cases [39].

In addition, the conversion of MCI to AD is varied between 2% and 30% for non-institutionalized and between 6% and 85% in clinical settings [40]. The conversion rate can possibly increase up to 50% from the first 2 to 3 years since the initial stage [37], while after 6 years, 80% of MCI patients have AD [14]. The inconsistencies of findings from each epidemiological study and clinical statistic about the conversion rate are probably due to the selection of test subjects or population in general, test screening and procedural, as well as neuropsychological tools to evaluate memory functions and to diagnose the disorder.

Nonetheless, each AD patient poses and portrays a different cognitive and behavioural change that varies from one another. This issue has led to the difficulty in classifying individuals into very specific stages of AD, due to the dissimilarity of symptoms they convey. Then again, with the exhaustive information on these apparent impairments as mentioned above, it is appropriate to observe, assess and categorize these data as a global indicator of cognitive functioning or declining and composite measures of cognitive ability. Figure 1.1

below illustrates the continuum of AD that summarized the stages and the symptoms in each stage.

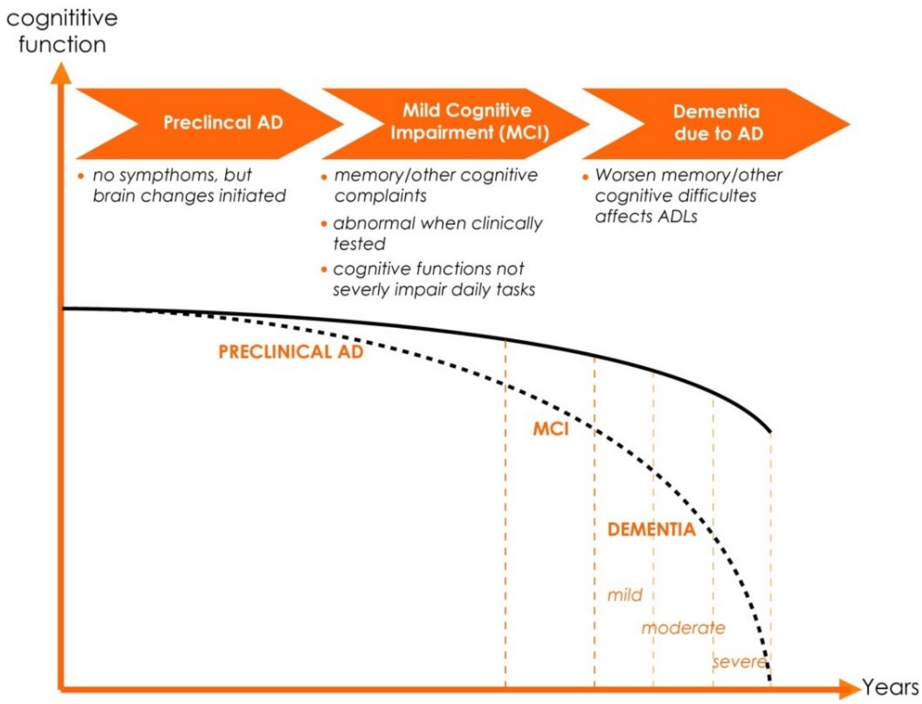


Figure 1.1: The continuum of AD and the decline of cognitive functions in according to the stages. Adapted from [31]

Indeed, there are numerous cognitive-based ratings being used to rate the severity of individuals' cognitive impairment or dementia, and these established measures are constantly reviewed. They are Short Blessed Test (SBT) [41], Informant Questionnaire on Cognitive Decline in the Elderly (IQCODE) [42], and many more. And yet, the most common and frequently used instruments for detection of cognitive impairment are still Mini Mental State Examination (MMSE) [43] and Clinical Dementia Rating (CDR) [44].

The CDR is a dementia staging instrument which is derived from a semi-structured interview with the patients to rate the cognitive function of 6 cognitive categories: memory, orientation, judgment and problem solving, function in community affairs, home and hobbies, and personal care [45]. In this rating, scales are used to indicate the patients' stage of dementia. The scales are as follow:

i. *0 = Normal*
ii. *0.5 = Very Mild Dementia*
iii. *1 = Mild Dementia*
iv. *2 = Moderate Dementia*

v. *3* = *Severe Dementia*

MMSE on the contrary, is designed as a clinical method to rate cognitive impairment and produce a score that can be used as a detection technique [46]. It is most widely used as an established clinical rating and available in many languages [47] due to its practicality to detect the cognitive change and predict the severity of cognitive impairment [46]. MMSE is built on a variety of questions that are usually categorized into seven cognitive domains: orientation to time and to place, registration of three words, attention and calculation, recall of three words, language and visual construction [47] [46]. It has a maximum score of 30 and a minimum of 0. The interpretation of the score is described in Table 1.2 below.

Table 1.2: Interpretation of MMSE and MMSE scores [47] [46]

Interpretation of MMSE		
METHOD	SCORE	INTERPRETATION
Single Cut-off	<24	Abnormal
Range	<21 >25	Increased odds of dementia Decreased odds of dementia
Education	21 <23 <24	Abnormal for 8th grade education Abnormal for high school education Abnormal for college education
Severity	24-30 18-23 0-17	No cognitive impairment Mild cognitive impairment Severe cognitive impairment

Interpretation of MMSE Scores			
SCORE	DEGREE OF IMPAIRMENT	FORMAL PSYCHOMETRIC ASSESSMENT	DAY-TO-DAY FUNCTIONING
25-30	Questionably significant	If clinical signs of cognitive impairment are present, formal assessment of cognition may be valuable.	May have clinically significant but mild deficits. Likely to affect only most demanding activities of daily living.
20-25	Mild	Formal assessment may be helpful to better determine pattern and extent of deficits.	Significant effect. May require some supervision, support and assistance.
10-20	Moderate	Formal assessment may be helpful if there are specific clinical indications	Clear impairment. May require 24-hour supervision.
0-10	Severe	Patient not likely to be testable.	Marked impairment. Likely to require 24-hour supervision and assistance with ADL.

Knowledge pertaining to AD and its stages are important for theoretical and clinical reasons alike. From the theoretical point of view, the conversion from healthy ageing to dementia helps researchers to recognize how the disease progresses. Clinically, detecting healthy older adults or any individual with the potential to be affected by the disease from early stage helps to strategize a proper treatment, as well as maximizing treatment efficacy [48]. For instance, many studies on MCI emphasize to differentiate individuals with the risk of conversion to AD or otherwise. The body of work in MCI study leads to the increasing and better potentiality for more pharmacologic interventions to delay the progression to AD [15].

Nevertheless, despite the severity of cognitive impairments, elderly with AD typically demonstrate and struggle with other ageing issues, which are closely linked to many health-related concerns. As a result, this increases the rate of disease progression, indirectly requiring intensive supervision, and finally the high possibility to be relocated into nursing homes. The next subtopic presents in detail the factors influencing the individuals with AD to be hospitalized or institutionalized.

1.3.2 Institutionalization of Persons with Dementia

Institutionalization of persons with dementia is not fixed. Many people with dementia have serious medical conditions, such as heart disease and physical disabilities, who need hospital care. Some of them need supervision because the symptoms are related to the disease itself. In spite of the physiological and cognitive changes of the patients, reasons for this institutionalization reside on many factors coming from who gives the care (both informal and formal caregivers) and caregiving level. Informal caregivers are usually the patients' spouses, family members or close relatives [49]. Typically, caregiving may cause a bad impact on informal caregivers' physical and mental health and well-being, such as anxiety, poor sleep, exhaustion, and depression and also sadness [50] [51].

Factors that influence the decision to institutionalize dementia patients by their informal caregivers are presented by [52] in their study. These factors are mostly linked to the increasing burdens and stresses of caregiving, immediate and non-immediate family caregiving, demographic of the caregivers and patients such as gender and race, and the pre-institutional programmes. So, the level of caregiving of person with dementia gradually increases with the severity of the disease. This means, when compared to the first stages of the disease, the patients in the severe levels of dementia manifest personality and mood changes which require intensive care and supervision by caregivers [53]. At this stage, they depend completely on the caregivers to do even the simplest tasks. This indirectly leads to the negative influence on the caregiver's life as previously mentioned and in the end resulted in sending the patients to the nursing homes or the dementia institutions.

As reported by [54], about 20% of patients are institutionalized in the first year after a diagnosis of dementia. This percentage of institutionalization is increased to 50% during the following 5 years whereas the rate reached 90% after 8 years. Additionally, [55] suggest that the predictors of time to the institutionalization are sex, age, marital status and severity of dementia [55]. It is indeed hard to tell at which stage of dementia the patients are institutionalized. However, as mentioned in the previous chapter, the diagnosis of dementia due to AD starts with the mild stage. Thus, based on the preceded factors and predictors, Figure 1.2 below demonstrates when the institutionalization begins.

STAGES OF AD	Preclinical AD	MCI	Dementia due to AD		
			Mild	Moderate	Severe
SETTINGS	*Still live at home*		*Institutionalized*		

Figure 1.2: Institutionalization of persons with dementia

Usually, those in preclinical until MCI stage still live in their home environment, and are taken care by their informal caregivers. Only after the cognitive decline advances and once they are official diagnosed to have dementia, the caregivers then may consider sending them to the nursing homes. This explains the 20% rate of institutionalization in the first year of diagnosis [54]. Even if the institutionalization is for a medical condition, the persons with dementia affect many parts of the process. There are also many cases of unnecessary hospitalization. This is probably due to the lack of knowledge and awareness about the disease and its caregiving process.

Relocation of persons with dementia into the nursing homes is not a delightful experience, as it may cause the harmful effects, such as morbidity and even mortality[56]. A new environment with unfamiliar sights, sounds, odours, changes of daily routine, medications and tests as well as the progression of the disease contributes to the rise of confusion, anxiety and agitation to these individuals.

Furthermore, staying at a hospital can make anyone feel anxious and upset, let alone for a person with dementia where it can be a traumatic experience. The change from home environment to an unfamiliar one, added with the stresses and possibly pain caused by the programmed medical treatments in the institutions probably make them more confused than before. Then again, one of the most reported problems occurring during this relocation is related to the spatial orientation and wayfinding incapability.

Many earlier studies focus on the confusion arising from spatial disorientation and wayfinding issues in the new environment of the nursing homes [57] [58] [59] [60] and the possible solutions by means of improving the design of the spaces [61] [62] [63]. Also, there are existing body of research on the interventions which seek to curtail caregivers desire to institutionalize their loved ones by reducing the symptoms of burden and depression in caregivers [54] [53] [64]. Nevertheless, what we found lacking in the existing body of works is the interventions to support and assist the persons' wayfinding ability before they are relocated to the nursing homes.

Understanding the physiological and mental changes and knowing what to expect from the issues presented may generate the necessary clues to help these patients in the future. This is what this study aims to investigate, which is to recognize the mobility-related and wayfinding disability problems (before the institutionalization) in order to find and propose the possible ways to support it.

1.4 Needs of Alternative Non-Pharmacological Interventions

AD and dementia in general are a lengthy cognitive degenerative disease, which may take up to more than 20 years for those surviving the final stages [65]. Patients especially in the later stage of AD are severely impaired in terms of mobility and communication; the very basic human necessity for well-being, self-worth, social interaction, autonomy [66]. Thus, it is critical to ensure these basic and higher human needs are persevered to maintain the overall normal functioning and good quality of life.

The emergence of pressing needs caused by the disease deliver numerous chances for many forms of therapies. To date, there are worldwide efforts in finding better ways to treat the disease, delay its onset, and temporarily reduce its symptoms from worsening. Then again, although pharmacotherapy may possibly reduce the AD symptoms from rapidly evolving, many have agreed that current AD treatments cannot totally stop its progression. The constraints of current pharmacotherapy on the drugs' efficiency and availability provide the needs to promote more on nonpharmacological therapeutic intervention in AD [67].

As a matter of fact, there is an increasing body of interest at present on non-pharmacological therapy (NPT) or non-drugs approach [68] [69] being used for intervention purpose. The available form of therapies with this approach range from musical intervention, animal-assisted intervention, physical therapies and more design and technological approach like wearable technology, naturally-mapped environment, intelligent ambiance and so forth. Notwithstanding, the concrete knowledge in the involved fields of interest should be primarily founded, so that the balance between theoretical and practical requirement can be initiated. In conjunction with this, there is still a lack of support on the efforts, for instance on the research about NPT, despite the worldwide growing rate of AD and the constant costs for the care [70]. Additionally, there is a dearth of necessary findings and evidences on NPT, making the need to encourage more studies in this field undoubtedly worthwhile.

Moreover, memory, visuospatial and spatial orientation deficits are common in the early stages of many diseases causing dementia, and they are the deficits contributing to wayfinding difficulties to the persons [71]. Wayfinding difficulties affect the persons' mobility, navigation and autonomy; causing them to get lost in both familiar and unfamiliar environments. This problem enforced them to require exhaustive care and eventually being hospitalized.

The ability of patients at their old age to cope with disease they are suffering from is influenced by the unfamiliar environment, such as nursing homes or any health institutes. Non-pharmacological intervention in the form of supportive or dementia-friendly environment for instance [61] [62] [63], is designed to specifically meet the needs of people with AD. This form of therapy allows them to utilize their remaining abilities with minimal frustration, and experience the highest possible quality of life. Thus, it is important to know that any purposively designed intervention can only be produced with a great knowledge and understanding about the sufferers and their needs.

As this form of NPT could sustain AD patients' functioning in daily routines, so does the application of design and technology that may represent a potent factor in the rehabilitation strategies of wayfinding disabilities. The adoption of design and technological solutions could possibly enhance the existing interventions of orientation strategies or at least provide a better option to the existing solutions of purposive design interventions.

In the same way, as mentioned in the earlier sections of this chapter, therapies that are intended to cater to the emerging needs and issues of early symptoms of AD or to support the individuals in early dementia stage are highly recommended. This is due to the possibility to preserve the brain function before it deteriorates progressively. One of the promising ways to delay the onset and reduce the risk of conversion to AD is by reducing its symptoms. This can be done by maintaining the active lifestyle, by means of constantly performing ADLS task independently in the elderly.

1.4.1 Benefits of Maintaining Active Lifestyle among Elderly

Many believe that maintaining an active life preserves physical and mental health in older adults. Simultaneously, it could be a protective influence towards cognitive decline and dementia in elderly persons. Moreover, the correlation between an engaged lifestyle on cognitive decline has also been studied for decades. For instance, there are evidences to suggest that preserving an engaging active lifestyle could reduce the risk of specific disease like cardiovascular disease, improve physical health and extend life as a whole [72]. Likewise, the effect of social network on cognitive ability of older adults is that social isolation accelerates the progression of cognitive decline [73].

The conservation of active lifestyle is usually associated with social networks, besides physical and leisure routines. In term of social networks, the findings from many studies suggest the link to mortality. And yet, persons with bad social engagement or socially isolated have increased up to four times the chance of mortality, while indirectly affecting their close community [74] [75] [76].

Leisure activities refer to the voluntary use of free time for activities outside of the daily routines [77]. For example, participating in the community's cultural events, playing music, singing in a choir, joining acting class, or just having any hobby are one of the major components of leisure activities that keeps the healthy lifestyle of older adults. Mental stimulation or mind-engaging activities such as arts and crafts, puzzles and other memory-recalling games are certainly beneficial to stimulate the brain function of the elderly. The participation in this kind of new and different activities in the early stage of dementia encourages them to constantly use their brains, which are less suitable to do at the later stages of life or when the disease has worsened. Also, as mentioned by these studies [78] [79], those who participate in these activities have a positive impact on their life, and survive longer than those who do not.

Similarly, although the connection between physical activities and the effect towards brain biology and function is still one of the most discussable topics among medical experts, high levels of physical activity are associated with reduced risks of cognitive impairments [80]. Studies of physical activity programmes for people with dementia have demonstrated either improvements in cognitive functions or slower decline in cognitive abilities [81]. In fact, it is one of the most promising protective factors to reduce the risk of conversion into dementia of AD type, as presented in the Table 1.3 below.

Table 1.3: Protective factors for AD [18]

POSSIBLE	UNLIKELY
• Physical activity	• Drugs used to treat established Alzheimer's
• Ongoing intellectual stimulation	• Omega-3 fatty acids
• Leisure/social activities	
• Higher education	
• Anti-inflammatory drugs [a]	
• Cholesterol lowering drugs (statins) [a]	
• Anti-hypertensive (blood pressure lowering) drugs for those with high blood pressure	
• Moderate alcohol intake [b]	

a. Findings are from epidemiological studies and no prospective randomized trial has yet demonstrated benefit. These drugs can have serious side effects and it is important to take these drugs only with doctor's orders.

b. This may depend on gene status as some studies have found that moderate alcohol is not protective for those with the apolipoprotein E – epsilon 4 allele.

Equally important, the brain continues to grow new cells or sometimes referred to as brain plasticity. We also know that the brain requires adequate blood flow to receive the oxygen and nutrients it needs to function well. So, performing a constant physical activity supports both these important aspects of brain biology [82]. Demonstrated benefits have also included conservation of ADL, improved physical fitness, and at the same time improved wellbeing.

There are many studies that demonstrate the benefit of maintaining an active and heathy lifestyle towards the cognitive functions in general for the older adults. For example, as reported by [83], performing leisure time physical activity at least twice a week at midlife reduced the risk of all dementia and AD up to 52% and 62 % accordingly. Doing physical exercise at least 3 times per week for older adults above 65 years old may decrease 38% reduced risk of dementia after 6 years follow up [84]. Finally, in a different study by [85], participating in a high number of different activities (such as walking and also other intellectual, leisure and social activities) resulted in lowering the risk of dementia progression over an average of 3 years for person over aged 65.

In maintaining an active lifestyle in elderly with AD, the same activities done by normal elderly could probably not be practiced since the decreasing in cognitive domain would worsen most of the body functions. So, simple routines like daily walking, standing, lifting up things could be beneficial and sufficient. Thus, only regular physical activities can support the brain biological function and they need to do it on regular basis.

In recent decades, there is an increasing attention given to the role active lifestyle as a protective factor against the occurrence of dementia in old age. However, it is not easy to provide the appropriate care for individuals with this neurodegenerative illness, let alone to develop series of stimulating, meaningful, feasible, and daily routines that are appreciated by them. One of the most challenging aspects of providing care for someone with a dementing illness is to develop daily routines and activities that are interesting, meaningful, do-able, and valued by the person with the disease. Conceptualizing the intervention which include mixed activities for them in accessing social, physical, mental, and spiritual needs is a very challenging-yet-complex task to do.

Besides, there is an emergence of need for constant changes in the programmed activities, due to the disease progression and worsening of cognitive decline, while simultaneously retaining the features so that the activities are still valued by these individuals. That being said, the aforementioned protective factor for cognitive dysfunction or dementia in particular, is somehow connected to the person' ability to move freely without obstruction. In order to perform these sorts of activities involving countless movements; stable mobility and spatial navigation skills are acquired. Unfortunately, this important necessity is also often impaired in both elderly with or without AD.

Equally important, the obvious indicator of AD and dementia in general is the gradual declining of ability to perform and maintain ADL, while at the same time progressively decreasing independence, relative to the severity of the disease [86]. The dramatic changes in cognitive, functional and behavioral domains causing the critical state of autonomy, need of assistance and may lead to institutionalization [87]. Furthermore dependency level is an acceptable way to assess the level of severity, resource consumption and quality of life of the patients [88]. Therefore, all the required bodies in a social system or a community should work together to produce suitable options of programmes and activities to effectively meet these pressing needs.

In this Chapter, we have equitably introduced the topics underlined in this study, but the actual issues have not been entirely delineated. Thus, Chapter Two is intended to report further on the theoretical framework and investigate profoundly on the main critical issue of the present study – the problems of mobility. Before proceeding to the next chapter, the research questions and objectives are declared beforehand so that the absolute goal of the study can be defined.

1.5 Research Questions

Main Research Question (RQ): How to provide the possible solutions in facilitating the wayfinding of older adults with dementia from the design and technological perspective?

Sub RQs:

1. What are the current (design and technological) solutions to be adopted as an alternative navigational assistance for elderly with dementia?
2. How to conceptualize a new navigational assistance in consideration of previous works?

3. How to evaluate the proposed design of navigational assistance so that it may be realized in the real world?

1.6 Research Objectives

Main Objective: To understand the decline of wayfinding ability in elderly with dementia and finding possible ways to assist or improve it.

Specific Objectives: To develop and assess a conceptual navigational assistance tool to assist the wayfinding of older adults with dementia.

CHAPTER TWO

2 Intersected Mobility Issues

2.1 Introduction

This chapter and the following one in particular contribute the most in the theoretical requirements for the study. It discusses further on all the aspects that should be taken into account in order to achieve the overall goal. It consists of the related works for the issues raised in the problem background and the research questions. The review starts with the problem of mobility as an umbrella issue and its consequences for older adults with cognitive impairment. The causes and effects of the decline in mobility which lead to many other implications are discussed in this chapter. The review is also made on the existing interventions to cater to controversial issues being debated relating to dementia, while at the same time highlights the potential of new application that can be proposed for the design project.

2.2 Mobility in Elderly with and without Dementia

It is important to find ways to promote the functional capacity of older people to ensure their sustainability in health and social care system, while at the same time enriching the good quality of life. One of the key issues emphasized here is the mobility in elderly. The term mobility refers to a person's ability to move independently and safely from one place to another [89]. Individual's stable mobility is indeed beneficial for everyone and for numerous reasons, regardless of the age ranges.

Outdoor mobility for older adults in particular, is highly essential for accessing the commodities, using public facilities, socializing purposes, and also for physical activities. These necessities and many others are hard to achieve without a stable mobility. Consequently, without a stable mobility, older adults could not have the access they need the most without the help and supervision from others. Hence, this simply indicates that one significant factor to maintaining the independence in old age is mobility.

It is the norm that when we grow older, the limitations in mobility are beginning to be noticeable. In fact, mobility decreases with advancing age, and it is the obvious earlier sign of further (physical and social) functional declines [90][91]. Equally important, the decline of mobility obstructs the ability to perform and maintain daily life and social functioning in older adults. This in the end results in the increase of assistance, supervision and burdens, which leads to the risk of institutionalization [92] [93].

In the same way, as people age, they change in countless ways, both biological and psychological. When this is the case, the most feared aspects of growing old is the cognitive decline [94]. This decline may lead to more serious issues, which is the Mild Cognitive Impairment (MCI). Some cases of MCI remain mildly impaired and others are reversed, but the probability of the developing the AD or other dementia types are disquieting [95][96].

The neuropsychological deficits in people with dementia mainly due to AD are indeed recognized and apparent. As reported by [97], these obvious deteriorations include episodic memory, language and semantic knowledge, executive functions, working memory, attention, and also the visuospatial abilities. Similar to several other common deficits such as the deterioration of cognitive mapping and spatial disorientation [71][98], the decline of visuospatial abilities as preceded above is associated with the mobility issue in dementia.

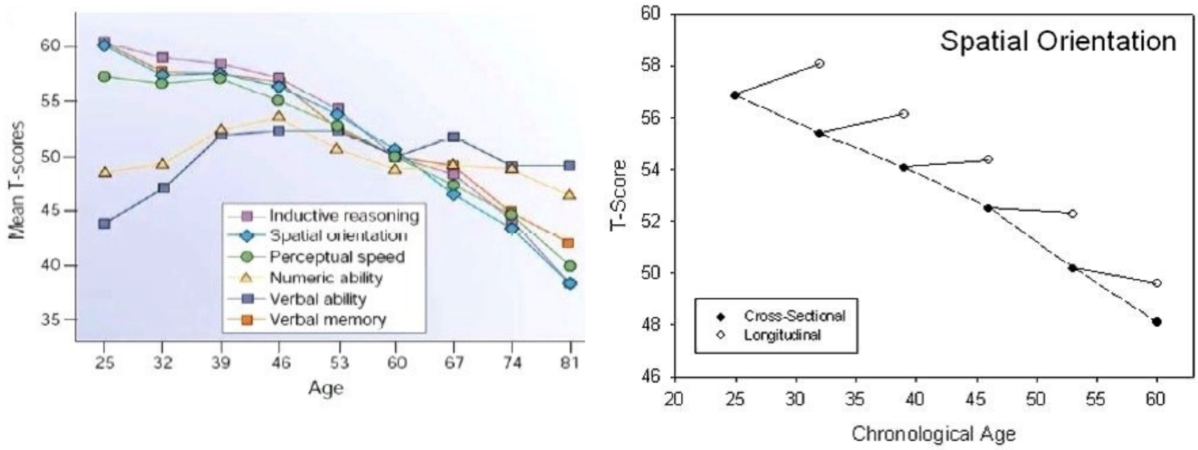


Figure 2.1: *(Left)* The graph of the gradual mental decline with aging and *(Right)* the graph on nearly monotonic spatial orientation declines according to age [334]

Moreover, the concern on this matter is not only common for people with dementia. In fact, it is one of the most serious complications caused by age related cognitive decline, and the studies on this relation are established, for example by [99][100][90]. Figure 2.1 above demonstrates the reports on mental skills deterioration with age, (and spatial orientation being one of them) by different studies.

The necessity of maintaining the stable mobility in older adults has been previously emphasized. In a nutshell, this study focuses on the umbrella issue in the decline of mobility and what are allied to it that affect especially the normal functioning of older adults with cognitive impairment due to dementia of AD type. In conjunction with this, dementia has an undesirable impact on endurance, lower-extremity strength, balance on body functions and body structures, as well as mobility [101].

The body functions of people as above-mentioned are important for effective activities of daily living (ADL). They are indeed the fundamental requirements for both categories of ADL, which are instrumental ADL (such as housework, preparing meals or taking a walk in the neighborhood) and basic ADL (such as bathing, eating and dressing) [102]. For that reason, there is a robust correlation between the weakening of capability to undertake ADL and the severity of cognitive impairment in persons with dementia, though performance of these activities is compromised in the mildest stage of the disease [103].

Unfortunately, this neurodegenerative disease namely dementia cannot be cured, but the negative consequences caused by the disease may be controlled systematically. There are many studies such as [104], [105], [106] on how body functions are highly trainable by means of keeping the healthy lifestyle that leads to the enhancement of ADL. Equally important, active lifestyle represents a protective factor for cognitive decline and dementia in elderly persons [80] [81]. Therefore, since ADL is the basic needs for human, let alone for the people with dementia, finding ways to support or maintain it are highly appropriate.

To be precise, the poor performance of ADL underlined in this study is correlated to the root cause of mobility decline and its related issues mainly the spatial orientation and navigation disability due to both ageing and cognitive changes. Hence, understanding this deficit helps to find the ways or possible solutions in supporting their independent and stable mobility. So, the next section discusses further on the wayfinding deficit or spatial disorientation in elderly with dementia.

2.3 Concept of Wayfinding and Navigation

Wayfinding process is essentially a problem-solving activity, and is affected by many factors. The process involves factors such as perception of the environment, availability of wayfinding information, ability to orientate, and cognitive and decision-making processes. These will determine the effectiveness of their wayfinding. Wayfinding has the information systems meant to guide people through an environment, while simultaneously improve their understanding and experience of the space [107].

Wayfinding is defined as the ability to reach a destination in the everyday environment, both cognitively and behaviorally [108]. Wayfinding in a nutshell involves a series of decision makings - emotionally, cognitively and behaviorally. It usually starts with deciding the destination of a journey. Later, the users decide the possible strategy or method to get to the intended destination, and the most appropriate route to be taken. During these decision makings moments, there are potential emergences of influences which require several other decisions. For example, the environment and provided information along the journey. At the end, all the wayfinding decisions are interrelated as they influence each other.

The three key procedures in the wayfinding process are described by Arthur and Passini [109] in their study. Figure 2.2 below shows the relationship of these procedures. As previously mentioned, to ensure a successful wayfinding, these wayfinding processes require a person to decide, take actions and process the gather information

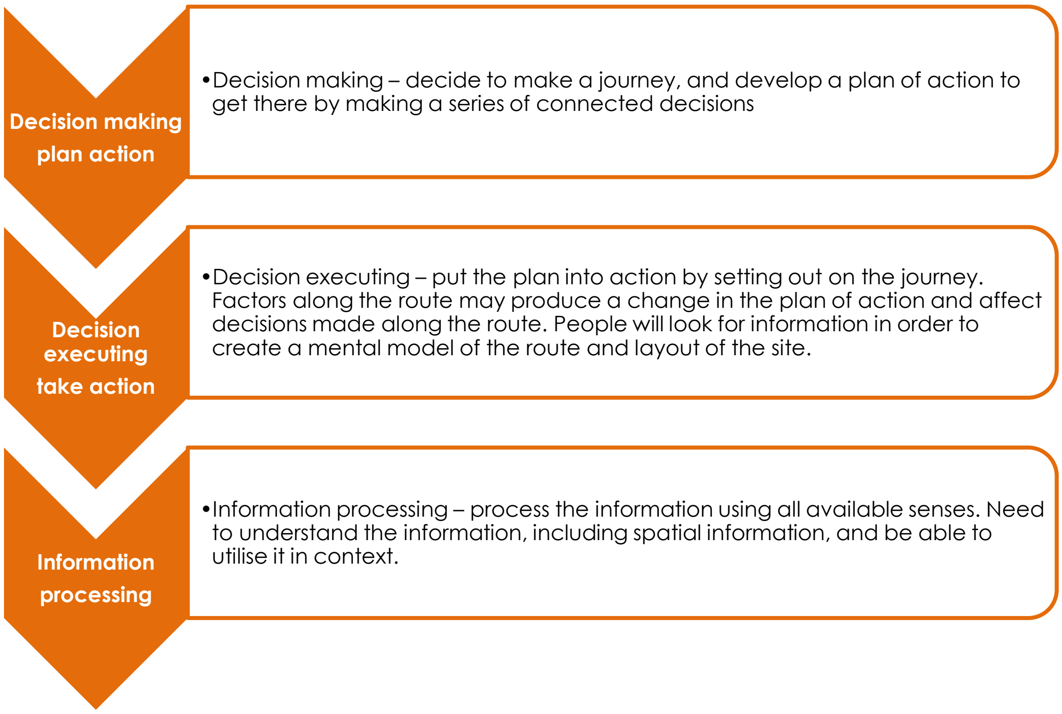


Figure 2.2: The three key procedures in the wayfinding process, adapted from Arthur and Passini [109]

Nonetheless, wayfinding and navigation are two related concepts, but they are not exactly identical. Wayfinding is the broader term, refers to how people find their way around environments [110] [111]. Navigation in contrast, is a more specific process or activity used to find way and accurately ascertain position while following a route [112]. The established form of navigation includes route, landmark, and map navigations. As mentioned by [113], navigation also relies on the ability of a person to self-project or to shift from one’s current perspective to an alternative perspective. During navigation or while moving around an environment, one needs to maintain a sense of direction and location within the route. This could be realized with the support of external representations (maps) or with internal mental representations (based on sensory experience) [114].

Whilst, in a more complex level and also correlated to wayfinding and navigation, spatial skill is a cognitive ability which involved understanding, manipulating, reorganizing, or interpreting relationships visually [115]. It refers to the ability to generate, retain, retrieve, and transform well-structured visual images [116]. As claimed by [117], spatial skill can be classified into different categories: (1) spatial perception, (2) mental rotation, and (3) spatial visualization.

Nonetheless, spatial ability as a term is difficult to be defined precisely, as it has different versions of definition. Again, the concept of spatial ability is constantly allied with spatial orientation and spatial visualization [118]. Spatial orientation is "the comprehension of the arrangement of elements within a visual stimulus pattern and the aptitude to remain unconfused by the changing orientation in which a spatial configuration may be presented"[119]. In a simple statement, it is an ability to relate position, direction and movement of objects in space [120]. Spatial navigability instead is "the ability to mentally manipulate, rotate, twist, or invert pictorially presented stimuli" [119].

As both of these spatial factors interrelated with each other, the tasks can be distinguished by identifying what is to be moved [119] [121]. Here, it means if the representation could be mentally moved or altered, it is considered as a spatial visualization because orientation does not involve mentally moving an object, but the perceptual perspective of the person viewing the object is changed or moved [115]. Besides, spatial ability can possibly contribute to the navigation strategy and geographic knowledge [122], which are also essential for successful wayfinding.

There are several significant studies [123] [124] [122] on investigating the spatial ability differences between men and women, proving that the gender factor also has an impact on their navigation performances. For example, spatial ability task requiring the manipulation of object in a space, which men usually do better [125] [121] as compared to women. On the contrary, women are known to be better at keeping track and finding objects, as compared to men [126]. Understanding this difference and other influences of spatial ability can help the researchers to predict the outcome for the assessment that involves the spatial navigation tasks.

Complementary to this, spatial navigation skill is also a complex domain that involves several cognitive processes such as spatial skills, explicit memory, working memory and executive processes [127]. It refers to the process of determining and maintaining trajectory from one point to another [128]. This skill contains the information of person's position in a space, self-to-object distance, and self-motions, which is a set of useful data to keep going from the current direction [128]. Thus, one may find difficulties if this necessary aptitude is weaken, because spatial navigation skill allows the persons to find and to learn to find their way from one place to another in the environment [129].

Navigation (in a nutshell) is a complex concept and yet is an important basic human skill as it comprises both external representations and internal mental representations. In addition to the previously mentioned factors, navigation requires a self-projection for episodic memory and episodic future thinking [113]. Episodic memory is referred to as a neurocognitive (brain/mind) system that enables human beings to remember past experiences [130]. It is the memory of narrative events that can be clearly stated; for example, time, places, associated emotions and other contextual knowledge. Unfortunately, one of the most obvious neuropsychological declines due to AD is episodic memory [97]; apart from executive functions, working memory, and attention, visuospatial abilities and so forth.

The ability to navigate in the environment certainly requires an understanding of all the above-mentioned influences, and links between intuitive geometry and intuitive physics [131]. Thus, it is predictable that spatial abilities are often linked to navigational abilities. Mobility as an umbrella issue has been deliberated in the previous chapter. The relationship between ageing and cognitive decline was correspondingly discussed there. Hence, since the concept of wayfinding and navigation are interconnected with mobility, it also proves that wayfinding ability is deteriorated by age and severity of cognitive impairment [132] [133]. The next subtopic discusses on the deterioration of wayfinding and navigation ability among elderly with cognitive impairment especially due to AD.

2.3.1 Ageing and AD-related decline of Spatial Navigation Skills

Elderly without dementia remain stable with spatial navigation skill, an ability to find one's way in familiar surroundings relies on different kinds of spatial reference frames [128]. However, it is not for the case of AD since this important skill is often impaired and it is suspected to be related to the declining of cognitive function, besides the aging factor [127]. Spatial navigation skill is crucial as it is mostly used for everyday functioning, to find the way around both familiar and unfamiliar routes, as well as for both indoor and outdoor environments.

Moreover, this problem resulted in negative implications on the subjective measures of normal social functioning and ADL in general [31]. The impaired spatial cognition in AD is usually denoted as spatial disorientation (SD). SD, is also referred to as topographical disorientation, topographical amnesia and visual disorientation [134] where it is defined as an individual's inability to orient in the environment as a result of focal brain damage [71]. It affects the individuals with AD in terms of impaired linking of landmarks and routes, which resulted in getting lost in both familiar and unfamiliar environments [134].

SD is dramatically worsened according to age [127] [132] and as the disease progresses [132]. Indeed, it is initiated early in the development of AD and as early as during the development of MCI [135]. Although not every MCI cases end up with full-blown dementia, the possibility is still very high [136]. The worsening of spatial orientation ability leads to a person's inability to self-orientate and find ways in the environments, and he/she stands a high risk of injuries. In the same way, it limits the autonomous performance of ADL mainly activities which involve the outdoor navigation [137]. As a result, individuals with this deficit require high level of care round-the-clock to reach certain places and to perform even basic everyday tasks. In fact, it is one of the major reasons for institutionalization [138].

AD patients with deficit in executive function (EF), typically experience delayed motor response in spatial mobility, as a form of spatial disorientation or declining wayfinding ability [139]. This specific cognitive dysfunction is by some means also associated with the weakening of individuals' spatial representation which involves mostly the allocentric and egocentric representations, apart from the cognitive mapping, landmark processing and spatial memory [128].

Moreover, the change in cognitive map towards the spatial navigation ability is based on a configuration of distal landmarks from the navigation to and from landmarks [140], and it dissociates both allocentric and egocentric navigation. The difference between egocentric and allocentric in spatial representation is that, egocentric involves an object-to-object representational structure and encode information about the location of one object or its parts with respect to other object. While allocentric is a self-to-object representational system, and one locates points within a framework external to the holder of the representation and independent of his or her position [141].

Apparently, age-related and cognitive changes in spatial navigation skill, visuospatial abilities, mental imagery and navigational skill in elderly and persons with AD have been documented by a few earlier studies [128] [142] [140] [143] [139]. Age-related weakness in route learning or large scale spatial memory is indicated when older adults often experience difficulties in navigation and often avoid unfamiliar routes [144]. This makes the elderly not wanting to go to the places/location they have never been before. Then, the weakening of navigation skill is shown when older adults took more time to find their way around, while at the same time made more direction errors during navigation, as compared to the younger persons [145].

In addition, the healthy older adults also demonstrate poorer visuospatial ability when comparing the age-related performance in passive and active visuospatial tasks. This deterioration is caused by the inability to manipulate and transform visuospatial information [146]. Likewise, older adults usually have difficulties in processing information to provide the spatial judgements [147]. Again, in terms of spatial abilities, there is an obvious deterioration in older adults when dealing with mental laboratory tasks, especially for the unfamiliar tasks [148] [149] . Usually, elderly can still manage their everyday spatial task, and to perform spatial task in a familiar environment.

On the contrary, degeneration of cognitive function due to AD affects the visuospatial modality which relates to spatial location, object location, spatial patterns and several other spatial memory processes domains. Indeed, the neurodegeneration in AD disconnects hippocampus with is important for visuospatial processes, such as topographic orientation, egocentric and allocentric processing [139]. This dissociation may result in spatial disorientation and disorders of episodic memory.

In one study, [150] claimed that the limitations of working memory functions weakened the passive and active processes in AD as compared to healthy older adults, mainly on the active verbal and spatial processes. In addition, apart from the deficit in visual memory, AD patients typically showed difficulties in static spatial contrast sensitivity, visual attention, shape-from-motion and visuospatial construction [151]. The decrements in other cognitive domains can be caused by the visual neural pathways and visual dysfunctions that are involved in neurodegenerative processes[151] .

At the same time, information about degeneration of individuals' visuospatial functioning is valuable in understanding how it can be used to diagnose the disease when it is still in the early stages. This could help minimize the complexity of timely diagnosis of AD and its prevalence from MCI stage. In fact, there is also body of works on the deterioration of spatial abilities in general that could predict the occurrence, or as a biomarker to the diagnostic of AD [152].

For instance, [153] [154] claimed that even persons in early stage of AD demonstrate the impairment in visuospatial short-term memory. These studies suggested that the visuospatial deficits could possibly be the early detector of this degenerative disease, while the change of cognitive function may be detected with the declines in linguistic, as well as in visuospatial domains. Meanwhile, early visual motion perception deficits could precede navigational impairments and lead to topographical disorientation in AD patients [155]. Here, it is proven that AD patients are usually impaired in visual motion perception, as compared to healthy elderly and those in mild stage or MCI [156].

These contributive factors lead to the hypothesis that the severity of cognitive impairment does influence the worsening of individuals' spatial ability. As agreed by [155], visuospatial deficits could indicate the early neurodegenerative disease, like AD itself. Essentially, persons who are diagnosed with AD manifest worse deficit in the visuospatial modality than those in MCI. This is shown in the visual recognition task conducted in the study by [157], where persons with MCI do not show difficulties like the AD patients when they were asked to recognize similar images repeatedly.

Another essential point is the seriousness of impairment in attentional resources and visuospatial memory that originates the cognitive origin and the neurofunctional bases deficits shown by MCI and persons with AD [157]. These data certainly help to identify and better define the level of spatial disabilities and its predictive value, according to the stage of AD. Also, the occupational therapy that aims to facilitate the decline of spatial abilities in AD patients should include the assessment of spatial orientation skills in individuals in the early stages of the disease.

Nevertheless, even though there are many existing studies documented on the decline of spatial abilities and all the associated aspects which influence these deteriorations, there is still a dearth of concrete evidence either from therapeutic, pharmacology or even technological approaches to preserve wayfinding domains in AD patients. The efforts to develop more promising therapeutic or non-therapeutic interventions using present technology to cater to this issue are highly appropriate.

Equally important is to understand the actual issues and emerging needs due to this problem before deciding the appropriate concept of intervention for this purpose. As agreed by [158], in terms of object-location memory, there is an impairment of explicit but not implicit spatial memory in AD patients. The preservation of implicit memory in AD is extended to the spatial domain. Hence, this could have an important rehabilitative value, for example in conceptualizing the navigational training intervention for AD patients,

As AD is mostly affecting the older population, it is normal for them to experience the sensory changes. Due to the sensory integration dysfunction, individuals with AD show difficulties to fulfill the expected roles to achieve in their life. In addition, this problem caused them to demonstrate the behaviours that can hinder their participation in daily life. Since this study highlights the issues relating to the performance of ADL especially in wayfinding, the following section discusses on how sensory declines affect their spatial navigation skill in general.

2.4 Sensory Changes affects Wayfinding

The human five senses: vision/sight, hearing, touch, taste and smell help to receive and process the information from the surroundings. They seem to function separately as five separate modalities in perceiving the world, but as a matter of fact they collaborate closely in order to allow the mind to understand the environment better. This collaboration is obvious and can be very crucial under some circumstances. For instance, blind people need to brilliantly train their other sensory like hearing, to maintain their independent wayfinding. Unfortunately, these important senses undergo biological changes and diminish due to age

[159][160]; thus, making the reception, interpretation and processing of the perceived information disturbed or distorted. Because of this, the elderly tend to avoid or give up the tasks or activities they used to do before, and at the same time jeopardizing their social relation and involvement in their families and community.

Studies on the investigation of human interactions related to the sensory between users and end-products are quite common in the design field. In fact, this is one of the fundamental elements in the design development process. Usually, users being the main prospective subjects in designing products or spaces are utilized during this phase [1]. It is quite rare that existing research in design field uses elderly or more precisely cognitively dysfunctional aged people as their subjects or end users in designing products, systems or services.

Furthermore, conducting a research on the specific needs by specific population requires a good knowledge about the subjects. This highlights the importance to also understand how sensory changes and declines affect older adults with or without cognitive impairment. Once the difficulties and limitations are recognized, modifications and adaptations (to the environment for instance) can be restructured to make up for the losses. Similarly (important), by accepting the process of ageing sensory system, it could ease the transition of modification they need to face in performing daily tasks.

Sensory impairment is synonymous with being old, despite the immense debates on sensory decline being the feature of old age. Nonetheless (whether or not), it still brings one of the greatest difficulties to the modern society at present. Anyhow, age still represents the major risk for all the sensory impairment. In a simple word, the longer people live the worse sensory decline they will experience. In addition, the sensory impairment on the most important ones -visual and hearing- has an impact on the quality of life of the elderly. It is quite unfortunate that they are highly associated with conditions that affect the older persons [161]. The health-related impact of sensory loss is significant, even though the impairment of senses is not an actual life-threatening cause.

While this is the case, the decline of sensory takes place unequally and varies according to the age of an individual. As mentioned by [162], age-related changes accelerate at these approximate age ranges: (1) Vision: mid-50s, (2) hearing: mid 40s, (3) touch: mid 50s, (4) taste: mid 60s, and (5) smell: mid 70s. On top of that, this condition similarly affects the individuals with AD, since most of them are elderly [18]. The older adults with AD also manifest the worsening of sensory decline as they grow older and as the disease progresses alongside with cognitive and behavioural changes.

The limitations caused by sensory declines as a consequence of AD are qualitatively similar to the limitations caused by senescence (or biological ageing) [163][164]. The differences could be apparent in terms of interpreting the information gathered and interpreted. There is also a possibility that sensory impairment can increase the risk of diagnosing with AD and clinically increase its severity, for example the visual and hearing impairment [165] [166]. In conjunction with this, as explained by [167], the oriented search is linked with cognitive mapping and several other spatial-related cognitive processes. In oriented search, the individual often orientates based on the source of destination, then systematically searches until he/she reaches the intended destination. For normal persons without sensory disability, they tend to rely profoundly on visual, despite the accessibility for the other senses [167].

On the contrary, for persons with visual impairment or blind people, they may be depending on auditory, vestibular (sense of balance) and proprioceptive (sensory receptor that detects the body position/motion by responding to stimuli arising within the organism) information [167]. Nonetheless, in the case of AD, since the older adults experience sensory decline due to ageing, it affects their sense of directions indirectly. This problem may gradually worsen their spatial cognition [168] that is needed for precise wayfinding.

As the most needed sensory for wayfinding, the decline in persons' vision and cognitive aptness due to ageing has an undesirable implication on their spatial skill. The loss of vision affects contrast sensitivity, visual processing and visuospatial that subsequently impairs the ability to orientate and navigate in the environment [169] [170]. Hearing loss could also affect AD patients' wayfinding abilities due to the deficits in central auditory and resulted in the visuospatial dysfunction [171]. These changes and limitations of sensory impairments shown by older adults with and without AD are presented further in this section.

In this study, the priority on the review of sensory impairments is given to the mostly correlated sensory for wayfinding or navigation. The notion on wayfinding is associated with sensory acuity is yet to be justified in this research work. Thus, the following subtopics discuss the details about the declines of vision, hearing and touch in normal elderly and elderly with AD.

2.4.1 Sight/Vision

While undoubtedly that all the senses are important for one's well-being, vision and hearing are particularly the most vital factors since they affect a person's ability to function normally in any given physical environment. The changes in vision and hearing will possibly lead to isolation. Age affects the shape of people's eye lens, and making the pupil becomes smaller. Simultaneously when the pupil gets smaller, it causes the thickening of the lens, while both lens and cornea become less transparent. This results in less light reaching the retina and the field of vision shrinks [172] [173]. Older adults usually have trouble to see at low light environment, discern objects with low contrast colour and differentiate the shades of colour. They indeed need more light to see well.

The changes in vision due to ageing can be recognized by several aspects of declines in: (1) sharpness of vision (or visual acuity), (2) ability to focus on objects at different distances, (3) ability to discriminate between certain colours, (4) functioning in low light levels and adapting to dark, (5) ability to adapt to glare, and (6) judging distances [174]. The inability of the eyes to see clearly due to the decrease sharpness of vision or acuity is the most common age-related vision change. Visual acuity refers to acuteness or clearness of vision that of uncorrected visual acuity in the better system's [165], or the ability to resolve high-contrast spatial. Visual acuity is at its top for the late teens and remains so until the age of 45 to 50, after which it progressively declines. As reported by [175], one-half of people by 65 years old have a visual acuity of 20/70 or less. This means, what can be seen from 70 feet by a person with perfect vision can be seen only from 20 feet.

The other common change of aged vision is the gradual loss of ability to focus, as the lens of the eye becomes less elastic and causing slowed vision [176]. This condition is called 'old eye' or presbyopia which refers to inability to read small print and apparently it starts early, around 45 years old [175]. This cause the eye to take longer to focus on close objects, and it will cause more inconvenient blurring. Due to this condition, older adults require more time to recognize objects or to focus on objects at different distances and also the ability to shift focus is delayed.

Colour discrimination and contrast sensitivity will also decrease with age [177]. The consequences of aged lens and cornea will cause the glare when light scatters. This leads to poor vision quality, mainly when the pupil dilates in the dark. In addition to this, aging persons tend to see the fading and dullness in colours. For instance, due to the yellowing effects in the lens, colours at the blue end of the light spectrum seem to be fading the most and to merge into greens. This results for older adults not being able to distinguish between shades of colours, especially for blues, greens, and violets. The changes in colour discrimination and contrast sensitivity decline are illustrated in Figure 2.3, as describe by [178] where it displays the same scene through the lens of people at different ages.

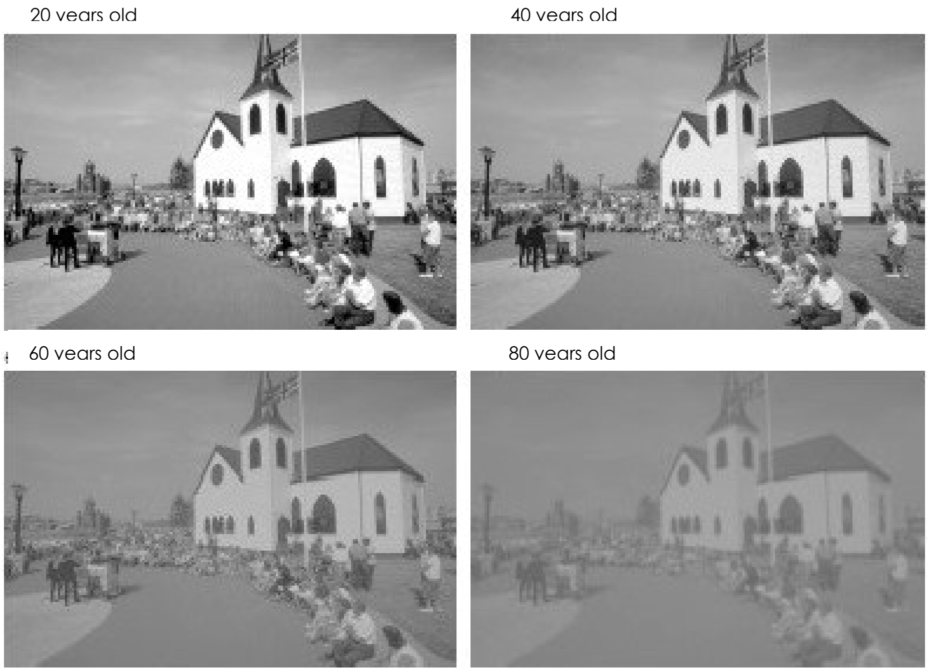


Figure 2.3:The same scene observed by different age groups (20, 40, 60 and 80 years old) by [178]

In terms of how the age affects people's eye lens physically and the impacts of these changes towards the vision are relatively similar to both older adults with or without cognitive impairments. What makes the vision of dementia patients different is closely dependable upon how they perceive the information they see. In relation to this, due to deficits in the working memory, older adults with AD require more time for feature extraction and feature search [179]. Here, persons with AD and advanced ageing usually experience the reduced control of spatial focus of attention [151].

Visual function is affected by AD early in the course of the disease and the visual function decline correlates with the cognitive decline [180]. For someone with AD, there are several common deficits in vision they manifest, such as: (1) contrast sensitivity deficits in the lower spatial frequencies, (2) motion perception (ability to detect movement) is reduced, (3) visual field defects and (4) colour discrimination of blue (short wavelength hues) is reduced [180][181] . The changes of vision caused by both aging and cognitive dysfunction factors do have an impact on the person's spatial skill. For example, dementia patients show a decline in spatial vision in terms of (i) static acuity; (ii) contrast sensitivity, and (iii) visual processing in the periphery [170]. This depends on the fact that the density of photoreceptors in the periphery declines with age and/or dementia, but the effects is substantial.

As also agreed by [169], persons with AD getting lost in the environment do not necessarily mean it is due to their confusion, but because of their visual processing associated with akinetopsia (motion blindness) is impaired. Likewise, the disease also could impair form identification (parvo-cellular stream) and visuospatial (location) skills that affects the ability to judge depth [169]. This results in their ability to orientate and navigate in the space gradually diminishing, as the disease worsens. Then again, visual impairment is potentially contributing to the cognitive dysfunction in AD. This is approved by [165], as they documented that poorly uncorrected and poorly usual near- and far-vision acuity were significantly associated with poor cognitive functioning as measured by the MMSE. According to this estimation, the near-vision acuity for demented persons is 20/200 and 20/100 for non-demented, while far-vision acuity for demented persons is 20/70 and 20/60 for non-demented.

Visual impairment is defined by the World Health Organization (WHO) [182] as best-corrected visual acuity of less than 0.3 (20/60) but no less than 0.05 (20/400) in the better eye The classifications of visual impairment and blindness as reported by WHO are:

I. mild vision loss/near-normal vision: 20/30 - 20/60
II. moderate VI/moderate low vision: 20/70 - 20/160
III. severe VI/severe low vision: 20/200 - 20/400
IV. profound VI/profound low vision: 20/500 - 20/1,000
V. near-total VI/near total blindness: < 20/1,000
VI. total VI/total blindness: no light perception

The impairment of visual perception of older adults with AD caused many negative impediments on their daily life. The effects and changes of vision by AD are exemplified in the Table 2.1 below. Indeed, visual impairment is a well-established cause of depression, personal injury and social isolation [178].

Table 2.1: Effects of AD towards visual functions [169]

VISUAL FUNCTION	EFFECT OF AD
Visual Acuity	Normal for age
Color vision	Deficits in color discrimination particularly on the blue axis
Stereoacuity	Deficits in both monocular and binocular depth perception
Contrast Sensitivity	Deficits in seeing both low and high spatial frequencies
Motion Perception	Deficits in motion discrimination
Evoked responses	Deficits in Flash Visual Evoked Potential (FVEP) and Pattern Electroretinogram (PERG) particularly for high temporal Frequencies

The efforts to overcome their weaknesses through providing the appropriate interventions and therapies would give a huge benefit to their well-being. For example, improved color contrast may support the wayfinding by increasing both short-term memory and spatial awareness [169]. Also, improvement of visual environment or stimulus may augment some cognitive functions in AD patients.

2.4.2 Hearing

After vision, loss of hearing is possibly the next most serious sensory impairment since it is related to "social sense." Due to its non-obvious feature, the change in hearing seldom garners people's empathy and understanding, unlike the poor vision. This is simply because blind people or those with severe visual impairment may appear with white cane, thick glasses and maybe a dog, but deaf persons or someone with hearing disability is not easily recognizable.

The change of hearing is relatively gradual and it will certainly decline with age [183] [184], starting at middle age. Age-related hearing loss (or presbycusis) is the loss of hearing that gradually occurs in most of us as we grow older [185]. It is obviously a very common condition affecting older and elderly adults. The decrease in elasticity of the eardrum causes the hearing loss, and the ability to hear clearly declines with age.

Meanwhile, hearing loss is defined as the average hearing loss thresholds at 500, 1000, 2000 and 4000 Hz, greater than 25dB of hearing loss in the worse ear measured by pure-tone audiometry [186]. Instead, hearing impairment refers to a hearing loss that prevents a person from totally receiving sounds through the ear and present as 25 dB or more at the best ear. According to [186], the degrees of hearing impairment are categorized as: (1) mild (>25 and ≤40 dB of hearing loss), (2) moderate (>40 and ≤ 60 dB of hearing loss), and severe (>60 dB of hearing loss).

The hearing loss begins at a young age and decline progressively during the 20s, 30s, and 40s. Then again, the stable hearing remains until the age of 60 and progressively declines [174]. [187] stated that, around 40% to 45% of adults at the age of 65 and older show some degree of hearing impairments. This condition is rising to 83% in adults over 70 years. In relation to this, approximately 17 % of the UK population between 61–80 years old are unable to hear sounds at 45dB, which equals to a moderate whisper [178]. Figure 2.4 illustrates the prevalence of vision and hearing impairment in aged British population.

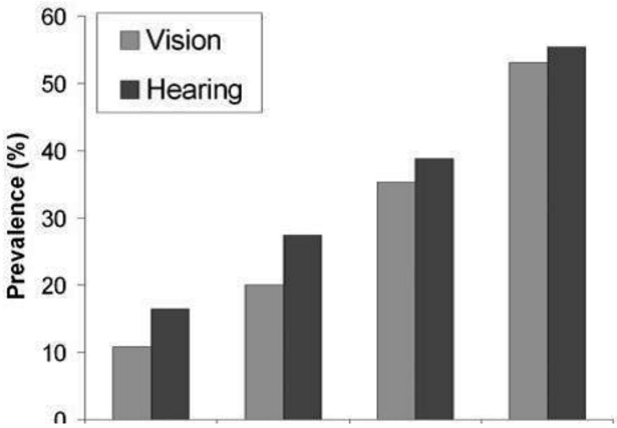


Figure 2.4: Effect of age on the prevalence of vision and hearing impairment in the British population. *Vision impairment is defined as a visual acuity of <6/12 and hearing impairment as failure of the 'whisper test'*[335].

The age-associated changes in hearing can be caused by the damage of delicate hair cells in the inner ear function that translate soundwaves into nerve impulses [188]. The difficulties in hearing is obvious in the higher frequencies, in the range of frequencies from 250 to 6,000 Hz [178]. Nonetheless, many people do not realize the changes in hearing until they find difficulties to hear in high frequencies, usually around 50 to 60 years old [189]. For instance, higher frequency consonants like t, p, k, f and s are hard to hear because of the loss in sensitivity. Also, it would be difficult to hear the words which sound similar, such as tea/pea/key, shop/shot/shock or fine/shine/sign.

The loss of hearing may cause a number of serious psychosocial consequences, which may include social isolation, tendencies to be paranoid, depression and loss of self-esteem. Then again, one of the most obvious and adverse consequences of this condition is it impairs persons' communication skill. This is contributed by the deficits in central auditory processing capacity and cognitive decline in collective that diminish speech understanding in everyday situations [190]. It certainly has a significant impact on communication in social situations and a major emotional reaction as a result of communication difficulties.

Moreover, hearing loss could jeopardize relationships and independent living which lead to the increase of need for care. Even worse, the decline of hearing is a co-factor in senile dementia. For older adults with AD, the cognitive impairment is impacted by the change of hearing. As documented by [187], the impaired hearing and the deteriorated central auditory increases the risk of conversion from non-demented to dementia 5 to 10 years later. Likewise, in MCI and AD, the progression of hippocampal loss was detected over 6 months and accelerated over 1 year [191].

Auditory scene analysis (a proposed model for the basis of auditory perception [192]) for deficit in AD appeared to be seen as a problem to understand and follow speech in the presence of unnecessary noise; salient environmental noises for instance [193]. The poor performance on both verbal and nonverbal cognitive tests in a study by [187] is greatly linked with the more severe peripheral hearing loss. This is supported by these studies [194][166] that agree on the decline of central auditory processing due to the severe peripheral hearing loss results in great occurrence of cognitive impairment, and finally diagnoses with AD.

In relation to this, as reported by [171], the performance of auditory scene analysis tasks in AD is influenced by nonverbal working memory capacity. This is supported by the study by [195], who mentioned that temporoparietal dysfunction is initiated by working memory deficits in AD. While this is the case, from the perspective of deterioration in spatial navigation skill, the contributive association between the working memory of AD and central auditory remains uncertain. Furthermore, the study by [171] presents a common foundation for non-verbal working memory deficits which affects the visuospatial and auditory information in AD.

As previously highlighted and discussed, apart from spatial orientation and working memory deficits, visuospatial is also common conditions of ageing and cognitive impairment [155] [157]. These deficits apparently resulted in the impaired of wayfinding abilities to the persons with AD. Therefore, it could be said that there is a correlation between the hearing impairment in elderly with AD and their decline of spatial ability.

2.4.3 Touch

Touch is definitely a magnificent and necessary sense. The sense of touch enables the person to gauge the distance between objects, to be alerted to danger, to enjoy the touch of another person, and most importantly in the condition where other sensory (like vision and hearing) is disturbed or non-functioning. This shows that many of our daily activities rely on this important sensory. However as we aged, comparable to vision and hearing, the sense of touch or tactile acuity is also progressively weakened [196] [197]. Tactile acuity refers to the extent to which one can discern small structural details in objects that touch the skin [198]. As reported by [178], the numbers of receptors decrease due to ageing, possibly because the drop in receptor renewal rate (threefold decrease in Meissner corpuscles in the little finger from 25 per mm^2 at 20 years to 8 per mm^2 at 80 years).

Human's sensitivity of tactile is diverse according to the body location. For example, the detection thresholds is lowest at the finger-tips, lips and tip of the tongue, while it is comparatively high on the back of the hands and feet [178]. Unfortunately, the skin becomes less taut and it loses the elasticity as people grow older [199]. Simultaneously, the loss of tissue occurs instantaneously below the skin. This contributes to the changes in the amount of fat below the skin and at the same time reducing the numbers of nerve endings. As mentioned by [178], the diminished cutaneous sensitivity towards the tactile and vibrotactile stimuli is a norm for older adults. Accordingly, the diminished sensitivity leads to the person's inability to discriminate between different stimuli and bring about the decrease of reaction time.

The abovementioned conditions are greatly allied with a higher threshold for pain [178]. The decline in nerve endings and the loss of skin sensitivity will cause an older person not to notice injuries like cuts and sores, which leads to a more serious health impact due to infections. The impairment of tactile acuity is often referred to as tactile agnosia. It is inability to recognize objects by touch, in the presence of intact cutaneous and proprioceptive hand sensation caused by a lesion in the contralateral parietal lobe[200].

In a nutshell, age-related changes in touch, skin, and thermoregulatory system (the process that allows the human body to maintain its core internal temperature) can be seen in: (1) decreased of response to thermal stress, sensation to pain, vibration, heat, cold, and pressure and reduced skin elasticity, (2) subcutaneous fat thinning that weaken the ability to maintain body temperature, (3) inefficient sweat glands that keeps cool in heat and (4) skin takes longer to heal of cut or wound. Ageing also affects elderly common manual functions, such as the important roles of the fingers to grasp, lift and manipulate objects [201].

Furthermore, the weakening of manual function is due to the decreased tactile sensitivity that continues with age, and not because of the change in hands' muscular strength [201]. More importantly, during ageing, the perceptual impaired tactile acuity caused by physiological, structural, and metabolic changes may lead to the age-related sensorimotor and cognitive domain declines [202]. Nonetheless, even if this condition has an impact on older adults' cognitive ability, implicit memory for haptic-explored objects is preserved in individuals with mild AD, despite the great impairment of AD patients' explicit memory [203]. Explicit memory is referred to as a memory of past information or experiences that can be intentionally and consciously retrieved [204]. On account of the cognitive dysfunction, the two elements of explicit memory: (1) episodic memory (retrievable personal events) and (2) semantic memory (retrievable facts and figures) are also affected.

In contrast, implicit memory refers to an unintentional or nonconscious experiential or functional form of memory that cannot be consciously recalled [204]. Since implicit memory is conserved in the early stage of AD, one of its most important types i.e. 'priming' is probably preserved too. As documented by [203], patients in the early stage of AD maintain intact haptic priming. The term 'priming' can be defined as an implicit memory effect where the exposure to one stimulus (namely perceptual pattern) influences the response to another stimulus [205].

The conservation of complete haptic priming is proven with the assessment of a speeded object naming task, even though the recognition performance is highly impaired [203]. As reported, the priming effect is compatible with the healthy older or young adults. In implicit memory, things that we do not try to purposely remember are stored, because it is both unconscious and unintentional. Therefore, designing an intervention that involves the continuous practice of a task could benefit the people with dementia. The most beneficial factor of preserved implicit memory could be to maintain the performance of the daily activities, such as riding a bike, driving a car or simple cooking tasks. Consequently, this would also work for therapeutic and training purposes for elderly with AD; for example, in wayfinding intervention strategies that require constant practice of navigation task.

It has been shown that the use of the skin or tactile perception as a medium to convey information could certainly be beneficial , exclusively when the visual and/or auditory sensory are overloaded or weakened [206][207]. Equally important, visual and hearing as they are the most needed sensory for navigational purpose, they are apparently the most affected [162] due to the age and deterioration in cognitive domain. Therefore, in conceptualizing the appropriate intervention for wayfinding assistance in particular, the use of multimodal system through the rich sensation available in human skin via tactile communication should be further explored.

To summarize, it is relatively a norm that human sensory in general is degenerated as we aged and as the cognitive domain declined. In relation to this, wayfinding also depends on the sensory acuity, as oriented search is linked with sensory mainly the visual [167]. Thus, we can conclude that the sensory impairment does have an influence towards the declining of wayfinding ability. Table 2.2 below summarized the changes in older adults and elderly with dementia for vision, hearing and touch, as preceded above.

Table 2.2: Profile of sensory (visual, hearing and tactile) change or impairments in older adults with and without dementia

IMPAIRMENT	CHANGES
Visual	• Presbyopia (old eye) manifests at around the age of 45 • Elderly have trouble to see at low light environment, discern objects with low contrast color and differentiate the shades of color. • They manifest declines in sharpness of vision, ability to focus on objects at different distances, ability to discriminate between certain colors, functioning in low light levels and adapt to dark, ability to adapt to glare, and judging distances. • One-half of all people by 65 years old have a visual acuity of 20/70 or less. • Elderly experience gradual loss of ability to focus, that makes them need more time to recognize objects or focus on objects at different distances • Color discrimination and contrast sensitivity are decreased with age • Older adults not able to distinguish between shades of colors (especially for blues, greens, and violets). • Due to deficits in the working memory, AD patients require more time for feature extraction and feature search.

	• Visual function decline correlates with the cognitive decline. This resulted in contrast sensitivity deficits in the lower spatial frequencies, motion perception are reduced, visual field defects and color discrimination of blue (short wavelength hues) is reduced. • AD patients show a decline in spatial vision in terms of static acuity, contrast sensitivity and visual processing in the periphery. • AD patients got lost in the environment because their visual processing associated with akinetopsia (motion blindness) is impaired. • Visual impairment contributes to the cognitive dysfunction in AD. Poorer uncorrected and poorer usual near- and far-vision acuity were significantly associated with poorer cognitive functioning as measured by the MMSE.
Hearing	• Age-related hearing loss (presbycusis) gradually occurs in most of us as we grow older. • The decreased in elasticity of the eardrum causes the hearing loss clearly declines with age. • Age-associated changes in hearing caused by the damage of delicate hair cells in the inner ear function as to translate soundwaves into nerve impulses. • Hearing difficulty is obvious to the higher frequencies (250 to 6,000 Hz) • Higher frequency and the words which sound similar are hard to hear because of the loss in sensitivity. • The loss of hearing results in social isolation, tendencies to be paranoid, depression and loss of self-esteem. • One of the most obvious consequences of hearing loss is the impairment in communication skill, due to the deficits in central auditory processing capacity and cognitive decline that diminish speech understanding. • Decline of hearing is cofactor in senile dementia. It increases the risk of conversion from non-demented to dementia 5 to 10 years late. • Auditory scene analysis deficit in AD is appeared as a problem to understand and follow speech in the presence of unnecessary noise. • The poor performance on both verbal and nonverbal cognitive tests is linked with the more severe peripheral hearing loss. • Decline of central auditory processing due to the severe peripheral hearing loss results in great occurrence of cognitive impairment. • There is a common foundation for non-verbal working memory deficits which affects the visuospatial and auditory information in AD. Visuospatial is common conditions of ageing and cognitive impairment. These deficits resulted in the impaired of wayfinding abilities in AD.
Touch	• As we age comparable, sense of touch or tactile acuity is progressively weakened. • Numbers of receptors decrease due to ageing, because the drop in receptor renewal rate. • With ageing, skin becomes less taut, it loses the elasticity and the loss of tissue occurs below the skin. It changes the amount of fat below the skin and the numbers of nerve endings. • The diminished sensitivity makes persons unable to discriminate between different stimuli and cause the decrease of reaction time. • Loss of touch sensory allied with a higher threshold for pain. Declined in nerve endings and because the skin loses sensitivity make older person not noticing injury like cuts and sores. • Age-related changes are decreased of response to thermal stress, sensation to pain, vibration, heat, cold, and pressure and reduced skin elasticity, subcutaneous fat thins that weekend the ability to maintain body temperature, inefficient sweat glands that keeps cool in heat and skin takes longer times to heal of cut or wound. • Aging affects manual functions: roles of the fingers to grasp, lift, and manipulate objects due to the decreased tactile sensitivity. • Perceptual impaired tactile acuity caused by physiological, structural, and metabolic change lead to the age-related sensorimotor and cognitive domain declines. • Implicit memory for haptically explored objects is preserved in individuals with mild AD. • Implicit memory is conserved in the early stage of AD and these persons maintain intact haptic priming. Even though the recognition performance is highly impaired, haptic priming is conserved. • Tactile perception as a medium to convey information is certainly beneficial, when the visual and/or auditory sensory are overloaded or weakened. • Visual and hearing are the most needed sensory for navigational purpose, but the most affected due to the age and deterioration in cognitive domain.

CHAPTER THREE

3 Related Works on Intervention Strategies

3.1 Introduction

Spatial navigation skill gradually declines for elderly with AD as the cognitive impairment increases and the disease progresses. Nevertheless, there is still lack of information on the level of wayfinding disabilities due to their severity of AD and the socio-economic impacts towards caregiving. Thus, it is important to reflect the emerging issues as a first step towards finding out the potentials of using design and technological supports to improve AD patients' wayfinding skills. The needs to develop more promising interventions or therapeutic approach on wayfinding deficit are appropriate at present.

For this section, systematic review method is used to identify and address the related literatures on wayfinding strategies which are being discussed next. Systematic review technique is chosen due to its efficient scientific technique, generalizability, consistency-and inconsistency, power and precision and accurate assessment [208]. The method is practical for both consistent scientific findings that can be generalized in terms of populations, settings, and treatment variations or if the findings are varied. Additionally, to be considered for the review, the selected articles should provide evidence regarding one of the key questions raised, and address the predictor variables of the topic [208]. In this case, it is the wayfinding strategies for people with AD or dementia.

As reported by [209], there are five main steps to be considered in conducting a systematic review: (1) framing questions for a review, (2) identifying relevant work, (3) assessing the quality of studies, (4) summarizing the evidence, and (5) interpreting the findings. But again, the search and review of related works for the question raised was divided into: (1) wayfinding intervention strategies and (2) assistive wayfinding technologies. The first review discusses on general design and technological application/intervention for wayfinding, while the second review emphasizes primarily on assistive technology.

3.2 Wayfinding Intervention Strategies

Researches that focus on other deficits of people with AD or dementia and studies about wayfinding strategies for other disabilities, mainly visual impairment in general are not less noteworthy. Moreover, the studies on these subject matters are known and well-established. Quite the reverse, research works that aim on the intervention strategies in supporting the wayfinding disability for individuals with dementia are topical and should be further promoted.

In this first review, the goal is to search and review on the existing body of works on design and technological wayfinding intervention strategies for AD or dementia patients in general. This review is indeed useful as the first step in finding the important gaps from the previous studies on the mentioned subject. The found gaps are crucial as a 'point of departure' in further developing the research.

In finding the related works to meet the aim proposed above, a computerized search using five major electronics databases was carried out. They are: (1) PubMed/MEDLINE (http://www.ncbi.nlm.nih.gov/pubmed), (2) Scopus (http://www.scopus.com), (3) SAGE journals (http://online.sagepub.com), (4) IEEE (http://www.ieee.org) and (5) Springer Link (http://link.springer.com). Relevant articles were identified through searches using the combinations of the following keywords: (1) Alzheimer's disease, (2) wayfinding or navigation, (3) orientation intervention strategy (4) design and/or technology, and (5) dementia-friendly design.

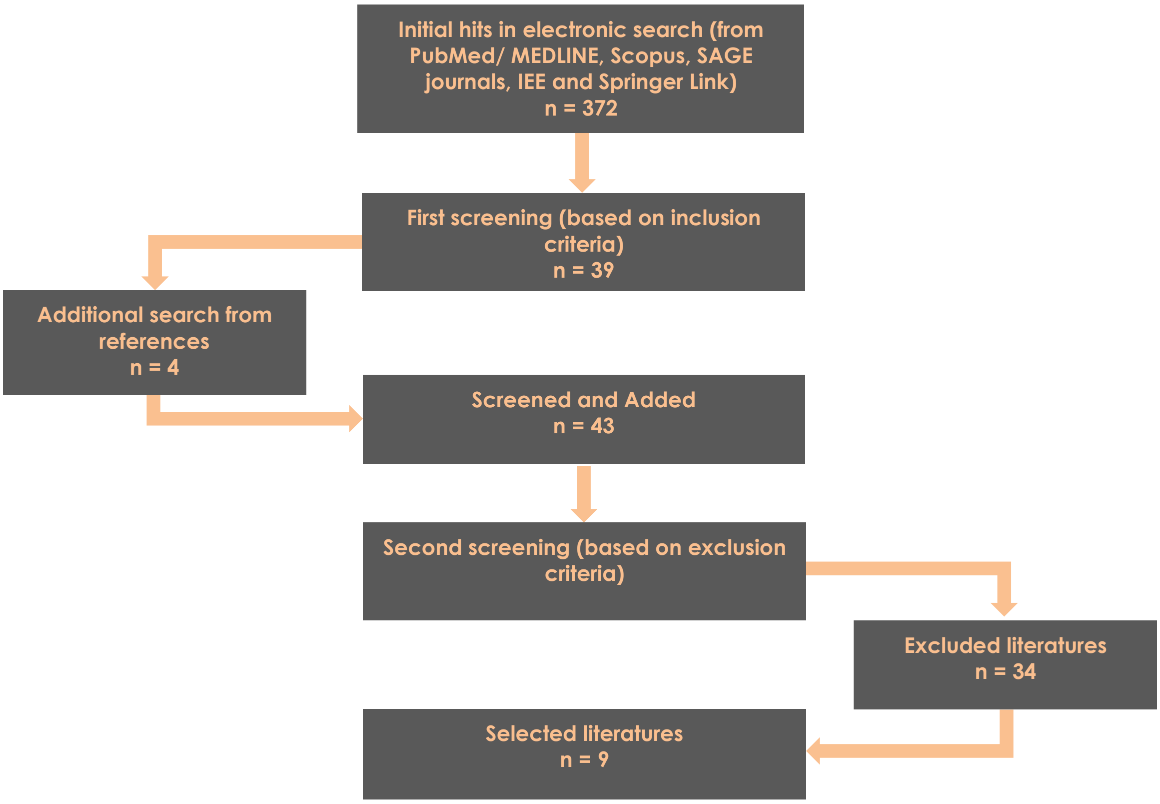


Figure 3.1: Search strategy for the selected literatures

The literatures were selected based on the iterative process and according to the topic's relevancy. Articles were included in the existing review only if they met the generic criteria of inclusions: (1) orientation strategies (or any form of intervention) by means of experimental studies that promotes the application of design and technology, and (2) an intervention to assist SD (or any terms of orientation deficits) who suffered mainly from dementia of Alzheimer's type (DAT), and (3) must be peer-reviewed articles in English language only. Recent literatures were prioritized to provide a review on the existing and advance interventions to promote diversity and avoid reiteration of similar approach. Therefore, the search was limited from 1994 onwards.

Furthermore, references listed in the selected articles were also searched using the same computerized strategy, in case of omitting appropriate articles for inclusion. Once the additional search was added, articles were once again screened and excluded if; (1) the experimental studies did not involve at least one participant who suffered from AD, and (2) qualitative or self-reported studies which were not intervention on orientation strategies. The literatures were only selected after they went through the screening procedures. The search strategy to identify and finalized the selected literatures is summarized in Figure 3.1 above.

3.2.1 Findings

From the search strategy, nine articles concerning intervention strategies to support orientation deficits caused by cognitive impairments of AD or dementia were finally selected. They were categorized into; virtual reality-based (n= 4), assistive technology (n=3), and environmental enhancement (n=2). Table 3.1 shows these selected literatures according to the main topics of discussion; demographic of participants, aims of the study, intervention strategies or the methods and the outcomes of interventions. At the outset, it should be noted that a few studies were found relevant and therefore for the purpose of generalization careful considerations should be taken into account.

The selected literatures were basically current research works with the earliest was in 2000 (n=1) and the latest were in 2014 (n=1) and consequently reveals that this area is still green. Participants of the experimental studies are one of the important topics to be discussed since the review focuses on individuals with mainly DAT. As mentioned in the criteria of inclusion earlier, recruited participants must consist of at least an individual with AD.

All the participants in these literatures varied from young adults (mainly for control population) to elderly with AD which gives the range from 25 to 94 years old. Four studies recruited control group (CG) in their experimental studies basically to compare the efficacy of interventions towards both groups of participants [142], [210], [211] and [212]. Most of the recruited participants were diagnosed with AD, but vary from preclinical, mild cognitive impairment (MCI) and DAT; mild, moderate and severe patients. The severity of AD reported in the studies was mostly based on the assessment of the oft-used Mini Mental State Examination (MMSE) test, with scores ranging from 4 to 24.

The other ratings used were Montreal Cognitive Assessment (MOCA), Cognitive Ability Screening Instrument (CASI), Clinical Dementia Rating Scale (CDR), Consortium to Establish for Registration of Alzheimer's Disease (CERAD) and Neuropsychiatric Inventory (NPI). In one study [213], specific information on type of dementia suffered by participants was not reported but ranged from mild to severe dementia.

Table 3.1: Selected literatures of intervention strategies to facilitate AD patients with wayfinding deficits

STUDY	PARTICIPANTS	AIM	INTERVENTION / METHOD	RESULT
virtual reality-based				
Zakzanis et al. [142]	8 young adults (mean age; 25.3) and 7 older adults, 2 of them diagnosed as preclinical AD (mean age: 61.6)	To examine age- and AD-related differences in route learning and memory using VR.	Spatial memory task took place in a VE integrated with virtual city.	Young adults more efficient in path navigation than older participants. Whilst, patients with AD made more mistakes on the recognition task, mistook the elements in the (virtual) city
Jheng and Pai [210]	19 Patients with early AD(mean age: 67.6) and 18 normal control (mean age: 66.4)	To investigate the cognitive maps in early AD patients and their application in a computer-generated arena (CGA).	Hand-drawing tests (for assessing cognitive map of familiar environment) and CGA (new environment learning)	Early AD patients maintain the ability to use a cognitive map and keep pretty good allocentric representation of their familiar environments similar to control group. However, both groups might not properly use their cognitive map to navigate in everyday life
Morganti, Stefanini, and Riva [211]	26 AD patients (mean age 81.0) and 26 (control) healthy, elderly subjects (mean age: 77.2)	To study whether there is a decline in performing the allo- to egocentric translation of spatial knowledge during different types of wayfinding in AD patients	Two virtual reality tasks; the VR-Maze and VR-Road Map tasks	There is a specific reduction in performing allocentric to egocentric spatial tasks in AD. But this reduction is not as obvious in equivalent allocentric spatial tasks
Zen et al. [212]	8 individuals suspected of mild to moderate AD (mean age: 71.1) and 11 cognitively healthy controls (mean age:	To investigate the orientation ability of individuals with AD using Virtual Reality Navigational (VRN) test by analysing the	VRN experiment test (a virtual cubic 3 story building, which looks identical from each side)	People suspected of Alzheimer's cannot perceive the VR without the help of a physical model. The required mapping to

	70.4)	type of user error such as “side error” and “corner error”		transfer between virtual and real world settings is deteriorated in AD subjects
assistive technology				
Lancioni et al. [214]	3 patients with mild to moderate AD (73 to 83 years old)	To assess whether AD patients could learn to use basic orientation technology to reach different rooms within their day centre.	Basic AT-based programme that provide brief verbal messages (cues)	The orientation system was effective in helping the participants to reach the target destinations within their day centre successfully
Lancioni et al. [215]	5 patients with moderate AD (72 to 80 years old)	To investigate the effectiveness of orientation programme involving auditory cues and to compare with a programme which use light cues	Auditory cues (verbal messages automatically presented from the destination) vs. light cues (strobe lights were used instead of the verbal messages) AT programmes	The programme with auditory cue system is effective. It gives comparable significant results similar to light cues programme in helping all the participants reach the target destination
Caffo et al. [216]	4 persons with moderate to severe AD (67 to 89 years old)	To compare between compensatory (AT Programme) and restorative strategy (Backward Chaining procedure), in reducing wayfinding deficit and promoting indoor travelling in AD	Comparison between AT programme (AT, i.e., remotely controlled sound/light devices) and Backward Chaining procedure (familiar objects of the environment)	AT programmes can be valuably employed for restoring and maintaining independence indoor traveling in people with moderate to severe AD. Whilst, BC procedure might be preferable in conventional teaching strategies
environmental enhancement				
Marquardt and Schmieg [213]	450 residents with dementia in 30 German nursing homes (mild, n= 91, moderate, n = 183, and severe, n = 176). Age not specified	To implement the results of the study into the design of new or remodelling of the existing facilities, mainly on floor plan typology	5 wayfinding route tasks in nursing homes which had to be a part of the activities of daily living conducted by skilled nurses.	Most significant supportive factor in floor plan typologies is the straight circulation system. Dependency on supportive environment is increasing as the severity of dementia progresses
Passini et al. [217]	6 patients with moderate to severe AD (76 to 94 year old)	To generate design criteria in order to encourage and facilitate wayfinding for advanced Alzheimer’s patients	Interviews with the staff of a typical urban nursing home, and wayfinding experience with its residents	Supportive environmental information is crucial to help wayfinding. Physical environment may result in either positive or negative impact in wayfinding.

3.2.1.1 Virtual Reality (VR)-based

There is a variety of conventional table-top assessment techniques used to measure degenerative of cognitive functioning domains, like SD as one of the major deficits in AD. However, these conventional techniques seem to be lacking of important aspect of real-world navigations, namely translocation, or at least the illusion of movement of the body in space [218]. The alternative and advanced technological application that may artificially recreate the real-world [219] is called Virtual Reality (VR) system. It is defined as technology that integrates real-time computer graphics, sounds and other sensory input to create a computer-generated world which the user can interact [220]. The adoption of VR system is meant to be dynamic, interactive and testable via Virtual Testing method [221]. It is suitable for therapeutic and assessment purposes that involve construction of physical environment. Here, four studies [142], [210], [211] and [212] that utilized the distinctive flexibility of VR in their interventions for assessing AD's wayfinding deficits are discussed.

In one study conducted by Zakzanis et al. [142], they implemented VR system to examine the relationship and differences between age and AD in route learning and memory factors. The spatial memory task was conducted in a Virtual Environment (VE) ground. In order to experience the immersive VE, video unit goggles were placed over their eyes using a Head Mounted device. In this test, they needed to navigate within the virtual city effectively and by the end of the session they were assessed on their level of recognition of the buildings and objects incorporated in the immersive VE. The test module consisted of the reallife navigation like walking on sidewalks, and crossing the street. Comparing the results of navigational task, older adults have lower average of distance travelled (effect size of d=1.17) and high number of wrong turns (mean effect size of d=1.04) as compared to young adults. This suggests that older adults faced more difficulties and took longer time to finish the navigational task, whilst AD patients took the longest and made most mistakes especially in recognizing elements and objects in the VE.

Jheng and Pai, [210] aimed to investigate the cognitive maps of individuals in early stage of AD and its application towards navigational skills in computer-generated arena (CGA). In this experimental study, they assessed at least two orientation strategies using egocentric and allocentric approaches in order to develop specific cognitive map. They posited that the individual's cognitive map could be developed by reiterating the same navigation in a particular environment. In this intervention, assessment of new environment learning and the application of the old map were conducted in CGA. The results of new and old environment learnings verified that normal controls (NCs) did slightly better and took less time than AD group, but there was no significant difference ($t=-0.47$, $p=.641$) detected. They verified that individuals with early AD were still able to use cognitive skills during navigational tasks and maintained their cognitive maps of familiar environments. The finding suggested that the declining spatial ability in early AD patients might be due to the improper use of cognitive maps in their daily wayfinding.

Morganti et al. [211] investigated whether there was a decline in performing the allocentric to egocentric translations of spatial knowledge during different types of way-finding in AD patients. Two virtual reality tasks; namely, VR-Maze spatial task (VR-MT) and VR-Road Map task (VR-RMT) were used to evaluate their abilities to explore complex environments using allocentric map but applying egocentric way-finding technique instead. The results of the correlation between neuro-psychological tests (MMSE) and (1) VR-MT (Pearson's .678, $p < .001$), and (2) VR-RMT (Pearson's .371, $p < .018$) demonstrated that VR tasks could assess general cognitive functionality and specific ego- and allocentric spatial cognitions. This indicates that AD patients portray a decreasing ability in performing allocenric to egocentric spatial tasks, but it was not as obvious in equivalent allocentric spatial tasks. In comparison, most of the participants in CG showed the ability to plan a path in the VE when provided with the same perspective.

Zen et al. [212] in their study investigated the orientation ability of individuals with AD using Virtual Reality Navigational (VRN) test by analysing the type of users' errors, such as "side error" and "corner error". This test made use of virtual cubic 3-storey building. They hypothesized that even in the early stage of AD the ability to orient using egocentric information decreased, while general orientations might be preserved by using allocentric perspective in mild AD patients. During the VRN experiment, all AD subjects were unable to find the target room as contrast to CG with the maximum error score of 80. Results of their statistical analysis showed that there was significant difference between AD subjects and CG ($p=2.5e-5$). Thus, they suggested that individuals suspected with AD were unable to perceive VR without the help of a physical model. AD subjects were able to perceive VR after practicing with the physical model that imitated VE. From this study, it could be concluded that depreciation of cognitive mapping which was transferred from virtual to real world setting was obviously demonstrated in AD patients.

3.2.1.2 Environmental Enhancement

Improvement of physical and social environments in supporting individuals with AD has gained a significant attention and carries weight in dementia care research works. However, AD patients usually show difficulties to adapt to the provided environment and less capable to control the environmental factor due to their cognitive and behavioural deficits [213]. Therefore, it is crucial to consider that their environment is designed to meet their needs. This somehow allows the autonomy to take place by maintaining an active everyday practice. Environmental factors like lighting, acoustic, climate, colour, furnishing, materials and flooring are able to be modified, manipulated and combined to meet the needs and supporting the inabilities of AD patients, which include SD, when we refer to dementia-friendly design.

Marquardt and Schmieg [213] aimed to implement the results of their study into the design of new device or remodeling of the existing facilities and the development of design criteria. They reported that architectural design of the environment might support the way-finding skills in dementia and there were two discussed aspects: flooring and environmental cues. They posited that the level of resident's way-finding abilities that were influenced by characteristics of architectural structure could be measured by the destinations reached independently by the residents in the nursing homes. Five distinctive routes were chosen within the living areas of the nursing home in supporting the residents' autonomy. Three major floor plan typologies were then identified through an empiric-qualitative exploration and were subdivided into (1) straight circulation systems consisting of (2) layouts that featured one shift in direction and (3) continuous paths around an inside courtyard. Statistical evaluation demonstrated that the most significant supportive factor in the case of floor plan typologies was the straight circulation system, with $P = 0.001^c$ (as ^{c} is extremely significant). This study shows that the dependency on supportive environment increases as the severity of dementia progresses.

In a research conducted by Passini et al. [217], they aimed to generate design guideline in encouraging and assisting navigation for AD patient with advanced severity. This study used interviews (with 10 staff members of the nursing home) and way-finding experience (with patients) as the complementary methods of data collections. The selected staff members consist of the director of the nursing home, a security agent, an occupational therapist, a physiotherapist, a recreation guide, 2 orderlies, and 3 nurses. Performance in wayfinding tasks were varied among participants and no further statistical analysis was reported.

However, the results suggestedw that even patients with severe cognitive deterioration are able to reach certain destinations provided that the environmental information was well programmed and easy to access. This study concludes that the physical environment determeines the efficiency in wayfinding techniques albeit it is able to create problems and provide solutions for the wayfinding issues.

3.2.1.3 Assistive Technology

The term assistive technology (AT) may refer to a device, system or tool that allows individual to perform a task that they would otherwise be unable to do, or increases the ease and safety with which the task can be performed [222]. Available technologies for assisting AD patients can be classified into screening, memory aids, monitoring health or safety, information sharing or tele-care, and also communication support and therapy [223]. AT in promoting navigation or wayfinding due to spatial orientation deficits are yet to be explored and this may be significantly beneficial mainly for individuals with cognitive impairments. Studies by [214], [215] and [216] implemented AT programme in the orientation strategies quite successfully. The general aim is to assist wayfinding and allow independency among this segmented population.

Lancioni et al. [214] for instance, assessed that individuals with AD could learn to use AT in the form of basic orientation technology to find different rooms in their nursing home. In their study, orientation system which included a sound source at each of the destination and a portable control system to activate and deactivate each of those sources was set. Brief verbal messages (cues) from targeted destinations were also provided during the test. From the results, the orientation system provided was effectively used by the participants to reach different room destinations within their daycare center. The percentage of travel accuracy was improved to almost 100% from 30% to 40% during the baseline sessions. This credibly demonstrates the efficiency of this form of basic orientation technology to inexperience populations and provides the promising alternatives for maintaining minimal orientation ability within individuals with cognitive impairment.

In a different study by Lancioni et al. [215], they investigated the effectiveness of orientation programme involving auditory cues and compared it with a programme which used light cues. In this study, auditory cues used the verbal messages automatically presented from strategic destinations; while in the light cues procedure, strobe lights were used instead of the verbal messages. Results showed that the programme with auditory cue system was effective and gave equally strong impact on the programme with light cues in helping all participants to reach the target destinations. There was a significant increase in mean percentages of correct travels (up to 95%) by most of the participants during the intervention phase, as compared to (10% to 30%) during the baseline sessions. In addition, results from the social validation assessment recommended that programme using light cues was more practical and preferable by the social raters although both cues were equally worthy.

Caffo et al. [216], in their study aimed to compare between a compensatory (AT Programme) and a restorative strategy (Backward Chaining procedure), in supporting way-finding in an indoor environment of persons with moderate to severe AD. AT programmes include remote controlled sound and light devices, while Backward Chaining (BC) procedure include familiar indoor objects as landmarks for each section of the route like chairs, large pictures, small furniture, coloured pillars and automated doors. The results demonstrated that mean percentages of travel/route sections in participants was above 90 during the intervention with the AT, whilst only 37 to 54 in BC programme. This finding suggested that AT programmes were more adoptable in maintaining autonomy of indoor travelling for AD patients, and highly efficient in reducing their wayfinding deficits. BC procedure on the other hand, was more preferable for conventional teaching strategies. In the social validation assessment, higher results were given to AT programme in terms of comfort, competence and self-determination, whilst BC had higher score in the aspect of environment.

3.2.2 Discussion

This review has identified a growing body of research that aimed to assist spatial orientation deficits in individuals with AD to navigate, orientate, or find their ways to reach certain destinations within their given environments. Apparently, all the mentioned intervention strategies reported positive results on AD patients' spatial representation after the implementation of the interventions. The adoption of design and technological knowledge were brilliantly utilized and feasible in the reviewed experimental studies.

In virtual reality-based orientation strategies, VR system seems to be an appropriate tool of assessment in identifying the declining spatial orientation ability in AD patients. This review has revealed various acceptations by AD patients towards perceiving VR system in the interventions. [142] for instance, explained that AD patients took longest and made most mistakes in recognizing elements in VE as compared to the other participants. Additionally, AD patients showed declining wayfinding ability due to the confusion in their cognitive and spatial domains.

As agreed by [212], this problem challenges the ability of demented people to orientate in the VR tasks and are unable to perceive VR without the help of a physical model. This is due to the depreciation of cognitive mapping from virtual to real world setting. In contrast, [210] suggested that AD patients in the early stage were able to maintain their cognitive maps in both VE and real-world, but claimed that the decrease in orientation skills was possibly caused by improper use of cognitive in everyday practice. Despite the different perceptions indicated in individuals with AD, the use of VR system for assessment is still acceptable. For training purposes, although conservation of such route learning ability is not assured, it may give encouraging effects after constant practice.

For the interventions using AT, all the discussed results from the reviewed literature show promising results. The ATs used in the orientation strategies were not too complex and were easy to implement. This suggests that basic orientation technology is still effective even for inexperienced people and people with mild to moderate AD. This is recognized by more recent study by [215] that confirms the orientation programme using auditory cues is also as efficient as light cues in assisting the participants with moderate AD to reach the task destinations.

In addition, [216] who also used auditory and light cues as AT programmes claim that orientation strategies using AT programme was highly efficient as compared to BC procedure which use familiar objects in reducing wayfinding deficit in patients with moderate to severe AD. However, all the reported interventions took place in nursing homes covering limited area of the environment where AD patients live in. AT programme using uncomplicated system might be significantly helpful for indoor navigation within the nursing homes. However, there is lack of evidence that suggests it may have compatible positive effect on outdoor way-finding.

Similar to AT programme, interventions with environmental enhancement involve the use of physical environment as the apparatus of assessment. As claimed by [211], the dependency on supportive environment increases as the severity of dementia progresses and proves that uncomplicated floor plan typologies (straight circulation system) is the best in indoor travelling. The importance of providing appropriate environment to support wayfinding is also agreed by [217] as they claim that a well-designed physical environment with the appropriate environmental information could be useful even for more severed AD patients. The improvement of existing physical environment plays a significant role in defining the effectiveness of wayfinding, where it also may provide the solution to the existing wayfinding problems.

In general, pertaining to therapy perspective, AT programmes and virtual reality-based orientation strategies seem to be best employed towards less impaired patients, (mild to moderate stage of AD and the stages before fully-blown AD, i. e. preclinical AD and MCI), who are more capable to adopt and practice the remaining learning skills. Whilst environmental enhancement can be a good way in maintaining most of motor skills left in AD patients including SD, good knowledge in their specific and demanding needs is a must before a real physical environment can be constructed.

This review demonstrates that at present, a precise direction and magnitude of the effectiveness of one group of intervention towards significantly reducing the SD is yet to be conclusively found; considering the extraneous variability of population, intervention, comparators and outcomes. Nevertheless, the knowledge of design and technology has been adopted as mentioned in the literatures; hence, demonstrating its significant contribution as the domain of intervention concepts. For instance, creating the computer-generated environment as referred to VE that resemble the real-world environment almost accurately, requires both technical and aesthetic skills.

In addition, designing the appropriate technological devices to be used for these cognitively impaired individuals is quite a challenge. Besides understanding the exhaustive needs from gerontology and neuroscience viewpoints, other aspects like ergonomics, functionality and aesthetic perspective carry the same credible weight as well. Similar to the construction of enhanced physical environment to cater to these specific needs, the conceptual design went through several assessments before it could be approved to be built.

The whole process of designing the intervention concepts apparently resembles this fundamental approach of blending design and technology, regardless of the diversity of implementers' field backgrounds such as science streams, social sciences or in between. While this approach can at least carry a valuable supplement in conceptualizing the orientation intervention strategy, imperative study on identifying the limitations of this specific group due to their changes and impairments in cognitive and motor function as well as the sensory and physiology is highly recommended. This information in particular can help implementers and researchers in finding better alternative solutions, or design guidelines in terms of design and technological applications towards reducing SD and promoting wayfinding abilities.

Furthermore, there is a growing body of interest to use technology in assisting AD patients to perform and maintain their daily activities such as memory aids, health monitoring, and communication supports. Nonetheless, research works that focus on the use of technology for navigational assistance mainly for AD patients are still lacking and can be improved. This is the clear reason why this study highlights on the importance of using available technology as a form of supportive tool for this undervalued need. Therefore, we found that it is necessary to conduct another systematic review which stresses on this particular matter.

3.3 Assistive Navigational Technology

In this review, the emphasis is on technological applications that support wayfinding (or navigational assistance). The term 'assistive technology' is defined as any device or system that allows an AD individual to perform a task that they would otherwise have difficulty performing [222]. In terms of mobility and navigation of individuals with cognitive impairments, AT is utilized mainly to enable and improve their wayfinding abilities with less dependency, while at the same time recognizing their disabilities.

In one study by Caffo et al. [224], they reviewed and categorized the orientation and wayfinding intervention strategies into compensatory (performing cognitive and behavioral tasks to avoid cognitive deficits) and restorative (restoring the functions of specific domains to slowing the progression of the disease) approaches. They thoroughly reviewed methods or intervention strategies used to promote spatial orientations in individuals with dementia.

However, only one of the strategies definitively focused on the use of technological intervention in supporting navigation: Assistive Technology programme.

They presented many non-technological solutions, such as spatial cues (significant reference points), reality orientations (improving the ability to deal with reality), backward chaining (learning tasks in reverse for what were usually performed) and errorless-teaching (learning new information without error) techniques. Therefore, the needs to review technological interventions to help the wayfinding or to improve navigability for dementia patients would fill the epistemic gap. The technological approach adopted for a wayfinding strategy commonly relies on its fundamental goal and varies according to the setting. For that purpose, the selected studies were reviewed in terms of the settings, participants, aims, strategies and results.

Once again, a computerized search strategy using the same major electronics databases in the first review was conducted. The relevant articles were identified using the combinations of following keywords: (1) assistive technology, wayfinding and dementia, (2) assistive technology, navigation and dementia, (3) assistive technology, wayfinding and AD, and (4) assistive technology, navigation and AD. The iterative selection process was more complex and based on the criteria of inclusion and exclusion, and commenced from pre-screen, post-screen and ended with the finalized selections. Figure 3.2 presents a simplified description of this search strategy and selection process.

The inclusion criteria used were: (1) intervention by means of experimental study, pilot research, design guideline or design concept, (2) technological applications used to promote or enhance wayfinding ability, (3) involve mainly AD or dementia participants, (4) written in English language, and (5) not earlier than 1995. Recent publications were prioritized in order to provide a review of current interventions and advanced technologies.

The initial hits of database search with the combinations of keywords as preceded above were first screened using these mentioned inclusion criteria. Furthermore, references listed in the pre-screened articles were searched for additional appropriate articles to include. Once the additional articles from the references were added, all of the articles were screened again. In this post-screen stage, some irrelevant articles were omitted from the finalized selections according to the exclusion criteria; (1) not involving at least one AD or other dementia participant and (2) no concrete validations by means of experiments or evidence-based strategy, and (3) insubstantial results. The final selection of articles was completed after following these two extensive screening stages.

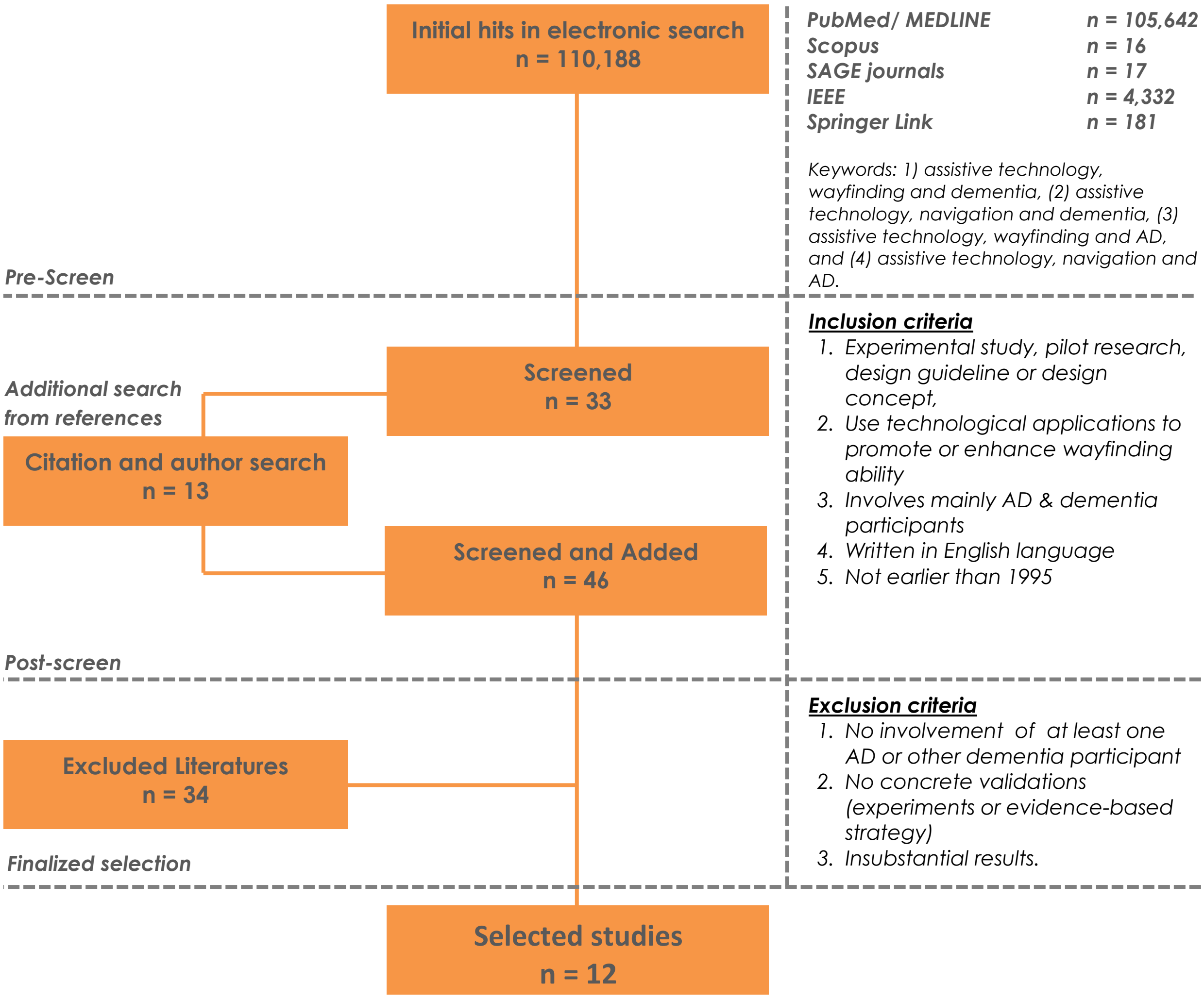


Figure 3.2: Overview of the search strategy and literature selection process

3.3.1 Findings

From the search strategy mentioned, twelve articles were finally selected for the review. These articles were then reviewed mainly in relation to four related themes: (1) demographic of participants, (2) aims of the study, (3) intervention strategies and assessment method and (4) outcomes and efficiency of strategies. The intervention strategies in the studies showed the utilization of diverse technological approaches, especially with regards to the settings (indoor and outdoor navigation). Thus, according to the finding patterns, these selected articles were divided into three intervention strategies; indoor (n=8), outdoor (n=3), and both indoor and outdoor (n=1) wayfinding strategies. We found that these articles were current, with the earliest publication appearing in 2008 (n=2) and the latest in 2014 (n=1).

Again, participants recruited in the studies are one of the most important matters to be discussed because this articles aims to review the available technological interventions by means of navigational assistance appropriate for AD and other dementia patients. Similar to the previous review, some flexibility was applied due to the fewer studies that only recruited AD and other dementia participants. For instance, there are articles selected although they did not mention the types of dementia diagnosed in their participants [225][226][227]. Additionally, in some cases, severity (or stages) of AD or dementia were not mentioned [225][226][227] [228] [229], and sometimes participants were only categorized as mild, moderate or severe dementia [230] [231]. We surmised that the concept 'dementia' itself referred to AD, since AD represents most (60-80%) dementia cases [232].

In addition, as discussed in Chapter One, there were three stages of AD: preclinical AD, (MCI) due to AD, and dementia due to AD which included variation of mild, moderate and severe [17]. Thus, the studies that recruited at least one participant diagnosed from any of these stages of AD were selected for review in this article. The cognitive impairment was identified mostly from the assessment of neuro-psychological tests. The most common test used was the Mini Mental State Examination (MMSE). The other cognitive-based ratings used were Clinical Dementia Rating (CDR), Global Deterioration Scale (GDS) and Neuropsychiatric Inventory (NPI).

In general, the selected studies aimed to investigate the efficacy of their specific wayfinding intervention strategies towards the recruited participants. The strategies varied from the utilization of simple technology (low-tech) to more complex electronic devices with Information and Communication Technology (ICT), where the use of these technological approaches were correlated to the settings of environment: indoor, outdoor or both. These subgroups of intervention strategies are summarized in Table 3.2. For that reason, the next sections reviewed the selected literature according to these (environmental settings) subgroups.

Table 3.2: The selected literatures of Assistive Navigation Technology based on the environmental settings

STUDY	PARTICIPANTS	AIM OF STUDY	STRATEGY / METHOD	RESULTS
indoor wayfinding				
Lancioni et al. [214]	3 patients with mild to moderate AD (73 to 83 years old). MMSE scores were not specified	To assess if AD patients could learn to use basic orientation technology to reach different rooms within their day center	Basic AT-based programme that provide brief verbal messages (cues)	The percentage of travel accuracy is improved. Orientation system was effective in helping the participants reach the target destinations
Lancioni et al. (2) [215]	5 patients with moderate AD (72 to 80 years old). MMSE scores were not specified	To investigate the effectiveness of orientation programme involving auditory cues and to compare with a programme which use light cues	Auditory cues (verbal messages automatically presented from the destination) vs. light cues (strobe lights were used instead of the verbal messages) AT programmes	Auditory cue system is effectives and gives equally promising result with the programme with light cues in helping participants reach the target destination
Caffo et al. [216]	4 persons with moderate to severe AD (67 to 89 years old). MMSE scores were not specified	To compare between a compensatory (AT Programme) and a restorative strategy (BC procedure), in order to reduce topographical disorientation in persons with AD	AT programme (remotely controlled sound/light devices) vs. Backward Chaining procedure (familiar objects of the environment)	AT programmes able to restore and maintain independence indoor traveling in moderate to severe AD patients. BC procedure is preferable for conventional teaching strategies within daily contexts
Ou et al. [233]	12 patients with AD (MMSE; 15.6), 12 patients with MCI (MMSE; 19.5) and 24 normal elderly subjects (MMSE; 26.4). Ages were not specified	To explore the effect and the difference between types of navigation maps (north-up map vs. track-up map), landmarks, and the map complexity on the wayfinding abilities of AD patients	Wayfinding task in VE using 2 electronic maps; track-up map and north-up map. 2 map scales; full-scale and small-scale	Less time taken using small-scale and track-up map, as compared to full-scale map and north-up map. AD took the longest times, followed by MCI and normal elderly
Chang, Tsai and Wang [226]	6 volunteers aged between 19 to 76 years old (mean age of 37.7) with different cognitive, one of them has dementia. MMSE score were not mentioned	To improve workplace and life autonomy in individuals with cognitive impairment based on geo-coded QR codes navigation system.	Navigation in 5 routes combining stairways, elevators, and turns using wayfinding system based on QR codes and PDA	Most participants failed the navigation task without the device. Human-computer interface in the system is user-friendly and has promising competency
Chang et al. [225]	6 individuals aged between 19 -76 years old (mean: 37.7) and only one of them diagnosed with dementia. MMSE score were not mentioned	To provide a distributed cognitive support of travel guidance for individuals with cognitive impairment	Navigation in 5 routes that combined use of stairs, elevators and turn on different floors and spaces using passive near-field RFID tags and scanning with PDA	High successful wayfinding rate and passive RFIDs tagging is able to trigger navigation prompt.
Viswanat-han et al. [227]	6 elderly with dementia (3 mild and 3 moderate dementia) aged between 66 - 97 years old (mean: 81.8). MMSE score between 15-25 (mean:18)	To provide an adaptive navigation assistance using an intelligent wheelchair for individuals with cognitive impairment	A maze task using intelligent wheelchair that includes 5 types of wheelchair movements and a user survey	Number of collisions is decreased. Wayfinding module helps participants with memory and vision impairments
Grierson et al. [234]	11 persons with AD and 1 person with mild MCI. Age between 61-85 years old (mean: 73.6) and MMSE score between 16-28 (mean: 20.6)	To access the applicability of the wayfinding signals to persons with dementia using wearable belt with vibrating motor	Wayfinding task using four-motor way-finding belt (that gives vibrotactile signals)	Individuals with mild dementia are capable, confident, comfortable and able to use with vibrotactile signal properly, but not advisable for moderate dementia
outdoor wayfinding				

Hagetho-rn et al. [228]	7 individuals with dementia, 4 of them were diagnosed with AD. Age and MMSE score were not mentioned.	To investigate the difference of navigational performance between landmark based and left/right instruction	WoZ park and town pedestrian walks using audio instruction controlled by wizard	Participants have difficulties to interpret direction indicators and using the wayfinding aids. Audio instructions could improve navigability and offers sense of autonomy
Veldkam-p, Hagethorn and Greef [230]	6 elderly with early dementia. Age and MMSE score were not mentioned.	To study the design options of a GPS-based navigation aid for elderly in beginning dementia.	Navigating in 2 routes based on; directional instructions and directional instructions with landmark using pedestrian navigation system made of PDA and audio information.	Navigation with landmark information has a lower number of errors and hesitation, also has slightly more positive results on participants' attitudes.
Olsson et al. [229]	3 individuals with AD (age of 72, 76 and 72 years old) and their spouses (age of 72 74 72 years old accordingly). MMSE scores were not mentioned.	To investigate the effects of using tracking technology on independent outdoor activities and psychological well-being of individuals with AD	Tracking system (PPA) using transmitter that provides location information to the spouses.	The tracking system supports patients' independence of outdoor activities. Spouses' worries were reduced.
indoor & outdoor wayfinding				
Sorri, Leinonen and Ervasti [231]	9 elderly with mild to severe dementia aged between 59 - 90 years old (median age of 84 years), with MMSE score between 3 - 23 (mean score of 12)	To develop a prototype of wayfinding aids in helping the wayfinding of elderly with memory disturbances	3 indoor and 1 outdoor routes using; audio and tactile, visual and tactile, and visual and audio wayfinding aids.	Wayfinding aids help the participants to succeed the routes. Using "left, right and go straight" commands were more successful than using landmarks.

3.3.1.1 Indoor Environment

Most of the navigational assistance strategies to strengthen indoor navigation took place in institutions, such as daycare centres, nursing homes, or hospitals. The proposed approaches are important, as they assist patients in distinguishing environmental elements or objects, which results in reducing confusion during the journey toward targeted destinations inside an institution.

There are three studies by Lancioni et al. [214], Lancioni et al. (2) [215], and Caffo et al. [216] that had been selected for the previous review, were selected again here. This was principally due to the relevancy (recruited participant and technological interventions for wayfinding), significance findings, as well as the strategies proposed meant for indoor wayfinding. However, these studies had been reviewed before; mainly on the aims, method/strategies implemented, and findings. Emphasis is now given on the undiscussed matters such as the recruited participants.

Lancioni et al. [214] recruited three patients with mild to moderate AD, aged between 73 to 83 years old (mean MMSE score of 16.7) for this experiment. While Lancioni et al. (2) [214] involved five participants, aged between 72 to 80 years old, who were diagnosed with moderate stage of AD with MMSE score below 17. On the other hand, in the study by Caffo et al. [216], there were four patients, aged between 67 to 89 years old with moderate to severe AD (MMSE scores were less than 17) participated. These studies reported positive results on the proposed strategies to assist the indoor wayfinding of dementia patients. In addition, they conducted social validation assessments to validate their experiments and to strengthen the findings. Perceived social validations were customarily performed to evaluate behavioural changes [235] after the implementation of an intervention. This form of assessment was found to be beneficial and vital to understand the significance of goals, intervention outcomes and procedural pertinence from a social perspective.

After these aforementioned studies, then came the study by Ou et al. [233] that aimed to explore the effect and the difference between several types of navigational maps (north-up map versus track-up map), landmarks, and the map complexity on the wayfinding abilities of AD patients. They recruited twelve patients with AD (mean MMSE score; 15.6), twelve patients with MCI (mean MMSE score; 19.5) and twenty-four normal elderly subjects (mean MMSE score; 26.4). The ages of participants were not mentioned in their study.

In contrast, the navigational task used in this study was composed of a simple 'virtual maze' that resembled an indoor space. Two electronic maps were evaluated: a track-up map which was (where the north side was always facing up, so users must turn to north when initiating travel). They provided two map scales: a full-scale (displaying the full turns), and a small-scale (displaying only three turns). Results showed better performance utilizing a small-scale and track-up map in terms of time taken, as compared to the full-scale map and the north-up map. Comparing all groups of participants, AD took the longest times. The authors concluded that uncomplicated map and removing landmarks could improve navigational performance. This finding suggested that the cognitive load of each task needed to be reduced if the task involved AD patients.

Chang, Tsai and Wang [226] aimed at improving workplace and life autonomy in individuals with cognitive impairments using geo-coded Quick Response (QR) codes navigation system. Six participants, age ranging from 19 to 76 years old (mean age of 37.7), took part in the experiment; with only one of the participants being diagnosed with dementia. But, MMSE scores or other neuropsychological test results were not reported. The system consisted of: (1) an electronic handheld information device, Personal Digital Assistant or PDA (that showed photos with directions and instructions when prompted by QR-code tags), (2) a tracking system (individual ID recorded by PDA and information of positions were sent to server), and (3) a training system (to introduce the routes, photos and directions). The system worked by scanning a QR-code, which prompted the PDA to send the user's location information via a local area wireless technology or Wi-Fi. Photo-embedded directions were then delivered to the PDA.

In the experiment, five routes were used. These routes combined the use of stairs, elevators, and turns on different floors and spaces to reach target destinations inside the building. Results showed that the prototype proved useful for most of the participants (four out of six), who would have failed in the navigation task without the device. They concluded that the human-computer interface of the system was user-friendly and had potential to support wayfinding. However, the success ratio may interrelate with the users' disabilities and the complexity of routes. Therefore, to assess the effectiveness of this intervention would require more participants and replications of the study.

In a later study by Chang et al. [225], they used a tagging system to provide distributed cognitive support for individuals with cognitive impairment in terms of travel guidance. This study recruited the same participants as in the earlier study. In addition, they also used five routes that combined stairways, elevators, and turns for the experiment. However, there were slight differences in their design of the wayfinding system. The authors proposed a concept using passive near-field Radio-Frequency Identification (RFID) tags (wireless use of electromagnetic fields to transfer data to automatically identify and track tags attached to objects) and a scanning function of a Personal Digital Assistant (PDA). The process of travel guidance begins with the sensing of an RFID tag, allowing the PDA to receive the users' location. GPRS then delivers the location information to a server and a photo augmented with an arrow is sent back to the user to support wayfinding. The researchers reported 90% success on wayfinding tasks from the thirty trips made by the six participants. This reveals the possible use of passive RFIDs tagging to trigger navigational prompts, though individual success varies.

In another study, Viswanathan et al. [227] aimed to provide adaptive navigation assistance for individuals with cognitive impairment using an intelligent wheelchair. In this study, six older adults participated. The ages of the participants ranged between 66 and 97 years old (mean age of 81.8), with MMSE scores between 15 and 25 (mean score of 18). The Navigation and Obstacle Avoidance Help (NOAH) system of the study consists of an intelligent wheelchair that uses computer vision and machine learning methods. The system works when the signals are sent from the laptop to the wheelchair, to allow or deny the movements of wheelchair in specific directions.

The maze or the navigation task included five types of movements: (1) 90° right turn, (2) 90° left turn, (3) entering a narrow straight line path, (4) weaving movements, and (5) ceasing. Following the task, the users completed a survey based on collision avoidance, concerns with powered wheelchair use, overall contentment with the system, and attitudes towards autonomy. Although participants voiced different practical abilities, results suggested that the number of collisions decreased and the wayfinding module managed to facilitate wayfinding for participants with memory and vision impairments. The findings of this study suggest that an automated navigation system could benefit older people with cognitive impairments, as it allows safe and independent mobility.

Grierson et al. [234], on the other hand, utilized a different approach using a less explored technology to support navigation. They aimed to investigate the applicability of tactile signals to assist the wayfinding of persons with dementia using a wearable belt with vibrating motor. In this study, eleven persons with AD and one person with mild MCI were recruited. They were between 61 to 85 years old (mean: 73.6) with MMSE scores of 16 to 28 (mean: 20.6). Vibrating motors were situated on a belt in the front, back, right, and left positions. In the experiment, participants were asked to wear this belt and navigate a series of routes within a hospital with the assistance of vibrotactile signals and locate the target destinations.

Although there were some hiccups during that intervention related to instructional mistakes (such as confusion of the given signals), they suggested that the built-in tactile signal on the wayfinding belt was potentially helpful as navigational assistance for individuals with dementia. Furthermore, tactile signal provides a simple, yet promising, form of directional cueing that allows users to concentrate more on the surrounding's visual and acoustic qualities during wayfinding [236].

3.3.1.2 Outdoor Environment

Declining wayfinding abilities encountered by people with dementia, is claimed to be one of the major reasons for patients being committed to an institution [135]. This is due to the fact that deficit in spatial ability may indicate impairments in cognitive functions [132]. Thus, providing support to enhance mobility and navigability for people in early stage of cognitive decline could delay the process of institutionalization, although there was no established way to actually terminate the disease's progression. In this subcategory, most of the navigational tasks in the experimental studies involve reaching common areas or destinations within a participant's everyday routine and surroundings. This demonstrates that the strategies are appropriate for patients in early stages of AD who still live at home.

In one study by Hagethorn et al. [228], Global Positioning System (GPS)-based navigation aids were used to investigate the difference in wayfinding performance among landmark-based navigation and left/right instruction. In the phase of investigating problems in wayfinding, seven individuals with dementia took part. Four of the participants were diagnosed with AD (although age and MMSE score were not reported). The authors identified that the most mistakes made during the navigational task without electronics devices were related to the process of decision-making when beginning to walk. Therefore, we can safely conclude that AT devices may reduce the chance of AD patients wandering aimlessly, at least as compared to having no AT device at all.

In a later phase of the same study, they evaluated the efficiency of an electronic navigational aid using a Wizard of Oz (WoZ) [237] approach, since they did not have a ready working system. The WoZ method enables the evaluation of unready technology through simulated system responses [238]. Four individuals from the earlier phase participated in this experiment. The system used was similar to existing GPS-based navigation aids. In this experiment, two routes were used: one through town and the other through a park.

During the walks, participants received audio instructions from a PDA controlled by the wizard (researcher) who assisted them determining the appropriate direction. The results showed that participants faced many difficulties, such as the interpretation of direction's indicators and the use of the wayfinding aids in navigation. In addition, the use of audio instructions as additional information for recognizing landmarks may improve the decision making of appropriate direction, while supporting a sense of autonomy during independent walks. There was another phase of experimentation in this study, but the strategy and procedure used were very similar and would be explained more clearly in the next literature review.

In a separate article, Veldkamp, Hagethorn and Greef [230] aimed to understand design options for a GPS-based navigation device for older adults in their early dementia stage. This study is the subsequent stage of the study mentioned above. Six participants with early dementia from a day care center were recruited in this experiment, but the age and type of dementia and MMSE score were not reported. As described previously, the experiment was conducted using the 'Wizard of Oz' (WoZ) method [237] since they did not have a ready working prototype. For this experiment, they created a pedestrian navigation system using a PDA.

Audio information was provided to the participants by the PDA through a Bluetooth system. Two outdoor routes with similar difficulties and a number of instructions were used, but with different navigation information: (1) directional (left/right/straight) instructions on decision points and (2) directional instructions augmented with landmark information. Comparing both route conditions, results showed that navigation with landmark information had a lower number of errors and hesitations (with almost 50% difference). In terms of participants' attitudes, navigation with landmark information yielded only slightly more positive results.

Olsson et al. [229] aimed to investigate how the use of tracking technology affects independent outdoor activities and psychological wellness of individuals with dementia. Three individuals diagnosed with dementia of AD type (age of 72, 76 and 72 years old) and their spouses were recruited (age of 72 74 72 years old accordingly). MMSE scores were not mentioned but Neuropsychiatric Inventory (NPI) ranged from 3 to 44. In this study, a system called passive positioning alarm (PPA) was used for tracking. The system comprised of a transmitter with GPS, and a cellphone. In the experiment, the participants carried the transmitter along with them during independent outdoor walks. If the participants travelled outside the predefined area (500m), a concise message (alarm) with location information was sent to the cell phone of a spouse.

For this intervention, participants' own premises and local surroundings were used in order to build upon the autonomy that came along with being in a familiar setting. Results showed that there was an increase in access to the PPA system during the independent outdoor activities, and this access reduced the level of spouses' worries. From these results, the authors concluded that the utilization of this tracking system could promote patients' independence during outdoor activities while reducing the concerns of their spouses.

3.3.1.3 Both Indoor and Outdoor Environments

Intervention strategies for both indoor and outdoor environments tend to rely upon technological approaches that can be implemented across different settings. These technological interventions are beneficial because they can be utilized both in the indoors and outdoors of homes or institutions. Additionally, they offer choices of modalities (in terms of functions and features inside the designed ATs), which enables customization according to individual needs and preferences of patients. However, not many studies aimed to implement their strategies for both indoor and outdoor wayfinding at the same time. This is probably due to the availability and suitability of the system and interface to be used that would be more fitting for a specific setting. In fact, for this subcategory, there is only one study found relevant to be reviewed.

Sorri, Leinonen and Ervasti [231] developed a prototype of a technological solution to assist the wayfinding of elderly with memory disturbances. They tested the wayfinding aid prototype in accordance to predefined indoor and outdoor routes using three procedures/modalities; (1) audio and tactile, (2) visual and tactile, and (3) visual and audio. In this study, nine older adults participated. These participants had mild to moderate dementia and were between 59 and 90 years old (median age of 84 years old), with MMSE score between 3 and 23 (mean score of 12).

The wayfinding aids included a visual signal made from augmented text and arrow on a picture, voice instruction as an audio signal, and vibrating wristbands as a tactile signal. Results showed that patients were better able to understand and comprehend visual and audio signals as wayfinding aids than audio and tactile or visual and tactile combinations. The authors suggest that using "left, right, and-go-straight" commands are more successful than using landmarks. The navigational performance of the wayfinding aids is, however, independent of the severity of dementia. Thus, even with a few misinterpretations of the cues, they found that orientation with technology-based wayfinding aids can help older adults with memory disturbances to reach predefined destinations. The findings demonstrate the need for future researchers to investigate customization of wayfinding aids modalities.

3.3.2 Discussion

Based on the studies described above, technological interventions aimed at supporting wayfinding strategies show promising results when implemented. As mentioned earlier, the utilization of a concrete strategy for wayfinding is highly dependent on context and the intended environment for the intervention. In indoor wayfinding interventions for instance, basic technology such as sound and light cues are useful even for inexperienced people and those with early dementia [214][215][216]. As visual and auditory supports were quite common in navigational assistance; these modalities did not always work for individuals with AD. Hence, less explored cues, like tactile signals, [234] in an appropriately designed system could give encouraging effects in supporting the wayfinding of AD patients.

One of the benefits of indoor navigation is the possibility of using the architectural elements or objects inside the indoor environment itself. Often, these elements are used as spatial cues or reference points (landmarks) in the environment. Here, some technological applications may benefit from the use of tagging and scanning strategies, such as RFID and QR Codes [226] [225] systems, applicable within the indoor and closed space. Besides, there are more advanced applications applicable for this method. For instance, near Field Communication (NFC); radio communication between electronic devices developed by Samsung [239] and iBeacon (indoor situating system by Apple Inc.) [240]. Wayfinding systems integrated with these technological applications could be considered as the new alternative for navigational assistances.

From the review above, the most prevalent technological applications used for outdoor wayfinding among researchers are GPS-based interventions. GPS provides real-time information about locations [241]. For navigational assistance purposes, GPS systems are beneficial in two ways: (1) the utilization of landmarks as a point of reference [228] [230] and (2) as tracking systems [229]. Comparing wayfinding with an indicator alone (without landmark reference) and indicators with landmark references, the review has revealed that the utilization of landmarks is much more practical and most preferred.

The reason why is because during the course of outdoor navigation, there is always a chance of missing the provided signals or guides [242], even with the most precise navigational assistance systems. Thus, with landmark-based wayfinding aids, even if a signal is missed, patients can still refer to their current location based on the real-time wayfinding situation. In addition, making the location information known or accessible is useful for tracking systems.

In contrast, in wayfinding situations that include both indoor and outdoor environments, the utilization of landmarks is less efficient as compared to indicators alone or directional instruction (left/right commands) [231]. The reason for this is probably because there are many indoor architectural elements that look identical, such as doors, windows, and flooring. The similarity among indoor elements can engender misinterpretations, which can result in even worse spatial cognition and navigability issues.

Apart from these reviewed literatures, it should be noted here that several other studies were not selected for review due to the lack of information or insubstantial evidence about the interventions. Kulyukin et al. [243] for instance, developed three intelligent walkers with specialized features (such as a self-powered walker with a haptic interface and autonomous navigation capability) to promote independence in familiar and unfamiliar environments for the elderly. The concept of an intelligent walker was acknowledged by nursing home staff as a useful way to support wayfinding of individuals with cognitive impairment, including AD patients. However, there is insufficient description that this experimental study involved any individuals with dementia as the participants; hence, it was not chosen for review.

Similarly, in another study [244], appealing/attractive/ interventions were introduced such as interface designs that include visual displays with map images, and audio cues for wheeled walker navigational assistance. The preferred design was grounded in the perspectives of nursing home staff and clients, but the authors did not describe if any of the clients were AD or dementia patients. However, their findings could be quite interesting to be tried and replicated with AD patients. They discovered that an interface with simple text and arrows, tonal alerts for signal, and voice prompts was a preferable form of navigation. Since the detailed results and credible samples were lacking, this study was also not chosen for review.

Finally, Goodman et al. [245], presented a two-part study regarding the utilization of landmarks to assist the navigation of older adults. The researchers conceptualized four versions of devices: (1) images, text and verbalization, (2) text and verbalization, (3) text only, and (4) verbalization only. They found that landmark-based navigation aids, and the use of images, text and verbalization are practical for older adults. Although this was indeed an interesting study, they did not recruit individuals with dementia. Hence, it was not included for review. However, the study strengthened the argument for landmark-based signals as a usable form of outdoor wayfinding.

Despite the variety of technological interventions presented in this review, the main target users or stakeholders are still individuals with cognitive impairments. Hence, the exclusions of many promising articles were because AD or dementia patients were not included, or researchers used ambiguous selection procedures for participants. Due to the progressive impairment of higher cognitive functions, it is believed that AD patients require constant support even for simple daily routines [246]. The review has identified several significant intervention strategies from selected studies that promote the navigation ability of individuals with cognitive impairments, mainly in regards to the three different settings. The findings relate to wayfinding intervention strategies in both indoor and outdoor environments that accommodate different purposes and are implemented using different technological approaches; therefore, caution is heeded for any generalization from the results.

Likewise, as most of the reported studies were targeting indoor wayfinding, it is highly recommended to conduct more studies relating to alternative outdoor navigational assistance. Priority is also given to interventions meant for outdoor navigation, since one of the research goals is to promote a healthier lifestyle in elderly with dementia through ADL that involve physical and outdoor activities. It is known that the good performance of ADL may possibly reduce the progression of cognitive impairments and result in the delay of institutionalization [86] [87]. It is imperative that the sociocultural contexts of patients need to be taken seriously to yield more valid and reliable results in the future.

This review supports the notion that uncomplicated technological interventions of navigational assistance work best, regardless of setting. Thus, intervention for AD patients should utilize straightforward wayfinding commands or signals, and navigational assistance with simple modalities and features. This has important implications for the development of technological wayfinding interventions, as even a minor interference may cause major confusion for them. In relation to this, prior to the development of new wayfinding solutions, concepts/strategies for wayfinding interventions should be based on consideration of the disabilities of people with dementia, while at the same time engaging their remaining abilities appropriately. As reiterated before, besides the decline of cognitive domain, these individuals also experienced sensory changes as they grew older and with diseases advancing. Therefore, there is a demanding need to find other possible solutions for their wayfinding disabilities along with the weaknesses shown by them.

3.4 The needs of Alternative form of Navigational Assistance

Each year, the prevalence of AD is constantly growing alongside the rapidly increasing aging population [7]. Even though age is not the main factor of the disease, most AD cases are among elderly [18]. Hence, older adults with AD also manifest physical and sensory declines similar to the rest of the healthy ageing population [159][160]. As wayfinding deficits in AD resulted in poor mobility, navigation, and loss of independent living, possible solutions for wayfinding support that incorporate current technology are desired. Map and route-based navigation is a very well established technique to meet the current wayfinding issues. Regrettably, the current method of navigation that supports visual interactions is not applicable in all situations. It is hoped with the rapid improvement of advance technological applications, a more sophisticated visual wayfinding support may emerge.

On the other hand, the common additional feature towards this conventional wayfinding is the integration of auditory support, i.e. speech instructions or sound cues. Individuals with visual disability may benefit from this method of navigation. It is obvious that environmental auditory is a crucial element in determining the successful navigation. Managing auditory support and auditory sphere simultaneously could be very distracting and confounding. Equally important, having to concentrate on both the surrounding and visual display may put the users in risks.

As discussed in the previous chapter, one of the biggest challenges they usually encounter is deterioration of wayfinding ability which indicates the AD-related cognitive decline that are associated with spatial skill, visuospatial, orientation disorders and so forth [71][98]. This condition is exacerbated by their decline in sensory acuity, as a consequence of both ageing and the disease [159][160]. Elderly with AD manifest worse sensory decline as compared to healthy older adults due to the deterioration of cognitive domain. In vision, for instance, with the loss of colour sensitivity and reduced depth perception and contrast sensitivity [162] [247], adults with dementia are significantly slower in motion search tasks [180], unable to sense movement [248] and also have reduced control of spatial focus [179] due to deficits in the working memory.

Similarly, older adults with AD usually show mild-to-moderate hearing impairment [249]. And yet, deficits in central auditory processing capacity and cognitive decline weaken the communication process [163], as well as visuospatial and auditory information in AD [193]. These sensory changes resulted in poor spatial navigation skill and wayfinding abilities in general. Even worse, wayfinding deficits increased exponentially with age and the severity of the disease [133][132]. Considering the limitations of AD patients, the existing map and route-based wayfinding system that rely only on the visual and the auditory senses may not be the best choice, as it should support their other abilities. In the section where the effects of sensory changes are reported, the idea to use alternative sensory which is the sense of touch or tactile for wayfinding/navigation purpose is initiated

In conjunction with this suggestion, even tactile acuity is progressively impaired due to ageing, comparable to vision and hearing [196] [197], but AD patients still have to maintain implicit memory for haptically explored objects [203]. The most valuable advantage of this conservation is that the haptic priming is preserved, as proven by a speeding object naming task [203]. Accordingly, even though people with AD often show difficulties to learn and remember new things, but tasks/activities that are performed on everyday basis become part of the implicit memory.

In designing a suitable therapy for AD patients, it is advisable not to burden their memory by making them to remember or follow complex programmes or interventions. Let performing the daily tasks/activities be unconsciously and unintentionally, and as a part of the implicit memory. Therefore, we propose that designing an intervention that involves the continuous practice could benefit the people with dementia. Due to its potential, the idea of using tactile perception as a substitute for visual and/or auditory display in wayfinding is highly plausible. Notwithstanding that visual and hearing are the most necessary senses for wayfinding, they are also the most impacted by age and AD. For that reason, this is exactly when tactile should be explored further – when vision and hearing are inaccessible and destabilized - [206][207]. The discussion and review of literature on current studies and potentials of using tactile modality for wayfinding/navigation are deliberated in the following section and its subtopics.

3.5 Haptics for Assistive Navigation

Before we go further to review haptic technology for wayfinding purposes, it is worthwhile to understand the fundamental conception of this modality from its essence. From the foundation of sensory inputs, Dahiya 2010 [250] categorized human touch sensory consisting of: (1) cutaneous – describe the perception based on sensory receptors located in the human skin and (2) kinesthetic – describes the perception of the operational state of the human locomotor system, particularly joint positions, limb alignment, body orientation, and muscle tension [251].

The variations of cutaneous stimulation exclusively founded the tactile perception [252]. Here, the system comprises of physical contact with the stimuli, while simultaneously provides awareness of the stimulation of the outer surface of body [252] [253]. The tissue in fingers for instance, has a number of different receptors embedded in the skin that stimulates the tactile perception. On the contrary, kinesthetic system delivers information of static and dynamic body postures that is commenced through positioning of the head, torso, limbs, and end effectors [252] [253]. The receptors in the joints and tendons send the brain information about the angle of limbs, allowing a person to know where the limbs are located so that they can be moved to the intended positions.

In relation to the aforementioned sensory inputs, the perceptions of both cutaneous/tactile and kinesthetic derived from the haptic system [252] [253] [251]. From the general definition, haptic refers to the sense of touch and movement (mechanical) interactions involving these elements [251]. However, its technical classification should be based solely on the kinesthetic and tactile perceptions properties. The taxonomy of haptic perceptions documented in [254] is able to outline its technical classification, based on the perceptions of kinesthetic and tactile. Figure 3.3 below summarized this taxonomy.

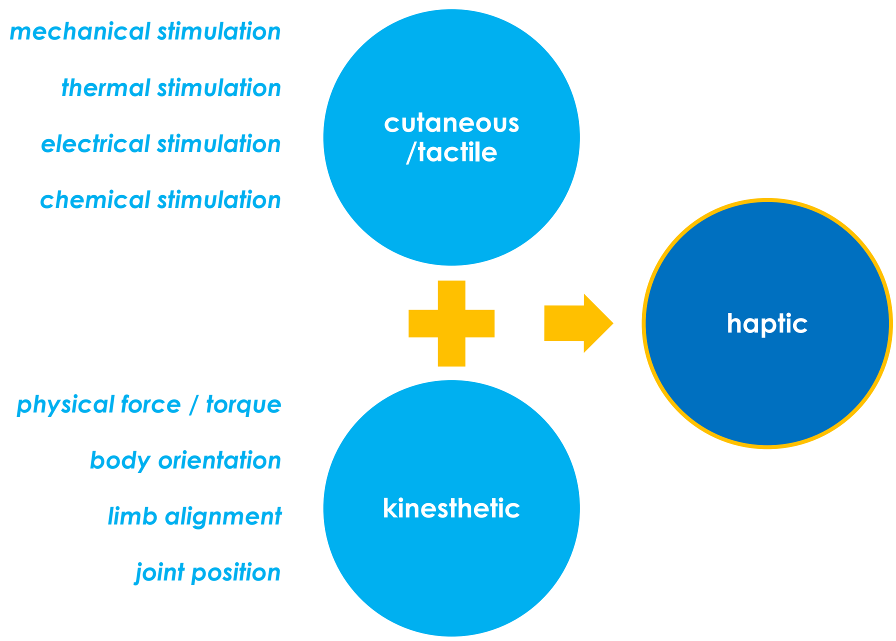


Figure 3.3: Taxonomy of haptic perception, adopted from [254].

Haptic modality is a viable choice for delivering information of a system, both as a personal interface or as an additional interface solution. This distinctive modality is most ideal to be used for alleviating and/or substituting the overloaded and distorted information by the visual and auditory modalities. To elaborate, haptic is often designed for the feedback information in conjunction with visual and/or auditory display. But then again, due to human, environments and other external factors, visual or auditory modality could be unsuitable and insubstantial both in theory and practice. Thus, this is when the haptic modality should come in handy and fittingly designed as a haptic device.

Another essential point, since the haptic device process information in input and output directions, its interaction ought to combine: (1) method of indicating the point where control is required, (2) executions of commands or control, (3) deliverance of feedback to the user [255]. In addition, the interactive should apply at least one of these physical attributes: Force, Shape, Size, Friction, Texture, Mass/weight, Hardness/softness, Temperature, Orientation, Location, Vibration, Duration, Motion and Deformation [255]. Currently, there is a wide range of uses of haptic/tactile in the domain of mobile human-computer interaction (HCI), communication, medical tasks, virtual environments, telepresence, assistive systems and so forth. Yet, the applications of tactile, kinesthetic or haptic interfaces as a whole for assistive technologies and special needs are increasing and become one of the most topical research subjects at present.

This unique modality has been explored in a variety of assistive system. It ranges from interactions for visually impaired persons [256] [257], interface arm for stroke patients [258], interface to assist vocational tasks of disabled people [259], virtual-based rehabilitation exercises system [260] and treatment of motor dexterity disabilities [261] and also for navigational instructions [262][263]. Nonetheless, without appropriate consideration of ergonomics, interoperability, user-experience, part from HCI principles may result in difficulties for the end- users. Moreover, incompatibility and conflicting intervention strategies integrated with haptics are the first things to avoid for users with special needs.

While considerable researches exist for wayfinding or navigational purposes, the existing body of works often focuses on individuals with severe visual impairment or blind people, and not specifically for the persons with cognitive impairment due to dementia. The current lack of research in this area of demanding special needs, rationalizes its worthwhile and appropriateness. The next subtopic presents the review on existing research and intervention strategies of haptic modality for wayfinding/navigation.

3.5.1 Existing Navigation System with Haptic/Tactile Display

Despite controversial debates on the pragmatic use of haptics for disabled people or those with special needs, the establishment of previous works on assistive technology with haptic interfaces has proven that this modality is not only beneficial, but also practical. Again, the applicability of interference could only be verified after it is properly assessed and accomplished. This study has put forward the interest of exploring the potential of haptic modality for assistive system, precisely in wayfinding. Based on these interest and motivations, the previous works of researchers on the assistive technology that utilized haptic interfaces/system were being reviewed.

One of the established related works on haptic for wayfinding was done by Van Erp et al. [264]. They presented a vibrotactile waist belt with waypoint navigation display as an alternative to visual display in especially military environments. The system encompassed of eight waypoint directions represented by the location of the vibrations, with each vibrator covering a 45-degree angle. In the previous work by Van Erp [265], they reported on the concept of vibrotactile displays with fifteen tactors placed at equidistance of the torso. The vibrotactile indicated spatial information in an instinctive manner because the tactors that produced the stimuli were mapped according to body coordinates. For example, the tactor embedded on the left torso represented left, on the right represented the right, and at the front represented the frontside.

The comparable haptic interface but with more complex displays is described in the earlier studies. Ertan et al. [263] for instance, described a wearable navigation system using haptic directional display consisting of a matrix of vibrators integrated into a vest. The system gave haptic signals 4-by-4 stimulator array at the users' back in the course of navigation. Likewise, Traylor and Tan [266] used matrix display containing a coarse 3-by-3 array of vibrotactile stimulators. These matrix of vibrators represented four directional signals (east, west, north, and south), and the system was proposed to be used in zero-gravity environment.

In a different study, Mann et al. [267] presented a blind navigational system with a Kinect 3D sensor range camera and a vibrotactile helmet. The vibrating actuators embedded inside the helmet convert in-depth information into haptic feedback, to allow the users in identifying depths for collision avoidances. On the contrary, Zöllner et al. [262] conceptualized a mobile navigational assistance with Microsoft Kinect and optical marker tracking to help the indoor navigation of individuals with visual impairments. They created a belt embedded with vibrotactile outputs that were used to detect obstacles during wayfinding tasks.

The aforementioned studies pioneered the likelihood of haptic stimuli to translate the fundamental directions, which again underlined the applicability of this modality in assisting persons' wayfinding. Nevertheless, despite its establishment, none of these works were intended for people with cognitive dysfunction problem and some were not even for people with disabilities, [263] [266]

The next work which was closer to our goal was done by Grierson et al. [234] who investigated the use of tactile signals to assist the wayfinding of persons with dementia. This specific study had been acknowledged in previous review, under the assistive technology for indoor wayfinding (Section 3.3.11). As mentioned before, they developed a wearable belt embedded with four vibrating motors that were adjusted to the cardinal positions, indicating front, back, right, and left directions. This was the very idea where our design concept commenced but with a different twist since this study implemented the navigational assistance particularly for indoor environment. This study found that it was important to highlight the potentials of haptic/tactile stimuli to assist or improve the wayfinding of individuals with cognitive impairments to serve their different needs and issues.

Haptic/tactile feedback as forms of signals provides a simple, yet a promising form of directional cues that allows users to concentrate on the surrounding with other senses (vision and hearing) during wayfinding [268]. Besides, the vibrotactile signals that created the haptic simulation are less disruptive as compared to the auditory instructions, which is a suitable substitute for continuous feedback [262]. The existing technological interventions that utilize haptic/tactile modality to assist wayfinding have shown positive results, though most of them are meant for visually impaired and blind people. Also, most of the existing wayfinding intervention strategies, which include the above-mentioned studies [262] [263] [234] focus on indoor navigation. This means, further research on navigational assistance for outdoor wayfinding purposes is highly recommended.

Another essential point is all the haptic interfaces/systems described above are the wearable technologies/devices. Designing devices to be wearable improve the practicality of handling and operating [269] [270]. To better observe the reviewed works, Table 3.3 below summarized the methods of intervention, target users and positioning of haptic interfaces.

Table 3.3: Existing works on haptic interfaces for directional/wayfinding

STUDY	INTERVENTION	TARGET USERS/ APPLICATIONS	POSITION
Van Erp et al. [264]	Vibrotactile of eight waypoint directions that represents 45 -degree angle each.	Healthy persons (Military)	Belt/ waist
Van Erp [265]	Vibrotactile displays with fifteen tactors that follow the body coordinate and indicate spatial information	Healthy persons	Vest/ torso
Ertan et al. [263]	Haptic directional display consists of a 4-by-4 stimulator array matrix of vibrators.	Blind persons	Vest/back

Traylor and Tan [266]	Matrix display contains a coarse 3-by-3 array of vibrotactile stimulators that represent east, west, north, and south.	Healthy persons (Zero-gravity environment)	Vest/ back
Mann et al. [267]	Blind navigation system with a Kinect 3D sensor range camera and a vibrotactile helmet to identifying depths for collision avoidances.	Blind persons	Helmet/ head
Zöllner et al. [262]	Mobile navigational assistance with Microsoft Kinect and optical marker tracking for indoor navigation using vibrotactile outputs on belts to detect obstacles.	Blind persons	Belt/ waist
Grierson et al. [234]	Wearable belt embedded with four vibrating motors on cardinal positions.	Persons with dementia	Belt / waist

The new wave of technologies and current trend in computing allows wearable technology to find its niche by combining social networking, entertainment and even healthcare. This motion sits well with the present needs to evolve into more portable, mobile, and also wearable gadgets. Well-designed device and its wearable form let users to experience an effective way to access its intended purposes. Moreover, combination of sensory inputs to the wearable device may offer the solution to the users' deficiencies, such as wearable haptic to address sensory impairments [271]. Therefore to be precise, it is laudable to deliberate the wearable aspect of technological proposals. Again, it is agreed by the previous studies presented in Table 3.3. Hence, this is the subject matter to be emphasized in the following section.

3.6 Wearability and Wearable Devices/Technologies

The needs for wearable form of devices/tools have long been desired. Many of the devices designed to be wearable such as the invention of time pieces and eyeglasses for instance, are for their obvious purposes: accessibility and practicality. Only after the abundance of technological platforms is available today, the integration of data-input is featured for local data storing purposes. Due to that, current wearable technology provides form for user communications and interaction capability and allows the wearer access to information in real time.

In addition, with the obscurity of current and future technology, devices evolve from wired to wireless, from monumental size to miniaturized, and last but not least mobile to wearable. The advancement of technology allows the existing devices to be scaled down or miniaturized into new improved forms that do not limit users' mobility but with maintained or better functionality. Among the most established examples of this scaling down / miniaturization evolution are the mobile phones, radios, and computers made more personalized and customizable. Yet, reducing the size of computing tools, for instance from the desktop computer to a smaller and portable dimension does not add much value to the existing one. In relation to this, designers and engineers should make the most of a whole new context of putting human physique as a framework to the proposed innovations/technologies.

In a simple definition, 'wearability' refers to the interaction between the human body and the wearable object [272]. Designing a device to be wearable relies upon the fundamental key in developing wearable computing systems; wear-ability, the physical form of wearables and their active relationship with the human form [272]. The terms wearable technology or wearable devices describe electronic technologies or computers that can comfortably be worn on the body or incorporated into items of clothing and accessories. Also, the reason of the "wearable" choice is indeed, readable in the meaning of the word wearable: fully functional, self-powered, self-contained computer [273].

From a wearable perspective, the issue that is often addressed is the user interaction. It can be possibly resolved with the incorporation of multiple modalities for input and output into the wearable devices. These wearable devices are expected to perform many of the same computing tasks and provide access to information and interaction with information, anywhere and at any time. Yet, it is acknowledged wearable technology can sometimes completely outperform the existing hand-held devices since it may offer sensory and scanning features like biofeedback [274], and tracking of physiological function [275] which are not commonly featured in mobile and laptop devices.

As one of the crucial aims of advancing the current technologies is to support and shape the human social system [276], wearable technology certainly should have its own way of contributing. The use of wearable technology can be developed further in more important fields such as health and medicine - that include fitness, ageing, and disabilities - and not only for the domains of education, transportation, enterprise, and entertainment. In fact, wearable devices have been used more in the past decade and give a positive impact on healthcare and medicine, way before the current demands for other applications. For example, Park and Jayaraman [277] reported a study on the basis of unobtrusively monitoring the patients' health and well-being. They presented "Wearable Motherboard™" worn as a shirt, aimed at monitoring vital signs and sending that biofeedback information to a hub station in real time.

Wearable technology promises great inspiration on gaming and entertainment as well as for health and fitness. For example, the integration of more advance interface like Augmented Reality improves the gaming experience (gamification) due to the realistic and immersive environment in real time. The famous invention and a recognized reference to the considerations of both wearable and aesthetically appealing technology is the Google Glass. On top of that, this invention has also been explored for different applications, such as medical [278] education [279] and even as an assistive technology [280]. However, the general goal of utilizing wearable technologies regardless of the aforementioned fields and inventions is to seamlessly integrate and improve portability, functions, and aesthetic of computing gadgets into individuals' daily lives. Just like the Google Glass which is known for the features it offers as well as its sleek, lightweight and unobtrusive design. This goes well with the current market demands that wearable devices/technologies are part of fashion.

Despite the fact that wearable devices should be able to be put on or worn and taken off easily, there are more advance concepts whereby the devices such as microchips or smart tattoos are implanted onto bodies. So, whether or not a device is worn on or implanted, it has the most direct contact to the human body. Also, for interaction and maybe communication purposes, it is the first surface that has the contact with others and environment [281]. This is agreed by [272], where human body is a very valuable supportive vessel for wearable device. When this happens, a worn device/technology can become a complete system to transmit interchangeable data. At the end of the day, the main goal of this unique artifact is to create constant, convenient, seamless, portable, and easiest-access interface to the system and information provided. Therefore, with better understanding of human forms and its roles for wearable product design, designers and engineers can explore new possibilities of what integration between technologies and human body may offer.

3.6.1 Anatomical and Physiological Consideration

In designing wearable device/technology, it is relatively imperative to consider its appropriate placements on human body. Yet, many aspects influence this decision, and the foremost criterion of wearability is comfort. As presented by [272], the other aspects include the analysis of: (1) wearable objects - clothing, body armours, and portable devices/objects, (2) human body - form and dynamics, part from human anatomy, anthropology, ergonomics, physiology and biomechanics, and (3) individual experiences with wearables – users' perspective on preparation, cooperation, and concept of wear and carry.

There are not so many available references or existing works on the recommendations to design wearable devices/technologies. One of the most referred studies in this area is conducted by Institute for Complex Engineered Systems (ICES), Carnegie Mellon University, led by Gemperle [272]. Here, they emphasized on the six criteria of considerations and necessary principles in designing the wearable products. These main criteria are as follow: (1) placement – appropriate positioning on body, (2) Form language – shapes/forms, (3) movement – dynamic structure, (4) proxemics – perception on space, (5) sizing – body (parts) measures, and (6) attachment – integration of devices into the body/clothing. The rest of the recommendations include weight, sensory interaction, accessibility and aesthetic.

In the guidelines, 'placement' is the first mentioned idea/suggestion and this shows it is one of the most important criteria. Hence, to achieve the dynamic objective of a proposed device to be comfortably wearable, it has to be placed at the positions where it will not hinder users' normal mobility, movement and functioning. As shown in Figure 3.4, these are the body areas that are suitable for device placement to accomplish the said dynamic wearability. Meanwhile, the suggested positions/placements on the areas of human body should be: (1) comparatively the same size among adults, (2) low in movement/flexibility, and (3) larger in surface area. The dynamic understanding and measurements of human body are pertinent aspects, since human body (mostly the skin) is a magnificent space and inspires the creation of technology intended. The strong relation between morphological and physiological factors in human towards the common bodily functions approves or disapproves the integration of technologies.

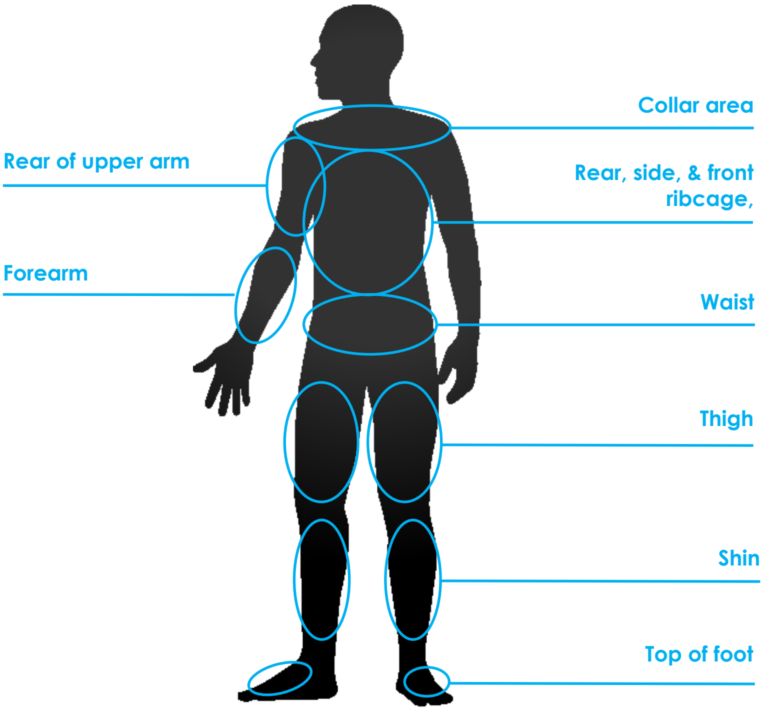


Figure 3.4: Areas with the most unobtrusive space for wearable objects, as documented by Gemperle et al. [272].

In the same way, current technological advancement may extend the biological capability of human beings by means of fully utilizing and incorporating multimodality of sensory. However, appropriate reflection on the limits of bodily functions and biological capabilities should not be neglected, so that they can be aptly incorporated with the proposed invention. In this study specifically, the limits and incapability of the target population i.e. elderly with cognitive impairment mainly due to dementia, need to be addressed.

However, implementing a new form of intervention to the persons with dementia (either pharmacologically or not) using unfamiliar technology is not an easy task and a big challenge. The use of assistive technology to support these persons in managing their daily activities is known to promote independence and optimize/maintain quality of life [282] [283], while at the same time it may delay the institutionalization processes [284]. Nonetheless, persons with dementia should be well exposed or introduced to a proper training to use the assistive technology as adaptive equipment on daily basis, such as simple mobile and electronic interfaces (everyday technology) [285]. To get the persons with dementia familiarized with the technology, they are encouraged at least with the minimum effort to learn new things (like interfaces) , help to gain their interest and maintain using one

[282]. Besides, the other crucial point is the design of the technology. As agreed by [286], badly design devices/technologies with great technical issues and complications are less acceptable, in terms of usefulness and frequency of use. Similarly, as reviewed earlier in this chapter, there are numerous assistive technologies that are in the form of wearable. Hence, the equivalent rules are applied for the implementation of wearable devices to these specific users.

To be comfortable is the key factor for any wearable design for healthy/normal users, let alone for people with specific disabilities. In fact, within the care of elderly with dementia, there is an understood postulation that the goal is comfort [287]. According to [287], comfort for dementia patients is not only about designing clothes to be more loosely and lack of restraint as dressing may result in both comfort and discomfort to these persons, it is more on what are socially acceptable and their implied meanings . What is worse, due to the physiological, behavioural and cognitive changes, they usually are no longer interested in their appearance or dressing and this may hinder the purpose of wearing the device.

The incorporation of technology to the person with disabilities lies greatly on the derivation of its design as a whole idea. Rosenberg, Kottorp and Nygård [288] came out with the recommendation on how to incorporate technology for people with dementia (with the support of significant others). They underlined several crucial points: (1) acceptance of the technology, (2) making it a habit, use on daily basis leads to familiarity, (3) uncomplicated interfaces with minimum learning and interaction required, (4) intelligent functions that may prevent users making mistakes and may automatically correct errors, (5) dynamic and flexibility of the technology, and lastly (5) not stigmatizing the users, probably making them less obvious.

To conclude, a properly design technology reflects all the considerations as preceded being wearable, portable or ordinary equipment. Again, the introduction/incorporation of technology can only succeed with the acceptance and readiness of the users, in this case; the persons with dementia. This can be achieved with the less-complicated design to be used daily effectively as well as the encouragement of their support system (spouses, family members, community, etc.)

3.7 Conceptual Framework

At this stage, the study has grown significantly based on the reviews, arguments, discussions and reflections of the previous related works mostly presented in these first three chapters. To represent the research's synthesis of literature based on the previous knowledge of other researchers' viewpoints and observations on the research subject, a conceptual framework is plotted to expound the required further actions.

In a simple term, a conceptual framework consists of what a researcher understands on the connection between variables in his study. In a research, the investigation of particular variables is necessary. As McGaghie et al. [289] postulate: The conceptual framework "sets the stage" for the presentation of the particular research question that drives the investigation being reported based on the problem statement. The problem statement of a thesis presents the context and the issues that caused the researcher to conduct the study. Hence in this study, if they were to be put into sequences, they start with the increasing number of older adults and those affected with the cognitive dysfunction disease namely dementia. Then it goes on about the common needs and issues of these individuals, and going deeper into one of the most prevalent and reported problems, i.e. mobility in general.

Mobility issues in elderly with or without dementia do not stand on its own, as it is interdependence between navigation ability, spatial skill, and essentially the sensory. The fact that the most vital sensory is often impaired in these people sparks the instigation to explore the promising and distinctive alternative modality for wayfinding – haptic. Nonetheless, the theoretical frameworks would not be complete without the review on existing strategies for wayfinding (navigation and orientation included) intended for people with dementia.

There are three stages of review of literatures included, the first two reviews were made systematically and in depth so that the reason to focus on assistive technology is enlightened, as well as justified. While the third review proves the relevancy of haptic modality for navigation purpose, as initially promoted in the former chapter. Equally important, the wearable aspect of existing assistive navigations is discovered and motivates its usefulness for this study. Figure 3.5 illustrates the conceptual framework of this study that employs the theoretical background/framework, predominantly of the collective literature review presented.

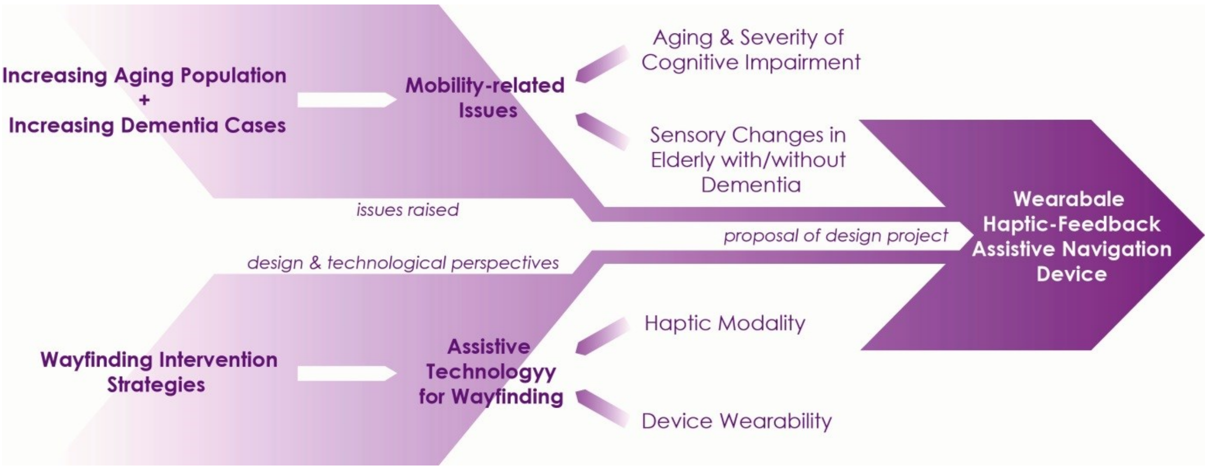


Figure 3.5: Conceptual framework of the current study

In the following chapters, the study reports on the proposed design project based on the theoretical requirement. All the aspects emphasized in the framework are used to develop the design concept of "Wearable Haptic-Feedback Assistive Navigation Technology". In a nutshell, the concept adopts the hybrid approach between (1) haptic/tactile as a navigation modality, and (2) device wearability.

CHAPTER FOUR

4 Setting and Focus

4.1 Introduction

Now that the theoretical requirements for the study have been presented and discussed, it is the time to set them into practice. This chapter principally presents the design project intended as an intervention strategy for the assistance of dementia patients in improving or assisting their declined spatial ability. Nonetheless, proposing a design concept could not be flourished without the reflection of several important design principles that are affiliated for the main goal of this study. Thus, before we go further on the design project that is used as a case study for this research, this chapter discusses on the adopted design principles in establishing it. These include: (1) User-centred Design, (2) Inclusive Design and (3) Design for Disability, apart from a couple of other principles that share the common philosophies and motivations.

4.2 Adoption of User-Centred Design Approach

Too often, the design of everyday objects assimilates eminently on business goals, impressive features, aesthetics and also the technological capabilities that they offer. Have a look at the various products in our daily lives that we are fascinated into buying due to the enticing advertising, but without proper product knowledge on their features, functions, uses, support requirements etc. This is probably the undesirable implication of when they were designed without bearing in mind humans as the end-users. As a consequence, they are not at all times intuitive, and bring about dissatisfaction to the users when they could not comprehend the features provided/offered.

In relation to this, employing the target users in the centre of development process of one proposed design is relatively critical, since they are the ones who are meant to enjoy the features/outcomes. One design principle that is best to describe this important aspect is the user-centred design (UCD). In a broader term, UCD refers to the practices of what a design should be like and that is influenced by the end-users. Nonetheless, the ideology of UCD is not solely about ensuring to place the users in the heart of the design processes, but also to construct a concrete placement where users can interact with the design outcomes (products, systems or services), as well as the characteristics of this interaction.

One of the earliest literatures found that used the term ‘user-centred design’ is documented in a study by Norman and Draper from the University of California San Diego, back in 1988. In their book entitled: User-Centred System Design: New Perspectives on Human-Computer Interaction [290], they presented the four fundamental rules of the appropriate designs, which are:

i. Possible actions are made easy, whenever needed.
ii. Conceptual model of the system, alternative actions and effects of the actions are made clear and understandable.
iii. The assessment of system’s current state is made easy.
iv. Intentions and the required actions follow the natural mappings.

These suggestions are the true reflection of UCD principle, where the designs should be made with the end-users at the centre and as the main goal. Although these suggestions seemed to be the basic of design processes, there are many designs being made without these proper considerations. Hence, it is the role of designers to create designs which let the users to utilize their intended features intuitively and definitely with minimum effort to learn.

For example, a newly bought home appliance should be equipped with the straightforward guidebooks with minimum graphics and wording complexities about the product's know-how. This is because incomprehensible and unwieldly user manuals are not following the UCD principle [290]. Here, the major difference between UCD and other design philosophies is made clear, where the aim is to enhance the designs (products, systems or services) based on the capabilities, desires, and needs of target users, instead of obliging the users to accept one design as it is, then learn to use a system, and change their behaviour and attitudes to accommodate the produced designs.

Then again, the principal criterion of UCD is not simply about producing intuitive designs. ISO 13407 [291], an international standard established in 1999 that "provides guidance on human-centred design activities throughout the life cycle of computer-based interactive systems", describes UCD from four prospective categories:

1. Rational – relates to advantages of usable systems, for example reduction of training and support costs, improved user satisfaction and productivity of users.
2. Principles – describes general principles that approved the UCD:
    i. active involvement of users and their task requirements,
    ii. proper distribution of functions between users and technology,
    iii. repetition of design solutions, and
    iv. multi-disciplinary design
3. Planning – guides to fit UCD activities into the overall system development process.
4. Activities - description of UCD activities (as illustrated in Figure 4.1), are identified as:
    i. Understand and Specify Context of Use - know the user, the environment of use, and what the tasks are for.
    ii. Specify the User and Organizational Requirements - Regulate the usability for the product, as well as guidelines and limits.
    iii. Produce Design Solutions – Integration of HCI knowledge (visual design, interaction design, usability) into design solutions.

iv. Evaluate Designs against Requirements – evaluation of design usability in contrast to user tasks.

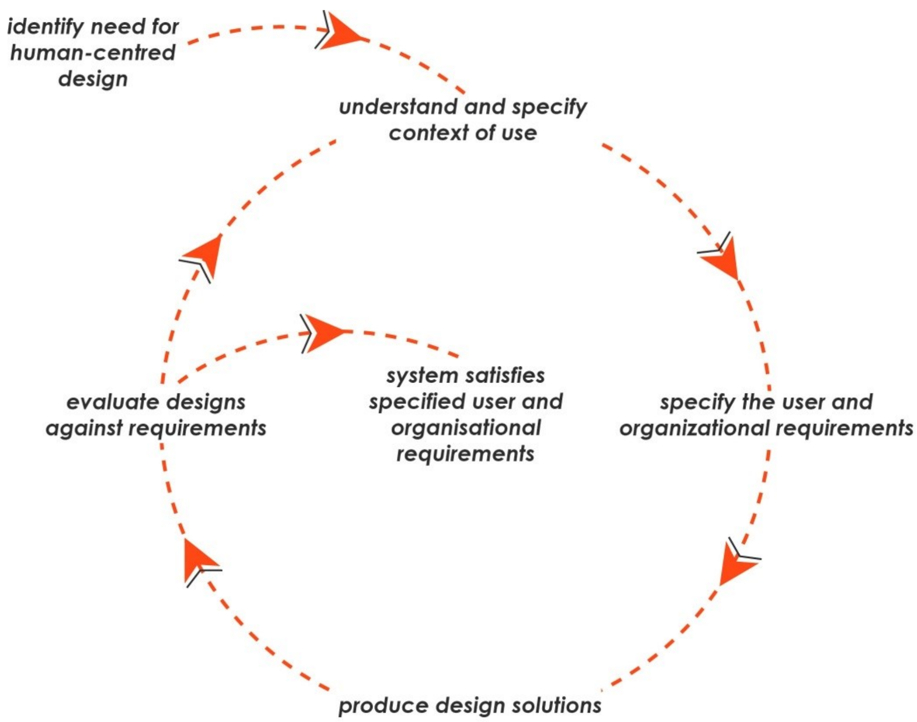


Figure 4.1: Activities of UCD, adopted from ISO 13407 standard [291]

As preceded above in one of the UCD activities, the decisions about the selections of appropriate users and the involvement of users in the design process should be carefully made. Usually there are layers/levels of users who are interconnected to each other in any design. We can take the users in this study as an example. First, older adults with dementia are obviously the primary users of the proposed design intervention. But, the caregivers (formal or informal) are the secondary users who are occasionally using the device, probably to assist or train the dementia patients with the intervention. Finally, the managers of a nursing homes or medical experts are the tertiary users who decide about the purchasing of the device.

All these users made up the stakeholders of a designated artifact or device. For that matter, the successful design of a product, system or service should take into consideration of this wide range of stakeholders. Nonetheless, as claimed by [292], although the outcome of produced artifact on the stakeholders is essential to be taken into account, not all of them must be involved in the design process. Following the UCD activities, the design team may develop the variety of possible design solutions, once the stakeholders of a proposed artifact have been identified by means of an in-depth investigation of their tasks and needs analyses. Subsequently, as the design process develops, the design team should take a closer look on the assessments of the artefact against the user tasks, since they contribute in recognizing the required measurable usability criteria.

The criteria are highly connected to the collective issues of measurable usability, such as effectiveness, safety, usefulness, ability to learn and memorization (of how to use the artifact or perform common tasks), acceptance and satisfaction. The evaluation is probably the most "dislike-yet-critical" phase of the design process, because to identify and visualize all the usability criteria that are important to the users are very challenging and abstruse. It is indeed an iterative process and could be succeeded through several data collections of stakeholders' feedbacks. Preece, Rogers and Sharp [293] propose the strategies to assess a design with the inclusion of users in the design and development process. They are summarized in Table 4.1 below.

Table 4.1: The techniques to involve users in the design and development process, adopted from [293]

TECHNIQUES	PURPOSES
Background Interviews and Questionnaires *[At the beginning of the design project]*	Collecting data related to the needs and expectations of users; evaluation of design alternatives, prototypes and the final artefact
Sequence of work interviews and questionnaires *[Early in the design cycle]*	Collecting data related to the sequence of work to be performed with the artefact
Focus groups *[Early in the design cycle]*	Include a wide range of stakeholders to discuss issues and requirements
On-site observation *[Early in the design cycle]*	Collecting information concerning the environment in which the artefact will be used
Role Playing, walkthroughs, and Simulations *[Early and mid-point in the design cycle]*	Evaluation of alternative designs and gaining additional information about user needs and expectations; prototype
Usability testing *[Final stage of the design cycle]*	Collecting quantities data related to measurable usability criteria
Interviews and questionnaires *[Final stage of the design cycle]*	Collecting qualitative data related to user satisfaction with the artefact

The strategies presented are eligible to be combined and altered according to the availability and suitability of the evaluation subjects who are also the target users. As mentioned earlier, the stakeholders of the design project consist of the dementia patients themselves, the caregivers, dementia medical experts and the responsible representatives of nursing homes/health institutions. Nevertheless, the selections of those who will participate in some parts of the design process or in the evaluation phases are subject to the suitability of their involvement. This study has three assessments during the development of the design project: preliminary assessment which did not target on the dementia patients as respondents, whereas first and second usability tests recruited dementia patients as the subject tests. The strategies used and their corresponding participants are all discussed comprehensively in the following sections and chapters.

Furthermore, designing for persons with special needs and disabilities is not an easy task, let alone the difficulties to involve them in the design process. Even so, proposing a design project without their involvement as the primary users of the stakeholders then would render it unaccomplished. Therefore, there are many aspects to be kept in mind in order to meet the main objective of the design project and eventually achieve the goal of the study. For this reason, we found that the principles and criteria of 'Design for Disability' and 'Universal Design' are adoptable and appropriate for this study.

4.3 The Inclusion of (Target) Users

In this information age especially, giving equivalent access and opportunities for everyone in a society has become top priority. With regard to the prefaced concerns or matters, the befitting design principle to be exercised is the Inclusive Design (ID). Inclusive Design is focused on particular design that include and address the needs of the widest possible number of consumers [294]. The establishment of ID was pioneered by the British Standards Institute (BSI) in 2005 [295]. Here, they define ID as 'The design of mainstream products and/or services that are accessible to, and usable by, as many people as reasonably possible ... without the need for special adaptation or specialized design.'

ID has five major groundworks as recommend by [295], which are: (1) situating people at the heart of the design process as in involving as many people as possible on the design, (2) acknowledge diversity and difference means designs are created to meet the needs of as many people as possible, (3) provide choices where a design solution cannot accommodate all users by considering people's diversity of obstacles and exclusions to achieve superior solutions that benefit everyone, (4) offers flexibility of use where design should be adaptable for different uses and demands, and (5) provides convenient and enjoyable spaces/environments for everyone by taking into account the elements (architectural and design) with sufficient information.

That said, ID gives the analogous explication to other design principles namely 'Universal Design' (UD) and 'Design for All' (DFA). Although they have different designations, they greatly patronize the thought in expanding the accessibility of the interactive system for the widest possible range of use [296]. What makes UD and DFA fairly distinguishable from ID is that it is initiated on the basis of disability and built environment [297]. As defined in the Universal Design Handbook [296] by Preiser and Ostroff from the Centre of Universal Design at North Carolina State University, UD is the "design of products and environments to be usable by all people, to the greatest extent possible, without the need for adaptation or specialized design".

For UD, the principal philosophies validated by [297] include: (1) Equitable Use – Useful and marketable design for people with diverse abilities, (2) Flexibility in Use - provides design with wide range of individual preferences and abilities, (3) Simple and Intuitive Use- Easy to understand design for every level of user's experience, knowledge, language skills, or current concentration level, (4) Perceptible Information - communicative design to deliver necessary information to the user, despite the ambient conditions or user's sensory abilities, (5) Tolerance for Error - Risk/danger reduction design and lower the chance of accidental or unintended actions, (6) Low Physical Effort- Easy-to-use, effective and comfortable design with a minimum effort, and lastly (7) Size and Space for Approach and Use- Proper dimension and space for approach, reach, manipulation, and use purposes for everyone.

Once again, the three design terms have a similar purpose but different origins. For example, UD originated in the United States of America and expanded to Japan and the Pacific Rim, while ID is used within Europe as it is pioneered by the United Kingdom government. However, the aim of this study is not to debate on the divergence on concepts of use and ideas of all these design principles. Indeed, there are existing works [296][4] that investigate and explore these differences in terms of evolvement, methodological and philosophical aspects of the concept. The different views/conceptions of each principle are acknowledged, but the attention is given more on their general/communal fundamental philosophy which are accessibility, inclusion, equal chances and many other terms by the same meaning.

This study, however, is mostly inspired by the conception of ID for older and disabled people and on other excluded groups by delivering mainstream solutions. It also begins with the perspective of product design and the highlight is to choose the segmented markets and users for a specific design. In general, UD and DFA also agree/consent that one product could not always meet the needs of the entire population [297]. With respect to the concerns raised in the earlier chapters, by some means it is related to the increasing number of people with disabilities. This problem is due to decreasing mortality, declining fertility, enhanced medical applications nowadays, and also the non-biological factors (such as accidents, natural disasters and dietary) [3] [4]. Additionally, the increasing of ageing population is also a significant influence to this statistic, because older people are vulnerable to the risk of disability relating to physical, mental and health conditions [298].

Whether or not the disabilities are caused by ageing or other biological and non-biological factors, disabled people are typically facing some common obstacles. The obstacles, as agreed by [298], can be in forms of: (1) Attitudinal – the perception of others towards them, (2) Policy and/or Organizational – in which it is drafted without the consideration of people with disabilities, (3) Physical/ Architectural – elements of built environment and spaces, as well as shared facilities that are inaccessible, and (4) Information/ communications – relates to both receiving and delivering information, where the disabled people are not listened to, referred to or involved in. These are the major obstacles besides the external issues, such as the lack of funding, researches (data and evidences), and consultations.

Persons with disabilities are those who have physical or mental impairments that markedly restricted their life activities. According to the definition by WHO [298], disability (or previously disablement) is an umbrella term covering the negative dimensions of impairments, activity limitations and participation restrictions. Besides, it is certainly a normal portion at different stages of our life, where we can be momentarily or permanently impaired depending on the aforementioned influences. For example, surviving until old age without any physical impairment does not mean we will not experience other bodily functions and mental conditions issues in the future. This highlights the issues of disabilities and the correlated aftermaths should not be taken lightly.

The barriers have an implication of disregarding disabled persons from the majority of social system. We can say that these are the leading constraints that hinder them to live like most of the people. Thus, the key to support and empower the disabled people is by getting rid of the barriers, making things less difficult and more accessible. This will indirectly encourage them to do the best they can and carry out their responsibilities, without being ignored or treated unethically by the society. The destructive discrimination and stigmatization towards disabled people should be expunged, as we are now living in a modern society, where the people should be more civilized and open towards differences. Therefore, the initiatives to breakdown these classic major obstacles should be promoted and persevered. Along with this effort, many of the established works focus on the approach of sustaining the independent living of disabled people [299][300], for as long as possible. To achieve this, the society is expected to include or take them into consideration before any societal decisions are made.

On the contrary, although disability causes many complications to the persons themselves and others, it is at the same time provides the opportunity in furthering more efforts to find the possible solutions to assist their reduced functionality. In view of this, aside from the social perspective by means of changing the attitude, increasing the funds on policies implementation, and improving the provision of services, the inclusion of disabled people in decision making can make good use of the advancement of current design and technological platforms.

In addition, disability caused by ageing and health-related conditions is different from other typical disabilities experienced by younger disabled persons. This is because the elderly are too often having a collective impairment of sensory, physiology and memory. Not only that, since the disability faced by older people is increasing with age [301], they probably need the support more than the younger disabled persons. For this reason, the approach used to design the assistive technology for them could be different and should especially meet their needs. Therefore, the design strategy for developing the necessary intervention must be carefully executed.

Here, the studies about assistive technology that are mainly to help reduce the difficulties and increase, maintain, or improve functional capabilities of these disabled people to do their daily routines [302] [222] will indeed advance this common cause/ground. In the premises, designing the appropriate technological interventions intended can only be realized by placing them in the core of design development process. Again, the primary doctrine of ID as previously described that is to place people at the heart of the design process matches the UCD principle, where designs should be made with the end-users at the centre.

Therefore, as a conclusion, this study takes into consideration the principle of ID (in parallel with UD and DFA) that upholds the philosophies of UCD at its substance, in order to promote more design and technological solutions for the mentioned issues through the creation of pertinent assistive technology. Figure 4.2 below portrays this intersected relationship. The discussed aspects give the weight in the design project proposed in this study, which is presented exhaustively in the next subtopic.

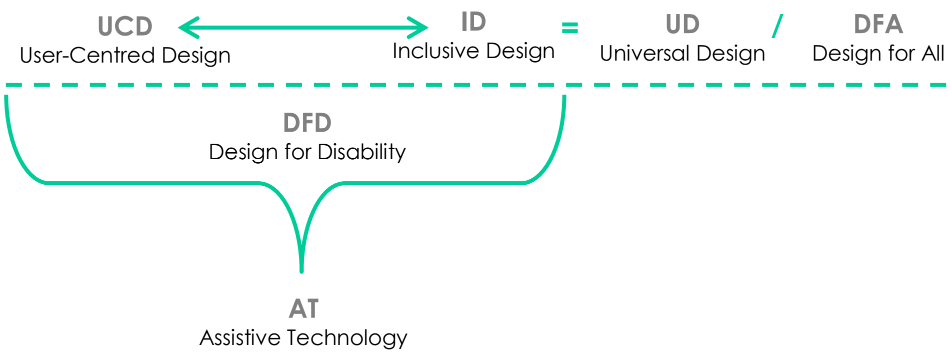


Figure 4.2: The correlation between the design principles that motivates the design project

4.4 Design Project

The development of design concept and proposal is principally based on the different phases of this study and consigned by the various aspects discovered in conjunction with the thesis flow. From the theoretical requirement that are mostly attained as a collective literature review, it is revealed that there is a pressing demand to find more solutions for the current wayfinding system or navigational assistance in particular for the said target users, i.e. elderly with dementia.

At the same time, from the design and technological point of view, the concept of intervention being proposed is the combined deliberation of:

i. Haptic (tactile display) as the modality for the navigation
ii. Wearability of the device
iii. Outdoor navigation, and the
iv. Principles of UCD, ID and Assistive Technology.

4.4.1 Conceptual Design

Based on the consideration of the previous works and the flaws the study thinks necessary to resolve, a new concept of wearable haptic-feedback assistive navigational device for the design project is proposed. This stand-alone and less-intrusive navigation device integrates haptic stimuli as the signals, instead of reading a map display or listening to speech instruction in the course of navigation.

The device provides the simplest possible information about the navigational instruction: left or right direction. The uncomplicated feature is crucial as to avoid distraction or confusion by the users when using this device during wayfinding tasks [262]. This is important because even a minor interference may cause misdirection to the individuals with dementia. For this reason, as well as for the ease and practicality of handling by the users, this device is meant to be wearable.

One of the most important principles in designing the wearables is the comfort feature [287], that has been discussed in the previous chapter. Nonetheless, people with dementia are known to experience dressing difficulties [303] and yet, comfort is the main goal within the care of elderly with dementia [287]. It is imperative for the device to be put on and taken off effortlessly. In addition, the device is also designed to be worn as a pair on both sides of the appropriately chosen body parts. These considerations are added to the design concept to maintain the uncomplicated features and practicality of a wearable device, especially for the target users, i.e. elderly with dementia.

The proposed positions to place the device are based on the recommendation by Gemperle et al. [272], as thoroughly discussed in Chapter Three. The general areas of human body that are the most unobtrusive and suitable for wearable objects are taken into consideration here. Equally important, the built-in haptic signals (from the tactile display) work most efficiently when they have the direct contact with users' skins [304]. Hence, for this initial design concept, the study proposes the integration with the clothes or underwear. In view of that, the positions that are found appropriate for the integration are as follow: shoulder, waist, thigh and feet. Figure 4.3 (B) shows these possible positions to place the device.

To better describe the design concept, a scenario is used to visualize how the proposed navigation system works, as shown in Figure 4.4. With reference to the illustration, to go from point A (home) to point B (local supermarket), there are three routes the user can follow; #1 (Option 1), #2 (Option 2), and #3 (Option 3). In initiating the journey from point A, one may turn left or right and the haptic signals embedded in the navigational assistance will start immediately. If he/she turns right, #1 will be the choice of route, whereas left is for #2 or #3. In order to go back from B to A, the signal will initiate as soon as the user moves out of the place (B), and directs him/her into the correct route (#1, #2 or #3).

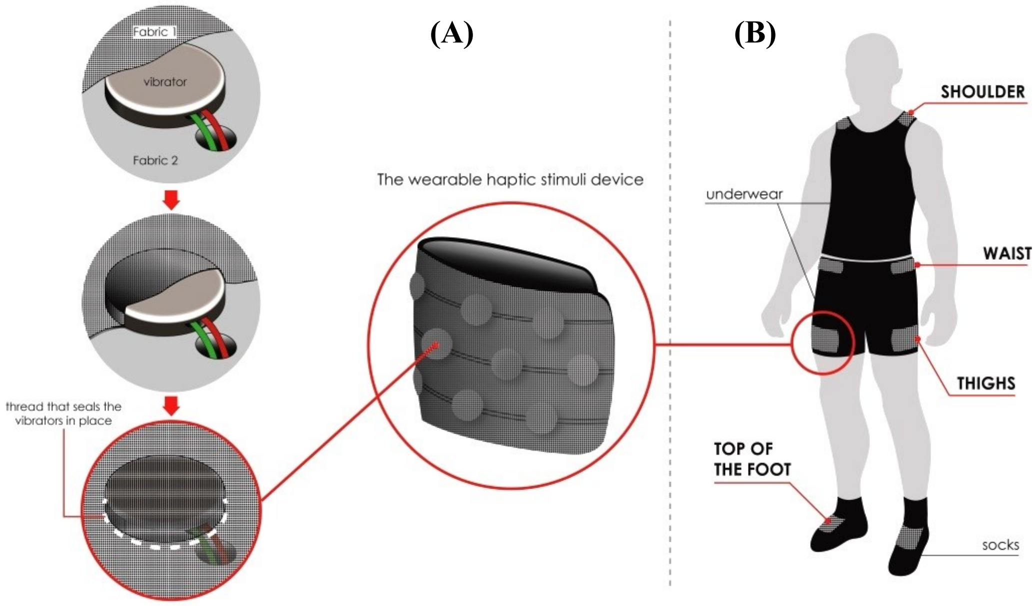


Figure 4.3: (A) The wearable haptic-feedback navigation, with (B) the possible body part positions

During wayfinding, the users are expected to travel within the estimated range. The suitable range for the users to travel independently with the device is yet to be determined from the preliminary assessment that is reported later in this chapter. Although the users are assumed to be aware of the intended destination, they may accidently go beyond the range in some inevitable cases. Thus, when this happens, a stronger signal will start immediately to guide them onto the correct path.

At this point, the design concept is in its preliminary phase and the working prototype has yet to be developed. On the surface, the system adopts the existing navigation system that works with GPS, but it should simultaneously support the main functionality or feature – haptic stimuli as directional cues. The proposed system architecture of the device is shown in Figure

4.5. It consists of (1) two sensors: directional sensor and GPS receiver, (2) microcontroller, (3) and the wearable haptic-feedback device. Technically, the sensors used are to detect users' real-time location and orientation, and the location information is then sent to the microcontroller. The microcontroller is used to control vibrators and input data from the sensors, and communicate with the host PC. The output voltages data allows the vibrators frequencies to be controlled. In addition, the haptic stimuli are created with multiple vibrators that function at regular intervals according to body positions. These series of vibrators will be embedded between the two layers of fabrics and sealed together using threads, as demonstrated in Figure 4.3 (A).

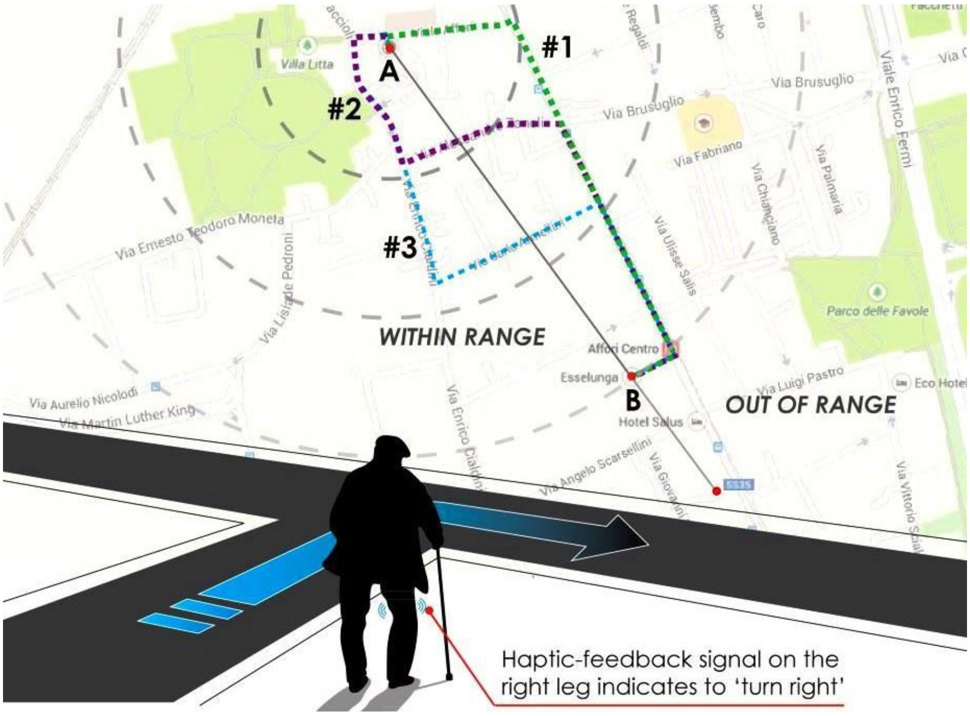


Figure 4.4: The illustration on how the navigation device works

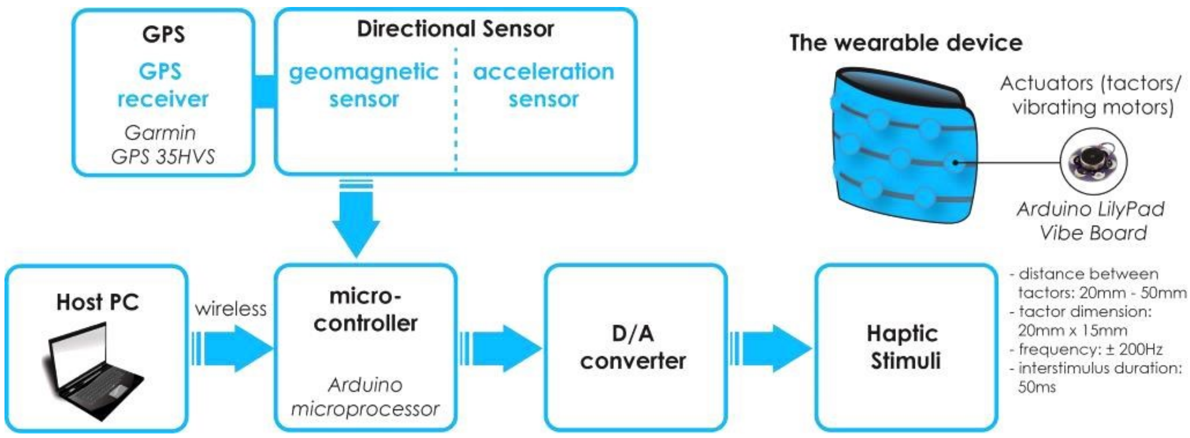


Figure 4.5: Proposed system architecture for the wearable device

Then again, the preservation on haptically explored objects [203] is based on the distinctive attributes of human implicit memory. Thus, to establish an encouraging result of intervention from this proposed project, the device should be used constantly or as a continuous practice. Above and beyond, since the concept employs a new technique of wayfinding, it may require continuous usage to get the users familiarized with the device functions and interfaces.

From the principle of UCD, it is highly recommended to implement the strategies of assessment at different (maturity) phases of the design and development process. Therefore, before materializing the functioning prototype of this concept, it is necessary to understand the potential of this first proposed conceptual design at its initial stage. The next section presents the preliminary assessment of the design project based on its aim, method, and finally results and discussions.

4.5 Preliminary Assessment

The preliminary assessment is conducted in the form of a survey. This survey is carried out as a proof of concept for the new navigational assistance to facilitate AD patients in finding their ways within the environment they live in. This stand-alone wearable device provides an alternative towards the conventional visual (map and route) wayfinding techniques. Accordingly, before implementing it in the real life situation, the need to comprehend whether this new concept is acceptable, suitable and practical is highly noteworthy. For this reason, the survey aimed to investigate the feasibility of the design concept in terms of: (1) acceptability of intervention, (2) usability on users, (3) wearability of the device, and (4) setting suitability of interventions.

The survey was made of both close-ended and open-ended questionnaire structure. Before partaking in the survey, respondents were given a summary of the conceptual design which described the proposed navigational assistance concept. The description was necessary since the proposed concept was unlike the ordinary or existing navigational devices. Also, there were many technical terms used in the questions that might not be familiar or understood by the respondents if the system was not sufficiently described beforehand.

In order to attain and justify the specific objectives of this preliminary assessment, the questions are subcategorized into several segments, exclusive of the question associated to the demographics of respondents. These segments include (1) acceptability, (2) wearability, (3) setting suitability, (4) usability, and (5) general concept. Henceforth, the following subsections elaborate comprehensively on the data gathered from the survey.

4.5.1 Demographics of Respondents

The questionnaire of the survey was distributed online to the selected AD and dementia institutions or research centers in the United Kingdom, Italy and Malaysia. The selections of these institutions were based on availability, recommendations and the established networking. In carrying out the survey, there were a few important thoughts or notions to be considered when conducting and distributing the questionnaire of this survey. The first sets of considerations were in regard to the population, sampling and the accessibility. Here, although the proposed intervention concerns individuals with AD, attaining feedbacks from them could be insubstantial. This was particularly disconcerting because this survey required a clear justification of preferences and definite reasoning. Accordingly, the target respondents of the survey were: (1) caregivers and (2) clinical/medical experts of AD, since they have the most knowledge base about patients' behaviour and caregiving need.

Additionally, despite the importance of this survey to determine the perpetuation of the proposed project, it was not the only and main data collection for the research. In fact, as mentioned previously, the proposed project needed to be preliminary assessed in order to understand the deficiencies to be improved from the conceptual design before the prototyping phase. Therefore, based on these considerations the number of samples did not represent the sample size. This was due to some limitations in performing the assessment that included the availability and cooperation from the respondents, suitability of the questionnaire and even time factor.

Hence for this survey, 42 respondents (23 Female and 19 Male) responded to the online questionnaire in total. The age of the participants ranged from above 65 years old (n=4) and the youngest was between 22 to 34 years old (n=11). Most of the respondents were the professionals and consisted of therapist/ neuropsychologist/ medical doctor/ student/ researcher in dementia & AD. It was followed closely by AD & Dementia caregivers. Some of the caregivers were the family members or the relatives of the persons with dementia.

Nonetheless, the feedbacks from the family members or the relatives were only considered only if they had the working experience at the nursing homes or at least if they had been dealing directly with dementia patients. This was to avoid the ambiguities in validating this preliminary assessment. Although none of the persons with dementia took part in this preliminary assessment since they might not be able to clearly opinionate their perceived views, the feedbacks from their caregivers might at least represent the patients' thoughts, and for this reason, the feedbacks gathered were a convincing dataset. Table 4.2 below shows the demographic of respondents in detail. The next subsection presents the results of the survey according to the five segments as mentioned earlier.

Table 4.2: Demographics of respondents to the survey

Demographics	Classifications	Numbers (n)	Percentage (%)
Gender	Male	19	45.2
	Female	23	54.8
Age	21 years old and below	0	0
	22 to 34 years old	11	26.2
	35 to 44 years old	6	14.3
	45 to 54 years old	8	19.0
	55 to 64 years old	13	31
	65 years old and above	4	9.5
Educational Qualifications	Primary School	0	0
	Secondary School	4	9.5
	Bachelor Degree	15	35.7
	Master's Degree	13	31
	Doctorate	6	14.3
	Other	4	9.5
Occupation	Professional	36	85.7
	Non-Professional	6	14.3
Eligibility to become Respondents	Therapist/neuropsychologist/medical doctor/ student/ researcher in dementia & AD	19	45.2
	Professional/ non-professional) AD & Dementia caregiver	15	35.7
	Others	9	21.4

4.5.2 Results and Analysis

For the quantitative data, where appropriate, we decoded the answers given by the respondents using scales. We used a constant scale that ranged from 1 to 5, with 1 representing the minimum score and 5 representing the highest. However, this scale gave different connotation and it went according to the segments of the questionnaire where it suited the questions better. For example in the 'Acceptability' segment, some questions referred the scale of 1 as 'highly unlikely', 2 as 'unlikely', 3 for 'neutral / I don't know', 4 for 'likely', and finally 5 signifies 'most likely'. Table 4.3 below presents the data collected from the survey.

Table 4.3: The results of the survey based on the acceptability, wearability, setting suitability, usability and general concept of design proposal

Questions	Segments	Number of Respondents	Percentage (%)
ACCEPTABILITY			
Would individuals with dementia use this new concept of navigation?	1. Most unlikely	3	7.1
	2. Unlikely	9	21.4
	3. I don't know	9	21.4
	4. Likely	15	35.7
	5. Most likely	6	14.3
Would they comply and cope with the continuous use to get familiarized with its functions?	1. Most unlikely	4	9.5
	2. Unlikely	6	14.3
	3. I don't know	9	21.4
	4. Likely	19	45.2
	5. Most likely	4	9.5
Is this new navigational device acceptable by individuals with dementia?	1. Highly unacceptable	2	4.8
	2. Unacceptable	2	4.8
	3. Neutral	6	14.3
	4. Acceptable	27	62.3
	5. Highly acceptable	4	9.5
WEARABILITY			
Which is the most appropriate position to place the device?	1. Shoulders	11	26.2
	2. Waist	11	26.2
	3. Thighs	4	9.5
	4. Heels/Soles	9	21.4
	5. Others	7	16.7
Suitability on Shoulders	1. Highly unsuitable	0	0
	2. Unsuitable	5	11.9
	3. Neutral	15	35.7
	4. Suitable	13	31
	5. Very Suitable	9	21.4
Suitability on Waist	1. Highly unsuitable	0	0
	2. Unsuitable	11	26.2
	3. Neutral	5	11.9
	4. Suitable	17	40.5
	5. Very Suitable	9	21.4
Suitability on Thighs	1. Highly unsuitable	3	7.1
	2. Unsuitable	13	31.0
	3. Neutral	9	21.4
	4. Suitable	13	31.0
	5. Very Suitable	4	9.5
Suitability on Heels/Soles	1. Highly unsuitable	2	4.8

	2. Unsuitable	17	40.5
	3. Neutral	6	14.3
	4. Suitable	13	31.0
	5. Very Suitable	4	9.5
Integration with underwear or clothes (Scale 1 to 5)	1. 1	2	4.8
	2. 2	6	14.3
	3. 3	10	23.8
	4. 4	13	31
	5. 5	11	26.2
Which is the most suitable attire/clothing to be integrated with the device?	1. Men's/women's singlet	15	35.7
	2. Men's/women's briefs	11	26.2
	3. Bra	0	0
	4. Socks	6	14.3
	5. Suspender	7	16.7
	6. Others (t-shirts that clings to your body so vibration can also go to your arms)	3	7.1
Suitability on Men's/women's singlet	1. Highly unsuitable	0	0
	2. Unsuitable	3	7.1
	3. Neutral	13	31
	4. Suitable	11	26.2
	5. Very Suitable	15	35.7
Suitability on Men's/women's briefs	1. Highly unsuitable	8	19.0
	2. Unsuitable	7	16.7
	3. Neutral	9	21.4
	4. Suitable	13	31.0
	5. Very Suitable	5	11.9
Suitability on Bra	1. Highly unsuitable	8	19.0
	2. Unsuitable	19	45.2
	3. Neutral	13	31
	4. Suitable	2	4.8
	5. Very Suitable	0	0
Suitability on Socks	1. Highly unsuitable	2	4.8
	2. Unsuitable	15	35.7
	3. Neutral	6	14.3
	4. Suitable	17	40.5
	5. Very Suitable	2	4.8
Suitability on Suspenders	1. Highly unsuitable	4	9.5
	2. Unsuitable	13	31.0
	3. Neutral	7	16.7
	4. Suitable	18	42.9
	5. Very Suitable	0	0
Is the device appropriate to be worn in long hours? (Scale 1 to 5)	1. 1	2	4.8
	2. 2	5	11.90
	3. 3	9	21.4
	4. 4	13	31
	5. 5	13	31
SETTING SUITABILITY			
This navigational device is	1. 1	0	0

to be used mainly in an outdoor environment, do you agree? (Scale 1 to 5)	2. 2	2	4.8
	3. 3	11	26.2
	4. 4	15	35.7
	5. 5	14	33.3
The device is useful to assist individuals with dementia to find their ways; (may choose more than 1 answer)	1. Within the neighbourhood	38	29.5
	2. To the nearest parks, markets, hospitals, etc.	32	24.8
	3. To use public transportations	23	17.8
	4. Socializing inside community	23	17.8
	5. Others (to find their way home, go to their family member's home)	13	10.1
Would you recommend individuals with dementia to travel alone with the assistance of this device? (Scale 1 to 5)	1. 1	9	21.4
	2. 2	4	9.5
	3. 3	12	28.6
	4. 4	13	31.0
	5. 5	4	9.5
Relevance distance individuals with dementia should be allowed to travel with this device?	1. Less than 1 km	13	31
	2. 2 - 4 km	11	26.2
	3. 5 - 6 km	10	23.8
	4. 7 - 8 km	0	0
	5. 9 - 10 km	0	0
	6. Other	8	19.0
Do you think this tool may also work in an indoor environment?	1. Yes, mainly inside the home	17	40.5
	2. Yes, mainly inside the building	21	50.0
	3. No	4	9.5
USABILITY			
Is this new concept of navigation helpful for individuals with dementia in wayfinding?	1. Very unhelpful	2	4.8
	2. Unhelpful	0	0
	3. Neutral	2	4.8
	4. Helpful	27	62.3
	5. Very helpful	11	26.2
Do you prefer this device to be a stand-alone device?	1. Absolutely no	11	26.2
	2. No	6	14.3
	3. I don't know	4	9.5
	4. Yes	19	45.2
	5. Absolutely yes	2	4.8
Are additional features, such as visual and auditory instruction needed?	1. Absolutely no	3	7.1
	2. No	5	11.9
	3. I don't know	15	35.7
	4. Yes	17	40.5
	5. Absolutely yes	2	4.8
What additional feature should be added to this device? (optional)	1. Speech instruction	17	40.5
	2. Visual instruction	4	9.5
	3. Both speech and visual instructions(similar to current mobile GPS application)	17	40.5
	4. Other (alert to police/passerby to assist patient to contact family)	4	9.5
How this device may be benefitted by individuals	1. Improved wayfinding ability	34	81
	2. Reduced dependency Improved wayfinding ability	32	76.2

with dementia? (may choose more than 1 answer)	3. Good performance of activities of daily living (ADLs)	25	59.5
	4. Increased mobility	23	54.8
	5. Other (improved relationships with family members; less restriction of movement)	2	4.8
Do you think this device is easy to use by individuals with dementia?	1. Absolutely no	2	4.8
	2. No	0	0
	3. I don't know	13	31.0
	4. Yes	23	54.8
	5. Absolutely yes	4	9.5
How practical is this new concept of navigation to be implemented? (Scale 1 to 5)	1. 1	0	0
	2. 2	0	0
	3. 3	10	23.8
	4. 4	19	45.2
	5. 5	13	31.0
GENERAL CONCEPT			
Do you believe the device could be useful to assist the wayfinding of individuals with dementia?	1. Very Negative	0	0
	2. Negative	2	4.8
	3. Neutral	3	7.15
	4. Positive	34	81
	5. Very Positive	3	7.15
Do you agree if this device may substitute or provide an alternative for current navigational devices? (Scale 1 to 5)	1. 1	0	0
	2. 2	0	0
	3. 3	17	40.5
	4. 4	19	45.2
	5. 5	6	14.3
Do you agree if this concept of navigational tool helps to promote active lifestyle among individuals with dementia? (Scale 1 to 5)	1. 1	0	0
	2. 2	2	4.8
	3. 3	4	9.5
	4. 4	25	59.5
	5. 5	11	26.2

From the results obtained from the survey, it was acknowledged that the proposed conceptual design of navigational assistance was highly acceptable by the users (persons with dementia). In fact, it is one of the primary concerns of the investigation, so that the design concept could be forwarded into the next stages: prototyping, usability testing and implementation. In this three-question segment, we needed to understand how the new proposed navigational assistance was perceived by users; either positively or negatively.

In particular, we asked if the persons with dementia would use this new navigational device, and if they were able to cope with the continuous use in order to get familiarized with the concept, since it was a new form of navigational assistance. The feedbacks confidently showed that the respondents received the proposal well, with most of the respondents agreeing that the concept was practical to be used by the target users.

The following questions directly looked into the 'acceptability' of this proposed design concept. Once again, most of the respondents (62.3%) rated acceptable and only 4.8% rated highly unacceptable. The qualitative analysis from the comments received supported this high percentage of acceptance, which was due to the fact that the proposed navigational assistance provided uncomplicated features. The simple system was obviously important for the target users since they could not afford to learn and remember new-yet-complex features. Likewise, the device should accommodate their cognitive incapability, and not to cause more confusion. On the contrary, the qualitative analysis of this segment also suggested that most of the respondents who gave the lower scales in this segment were uncertain if the proposed concept could minimize their spatial orientation and navigational disabilities of dementia patients. Figure 4.6 demonstrates the scales given by the respondents (by percentage) for each question in the mentioned segment.

The device wearability is another crucial criterion of the proposed design, in particular on the comfort and aesthetic aspects. Although at this preliminary assessment the respondents could not assuredly justify their positional preferences without the actual physical artifact, they still could help to indicate the preferred body parts based on their understanding of design concept which were supported by their passable experiences in dealing with the patients.

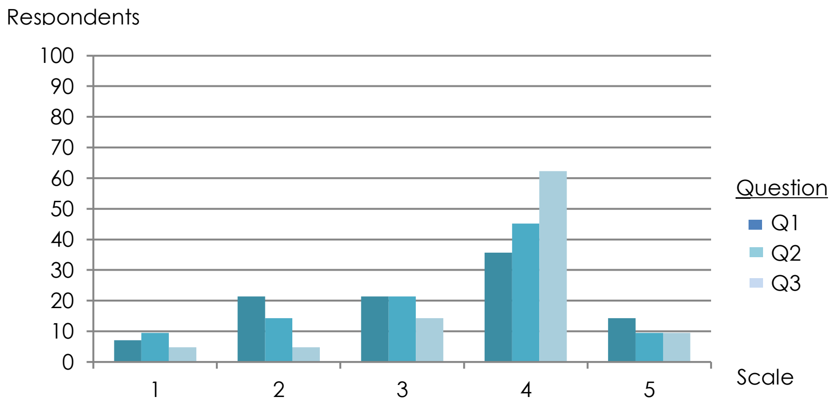
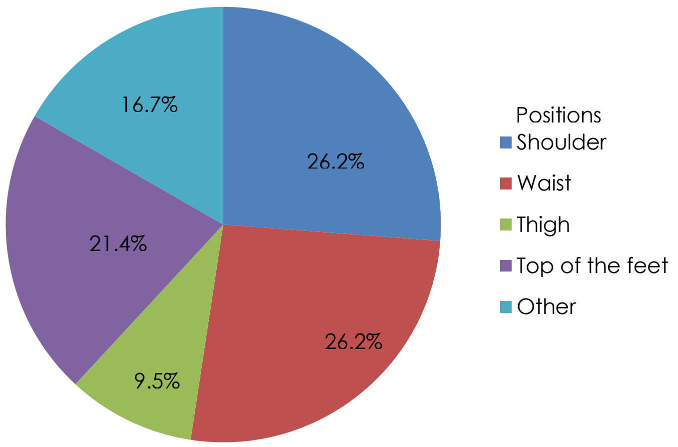


Figure 4.6: The percentage of feedbacks according to the scale of 1 to 5 for each question in the 'acceptability' segment

(A)



(B)

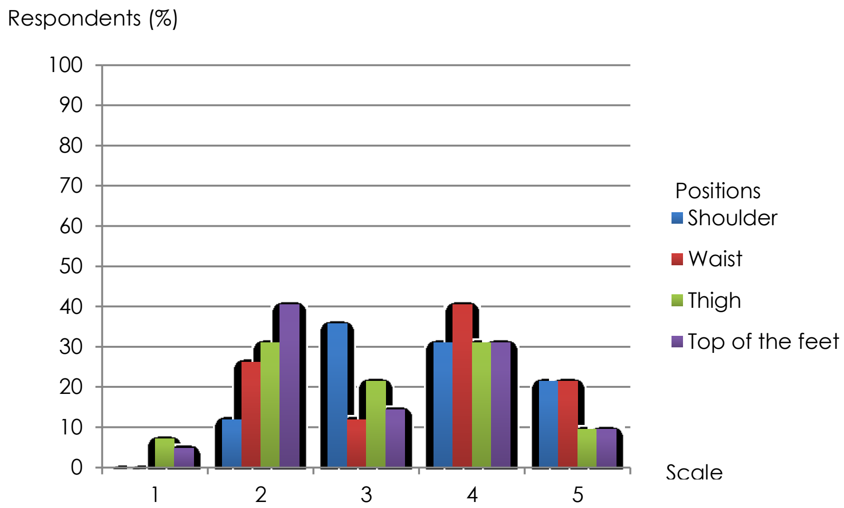


Figure 4.7 (A): Percentage of positional preference and **(B)**: percentage of scales (1 to 5, with 1 is the least and 5 is the most preferred) given to each position proposed

In this second segment (wearability) of the questionnaire structure, the respondents were required to choose the most preferred positions to place the device or to trigger the haptic stimuli. As underlined earlier, the body-part positions were based on suggestions by Gemperle [272] and with the possible integration on clothes. The results demonstrated that both waist and shoulder shared the same highest score of 26.2 %. Here, the percentages of positional preferences, as well as the given scale for each position are demonstrated in Figure 4.7 (A) and (B) above.

From Figure 4.7 (A) it is clearly revealed that 'thigh' is the least favoured, with only 9.5% percentage of preference. Similarly, as shown in Figure 4.7 (B)), the lower scales were not only given to thigh, but also for top of the feet. However, both shoulder and waist were rated with higher scales. In the comments about ‘other positions’, many respondents suggested for the areas of hands/arms. For example the wrist was mentioned because many existing wearable devices are found at this position which was quite a common position for the integration with timepieces.

The enquiries on the positional preference are indeed linked to the following questions concerning the fusing of device with clothes. This proposal of embedding is in line with the fact that the users/wearers should be wearing the device for a long time, and at least during the course of wayfinding. Furthermore, as mentioned before, the haptic stimulus works at its best when it has direct contact with the users’ skin. Based on these grounds, the study has considered that the integration with clothes is sensibly feasible. Here, the respondents were asked to rate (on the scale of 1 to 5) if it was appropriate to integrate or attach the device onto users’ clothes or underwear.

Positive feedbacks were gathered for this specific question, with 31.0% of the respondents rated 4/5 and 26.2% rated 5/5. The preference for embedding to the suitable clothes/underwear is shown in Figure 4.8 (A) and (B). It illustrated the percentage of preference, as well as the given scale for each clothes/underwear proposed. The proposed clothes/underwear were in accordance with the proposed positions as preceded in the previous question. From the proposal given, as shown in Figure 4.8 (A), respondents mostly preferred the singlets (35.7%) and secondly the briefs (26.2%) to be integrated or attached with the device, while socks (16.7%) and bra were the least favoured, with none of them choosing bra. The percentage of scales given to this proposed clothes/underwear also corroborated this preference, where lower scales were given on the bra and socks, while the singlets and briefs received higher scales of preferences.

The most significant finding here is that the feedbacks on the questions about the clothes-embodiment endorsed the most preferred body-part positions as reported before. We can synergize the clothes-embodiment with the device placement. For example, the singlets and briefs are chosen to be incorporated with the device, thus suggest that the singlets are suitable for the haptic stimuli on shoulder position, while briefs are appropriate for the waist. Nonetheless, the subjective analysis in this segment revealed many vindications by the respondents that support their preferences, either for the positioning of the device or the integration with clothes.

(A)

(B)

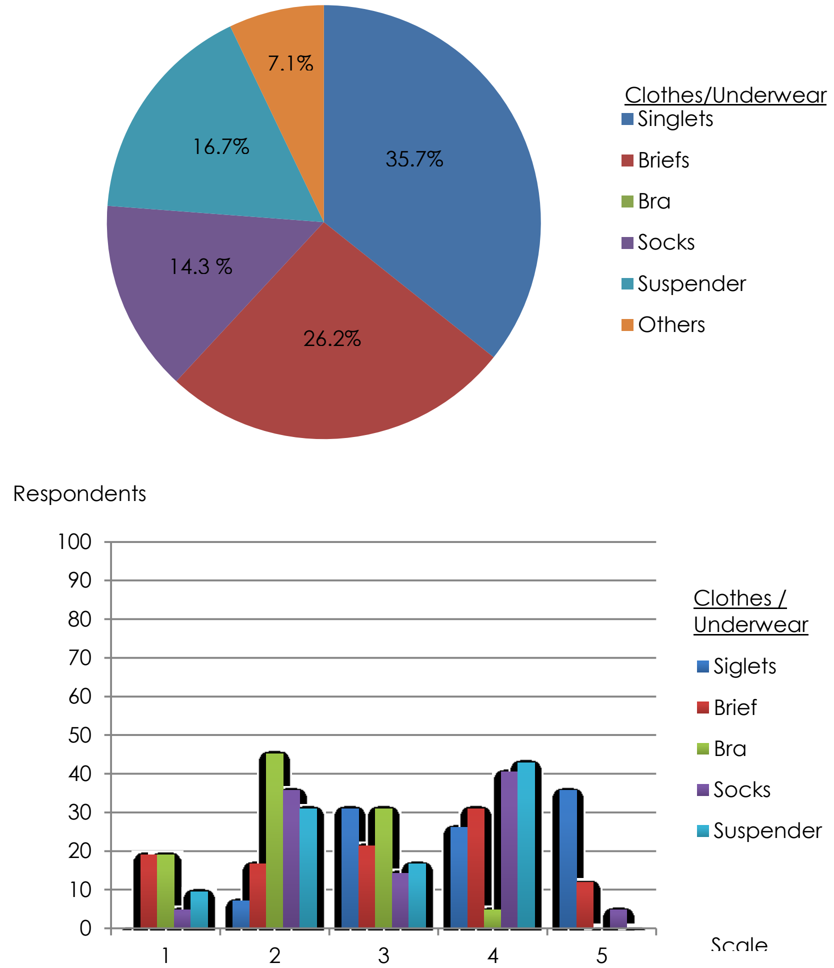


Figure 4.8 (A): Percentage of clothes-embodiment preference and **(B):** percentage of scales (1 to 5, with 1 is the least and 5 is the most preferred) given to each clothes/underwear proposed

First, we can observe on the pattern where the respondents who chose the most preferred positions agreed with the aspect of practicality, utility and accessibility of the device. For example, they commented that the shoulder was less likely to distract the dementia patients as compared to other positions. Another functional reason was that, the shoulder was closer to the ears and eyes, if the device was ever designed to incorporate the audio and visual signals. In addition, those who chose the waist position in particular assented that this preference was based on the reason that the device needed to be positioned where it was easily accessible and not burdensome for the users (or their caregiver) to reach, put and take off. This was also in conformity with the reasons for their choice to integrate with underwear, which was the waist or abdominal area that could give a ready access and comfort to the wearers. That being said, there were concerns on the problems of (urinary) incontinence in dementia patients and also on the possibility of the patients not wearing the same type of underwear.

In this segment, the respondents were asked if they agreed for the device to be worn by the users for long hours. This is in order to cope with the constant use or continuous practice and as it is designed to integrate with the clothes. For this particular question, the majority responses were: 30% rated 5/5 and 30% for 4/5. The promising results in this segment increased the feasibility to proceed with the design concept of device and lend indication of convenience on its wearability. Consequently, the findings on of the wearable aspect on the whole, need further refinement on the design concept before the physical and functioning prototype can be developed.

In terms of environmental setting suitability, the first question asked was to know if the respondents approved that the device should be used mainly in an outdoor environment. It is shown that the majority agreed with the proposal that the intervention was for the outdoor wayfinding use. Here, from the scale of 1 to 5 (as 1 representing strongly disagree and 5 was for strongly agree) 35.7% rated 4/5 and 33.3% rated 5/5. For the outdoor wayfinding, the respondents also agreed that the proposed navigational assistance should help to facilitate the users to: (1) go to the nearest parks, markets, hospitals, etc., (2) use the public transportations, and (3) socialize with the community. Thus, like other outdoor wayfinding interventions that serve those purposes [228][229][231], the results suggest that this device is greatly useful to be operated within the neighbourhoods they live in.

Furthermore, the respondents were asked if they agree to allow the users to travel/navigate alone with the device. For this question, 31.0% rated 4/5 (agree) and 28.6% rated 3/5 (unsure). The following question justified this uncertainty as most of the respondents recommended that the users should not be allowed to travel alone, too far with any navigational assistance device, including the one we proposed. Hence, given the proposed range of allowed travel distances, the highest percentage (31.0%) agreed with the distance of less than 1km. Whilst, 26.2% chose the range of 2 to 4 km, 23.8% preferred 5 to 6 km, and none of them chose the longer distance above 7 km. Figure 4.9 illustrates this distribution of percentages.

The qualitative analysis evidently clarified the observed data. One of the biggest hesitations learned from their comments were due to their concerns on the users' safety and their risks being in an open space alone without any supervision. In addition to this, many of them suggested to use the device for tracking the users and their whereabouts in order to ensure their safety, as well as to mitigate the risks. The secondary concern corresponded to sanctioning the users to travel further unaccompanied outdoor which was much more demanding as when compared to the indoor. Once again, this recounted to their dubiety over the safety matters.

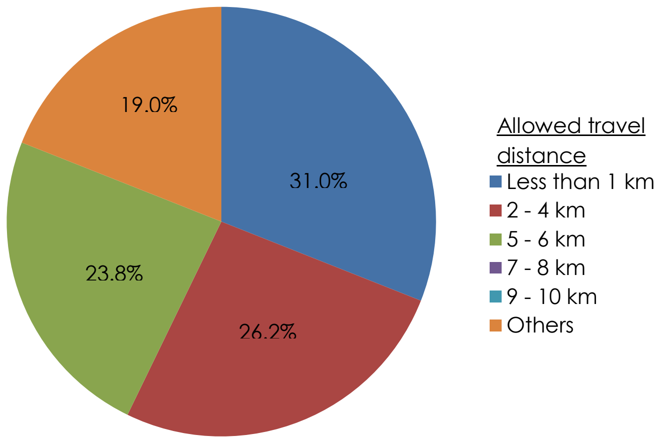


Figure 4.9: The percentage distance allowed for the users to travel alone with the device

Notwithstanding, there was also an agreement to not see the reason why this intervention could not be applied for the outdoor wayfinding. This is because people with dementia would not need too much assistance finding their ways in a closed space because their wandering behaviour is more apparent when they are in the open space or outdoor environment. Furthermore, the respondents acknowledged their judgement is also based on the availability of the existing wayfinding assistance intended for indoor use.

On that account, based on both quantitative and qualitative analyses, we may sum up this segment that the proposed intervention is recommended to be tried/attempted in an indoor environment first. Then if the complications or arising matters have been checked or appraised and exemplified, the application is put to test in the outdoor environment, while gradually increasing the allowed travel distances. Likewise, if it is used for an outdoor wayfinding, the navigation system should assist them to be able to access within the neighbourhood they live in and involves their daily routines/activities.

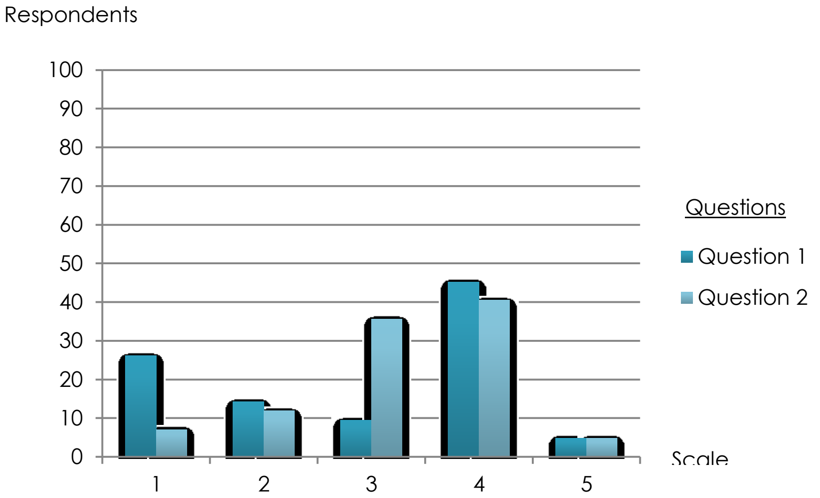
From the usability viewpoint, the respondents were firstly required to rate whether or not the device would be beneficial to the target users (again 1 represents very unhelpful, while 5 means very helpful). Most of them (62.3%) rated the device as ‘helpful’ which indicated its usefulness to help dementia patient in wayfinding. In the next question (Question 2), they were asked if they preferred the navigational assistance to be a stand-alone device. Stand-alone here means the device works on its own without the integration of another device, such as mobile phone or any electronic devices. For this, the majority (45.2%) approved the concept of stand-alone device.

However, when they were asked (Question 3) if additional features such as visual and auditory instructions were needed, 42.9% were unsure of this, and 33.3% preferred the additional features. The following question rectified this divergence when they were given the choices of additional modalities: (1) speech instruction, (2) visual instruction, and (3) both speech and visual instructions. Here, they unanimously acceded that the essential additional features to the device are: speech instructions (40.5%) and both speech and visual instructions (also 40.5%). Figure 4.10 (A) below visualizes the contradiction by the scored given to the questions asked relating to the device being stand-alone or integration, while Figure 4.10 (B) shows the preferred additional features to the design concept.

The following question inquired was if the device was easy to learn/use by the persons with dementia. Here they highest percentage (54.8%) answered 'Yes' (or the scale of 4/5), but the second highest (31.0%) answered 'I don't know (or 3/5). In contrast, the final question which was about their opinion on the practicality of the prosed concept, the first and second highest percentages were shown in the higher scales: 45.2% rated 4/5 and 31.0% rated 5/5. This is indeed a positive feedback where it means the respondents admitted that the prosed design is pragmatic and can be realized for actual use.

The comments given in this segment revealed the justification for these collected data. The rationalization can be categorized into (1) those who support the integration with additional features and (2) those who against it or preferred the device to work as it is (or stand-alone). The study noticed a pattern in those supporting the integration where it was on the basis of tracking or monitoring, aside from the reason that the users might disregard the haptic signals given during wayfinding. Here, as most of them suggested assimilating this device with the mobile phone, and the reason being was to allow their caregivers (spouses or family members) to operate the device when the users were travelling alone.

(A)



(B)

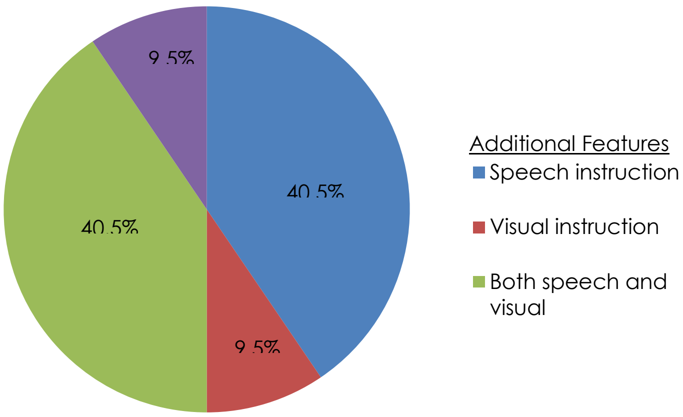


Figure 4.10: (A): Scales by percentages given to Question 2 and Question 3 and **(B):** Percentage of preferred additional features to the device

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In addition, many of them who agreed to integrate the additional features preferred the audio-related interfaces, i.e. voice command and sound cues. This is because they presumed that the audio instruction is a common feature in the existing GPS navigation systems, hence the users are probably familiar with this interface. Furthermore, the integration with audio instruction is less complex and will allow the users to keep the visual senses clear on the road.

Contrarily, the respondents who ratified the device to be autonomous were based on the pretext that by having more features might cause more confusion to the users. This also meant that the system would be more complicated, thus making it difficult for the users to use the device. Additionally, persons with dementia who were already gripping with the difficulty to follow simple instructions would be overwhelmed by the overabundance of technology. In the end, they would lose the interest to learn how the system works. The comparable preceded defense was also used by some whom were against the integration with audio instruction. They pointed out the suspicion on the reactions by the dementia patients towards the bodiless voice. Even by using a familiar voice, it might eventually trigger their traumatic episodes or issues and that should be avoided the most for these individuals.

The final segment of this survey was the 'General Concept', intended to identify how the respondents perceived the design proposal as a whole. The segment consisted of three simple but pertinent questions, to evaluate their general perception, as well as to conclude the survey. The first question was to identify if they were convinced of the usefulness of the device in assisting the wayfinding of dementia patients. Secondly, if they agreed that the proposed design could at least be an alternative for the existing navigation systems. While the last one inquired if the device could encourage the users to maintain a healthy lifestyle. The feedbacks obtained were as follow: the majority (81%) rated 4/5 for the first question, highest percentage of 45.2% scored 4/5 for the second question, while 59.5% and 26.2% rated 4/5 and 5/5 accordingly for the third question. This is shown in Figure 4.11 that displays these distributions of scales by their percentages.

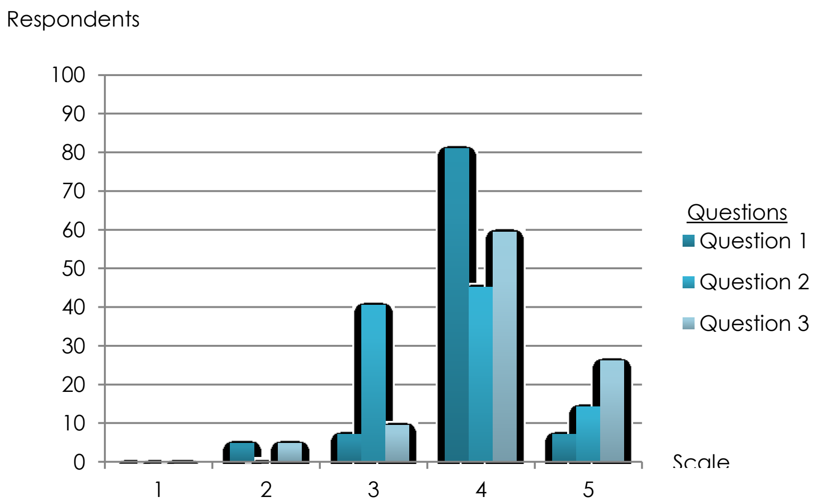

Figure 4.11: Scales by percentages given to the questions in the 'General Concept' segment.

There were many recommendations and constructive remarks left by the respondents for this last segment and for the whole design concept. This was signified by the higher scales given to the question, while at the same time indicating their encouraging support towards this project. One of the expected suggestions is to provide familiarization training in accordance to the introduction of this intervention, since signals other than visual and audio are quite unusual even for the normal users. In addition to this, choosing the appropriate positions to receive the haptic signals will determine the success of this proposed concept.

Many of them also agreed that this design concept goes conjointly with the current navigation systems which are already familiar to most people. Hence, any design concept that is not too complex and provides compatible features like the existing ones can boost the confidence of people with dementia to use and help in their wayfinding. Nevertheless, some of the respondents also suggested that this intervention could be appreciated more by those who were not in the severe stages of dementia. The study cannot totally deny this assumption since the respondents are apparently those who have the exact experience dealing with the dementia patients. Hence, they probably understand the behavioural and physiological barriers of these individuals more than anyone else. Therefore, it is important to collect some indications shown by the target users using the first prototype of this device. This is exactly the main goal for the next phase of this design project.

4.5.3 Discussion

The survey revealed the promising results for the evaluation of the design project in its initial stage. The study would like to highlight again a few significant findings from this survey, as the feedbacks gathered are used to improve the design concept before it can be forwarded to the next phase. Once again, although none of the respondents are the actual dementia patients, they are those who know best and deal directly with our potential users. Due to this reason, their feedbacks are undoubtedly valuable and helpful in this survey.

First and foremost are the combination aspects of acceptability and practicality in the proposed concept for the individuals with dementia. As thoroughly described in Chapter Three, the implementation of new (technological) intervention in particular for dementia patients should consider both their disabilities and remaining abilities. Even if assistive technology is a promising tool to facilitate and ease their daily tasks/activities management [282] [283], it should be properly introduced and primarily exposed to the target users. This could be done by designing the technological application to be not overly unusual and at least has the comparable characteristic with their everyday technologies/gadgets [284], in terms of physical looks, features or interfaces.

Moreover, to gain the interest of the persons with dementia in using the technology, the proposed design should critically minimize their struggle to learn it. It will at the end result in keeping their interest to continuously using the proposed technology. This explained the positive feedbacks and perceptions of the respondents towards the proposed concept, as they accepted the straightforward feature of the device and it was easy to be comprehended by the target users. The use of simple interfaces of one technology is also advocated by the respondents when many of them approved the concept of stand-alone device without any other additional incorporation (such as visual and auditory interactions). Having too many features or interactions augment the complexity of one device, which leads to adding more fuss and turmoil to the patients. The situation is even worse for those who already manifest the difficulties to perceive even the simplest instruction or task.

The qualitative analysis also suggests that unless the issues of familiarity and training can be resolved, the proposed concept can be successfully implemented. This is due to the fact that we proposed an uncommon navigational modality, not through visual and hearing, but through the sense of touch. Thus, it is recommended that a user manual in a simple lay language is provided to the caregivers and therapists, who will get familiarized with the device system before they can train the real users.

Another crucial point to be underlined here is the comfort of the device. This is in agreement with the wearability and also usability aspects. Firstly, comfort is certainly an important substance to be weighed and maintained in dementia patients [287], especially for the wearables. From the survey, we found many statements from the feedbacks that put forward this consideration. One of the related suggestions was to select the suitable materials to be used for the wearable device. This is again subjected to the appropriateness of long hours of use, as well as of different environmental and contextual climates.

This suggestion was also supported by the importance to choose the suitable position to embed the built-in haptic stimuli in the device. The placement should best fit its function, while not hindering their mobility. Here, comfortability and unobtrusiveness are the key criteria to be considered, to avoid the post-implementation issues faced by the users, possibly due to the skin sensitivity and differential climate conditions. Secondly, giving a discreet look to the design is definitely befitting because the “too noticeable” device may cause other discomfort issue to the users. This validates the suggestion made by Rosenberg 2012, [288] on how to engage the use of technology in person with disabilities. It is not to stigmatize the users with the technology, and making it less obvious is highly commendable.

In addition to the abovementioned findings, although many have agreed to implement the intervention in an outdoor environment, the dispute on users' safety and possible risks should not be neglected. The tangible and intangible elements (traffics, buildings, landscapes, geographies and soundscapes) in an open space would jeopardize the users' concentration [217]. Their concern upon this matter answered the reluctance of some respondents to allow persons with dementia to travel unattended, and too far with the device. This could possibly be the reason for them to recommend that the proposed device should be dedicated mostly to the early dementia patients.

The level of consciousness and cognitive ability in dementia patients are decreased as the disease progresses [19][17]. To boot, their spatial disorientation and the ability to navigate also worsens simultaneously [128][305]. Targeting on those in earlier stages is appropriate because it is doubtful that the severe dementia patients are able to perceive the haptic stimuli as forms of wayfinding signals. Anyhow, we take this suggestion on its bright side because it obviously goes along with one of the main research objectives - to provide a navigational assistance to the AD patients who have yet to be institutionalized. The advantages are for those who are still living at home in the early to moderate stage of the disease [306].

There were many important points raised from the analysis of the corresponding quantitative and qualitative data, and we managed to gather the valuable results of assessment from this survey, even without (1) getting the feedbacks by the real users, and (2) having a physical mockup device. This preliminary assessment is indeed a vital phase in the design and development process of our proposed design project. In general, it boosts our motivation to go further with this concept. But then again, as the biggest part in the standards of UCD principle, the involvement of actual users is the key criteria. Therefore, the next stage of the research is to develop the functioning prototype of this device in accordance to all the discussed considerations, critical aspects and issues, before it can be properly appraised by the real users. In fact, the next chapter is devoted specifically for this purpose, where it presents the development process of the prototype and subsequently the conducted usability testing using this prototype as an apparatus.

CHAPTER FIVE

5 Prototyping for Usability Testing

5.1 Prototype Development

In a nutshell, the device prototype that has been developed integrates tactile displays instead of the conventional graphic and audio interfaces. Unlike the existing navigation devices that require the users to read a map display and listen to speech instruction, this device uses haptic stimuli as the signals. As formerly highlighted, besides the practicality of handling and operating, the device is also designed to be wearable for the designated users since it may support the capabilities of the wearers while preserving personal privacy and functioning over a wide range of situations and contexts [307]. Even so, the wearable device may also lead to other issues mainly in the sense of comfort and usability to the wearers if it is designed without taking into account the view of the users' limitations and remaining capabilities

[308]. This is where the working prototype for the Usability Testing (UT) is highly essential in order to substantiate the proposed design concept.

The device prototype is partly fabricated during the attachment period at Polifactory, a designated makerspace with the joint of three departments of Politecnico di Milano: (1) Design, (2) Mechanical, and Electronics, Information and (3) Bioengineering. The aim of this attachment is primarily to develop the functioning prototype ready for the testing, while exchanging knowledge and experiences during the prototype development process. This makerspace provides most of the facilities, equipment, tools and assistance needed to build the prototype. Hence, there were two phases of the activities during the attachment or prototype development in particular, as shown in Table 5.1 below.

Table 5.1: The proposed activities for the prototype development

	FIRST PHASE
i.	**Understand the tools/equipment provided**: *Identify the tools or equipment provided (Rapid Prototyping machine, workbench for electronic and physical computing, cutting tools, etc) needed to develop the prototype.*
ii.	**Discussions on modifications and improvements of the conceptual design:** *Understand if the elements (in the design concept) are necessary to address the key question of research and product testing.*
iii.	**Refine the conceptual design:** *Identify the functionality, interaction of parts and whether the clinical problem can be solved with the design.*
iv.	**Finalize the system architecture:** *Identify all the necessary hardware/software (materials, electronic parts and physical computing) needed*.
v.	**Identify participants for the prototype development:** *Machinery and model making technician, and electronics and physical computing technicians) to be involved in prototype development.*
	SECOND PHASE
i.	**Build the model:** *Fabricate the prototype based on the drafted system architecture.*
ii.	**Run (preliminary) prototype testing:** *Identify and imitate the test scenarios for the real testing later.*
iii.	**Finalize the model:** *Modify and improve the mode by refining the prototype and add or replace the necessary elements.*
iv.	**Prototype is ready for the actual testing on target subjects**

In the conceptual design presented in the previous chapter, the study emphasized that the device's simplified interface was crucial to avoid distraction or confusion to the individuals with cognitive impairment that would lead to directional errors [262]. Due to this, the device provides the simplest possible information of navigational instructions, which is to turn left or right in the course of navigation.

Notwithstanding, an uncomplicated interface is not necessarily built from an uncertain and fragile hardware system. In fact, it required the similar materials selections or tasks and went through the equivalent phases of prototyping to build any device. For instance, the selections of electronical components and algorithms design came before the assembly of this prototype. The whole development processes that mainly include the system design and model making are presented in the next sections. The chapter is then deliberated further on the first conducted UT using the developed prototype. Results, analysis and discussion from this test are documented next.

5.1.1 System Architecture and Algorithm

The electronical components or hardware used to build the prototype comprise of an Arduino Uno microcontroller, a GPS receiver (GPS Bee kit with embedded antenna), a Micro Secure Digital (SD) card and its shield, a 4-channel 5V Relay Module, two 9V batteries, and mini vibration motors. The selection of hardware used for the device's system is in accordance with the limited resources, as well as since the prototype is meant primarily as an apparatus of the experiment. More sophisticated and advance electronic components in terms of their capacities, sizes, appropriateness, etc. will probably be used in the further development and commercialization purposes.

The prototype system consists of: (1) the input that made of the sensor, (2) the process, and (3) the output which is the tactile display. These three parts were formulated using the above-mentioned hardware and programmed using Arduino software to become a complete working prototype. Figure 5.1 illustrates the system architecture of the device. Building the device's system was not an easy undertaking, since the algorithms and coding should be properly assigned, and because it involved countless debugging tasks to get the system working as envisioned. Thus, there were several steps taken in developing the system as presented in Table 5.2.

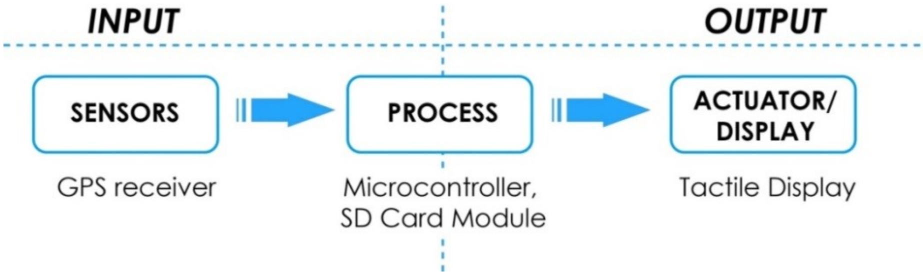

Figure 5.1: System architecture of the wearable navigation device with tactile display

Technically, the GPS receiver (sensor) is used to detect users' locations and this location information is saved into a SD card. These data are then processed and decoded by the Arduino microcontroller. This microcontroller operates as to allow the communication between the input data from the sensor and to control the tactile display. The tactile display works by indicating the directional signals when necessary. Once the algorithm framework has been structured, the actual values of the location information from the GPS data can be assigned into the built-in system. As described in Table 5.1, the specific information needed are the longitudes and latitudes, and these values represent the coordinates or orientation of the checkpoints. Meanwhile, these series of checkpoints create the route (exemplified in Figure 5.1) that one has to follow during the navigation. Then again, all of these data should be saved into the SD card in advance before the users can navigate with the device.

Table 5.2: Step-by-Step of the Algorithm Design Development

1 Obtain the real-time location information with GPS receiver		
INPUT	*PROCESS*	*OUTPUT*
GPS Receiver	Microcontroller	NMEA Messages (on Serial Monitor of Arduino programme)
2 Include LED to notify when receiving GPS data		
INPUT	*PROCESS*	*OUTPUT*
GPS Receiver	Microcontroller	(Blinking) Red LED
3 Log the GPS data into the SD card and add another LED when data is logging		
INPUT	*PROCESS*	*OUTPUT*
GPS Receiver NMEA Messages	Microcontroller + SD Card Shield + SD Card	(Blinking) Red LED + (Blinking) Green LED
4 Modify the logged data and save only the specific ones as CSV or txt file		
INPUT	*PROCESS*	*OUTPUT*

The obtained (raw) GPS data:	The modified data:		
320 325 322 $GPRMC 165103 A 4530.3979 N 909.8869 E 0 246.83 261015 A*6D 227 239 246 $GPRMC 165104 A 4530.3981 N 909.8871 E 0 255.30 261015 A*6D	N 1 2	Longitude 4530.3979 4530.3981	Latitude 909.8869 909.8871

5 Read the saved data in the SD Card

INPUT		*PROCESS*	*OUTPUT*
Save data:			Serial Print (as displayed in Serial Monitor):
N 1 2	Longitude 4530.3979 4530.3981	Latitude 909.8869 909.8871	45303979 9098869 45303981 9098871

6 Recall the data as an input and save the data into a 'data structure'

X (Longitude)	Y (Latitude)	c.x	c.y
45303979	*9098869*	*4530.3979*	*90.98869*
45303981	*9098871*	*4530.3981*	*90.98871*

7 Create an interface to bridge and compare between real-time GPS information and the saved data

Saved Location Data		Real-time Location Data	
X_1 *45303979*	Y_1 *9098869*	X_1 *45303979*	Y_1 *9098869*
X_2 *45303981*	Y_2 *9098871*	X_2 *45303981*	Y_2 *9098871*

8 Include another LED to notify when being in the saved positions

INPUT	*PROCESS*	*OUTPUT*
Algorithm Structure		(Blinking) Blue LED *(only to indicate if the system works and for debugging purpose)*

9 Build and add the actual output (tactile display) and clarify when to trigger

INPUT	*PROCESS*	*OUTPUT*
Algorithm Structure		(Blinking) Blue LED + (Vibrating) Vibration Motors, when users are at the saved positions

10 Test the system, debug and refine

Algorithm Structure ⟶ *Debug* ⟶ *Test* ⟶ *Debug + Finalize*

↓

Complete Device System

Figure 5.2 shows the example of a route that consists of several checkpoints, which represent the primarily saved data. From the figure, to go from checkpoint A (the starting point) to checkpoint F (the finishing point), a user needs to follow the route and passes through all the other checkpoints (B, C, D and E). These checkpoints are apparently the junctions, where the user needs to take the turnings. For example, from checkpoint A to checkpoint C, user walks pass the checkpoint B and here is where he/she needs to make the turn.

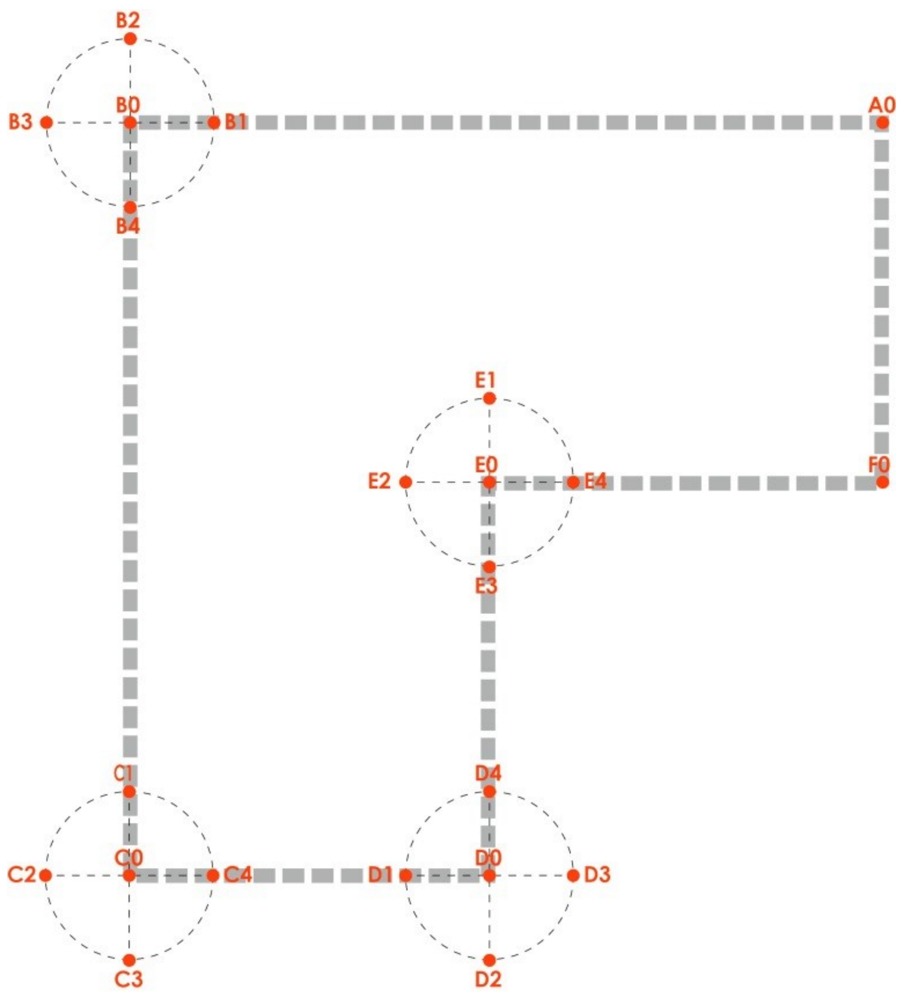

Figure 5.2: A saved route that consists of several checkpoints

At the checkpoint B, there are five coordinates that represent the user's orientation. When the user reaches B1, the navigation signal is initiated to direct him/her into the correct turn, which in this case, to turn left. However, in the event of missing the signals or to be precise missing the B1 coordinate, there are three other coordinates that can help to redirect the user. B4 represents reverse and B2 represents to go forward from point B0 (centre), while B3 is to turn right. Although for this prototype the signals given to the users are only to turn left/right, the supplementary coordinates (especially the forward and reverse) are important for the rerouting and debugging purposes.

Sequentially, to go from checkpoint C to checkpoint D and finally reaching the destination at checkpoint F, the same coordinating scheme is applied. As previously mentioned, each coordinate has the location information data and these data are decoded as 'X' value for the longitude and 'Y' value for the latitude. Therefore, the saved data based on the route shown in Figure 5.2 is represented in Table 5.3 below.

Table 5.3: Location information data for each checkpoint in the route shown in Figure 5.1

	Checkpoints					
Coordinates	A	B	C	D	E	F
0 (Center)	*X:550577152*	*X:550530624*	*X:550472640*	*X:55036539*	*X:55032468*	*X:55020177*
	Y:916458688	*Y:916475232*	*Y:916398208*	*Y:91625007*	*Y:91621342*	*Y:91618362*
1 (Left)	*X:550515776*	*X:550555008*	*X:550423761*	*X:55035472*	*X:55039843*	*X:55029073*
	Y:916481448	*Y:914393664*	*Y:916387623*	*Y:91626539*	*Y:91626366*	*Y:91610177*
2 (Forward)	*X:550590912*	*X:550576768*	*X:550443765*	*X:55034365*	*X:55039873*	*X:55026542*
	Y:916462016	*Y:916371168*	*Y:916385395*	*Y:91620912*	*Y:91629822*	*Y:91613487*
3 (Right)	*X:550581760*	*X:550576595*	*X:550454208*	*X:55035481*	*X:55037599*	*X:55029244*
	Y:916480512	*Y:916357697*	*Y:916353785*	*Y:91621357*	*Y:91629472*	*Y:91614973*
4 (Reverse)	*X:550563072*	*X:550542486*	*X:550409135*	*X:55030864*	*X:55039753*	*X:55025712*
	Y:916452480	*Y:916387609*	*Y:916375498*	*Y:91629753*	*Y:91629426*	*Y:91612539*

The algorithm structure is designed not to be read as point (.), for instance 55.0577152, 9.16458688 like the normal GPS coordinate, and the decimal point is presented up to 7 or 8 decimal points in order to increase the accuracy. Additionally, the file format that can be read from the SD card by the computing programme used is Comma Separated Value (CSV) or text file (txt). For that reason, the saved data only consist of numbers for each longitude and latitude of each coordinate. Since the system structural design is now accomplished, the physical component/hardware and exterior can be incorporated and accumulated together as one complete device prototype. The following section discloses profoundly the construction of the prototype model, before it can be used for the test with actual users.

5.2 Model Making

From the previously conducted preliminary assessment that concentrated mainly on the design concept of the device, there were two most preferred positions for the tactile display: (1) waist and (2) shoulder. Both of these positions scored the equal highest percentages of preferences by the respondents. Thus, since the prototype is used as the apparatus for the usability test, investigation on the suitability of these two positions using a working prototype is distinctly equitable.

The device prototype is created as two separate parts; (1) the tactile display and (2) the other built-in system's hardware. It is deliberately for the wearability reason and to allow the tactile display to be adjusted for the aforementioned positions. The complete prototype created as two parts is illustrated in Figure 5.3. The wearable feature is adopted from the conventional backpack and body harness. As shown in this figure, the hard case that contains the system's hardware is connected to the adjustable and buckled strap.

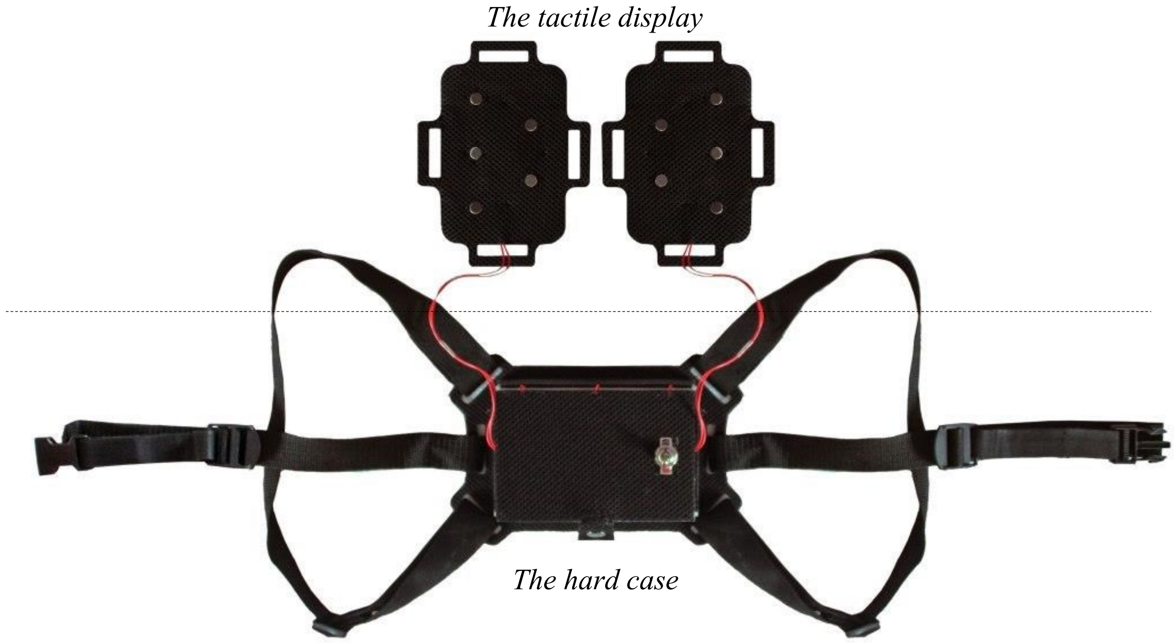

Figure 5.3: The complete prototype of the wearable navigation device

The tactile display is made of multiple mini vibration motors embedded onto the fabric to create the haptic stimuli for the directional signals. The frequencies of the vibrators change with voltages that work from 2V to 5V. The prototype runs with the constant 3V power supply that gives the frequency of 220Hz. Furthermore, the vibrators need to be embedded into the tactile display according to the tactile sensitivity of body parts. The two-point discrimination threshold (TPDT) measure is usually used to specify the density of a tactile display according to where it is placed on the body parts [309]. TPDT represents the distance between where the two pressure points should be, so that these two nearby objects touching the skin are perceived as truly two distinct points, and not only one [310] [311]. Figure 5.4 illustrates the TPDT for different areas of human body.

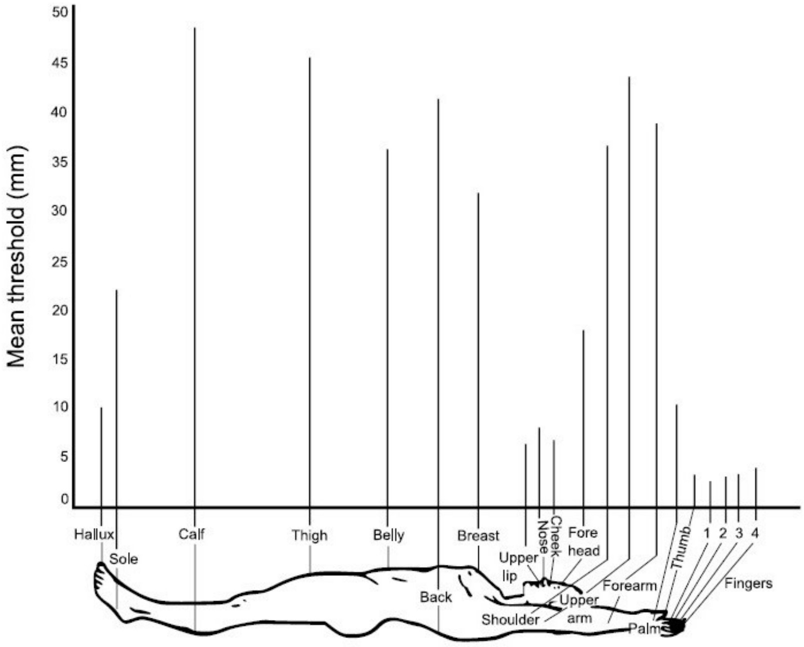

Figure 5.4: The two-point discrimination threshold (TPDT) for different areas of human body, after [309].

From the above figure, both of the proposed positions (waist and shoulder) for the device prototype have the similar mean threshold, which is between 35 to 45mm. For our prototype therefore, we arranged the mini vibration motors to each with the distance of 40mm (the average of 35 to 45mm). The back of the tactile display has the embedded Velcro straps used to secure its positions accordingly. The vibrations from these vibration motors generate the haptic stimuli for the tactile display that are intended as the directional cues/signals during navigation. Figure 5.5 shows the arrangement of the embedded vibration motors in the tactile display.

During the navigation test and the actual use, the wearers should feel comfortable wearing the device, and more importantly they should be able to sense the haptic stimuli. For that, the tactile display needs to be placed appropriately where it needs to be, in this case either on the shoulder or waist. The device prototype when it is being used in both positions is visualized in Figure 5.6. In our experiment, the test subjects were required to wear the device as shown in this figure, exclusively during the navigation tests.

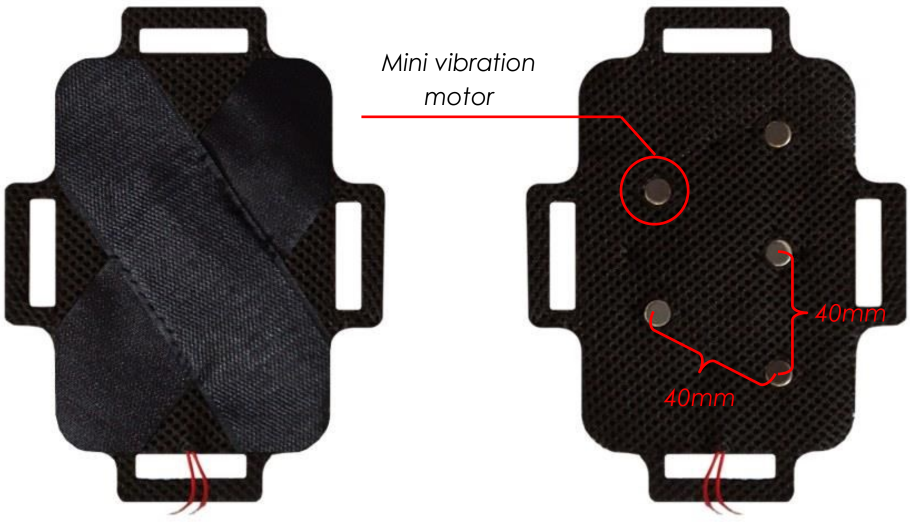

Figure 5.5: The tactile display, Rear (Left) and Plan (Right) Views

Figure 5.6: The positioning of the device's tactile display and hardware

Now that the complete device prototype has been achieved, the assessment can be eventually performed. This assessment namely Usability Testing (UT) is apparently an important and established method typically conducted as a part of the product design and development process. Certainly, it is one of the most used strategies in the final stage of the design cycle according to the UCD principle [293]. Therefore, before this study present this assessment using the developed prototype, it is appropriate to discuss on UT, in line with its principle, criteria and limitations.

5.3 Usability Testing (UT)

In this study, the design project formulates the tool for assessing the fundamental hypotheses and questions raised in the prior chapters. The proposed project in its initial stage has been preliminary assessed before the development of the functioning prototype. However, the main attention of this preliminary assessment is on the study's theoretical works and due to this, the design project still needed to be quantifiably evaluated, so that the hypotheses and questions raised can be thoroughly justified.

Besides, since the preliminary assessment conducted before the functioning prototype was ready, it did not involve the actual users or the specific population of the planned intervention. For that reason, the next assessment which is also the main evaluation of the proposed project is the Usability Testing (UT). UT is an essential aspect of user-centred approach that puts the user, at the centre of the development process [312]. Besides, adopting such an approach advocates that the users should be forefront in any design decision.

Concisely, this form of assessment is often used to label the method, procedure or strategy used to evaluate a product or system. To be precise, the term UT itself refers to a process that employs people as testing participants who represent the target audience/population to evaluate the degree to which a product meets specific usability criteria [313]. While according to ISO 9241-11: Guidance on Usability (1998) [314], "Usability is the extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use." As reported by Dumas and Redish [315], the aims of UT are to: (1) improve the product's usability, (2) involve real users in the testing, (3) give the users real tasks to accomplish, (4) enable testers to observe and record the actions of the participants, and (5) enable testers to analyze the data obtained and make changes accordingly.

Consequently, the motive behind the selection of this method of assessment for the proposed project is because the main goal of UT itself, which is to identify any usability problems, collect quantitative data on participants' performance [316]. This specific test is typically used to enhance the usability of the product that is being tested, apart of it could probably improve the product design development process by means of reducing the reiterative problems or issues [315]. Similarly essential, UT should be properly executed in agreement with its criteria and limitations.

5.3.1 Criteria and Limitations

There are several criteria to be properly deliberated for an assessment to be called UT. And yet, there can be diverse settings and strategies to conduct the test [317] [315]. Nevertheless, many reported guidelines on how to conduct this test typically have these common characteristics: (1) objective of the assessment, (2) participants who represent the real target users and perform the actual task, and (3) observe, record and analyze the data to identify the real problems and propose suggestion to solve them. Furthermore, in almost every proposed project, there are always some issues and restrictions that may challenge the data gathering for its assessment. For this study, the main challenge to conduct the UT is the recruitment of the test subjects who represent the primary stakeholder of the proposed intervention.

The participants enlisted for this test are older adults with cognitive impairment mainly due to dementia. The first issue related to the recruitment is to gather enough number of participants. This study could not find a single subject without the appropriate connection with the selected nursing homes, therapy centres or the hospitals. Although having prospective connections, not all of these institutions gave the anticipated collaborations, probably due to the uncertainty on the proposed project. Too often, this doubt was due to what individuals with this specific disability would normally respond to the new form of technological intervention. While this was the case, the assessment was definitely essential to be conducted with the real users because the intervention is exclusively designed for these individuals and eventually will benefit them in return.

Equally important, the number of participants for a test to be recognized as UT is not firmly defined. According to [315], a UT should comprise of at least two or three subjects in order to avoid seeing the distinctive behaviours. But, Rubin 2008 [313] suggest to test at least four to five participants, so that the massive majority of usability problems may be revealed. Then again, they suggest recruiting at least eight participants, if possible, to feel comfortable by means of reducing the chance to overlook a significant problem that could negatively affects the findings.

For this assessment however, the total number of participants who could partake in the test greatly depended on the number of available dementia patients from the institution we collaborated with. In fact, the recruitment was determined from the discussion with the responsible persons from the institutions (manager, therapist or the clinical staffs). With the comprehension of principles, as well as the reflections of criteria and limitations of UT, the subsequent subdivisions report on every detail of the test subjects, procedures, recorded data and finally the findings.

5.3.2 Preparation of the Test

As preceded, the test was conducted on subjects with dementia who represented the actual users of the proposed intervention. Therefore, the main aim of this assessment is to investigate how the subjects perceive haptic-feedback as a modality of navigation by using the working prototype as the apparatus. Then again, before conducting the test, two substantial decisions were primarily made: (1) the selections of the participants, and (2) the methods to test the device prototype, which is explained in the experimental procedure.

The experiment was conducted with the collaboration of Fondazione di Manuli, a dementia therapy centre in Milan, Italy. In fact, all the subjects involved in this experiment attended the therapy sessions here. Also, the experiment was conducted with the supervision of the subjects' caregivers, therapists or staffs of this therapy centre. The evaluations were divided into three phases: (1) orientation or training, (2) navigation test and (3) the following test. However, between Phase 2 and Phase 3, there was another assessment carried out which was the Subjective Assessment. Figure 5.7 below illustrates these phases of assessment. To be more organized, the preparations of test are described through these main sections:

1. Test apparatus,

2. Settings of the navigation tests, and
3. Demographics of participants

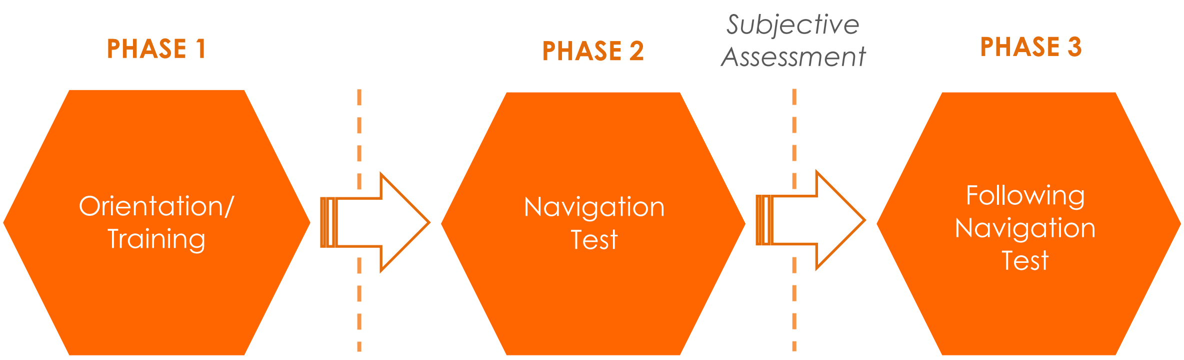

Figure 5.7: Phases of the pilot test

The chapter then reports on the experimental procedures of each phase, and follows by the presentation of data collection and analysis, results and discussion.

5.3.3 Apparatus

In this test, the study used the developed prototype of wearable haptic-feedback navigation device as the apparatus. The device system is designed to be used in a fully outdoor environment, where the GPS receiver functions at its best. However, due to some limitations, the navigation tests could only be performed in short routes or limited ranges. As a result, some alterations were made because the prototype did not have sufficient high accuracy of the GPS system to be functioning in a short navigation route.

The issues normally faced when working with GPS system is the insufficient accuracy of GPS receiver. This is mainly due to the noises of GPS data that depends on the position of the satellites visibility, characteristics of the surroundings, and even weather [318][319]. The modification of the device's system is needed in order to overcome the issues emerged, as long as the altered system supports its main functionality as the apparatus of the tests.

In the altered system, a Bluetooth serial module is used to connect between the microcontroller and a mobile phone. The series of vibrator motors from the tactile display are activated with the on/off switch in an Android mobile application. Figure 5.8 shows the mobile application created and used to trigger the haptic feedback during the navigation tests.

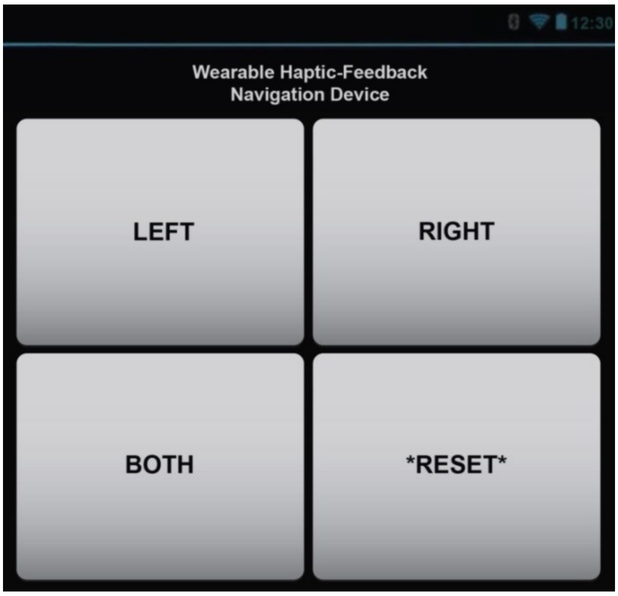

Figure 5.8: The interface of mobile application created to active the haptic-feedback

The mobile application has a simple interface: the 'LEFT' button is used to activate the tactile display worn on the left side, and 'RIGHT' for the right side, depending on the waist or shoulder position. 'BOTH' is used to activate the left and right tactile displays simultaneously, indicating users have reached the designated locations. Finally, the 'RESET' button is used to restart the system if the device encounters the malfunction issues, for example when the Bluetooth serial module loses the connection between the device and the mobile phone. The designed interface is controlled by one of the experimenters for all the test sessions and in all the test routes. The selection of navigation routes is reported in the next subsection.

5.3.4 Test Settings

The experiment started with the orientation or training phase to get the subjects familiarized with the device system and experimental procedures. This specific phase of assessment did not require a large space. Hence, it was instigated in the common area of the therapy centre, where the patients performed their activities or therapy sessions. Nonetheless, since the navigation test could be difficult for the elderly with dementia, the study needed to identify the appropriate subjects. Likewise, subjects were required to wear the device during the actual navigation tests. This justified the necessities of the orientation phase.

Consequently, only the subjects who succeeded in this orientation or familiarization phase and also those with the permission of their family members were allowed to proceed to the next phase (assessment of the navigation ability). The selection of routes and its difficulties were based on the accessibility and appropriateness of the settings to the subjects. Thus, for the first navigation test, two routes with same difficulty (same number of turns and distance) level were created as shown in Figure 5.9. The length of each of these routes was approximately 300 metres.

***Route 1**: From Point A to Point B* ***Route 2**: From Point B to Point A*

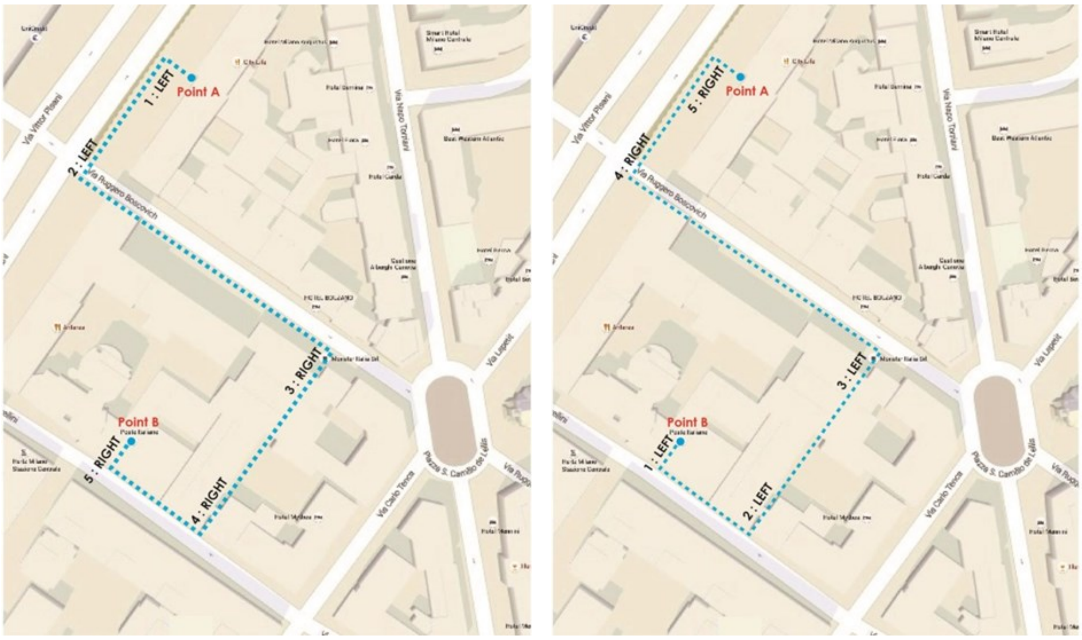

Figure 5.9: The navigation routes with same difficultly level

After this second phase was completed, the experiment continued with the third phase, which was the subsequent (navigational) test. The aim for this third phase was to investigate if there was an improvement of the navigation performance as compared to the previous one. Hypothetically, as they tried to navigate with the device before, they should be able to perform better in the following test. Here, the effect of familiarization in the form of training or constant practice was investigated. As mentioned in the previous chapter, practicing a task (for example, the navigation task) on regular basis is an example of implicit memories. Also, implicit recollection for haptically-explored objects is preserved especially in the early stages of dementia [203]. Thus, the following navigational test may justify the hypothesis that a continuous practice may result in positive outcomes of subjects' navigational performance. The route for the following test is shown in Figure 5.10.

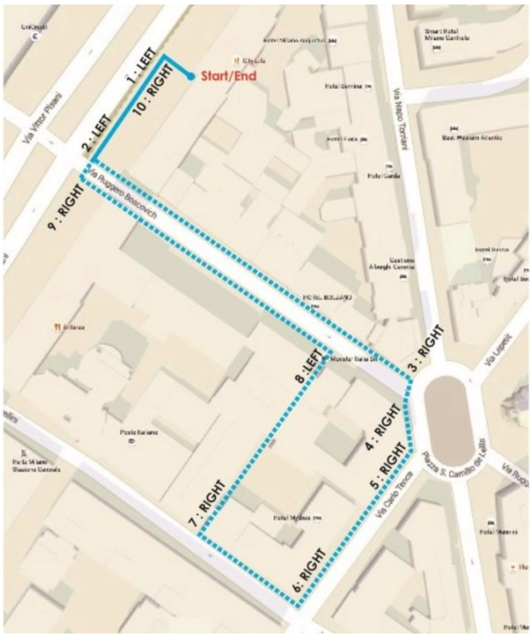

Figure 5.10: The route for the following test

In total, the distance a subject had to travel for the following test was around 600 to 700 metres, which was almost doubled from the previous routes. Similarly, the number of turns had also been increased, from five to ten turns here. The whole experiment took place at the mentioned therapy centre and the neighbouring area. But, due to the availability and restrictions of participants and time, plus the unpredictable weather conditions, the study managed to execute one test each day, namely, three tests a week. Thus, the whole experiment took approximately a month and half to be completed.

5.3.5 Demographics of participants

The participants recruited for the tests went to the therapy centre only on the days their therapy sessions were scheduled. These subjects were randomly picked for the first phase (the orientation/training) since they were only allowed to participate after the therapy session finished. Their severities of cognitive impairment were rated using the cognitive-based ratings of Mini Mental State Score (MMSE) [320] . The MMSE scores ranged from the minimum of 17 and maximum of 27, with average of 20.8.

The data of MMSE scores provided by the therapy centre were recorded when they first started the programme there. Only one of them did not have the recorded data of this cognitive-based rating, as she had just recently joined the therapy session there. Most of the subjects went to the centre with their spouses, other family members or the hired personal nurses. Once again, only one of them with the highest MMSE score of 27 went to the therapy centre by himself. Nevertheless, those who were recruited for the tests were able to walk properly with no serious mobility issues, even if some of them use the canes.

In total, ten subjects participated in the first phase. Subjects ranged in age from 74 to 81years old, with the average age being 78.5 years old. Among these subjects, three of them were male. From the total of ten subjects, six of them participated in the second phase (the navigation test). Consequently, for the third phase (the following test), only three subjects were recruited. This was due to subjects' availability, time constraints, and the approval from their caregivers. For easier description, the subjects were identified by their numbers, as shown in the Table 5.4 below.

Table 5.4: The route for the following test

Subjects	Age	Gender	MMSE Score	MMSE Test Date
1	76	Female	17	16/04/2015
2	76	Female	21	17/10/2013
3	76	Male	27	02/07/2015
4	81	Male	21	05/11/2013
5	78	Male	21	02/04/2015
6	80	Female	20	17/07/2014
7	86	Female	23	29/10/2015
8	80	Female	17	03/07/2014
9	78	Female	20	16/01/2014
10	74	Female	-	19/03/2015

5.4 Experimental Procedures

The assessment for the orientation/training phase (Phase 1) was conducted on the first day of the test and it was piloted after all the subjects finished their therapy sessions. This phase was divided into three sessions:

1. First, experimenters put on the wearable device onto the subjects' body (with the tactile display on both positions), and their reaction or acceptance were observed.
2. Then, only if the subjects reacted well to this wearable device, they would be asked if they could feel the haptic signals on both waist and shoulder positions.

3. Finally, they were asked to take a short walk inside the provided space and indicate which sides of the tactile display they felt by raising or waving hands or tapping on the body positions.

The second phase initiated after the subjects were carefully selected from the first phase. The selection was made based on the subjects' performances in the first phase, and was decided after a comprehensive discussion between the experimenters, therapists and also the caregivers. The subjects were not encouraged to travel independently, hence for these navigation tests they travelled in the designated routes with the assistance of their caregivers (or staffs from the therapy centre). Before starting the navigation test (Phase 2), both subjects and their caregivers (or those who could assist them) were given explanation about the test procedures. The caregivers were not aware of these routes since they should not be involved in the decision making of the turns.

Then again, one important data to be recorded before starting the navigation test was the walking speed of each subject. The recorded walking speeds (m/s) would be compared with the walking speed while navigating with the device. This would provide comparative data to show the effectiveness when using the technology while walking. During the test, they were required to make the left/right turns at the junctions accordingly, whenever they sensed the haptic stimuli from the device. In both routes 1 and 2 (Figure 5.9), there were five turns each, and these turns were apparently the actual junctions there, because the routes were based on the real streets close to the therapy centre.

Each subject navigated in both of the routes, but with the different positions of the tactile display. The test started with the first route (from point A to point B), but the starting position of tactile display was randomly picked. If they started with the shoulder position in the first route, they continued with the waist position in the second route, and vice versa. In the navigation test, haptic signals were initiated before subjects reached the junctions, and stopped after they were in the correct turns. Figure 5.11 shows when and where the haptic signals were triggered. For example, to go from point 1 to point 2, one had to turn left. Hence, the vibration (haptic signals) took place with the intervals of 3 seconds and pauses for 2 seconds within this length. The constant length of 6 metres was set for this haptic signal in every junction. For comparison, the subjects' walking speeds, which were recorded beforehand, were calculated as the travelled distance (of 6 metres) divided with the time taken.

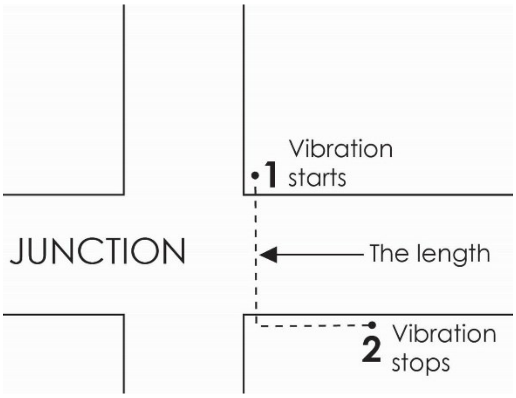

Figure 5.11: Where the haptic signals take place during the navigation test

During the navigation test in each route, experimenters recorded the performance of the subjects with regard to:

1) Time taken to make the turns, within the predetermined length of 6 metres.
2) Numbers of direction errors made, when the subject walked off course or not following the tactile display, and
3) Time taken to finish the routes or to reach the designated destinations.

Once each subject had completed his/her navigation test, experimenters proceeded with the subjective assessments. This assessment was carried out with the assistance of their caregivers or the staff of the therapy centre. This was because at times, the subjects could not understand or misinterpreted some of the questions. When this happened, the subjects were helped to understand the questions in the easiest and simplest sentences but keeping to the same meanings. The collections of data of this subjective assessment were principally based on the following questions;

1) If they could satisfactorily sense the haptic signals (on the chosen positions),
2) Which position they could sense better and comfortability of the device,
3) The usefulness of the device, and
4) If continuous use/practice could improve their performance.

After the second phase was completed, the experiment continued with the third phase which was the succeeding navigation test. This test followed the similar procedures as formerly deliberated, where the subjects needed to navigate in the designated route, but with higher complexities. This means that the numbers of turns and distance of the route were extended. The quantitative data to measure their performance were also recorded, parallel to the previous phase. The recorded documentations from the entire assessment phases were presented in the results section next, while the overall deliberations on the findings were discussed at the end of the chapter.

5.5 Results

The quantitative and qualitative results of this UT are presented according to the three phases: (1) Orientation/Training, (2) Navigation Test, and (3) Following Test, plus the mentioned subjective assessment.

5.5.1 PHASE 1: Orientation/Training

In the first phase, the evaluation was based mainly on the observations of subjects' reactions. Here, the study needed to go through the three sessions in order to select the appropriate subjects for the navigation test. Thus, these sessions were classified as: (Session 1) can they cooperate with the device wearability, (Session 2) can they feel the haptic signals, and (Session 3) can they indicate which side of the haptic signals. Results of this orientation/training phase are presented in the Table 5.5 below.

From the table, only Subject 7 did not get through even the first session out of all the subjects. Based on the observation, she showed the most unenthusiastic attitude in using the device, probably because she got tired after the therapy session. Whilst, Subject 1 and 5 did not pass the second session because they could not recognize the haptic stimuli either at one or both positions (waist and shoulder). Finally in total, seven subjects passed all the sessions. However, Subject 2 could not proceed with the next phase due to some ethical issues and health condition. For that, the total subjects recruited for the navigation test was only six.

Table 5.5: Results of the Phase 1

Subjects	Session 1	Session 2	Session 3
1	✓	-	-
2	✓	✓	✓
3	✓	✓	✓
4	✓	✓	✓
5	✓	-	-

6	✓	✓	✓
7	-	-	-
8	✓	✓	✓
9	✓	✓	✓
10	✓	✓	✓

5.5.2 PHASE 2: Navigation Test

In the navigation test, the comparison was made on the recorded control time (and walking speeds) of each subject while navigating with the device. Subjects tended to make mistakes (especially in the first route) when making the turns. This was probably because they were not able to perfectly understand the function of the device. Thus, it was necessary to determine the effective walking of the navigation, as reported by [264]. The time taken to make every turn (within the designated length as shown in Figure 5.11 before) and the overall time to finish both routes were also recorded. Table 5.5 presents the entire data of each subject's speed, control time, average time taken to make the turns and to finish both routes.

The shown average time taken was based on the cumulative time taken for each turn of both routes. The score was somehow influenced by the number of mistakes (or direction errors) while navigating with the device. As shown in Table 5.6, Subject 3 had the highest walking speed of 1.08 m/s, and shortest average time taken (6.24 seconds in Route 1 and 6.19 seconds in Route 2). His average time was also not distinctively different from the control time (5.53 seconds). In fact, he consistently had the highest/best scores for all the recorded data in both routes, as compared to the rest of the participants.

For the other subjects, their average times (for all the turns) were usually higher when they made more mistakes. This indirectly led to a longer time to finish the routes. In Route 1 for instance, Subject 6, 8 and 4 had the highest average time to make the turns (18.85, 23.55 and 17.62 seconds respectively), and they demonstrated the longest time to finish the route (776.43, 956.43, 733.81 seconds respectively). This assumption was also applicable for the other three subjects (9, 3 and 10), who scored the lowest average time (16.34, 6.24 and 16.56 seconds respectively), and shortest time taken (682.27, 337.82 and 602.05 seconds) to finish Route 1.

Table 5.6: The summary of recorded data for the navigation tests (Phase 2)

ROUTE: 1									
Subjects	**Walking Speed (m/s)**	**Control time (s)**	**Time taken to make the turns (s)**						**Overall time taken (s)**
			Turn 1	**Turn 2**	**Turn 3**	**Turn 4**	**Turn 5**	**Average**	
6 (Waist)	0.79	7.56	8.69	29.10	28.52	19.71	8.21	18.85	776.43
8 (Shoulder)	0.68	8.86	9.45	9.21	33.71	30.82	34.54	23.55	956.43
4 (Waist)	0.78	7.74	7.80	24.22	25.75	21.33	8.98	17.62	733.81
9 (Waist)	0.51	11.08	12.02	11.73	34.45	12.24	11.45	16.34	682.27
3 (Shoulder)	1.08	5.53	5.60	7.32	6.61	6.03	5.65	6.24	337.82
10 (Shoulder)	0.73	8.15	9.12	23.41	29.51	11.27	9.49	16.56	602.05
ROUTE: 2									
Subjects	**Walking Speed (m/s)**	**Control time (s)**	**Time taken to make the turns (s)**						**Overall time taken (s)**
			Turn 1	**Turn 2**	**Turn 3**	**Turn 4**	**Turn 5**	**Average**	
6 (Shoulder)	0.79	7.56	11.40	8.81	7.86	21.33	8.21	11.52	567.01
8 (Waist)	0.68	8.86	8.92	27.22	26.57	9.43	9.02	16.23	797.92
4 (Shoulder)	0.78	7.74	7.90	8.71	18.65	8.92	7.89	10.41	526.07
9 (Shoulder)	0.51	11.08	11.34	25.33	12.71	11.84	12.13	14.67	647.72
3 (Waist)	1.08	5.53	5.57	8.41	5.22	6.11	5.63	6.19	321.434
10 (Waist)	0.73	8.15	8.57	21.73	10.11	9.43	9.21	11.81	512.45

However, the justification for average time influencing the overall time taken is not true. This is invalid when comparing these data in both routes. For example in Route 2, Subjects 6 and 8 made the most mistakes (two errors each), but subject 9 with only 1 error had a longer average time (14.67 as compared to 11.52 seconds for Subject 6). Then, Subject 8 was the one who had the second longest overall time to finish Route 2 (797.92 seconds). In addition, Subject 4 had the second lowest average time (10.41 seconds) after Subject 3 in Route 2 but his overall time taken was not the second lowest. It was held by Subject 10 with 512.45 seconds.

What can be primarily highlighted here was, even if the subjects took less time to finish the routes as compared to the others, it did not mean they scored the highest effective walking while navigating with the device. This depended on their walking speeds and the hesitation before making the turns. For example, in Route 1 Subject 10 took 602.05 seconds to finish the first route and made two direction errors, while Subject 9 took longer time (682.27

seconds) but only made one mistake. This was because Subject 10 had the higher walking speed (8.15 m/s) as compared to subject 9 (11.08 m/s). Also, Subject 8 and 4 made three mistakes in Route 1; however, since the walking speed of Subject 8 was higher (0.78 m/s as compared to 0.68 m/s), he took less time to complete the route.

As shown in Figure 5.12, the study compared the number of direction errors made by each subject for both routes. From the graph, it clearly showed that the numbers of direction errors for all the subjects decreased when navigating in the second route. This was indeed an interesting indication, where it possibly suggested that the participants started to learn and understand how to navigate with the assistance of the device in the second route. Except for these two participants, (1) Subject 3 perfectly navigated with the device in both routes without any mistakes, (2) while Subject 9 maintained with only one direction error.

Figure 5.12: The comparison between numbers of direction errors made by subjects in both routes

Subject 3 who demonstrated the best navigational performance amongst the participants had reaffirmed the fact that he had the highest score of MMSE (27) and also, he was the only one who went to the therapy centre by himself without any assistance. The navigational performance of Subject 3 indicated that he did not excessively suffer from the spatial disorientation or wayfinding disability. For the other participants, the MMSE scores were varied from 17 to 21, which were way lower than Subject 9's score. According to [321] and based on the description of severity of cognitive impairment presented in Chapter One, MMSE score of: (1) 26 to 30 could be normal, (2) 25 to 20 is mild and in early stage, and (3)

19 to 10 is moderate and middle stage. Hence, Subject 4, 6 and 9 had the similar range, which was in the mild condition. Of all the subjects, only Subject 8 was in the moderate condition.

Nevertheless, we cannot simply justify that subjects in early stage has better navigational performance with or without the device than those in middle stage. This was because Subject 6 who had the MMSE score of 20 did the same number of directional errors with subject 8 with the MMSE score of 17. But then again, the other participants (with mild condition) demonstrated average or moderate navigational performances. This aspect and several other arguments are clarified better in the 'General Discussion', which is the final section of this chapter.

5.5.3 PHASE 3: Following (Navigation) Test

The recorded data for this phase were similar to the previous navigation test. In fact, all the variables used for the assessment of data were identical. The only difference was the complexity of the route had been increased. The study used the same walking speeds and control times for these three subjects (Subject 6, 8 and 10) as presented in the results of Phase 2 (refer Table 5.5). Identical to the previous phase, subjects' control times (and walking speed) were compared with the time taken for each turn. Table 5.7 summarized the recorded data for this phase.

The first indication in terms of the improvement of subjects' navigational performances was on the average time of all the turns. All the three subjects indicated lower average time taken to make the turns as compared to both phases. However, there were two routes in Phase 2, which meant there were two average times. Hence, the percentage of average time reduction was calculated by comparing the average time taken (from both routes) in second phase, with the average time taken in this third phase.

Table 5.7: The summary of recorded data for the following navigation tests (Phase 3)

Subjects	Time taken to make the turns (s)											Overall time taken (s)
	Turn 1	Turn 2	Turn 3	Turn 4	Turn 5	Turn 6	Turn 7	Turn 8	Turn 9	Turn 10	Average	
6	9.06	14.84	7.58	9.72	8.40	17.72	17.40	9.54	7.69	8.01	11.00	1082.70

8	8.98	9.60	18.90	9.56	9.64	9.65	23.69	20.77	35.21	8.90	15.49	1420.46
10	8.57	10.73	15.11	8.43	19.21	9.97	19.57	8.62	9.12	8.16	10.88	1101.39

For example, Subject 6 scored 18.85 seconds in Route 1 and 11.52 seconds in Route 2 of the second phase. Hence, the average for both routes was 15.19 seconds. This average score was compared to her average time taken in the third phase, which was 11.00 seconds. Thus, the time difference was 4.19 seconds, making the percentage of average time reduction in both phases as 27.58% (calculated as [4.19 ÷ 15.19] x 100%). Table 5.8 demonstrates the average time (to make the turns) reduction for all the subjects in Phase 3. From the table, Subject 6 had the highest percentage of time reduction of 27.58%, as compared to the other two subjects; Subject 8 with 22.12% and subject 10 with 23.32% respectively.

Table 5.8: Comparison of average time in making the turns between Second Phase and Third Phase

Subjects	Average Time Taken of Second Phase (Seconds)	Average Time Taken of Third Phase (Seconds)	Time reduction (%)
6	15.19	11.00	27.58
8	19.89	15.49	22.12
10	14.19	10.88	23.32

The second indication that could be highlighted here was on the overall time taken to finish the route of third phase by all the participants. While the overall time taken was not necessarily influenced by the average time as reported in the results of previous phase, but when comparing both phases, there were apparently decreases in the ratio of the average time (for all ten turns) to the overall time taken. Phase 2 consisted of two routes with each route having five turns and approximately 350 metres in distance respectively. The route of Phase 3 on the contrary, was almost doubled in terms of number of turns and distance. Therefore, the mentioned ratio of the subjects could be calculated by comparing the overall time taken to their average times of both phases.

For example, the average overall time for both routes in Phase 2 for Subject 6 is 671.72 seconds ([776.43 + 567.01] ÷ 2). It means Subject 6 took the average of 671.72 seconds to complete the routes. If this average time was doubled (taking the length in phase 3 was doubled to 700 metres), she should finished the route in 1343.44 seconds. Yet, she completed the route in only 1082.7 seconds instead, fewer 260.74 seconds than expected. Table 5.9 below demonstrates the expected and actual overall time taken for all the subjects.

Table 5.9: Comparison between the expected and the actual overall time for each subject and the number of mistakes they made

Subjects	Average overall time taken in Phase 2 (seconds)	Expected overall time taken in Phase 3 (seconds)	Actual overall time taken in Phase 3 (seconds)	Percentage of reduction (%)	Number of Direction Errors
6	671.72	1343.44	1082.70	19.41	3
8	877.16	1754.35	1420.46	19.03	4
10	557.25	1114.5	1101.39	1.18	3

The table above shows that all the subjects completing the route in Phase 3 were faster than they were expected to be. Again, Subject 6 had the highest percentage or the ratio of time reduction with 19.41%, while the lowest was Subject 10 with only 1.18% ratio. Also, these ratios of reductions could or could not have been due to the number of errors made. For instance, Subject 8 had lower ratio than Subject 6 probably because she made less mistakes. But this did not explain why Subject 10 had the lowest ratio since she did the same number of mistakes as Subject 6. This might be also due to each subject' control time (and walking speed), as presented in Table 5.6 from the previous Phase 2.

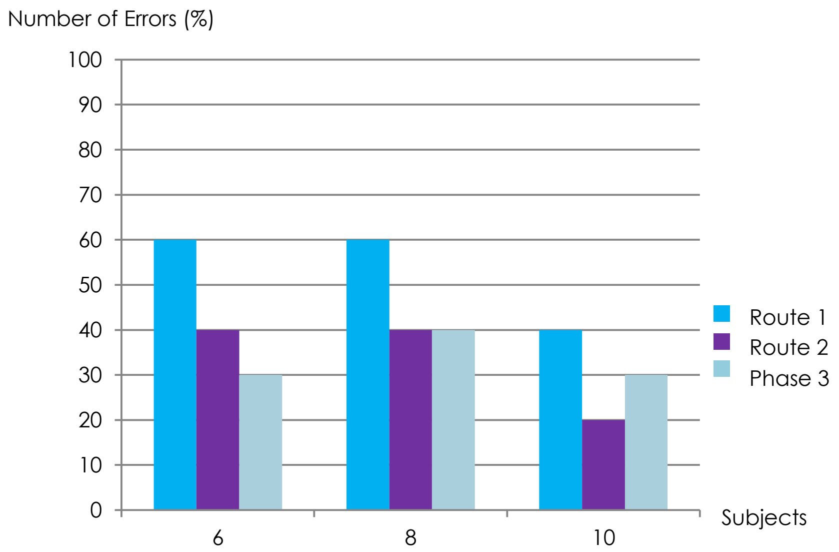

Figure 5.13: Percentage of directional errors made in Route 1 and 2 of second phase, and in the third phase.

Another aspect to be stressed here is on the number of direction errors made in this phase, to be compared with the previous navigation test. There was no significant directional errors reduction observed here, as the number of errors made was compatible. There was a consistent decrease shown by Subject 6, but not in the case of the other two participants. Figure 5.13 above illustrates the percentage of directional errors made by each subject in accordance with every route in both phases.

Nonetheless, this study is aware of the questions that may arise from the aforementioned justifications. Firstly due to the route length of the third phase which was not accurately doubled from the second phase, the exact length of the routes could not be calculated. Besides, the participants took less or more time to make the turns in Phase 3 due to the complexity of the route itself. Even so, the reductions in: (a) the average time taken, as shown in Table 5.8 and (b) the actual overall times, as shown in Table 5.9, by some means indicate that the subjects navigated better after the series of practices. And this is one of the proofs of their familiarization with the device system. Further clarification on this argument is presented in this chapter's last section.

5.5.4 Subjective Assessment

This subjective assessment comprised of the responses to the questions asked and comments offered. This assessment was to better clarify users' perception, acceptance and understanding about the interventions. Due to the subjects' language barrier and communications difficulties, the questions were simplified and translated into local language (Italian) with the help of the therapists. Also, instead of using scale (of 1 to 5, as 5 is the highest), we used 'less', 'moderate', and 'good' to rate their responses. For this, we decoded 'less' as the minimum (or scale of 1 over 3), while 'good' as the maximum (or scale of 3 over 3). Table 5.10 shows the questions and scores for each subject.

Although the set of questions provided were not extensive (due to the limitations mentioned earlier), the subjective data from this assessment might support the justification of the quantitative data from the experiment. This set of questions was meant to validate several key points;

1. Q1 for the ability to sense the haptic stimuli
2. Q2 for device's wearability and comfort
3. Q3 and Q4 for device's usefulness
4. Q5 and Q6 for the learning process or training

Table 5.10: Subjective assessment questions and the scales given by subjects

Questions (Scale of 1 to 3)		Subjects and Scale					
		6	8	4	9	3	10
Q1	Did you properly sense the vibration and which position?	3 (S)	3 (S)	2 (W)	2 (S)	3 (W)	3 (S)
Q2	Are you comfortable wearing the device	3	3	2	3	3	3
Q3	Would you like to have the device and use it?	2	2	1	2	1	2
Q4	Do you think the device is useful?	2	2	2	3	3	2
Q5	Do you need more time to learn to use it?	3	3	3	2	1	3
Q6	If you are given more time to use it, will you perform better?	2	3	3	3	3	3

For Q1, 4 out of 6 subjects (66.7%) scored the maximum scale of 3 over 3.This meant they could appropriately sense the vibration. Whilst, for the most preferred position for the tactile display was the waist (4 out of 6 subjects). In particular, only subject 4 and 3 preferred the shoulder position. For the next question (Q2) that stressed on comfort, 83.3% agreed that they were comfortable wearing the device as they rated 3 over 3. This was in contrast with subjects' perspective on the device's usefulness, where they mostly gave a low score to Q3 and moderate to Q4. The average score for Q3 is 1.67 showed that they were not so keen to have and use the device. Meanwhile for Q4, 4 subjects (66.7%) rated 2 over 3.

The data from the last two questions may explain the preceded scores. For Q5, 66.7% agreed that they needed more time to learn to use the device. Whereas, only Subject 3 scored 1 over 3 as he did not make any mistake while navigating with the device. Once again, the user familiarization was a crucial point as proven in Q6, where 5 over 6 (83.3%) rated the maximum scale. The final section discusses the findings and the unfolding arguments in all the phases, before it summarizes the entire establishment of this UT.

5.6 General Discussion and Conclusion

In the situation where visual and auditory cues are less appropriate, especially when these are the most affected sensory for example in the case of older adults, employing the sense of touch for navigational purpose could be a beneficial alternative. Thus, the conducted experiment aims mainly to verify if the tactile/haptic stimuli is a possible form of wayfinding modality for elderly with cognitive impairment.

There are obvious differences comparing the average time taken to make turns with the control times of each subject in every phase. This study presumed that it was partly caused by their hesitancy to receive the haptic stimuli as a signal to turn left/right at the junctions. Also, the control times were recorded when participants walked without the device at only one junction (in a 6meter distance). Unless we recorded the control times from all the junctions (or turns), it was fair to compare the control times with the time taken to take the turns. The study also did not have the data for the overall time taken to finish both routes without the device. Hence, the study could not justify the individual's navigational performance based only on these overall times. That being said, based on the observation during the navigational tests of both phases, participants took longer time especially when: (a) they hesitated for too long before making the turns, (b) they had to reroute after taking the wrong turn, (c) and not making the turns where they were supposed to.

As shown in the comparison between both routes in Phase 2, there were decreased number of directions errors made, shorter average time to make the turns and finally the reduced overall time by most of the participants in the second route. In addition to this, there were reductions in the average time taken and the actual overall time when compared to the expected ones in Phase 3. The study posited that they performed better which was probably due to the increased level of understanding and learning process in using the device. Equally important, the decreased errors indirectly suggested that the proposed intervention to use haptic signals helped the participants to navigate in the designated routes.

The effects of learning was not jeopardized even when there were no consistent decreased of the numbers of direction errors made by the three subjects (Subject 6, 8 and 10) in Phase 3 as compared to their errors in Phase 2. This was partly because the difficulty levels had been increased, since the length and number of turns had been approximately doubled. Unless they travelled in the same familiar route and not demonstrating any navigational improvement, then the study could deny the postulated justification.

This is certainly a common situation faced by dementia patients when navigating in both familiar and unfamiliar environments. In the earlier chapters of this study, their spatial disability that is closely associated with the cognitive dysfunction had been discussed. But, there are other external factors that may explain their wayfinding difficulties that lead to these directional errors when making the turns. As stated by Flicker [66] and Collister [322], the issues initiated by spatial disorientation are exacerbated by the poor concentration, communication, and reasoning skills. The deficiencies of memory also resulted in the problems to follow direction or asking for help in finding ways.

In view of this, the lost information (of directions) could possibly be replaced by the memory techniques, even if the recall might not be spontaneous [323][324]. During the course of navigation, it was quite normal for a person with dementia to forget the route and lose the directional information to get to his/her intended destination. In this situation, the memory could be induced and this information could be reacquired with the help of external stimulus. The external stimuli were in the form of reminders or directional cues, like the haptic signal itself. However, for these individuals, the obligation to remember such stimulus requires another learning process [324]. Once again, this relates back to the importance of familiarizing the concept of intervention. On top of that, navigating in an outdoor environment is obviously more difficult due to the complex architectural elements, landscape and their associated fixtures [325][217].

Although there were existing facilities that might help their wayfinding such as the noticeable signboards, street names and route signs, once these individuals got anxious or frightened as a result of spatial disorientation, their directional information from the cognitive map would be even more affected. Lynch [326] agreed that, the devastating consequences may happen to people with dementia who have difficulties to follow direction and cannot ask for help due to the communication issues. Therefore, apart from providing more accessible and supportive environments to promote better memory of the routes, while simultaneously lessening the effects of spatial disorientation, confusion, and impaired memory [327][328][58], so more assistive intervention in terms of directional/navigational prompts like the proposed project itself should be provided.

Another important argument raised from the whole phases of conducted assessments was the varied severity of cognitive impairment among the recruited participants, but none of the subjects' MMSE score was lower than 10. This means, they were not in the late stage of the disease. Yet again, even if several subjects with higher MMSE scored and performed better than those with lower scores, this study could not verify their abilities to navigate with or without the device solely on the level of cognitive severity. This is due to the irrelevant overall results of navigational performances based on subjects' MMSE scores shown during the test. Therefore, from both navigational tests, this study may suggest that the intervention works currently for individuals in moderate and earlier stages of cognitive impairment.

On the other hand, results from the subjective assessment support the crucial factor of appropriate training and the constant use of the device for this intervention. This is primarily revealed by the improvement of navigational performance by most of the subjects after repetitive navigational tasks. Then, the last series of questions in the subjective assessment found that the subjects agreed that they needed more time to learn to use the device and would perform better subsequently. This clearly proposes that getting familiarized with the intervention is important and somehow influences the device's effectiveness.

The subjective assessment also disclosed that the haptic stimuli given to the participants as the directional signals were sufficient and appropriate. On the other hand, in terms of the placement of tactile display, the majority preferred the waist positions. This is essentially in agreement with the existing related works on the wearable devices that chose the same position (abdominal area) for the haptic/tactile interfaces, such as the studies by Van Erp et al., [264] Zöllner et al., [262] and Grierson et al. [234] that conceptualized a wearable belt with tactile display for navigation. The reason for selecting this position is primarily due to the practical and comfort aspects, aside from the sufficient surface for haptic/tactile interaction.

The appearance of the device prototype might also influence the scores given to some of questions, despite the positive overall scores in the Subjective Assessment, particularly for question (Q3) that asked if they were willing to have and use the device. The lower scores given to this question by the majority conceivably due to the appearance of the prototype, since it was not so physically appealing. The comments from subjects, as well as their caregivers and the therapy centre staff acquiesced that the aesthetic aspect of the prototype needed to be improved, especially on the dimension, exterior design and material used.

This matter is not to be taken lightly, as the proposed project continues with the modifications and improvements to be made to the overall design. Beyond doubt, the major aspect accentuated subsequently is on the device comfort, which goes hand in hand with its practicality and aesthetic. This is also certainly the joint principal criterion for wearable devices and design for dementia patients [287]. Therefore, the design project develops and its progressions are revealed in the following chapter, Chapter Six, which will discuss profoundly on the further development and its conducted assessments.

CHAPTER SIX

6 Further Development

6.1 Second Prototype Development

The design project of the study continues with the development of the second functioning prototype and it is piloted to further justify the significance of the proposed intervention i.e. assistive navigation device for people with dementia. In this further development, the emphasize is given on the improvement of the previous prototype, mainly in terms of practicality of the device's feature and aesthetic aspects for comfort and proportions, as well as the commercial perspective.

Founded on the results of assessments in the first UT, there were three major issues revealed. First, despite the overall constructive remarks attained to the first developed prototype, this study was highly recommended to give greater attention to the comfort aspect of the device.

Secondly, the previous assessments together with the existing scholars suggested that the most preferred position for wearables was on the abdominal area. Finally, from the former navigation tests, it was observed that individuals with dementia faced more difficulties to navigate in the complex route/environment. Therefore, although the further development serves the similar purposes like the first one - to facilitate the users in finding their way around an outdoor environment, the adjustments and enhancements should be made in compliance with these three major issues preceded above. Accordingly, this prototype uses the already developed built-in system/interface since the device general features are maintained.

A wearable device counts greatly on its comfortability, since by definition it refers to devices that can comfortably be worn on the body or incorporated into items of clothing/accessories. This is to allow the effective interaction between the body and the wearable objects [272]. Besides, to design an appropriate wearable product, there are some guidelines to be followed as suggested by Gemperle [272]. Placement, appearance, dynamic, sizing and attachment of the device onto users' body are the primary factors to contemplate. This information is certainly useful to clear up the first and second formerly mentioned issues, as it is also agreed that the design of the device needed to be improved accordingly.

For the third issues, it is known that navigating in an outdoor environment is quite a challenge to anyone, not only for our target population. The complex elements and fixtures in outdoor settings aggravate the difficulties and confusions. These are obviously the crucial obstructions to be avoided for people with dementia. Thus, the design concept that is being proposed here by some means is intended to diminish the confusion of people with dementia when navigating in an already complex outdoor environment.

But then, based on the observations of the subjects' performances in the previous navigation tests, it was presumed that having left/right instructions were insufficient to assist their navigation. This was mainly true because during wayfinding, there were certain routes that required the travelers to not only turn left or right, such as in the more complicated junctions or roundabouts. For this reason, it was expected that additional directional signal was needed to help them navigate better with the device. Therefore, this chapter presents the improved design of the wearable device in accordance with the justifications heralded earlier. First, the next subsection reports profoundly on the flow of the second prototype development. And then, the following section and its subsections documented on the evaluations of the project together with the presentation of data and analysis, as well as the results and discussion. Somehow, this entire chapter adopts the similar flow of Chapter Five.

6.1.1 Prototyping

The verifications from the formerly conducted tests reassure the decision to choose only one most relevant position for the placement of wearable device on users' body, which is on the abdominal area or in particular on the waist. The selection relies profoundly on the reasons that this position: (1) provides larger surface area for the interactions with the wearables, (2) offers the appropriate access to the device, (2) provides a proper attachment since it may not hinder users' mobility/ movement, and (4) has a compatible size among the users.

These reasoning are line with the recommendations from Gemperle [272] on choosing the appropriate placement for wearables. Therefore, the proposed project is nurtured to focus on creating a new design of wearable device on the waist position. The device adopts the same system architecture and algorithm design like the previously developed schemes. However, the second device prototype is also used as an apparatus for the following assessments. Therefore, on this occasion, it was advisable to use the altered/simplified system that was specifically used in the previous tests.

In the altered device system, the haptic signals are activated using a simple mobile interface created as an android application. This application communicates with the built-in device system (that consists of a microcontroller and the output i.e. tactile display) through the Bluetooth connection. The development of this second prototype follows the common steps in the product design process, where it starts with the idea generations and ends with the model making or prototyping. Figure 6.1 below illustrates the early ideations of the new design concepts.

From the diagram, there are two conceptual designs proposed, but both of them have the same positioning of the tactile displays and the device hardware. The two tactile displays at the sides (left and right) are for the left and right directions, while the one in the middle is the signal to go forward. This is one of the additional features for the new device concept as underlined earlier. The middle tactile display should be centralized at the back part of the waist, so that it can create an instinctive haptic force. The signal at the back is expected to direct the users to go straight/forward when they are not required to turn left and right while navigating in a more complex route.

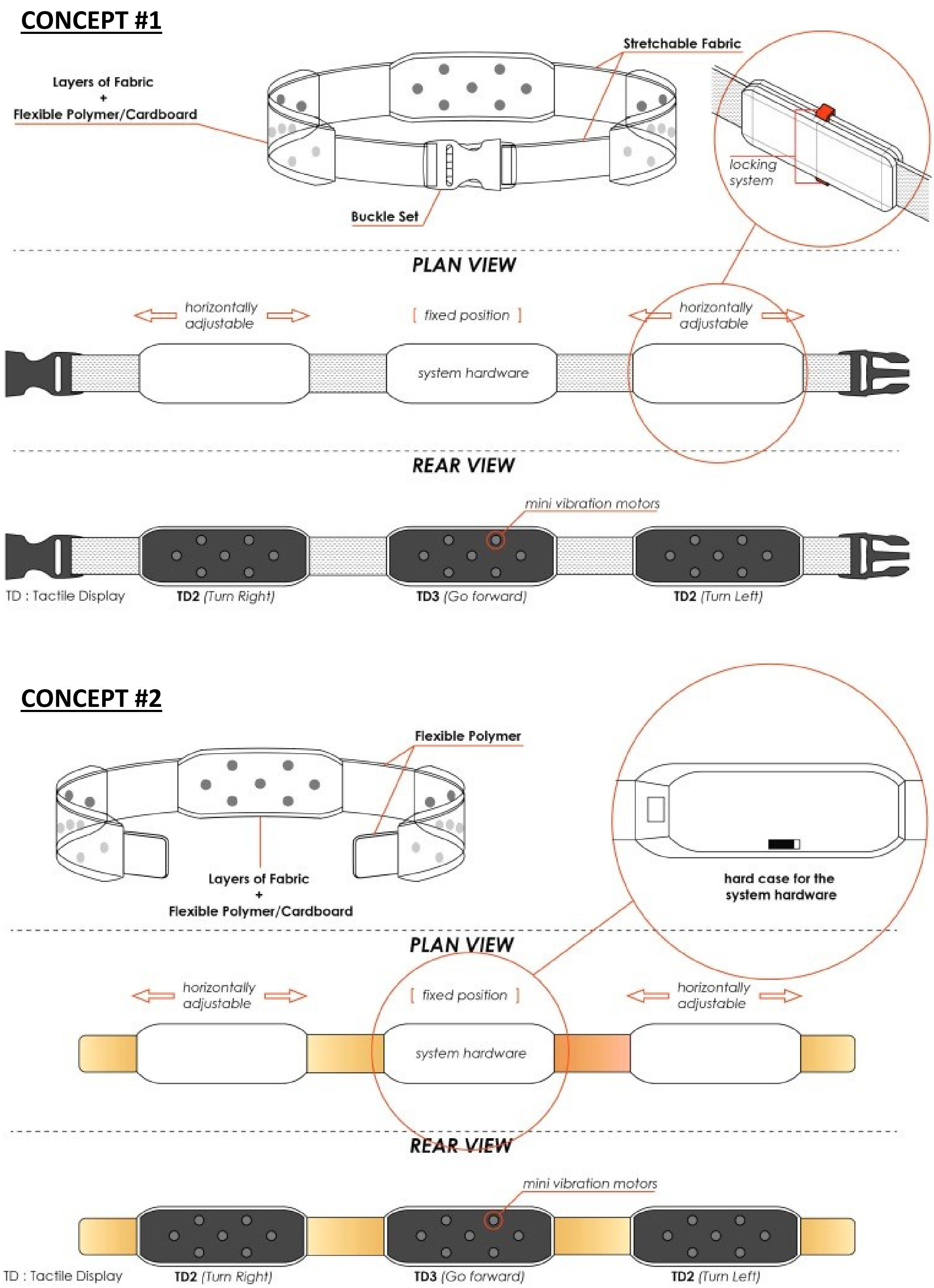

Figure 6.1: Early ideations of the new design for the device

Moreover, in the actual navigation situations, the pedestrians do not always turn left/right after they have reached the junctions. Yet, people with dementia (also based on the former observations) tend to doubt/hesitate more than healthy persons, whether to take or not to take the turns at the junctions. This hesitation may cause them to be more confused – an influence that should be avoided at all costs, since it probably leads them to abandon the wayfinding. Having the 'go forward' signal may help to reduce these confusions and at the same time lessen the directional errors. This is because this signal is meant to be activated even before they reach the junctions/turns that they do not need to take.

The difference between the two proposed concepts is mainly on the attachment of the device onto users' waists. Both of them embed the tactile displays and hardware on the belts. But the first concept has a belt made of a stretchable fabric and both ends are connected together with a buckle-like mechanism. On the contrary, the second concept has a stiffer belt that stays in shape. In this case, the belt does not require a locking mechanism since it is expected to hold the device in its intended positions. In addition, the tactile displays in both designs can be adjusted horizontally to fit the diverse body sizes.

Furthermore, the design process is continued by creating the three-dimensional (3D) model of the concepts in order to have a better view of the designs. Figure 6.2 shows the constructed 3D models for both of the concepts. The principal ideations of both designs are maintained from their early sketches. The first concept proposes the use of stretchable and more flexible belt, while the second one uses a more rigid belt that holds the device in place. The tactile displays in both designs synchronize the hard cases forms (that place the remaining of the device hardware) and at once inspire the overall looks.

After careful thoughts and deliberations on some restrictions, only one design concept for the prototyping phase was chosen. The first concept was chosen due to its practicality, applicability and comfort aspects. The stretchable belt in the first concept could fit onto users' waist more appropriately, and it would not cause any attachment issue. A wearable device without taking into account its dynamic structure and attachment might hinder users' normal bodily functions and mobility, and interaction with the device [273]. Carrying on with this design concept, the in-depth construction for the model is visualized in Figure 6.3 below

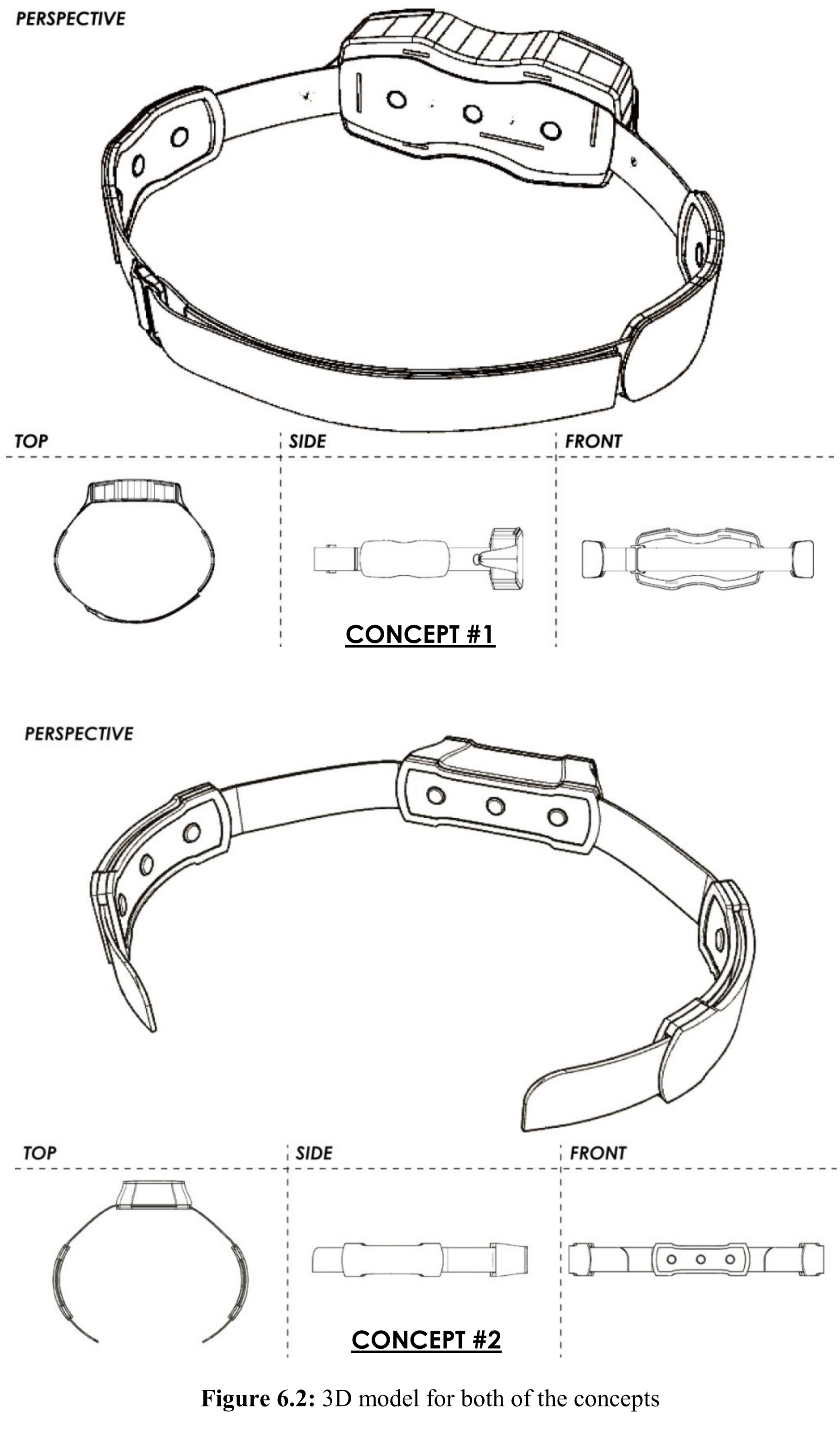

Figure 6.2: 3D model for both of the concepts

The actual mockup with the functioning system was then developed based on this comprehensive model construction scheme. For the prototyping purposes, the study tried to follow the framework as exactly and meticulously as possible. Then again, it very much depended on the limitations and availabilities that influenced the decision making in selecting the components /elements/strategies for the prototype.

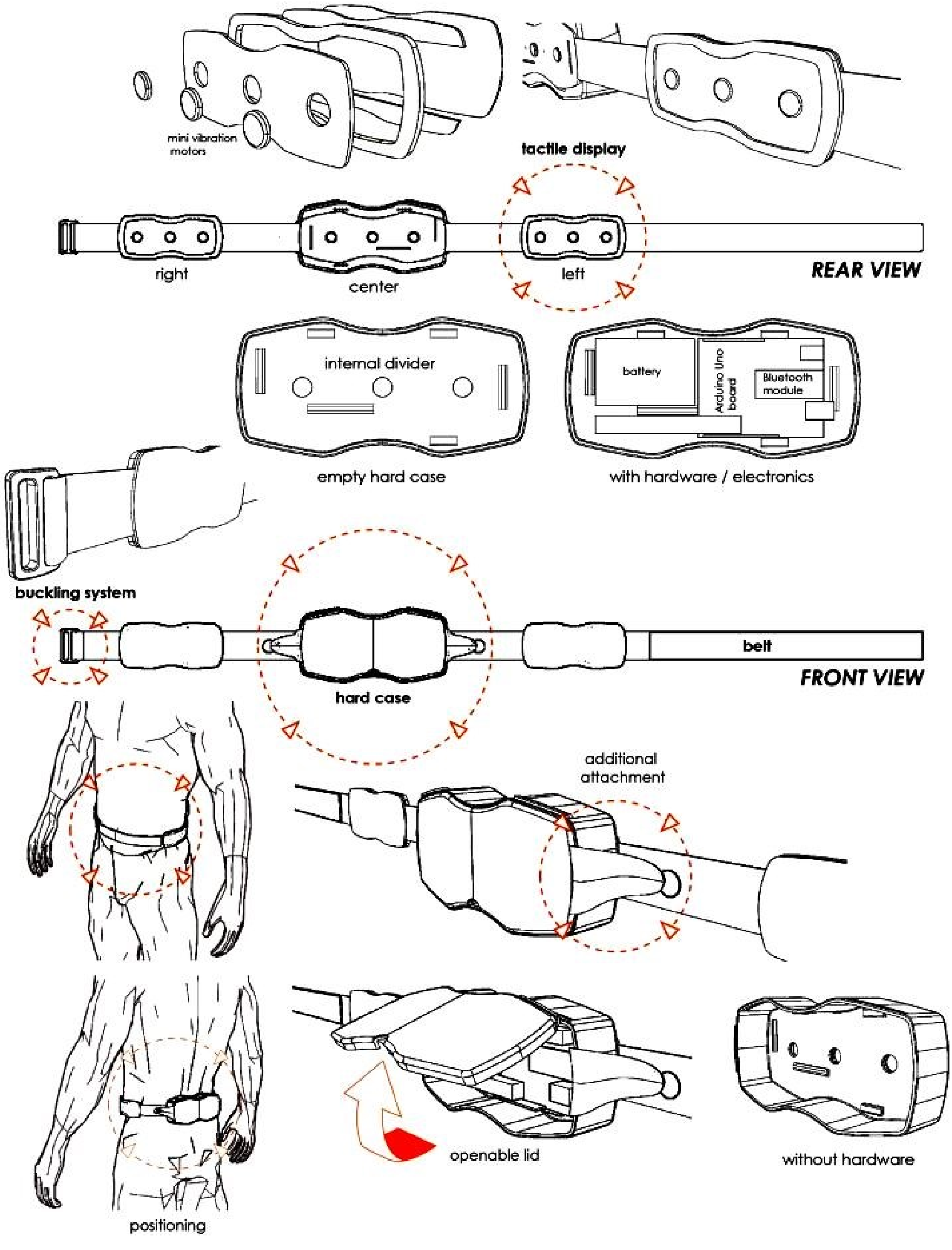

Figure 6.3: The detailed constructions and overall view of the proceeded concept

For example, with the limited time and budget, some of the electronics components from the previous prototype were recycled and the purchases were limited to only those truly necessary items. In addition, the materials such as the types of fabrics were not of the highest quality. Figure 6.4 exhibits the complete look of the physical and functioning second device prototype.

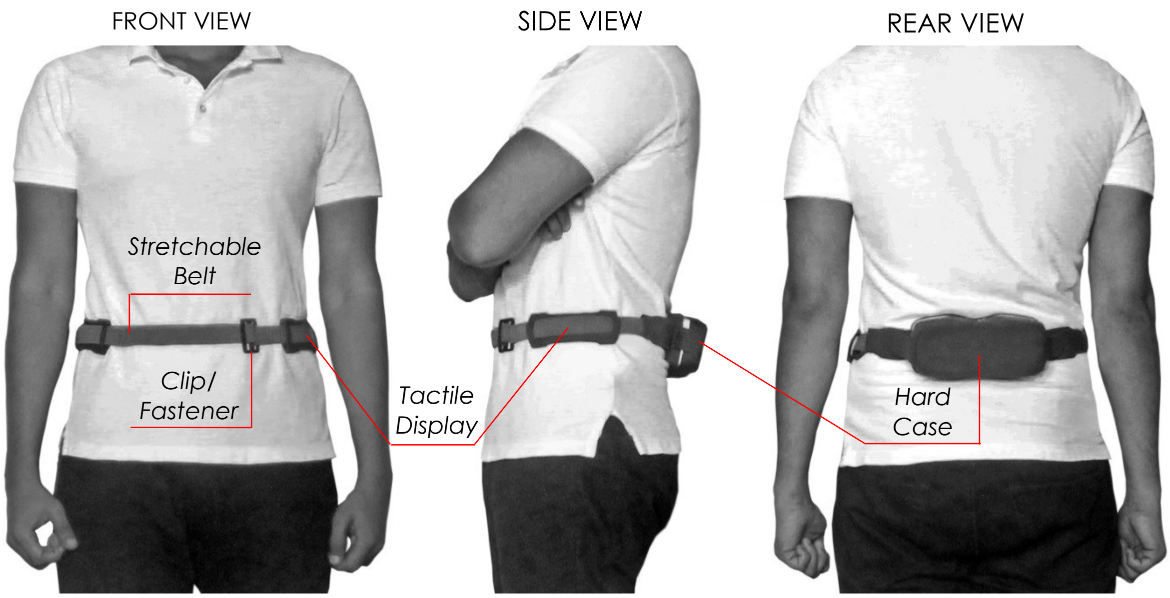

Figure 6.4: The finished look of the second prototype when in use

Most of the parts of this prototype were made of or covered in different types of fabrics. The hard case that contained the hardware was thermoformed using a thin layer of polymer, and then it was covered with the same fabric that held the tactile displays in place. The belt was made of stretchable fabrics and one of the ends was attached with the clip/fastener. The above figure also demonstrates the placement of the device prototype when it is being used by the users. But, to function at its best, the tactile displays should have direct contact with the skin, in order for the haptic stimuli to be sensed most appropriately. For this reason, the users and the subjects for the test were recommended to wear the device prototype underneath the clothes, on the waist line. After the prototype was completed, series of assessments based on Usability Testing (UT) principles were conducted once more, in line with the aforementioned aspects of project advancements. This is presented in the succeeding section.

6.2 Test and Validation

The validation over the effectiveness and usability of the second device prototype is described based on the (1) Demographic of participants, (2) Experimental Procedures, and (2) Results and Analysis, as documented in the following subsections.

6.2.1 Demographics of Participants

For further assessment, it was also conducted on the actual target users of the device i.e. dementia patients. However, due to the limitations of time provided, as well as the availability of the subjects and settings, the test was conducted in collaborations with different nursing homes as compared to the previous test. The enrolled participants were from (1) Genera Società Cooperativa Sociale Onlus in Bovisa, Milan and (2) Fondazione Casa S. Giuseppe – Onlus in Gazzaniga, Bergamo. Both institutions are nursing homes that provide the cares for the patients in their different stages of dementia, where some of them stay there fulltime and the rest come on daily basis.

Like most of the dementia care institutions, these nursing homes also used MMSE as the cognitive-based ratings to identify the individual level of consciousness or the severity of the disease. The total number of participants from both institutions was six persons and the age range was from 79 to 89, with the average being 83.5 years old. The MMSE assessment conducted on these patients were relatively recent. All of them were assessed in the year 2016, with the earliest was in March and the latest in July 2016.

The MMSE score ranged from the lowest 14 and highest was 20 with the average of 16.8. The average MMSE score of the recruited subjects in this test was lower than the previously conducted UT (16.8 against 20.8), making the assessment even worthy and interesting. With this, the patients in the higher dementia severity were observed on how they cope or perceive the intervention. Once again, as it was also an important criterion for the test, all the subjects in this test were able to walk properly with no serious mobility issues even though some of them use the canes. To be properly documented, the test subjects were identified by the numbers from 1 to 6. Table 6.1 below presents the necessary data for the demographic of participants involved in this test.

Table 6.1: Details of subjects participated in the second Usability Test

Subjects	Age	Gender	MMSE Score	MMSE Test Date	Institutions
1	84	Female	16	04/03/2016	Gazzaniga *
2	83	Female	15	06/04/2016	Gazzaniga *
3	85	Female	17	05/05/2016	Bovisa **
4	89	Female	20	15/05/2016	Bovisa **
5	81	Male	19	14/03/2016	Bovisa **

6	79	Female	14	04/07/216	Bovisa **

*Gazzaniga * : Fondazione Casa S. Giuseppe – Onlus*
*Bovisa ** : Genera Società Cooperativa Sociale Onlus*

6.2.2 Experimental Procedures

Since the evaluation of this second device prototype focused mainly on the practicality and aesthetic aspects, the test conducted was not as complex as the previous one. This second UT was divided into two main phases, where the first phase involved the orientation/training sessions and the second phase was on the subjective assessment. The data collections for the first phase were in compliance to the familiarization of the device by the subjects. For that reason, the assessment follows the procedures that represent these aspects:

1. Acceptance of the device by the patients
    - *Experimenters put on the device onto the subjects' body, and observe their reaction or acceptance.*
2. Reactions towards the haptic stimuli
    - *Subjects were asked if they can sense the haptic signals generated by the tactile display at all the positions (Right, Left and Middle).*
3. Understanding the meaning haptic signals
    - *Subjects needed to indicate if they can understand what the haptic signals represent. For example, if they sense the vibration on the left, they can raise left hand, turn left, take a few steps to the left or by even simply showing where they sense it.*

All of the experiment phases were executed in an open space but still within the nursing homes' buildings, so that a simple navigation assessment could be conducted. Unfortunately, the researcher could not perform the navigation assessment in an outdoor environment using the actual streets like before as in the first UT, since the patients were not encouraged to go out of the premises. In addition, the permission from their families to bring the patients out for the test was not granted due to their concerns over the patients' safety. Anyway, after each subject completed the first phase, he/she was required to take a walk wearing the device in a simple route in the indoor gardens of the institutions. Here, subjects were asked to travel with the device and make the turns accordingly when the haptic signals were triggered.

Once each subject was assessed on his/her ability to navigate within the indoor garden with the assistance of the device, the test was proceeded with the second phase i.e. subjective assessment. The subjective assessment consisted of the queries related to how the subjects perceived the device. The similar set questions from the previous subjective assessment presented in Chapter Five was adopted, but with additional and detailed questions about the device, mainly from the aspect of comfort. The researcher also interviewed the nursing homes' caregivers, managers or therapists to support the findings from this subjective assessment.

6.2.3 Results

The results from this test are reported based on the two phases (training session and subjective assessment). Each subject spent about 30 to 45 minutes to complete all of the evaluations. First, the orientation/training as describe previously has three aspects of measurements or variables: acceptance, reactions and understanding. Subjects' performances for the said aspects were observed and the scales of 1 to 5 to rate them, with 1 as the minimum and 5 as the maximum scores were used. The scores of every subject according to the three aspects are represented in Table 6.2.

Table 6.2: The Subjects' Scores for the First Phase (Orientation/Training)

Subjects	Acceptance of the device					Reactions towards the haptic stimuli					Understanding of the haptic signals				
	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
1					✓				✓						✓
2					✓					✓					✓
3					✓			✓					✓		
4					✓					✓					✓
5					✓					✓					✓
6					✓		✓					✓			

From the results, half of the participants (Subject 2, 4 and 5) scored the maximum scale for all aspects of assessment. Most of the participants did not show any obvious reluctant attitude when being introduced to use the device, except for Subject 2 where she was rather skeptical and hesitated. But still, she indicated good recognition and understanding for the given haptic signals and accepted to use the device.

Whereas for the other participants who did not score the maximum scale in the recognition and understanding aspects, it was mainly because they took a while to perceive the haptics signals or had difficulties to recognize and understand what the signals represented. For example, Subject 6 who scored the lowest in the recognition and understanding aspects could not properly sense the haptic stimuli in most of the positions, and it took her a while before she could indicate the meaning of the stimuli. However, she accepted the intervention very well as she was being really cooperative during the whole test sessions. Furthermore, some of the participants were noticed to have difficulties to recognize the haptic signal from the tactile display at the back. Here, they took more time to indicate if they sensed it, and it was not as impulsive and efficient as sensing the haptic signal from the left and right tactile displays. Again, Subject 6 indicated the most poor performance in recognizing the haptic signal at the back as compared to the other participants.

Subjects' navigation abilities in this UT were evaluated solely on the experimenters' observation with the assistance from the staff of the nursing homes. For this valuation, those who scored the higher scales in the first phase also performed sufficiently well here. In the course of navigation, the haptic signals triggered randomly, depending on the availability of the route within the indoor garden. Of all the participants, only Subject 6 was not assessed on her navigation ability with the device because she did not satisfactorily understand the left, right and go forward signals.

In addition, since the route within the indoor garden was too short, the subjects were not given the 'go forward' signal (from the tactile display at the back position) as many as the left/right signals during this simple navigation assessment. Besides, giving different signals at different positions in a short range of time (for example with the intervals of 10 to 20 seconds) may lead to confusion for the subjects. In addition, the more important evaluation was if they could effectively decide to turn left/right every time they sensed the signals. The subjects were required to walk forward along the route when they were not sensing any haptic signal. Surprisingly, even when they were not given the signal at the back, most of the participants still managed to navigate sufficiently well with the device.

However, the 'go forward' function could not simply be removed just because the participants performed better without it. This could be related to: (1) the limited route size that created confusion as stated beforehand or (2) probably due to the design of device prototype itself that made the subjects not adequately sensing the haptic signal on back. In any case, further investigation might help to justify this matter, before deciding whether or not to keep the 'go forward' signal.

The second phase of the assessment was purposefully to justify deeper on how the subjects perceived the use of this device and the overall intervention as a concept of assistive technology. However, as the device usefulness for the target users was an important aspect to look for, there was another crucial factor to be added and highlighted in this second subjective assessment, essentially from the comfort point of view. Once again, the scale of 1 to 5 in rating the answers for each question asked, with 1 as the minimum and 5 as the maximum was used. In conjunction with this, the scale of 1 was interpreted as 'Absolutely No', 3 for 'I don't know', while 5 for 'Absolutely Yes'. The questions asked in the subjective assessment were categorized into three segments, which were related to the (1) Functionality, (2) Comfort/ Wearability, and (3) Usefulness of the device.

This evaluation was carried out on a one-to-one basis, like an interview session. The subjects were encouraged to use the scales given to rate their answers, but at times the experimenters (with the assistance of the nursing homes' staff) had to restructure or simplified the questions to help them understand better. For this, the experimenters had to interpret their responses and decoded them again into the scales. Table 6.3 below records the scores for each question by all the participants.

Table 6.3: The subjective assessment questions and the scores given by the subjects

QUESTIONS		SUBJECTS	SCALE (OF 1 TO 5)				
			1	**2**	**3**	**4**	**5**
DEVICE FUNCTIONALITY							
Q1	Did you clearly sense the vibration (haptic stimuli)?	1				✓	
		2					✓
		3			✓		
		4				✓	
		5					✓
		6		✓			
Q2	Do you need more time to learn to use it?	1					✓
		2		✓			
		3					✓
		4					✓
		5					✓
		6					✓
Q3	If you are given more time to use it, will you perform better?	1					✓
		2	NA *(no useful answer given)*				

		3					✓
		4					✓
		5					✓
		6	NA *(no useful answer given)*				
	DEVICE COMFORT/ WEARABILITY						
Q4	Were you comfortable wearing the device?	1					✓
		2					✓
		3					✓
		4					✓
		5					✓
		6					✓
Q5	How comfortable is the device related to the material?	1					✓
		2					✓
		3					✓
		4					✓
		5					✓
		6					✓
Q6	How comfortable is the device related to the shape of the hard-case?	1					✓
		2					✓
		3				✓	
		4					✓
		5					✓
		6					✓
Q7	Attachment: Does the device excessively noticeable/perceivable when putting it on the body?	1	✓				
		2	✓				
		3	✓				
		4	✓				
		5	✓				
		6	✓				
Q8	Movement: Did you feel if the device move around and restrict your movement?	1	✓				
		2	✓				
		3	✓				
		4	✓				
		5	✓				
		6	✓				
Q9	Harm: Was the hard-case of the device hurting your back?	1	✓				
		2	✓				
		3	✓				
		4	✓				
		5	✓				
		6	✓				
	DEVICE USEFULNESS						
Q10	Do you think the device is useful?	1					✓
		2	NA *(no useful answer given)*				
		3			✓		
		4				✓	
		5					✓
		6	NA *(no useful answer given)*				
Q11	Would you like to have the device and use it?	1					✓
		2					✓

	3			✓		
	4				✓	
	5					✓
	6	NA *(no useful answer given)*				

From the table, several remarks of NA (not available) in the scale r were marked when the informative feedbacks from the subjects regarding the questions could not be gathered. This happened when the subjects still could not properly understand the questions after several attempts of questions restructuring, or the experimenters failed to interpret the responses given to the questions, or simply because the subjects were not being collaborative. For instance, Subject 2 was not giving good cooperation since the first phase. Yet, the same thing happened during this subjective assessment session when she was not responding reasonably for some questions. The nursing home staff mentioned that she probably had a bad day, and maybe because she did not appreciate the idea of being the test subject. On the contrary, Subject 6 was being very responsive to the entire questions asked and sufficiently collaborative during this assessment. The only issue was she could not apprehend some of the questions and for that she misinterpreted them. This resulted in uninformative feedbacks to some of the questions.

In terms of the functionality, the feedbacks on Q1 showed that the participants managed to sense the haptic stimuli adequately, as 4 over 6 participants (66.7%) gave the higher scales of at least 4 over 5. However, they certainly needed more time or more training to get familiarized with the device system/features. This was proven when only Subject 2 mentioned that she understood well on how the device worked in Q2. It was supported by the next question (Q3) when the majority agreed that they could perform/navigate better with the device if they were given appropriate and sufficient trainings. Then again, there were exceptions to Subject 2 and 6, where they could not clearly state if they would perform better after familiarization. Nonetheless, based on the observations of overall performances, it was quite certain that Subject 2 could perform better after a proper training but it was doubtful in the case of Subject 6.

Encouraging results were revealed in the comfort and wearability segment, where it was evidently shown that most of the questions were given excellent scales. The feedbacks for this segment by some means represented the justification of improvement made to the current prototype, since the issues raised from previous prototype were expected to be undertaken and solved here, especially from the comfort and aesthetic perspectives. Thus, the positive remarks in the mentioned aspects relatively indicated the accomplishment.

To be more specific, Q4 to Q6 genuinely exemplify the queries on the device comfort as a complete prototype. Due to the long hours of use during the wayfinding, it was surely essential for the device to sit properly and comfortably on users' bodies. Therefore, the feedbacks for these three particular questions validated that there was no discomfort issue of the device. In addition, Q6 was brought up intentionally because the hard case that contained most of the electronics and hardware components might disturb/annoy the wearers. Yet, the feedbacks for this question and supported by Q9 clarified this hesitancy, where 83.3% gave the scale of 5/5 in Q6 and 100% approved that the hard case did not bring any pain when wearing the device (as shown in Q9).

Equally important, one of the main criteria to ensure the comfort of wearable devices is it should not constraint the normal bodily functions of the users/wearers, such as movement/mobility and physiological abilities/disabilities, aside from not stigmatizing the users with too obvious artifacts. This crucial point is answered after all the subjects gave the lowest scale of 1/5 to these three sub-criteria: attachment (Q7), movement (Q8) and harm (Q9). It means that the device is not excessively noticeable, it does not move and limit the users' movements and finally it does not cause any form of pain when wearing/operating it. All the questions asked and feedbacks given in this particular segment validated whether or not the comfort aspect was taken into consideration in the design project. Thus, the study can affirm that based on the results shown here, the device is adequately comfortable to be used by the target users.

The final segment for this subjective assessment was on the usefulness/utility. Here, we asked two forthright questions about the subject's opinions on overall helpfulness of the device. Although both the questions (Q10 and Q11) had their own distinguished probes, they shared the common objectives to draw attention to its likelihood to be further developed for commercial use. Thus, they were equally essential to be retorted by test participants. Acceptable feedbacks to both questions were received where three subjects rated the higher scale (of at least 4/5) for the Q10, and four subjects gave at least 4/5 in Q11. Furthermore, in this case, the study did not take the uninformative feedbacks as an individual response to be counted into the success rate. Therefore, 75% of the subjects (cumulative of 25% for 4/5 and

50% for 5/5) approved the device usefulness (exclusive of Subject 2 and 6 for Q10) and 80% (cumulative of 20% for 4/5 and 60% for 5/5) agreed that they were willing to have and use the device (exclusive of Subject 6 feedback for Q11). This is a positive indication that the subjects sanction the possibility for the device to be commercialized.

The whole data collected for this second UT had been reported, but as mentioned, the researcher also conducted interview sessions with the staff of the nursing homes after both the phases were completed. Thus, the further analysis is presented in the next subsection, demonstrating the feedbacks from these interviews to support and further justify the gathered results for this test.

6.2.4 Further Analysis and Conclusion

In general, the study managed to obtain the encouraging information from both phases, despite the number of issues faced. Yet, from the interview sessions with the staff of both nursing homes, two more important arguments were highlighted: (1) relating to the device system, mainly on the additional 'go forward' signal and (2) relating to users' familiarizations of the device. To begin with, as stated earlier in this chapter the second prototype was built to be worn as a belt with the tactile displays positioned on the waist, based on the previous findings of the first UT. Also, the 'go forward' signal was added to this new prototype because it could be more assistive in navigating in a more complex route.

However, in this test the study could not carry out the actual navigation test like before. Hence the practicality of this specific additional function was not fully assessed, and not being questioned. Having said that, the comments received from the interview sessions helped to at least provide the useful information on this matter. For example, a physical therapist from Fondazione Casa S. Giuseppe – Onlus Genera in Gazzaniga stressed that the dementia patients were usually unable to cope with the complex device or technology, thus asking them to practice complicated tasks would not lead to a positive outcome. This is simply because they will require more time to learn and remember how the device works before it can actually be used to help them. Along with this argument, she added that the haptic signal on the back to tell the person to go forward could not be of much help, and conversely it could lead to more confusion to the patients.

This was also agreed by the physical therapist from Genera Società Cooperativa Sociale Onlus nursing home in Bovisa, where she pointed out that bringing any cause of confusion from a therapeutic intervention should be one of the most avoided elements. To support her debate, she posited that in the course of navigation (either indoor or outdoor), going forward was an impulsive and instinctive action. Giving a situation where an individual is undecided where to go or which turn to take, he/she tends to go forward until he/she receives the next directional hints. This is applicable for our proposed design project, where she has suggested that the 'go forward' signal is somehow unnecessary and excessive, since it may cause the users' misjudgment.

The second argument on the importance to provide a proper training in getting the subjects familiarized with the device function is also justified from the interview sessions. The physical therapist from the nursing home in Bovisa raised this concern since some of the participants from this nursing home did not perform satisfactorily, especially in recognizing and understanding the haptic stimuli as forms of directional signal. Failing to recognize and understand these signals resulted in the poor navigational performance, as revealed in the simple navigation test. For that, she recommended for all the subjects to be given an appropriate training (approximately half a day) to understand and successfully use the device, since she predicted that most of the subjects recruited from this nursing home could eventually demonstrate better overall performance after the familiarization.

Once again, this matter was also brought up in the interview conducted in the nursing home in Gazzaniga. The additional comment given was the importance of getting the users habituated with the system, but making the learning process easier was even more vital. This is because patients with dementia are known for their reduced interest to learn new things [19] [20]. Thus, keeping their interest by providing the proper training to learn the device function (and maybe with the injection of fun activities) helps to maintain the continuous use.

Additional important point to be highlighted from the interview sessions is on the agreement of wearable device's positioning on users' body. Both agreed that the abdominal area provides a larger 'working' surface and suitable to trigger the haptic signals. This position is considered to be one of the most unobtrusive areas of human body for wearables and for the haptic-feedback, making the haptic recognition to be more intuitive. However, the only comments given on this aspect were on the sizing and aesthetic aspects. Although this wearable device was designed to fit most of the body size since the belt was made of elastic fabric and the length was adjustable, there could be some users who might not fit well to this universal size. When this happened, another discomfort issue might occur and the device could not work as how it was envisioned to be, probably because the tactile displays would not be placed at the appropriate positions. The suggested solution is to provide several sizes for this device, similar to the available sizes for clothing, specifically for the belt part.

Moreover, they also mentioned about the overall physical look of the device. For commercialization purpose, it is the first thing that attracts the buyers' attention in purchasing it. In the case of this proposed concept, even though it is intended to be used mainly by individuals with dementia, they probably are not able to purchase this artifact by themselves. For this reason, the device should also be pleasing to attract and convince the potential buyers (could be the spouses, family members or the nursing home managers) to buy it. Besides, making the device less noticeable is also a crucial point, as to avoid stigmatizing. In fact, this is one of the criteria to incorporate technology for people with dementia, as recommended by Rosenberg, Kottorp and Nygård [288]. The combination of comfort, excellent-yet-dynamic features, and aesthetically pleasing appearance will surely guarantee the success of device design concept. At the same time it may increase and maintain users' interest to keep using the device on regular basis.

To conclude, the proposed design concept has significantly improved since the earlier stages of its development and the assessments conducted for the second time using the second device prototype elucidate the achievement of the design project at its current stage. What made the reassuring findings of the tests even worthwhile was because it was conducted on the primary stakeholders of the proposed intervention. That being said, as much as the encouraging outcomes from the results and analysis of both phases of assessments in this second UT are important, the critics attained and arguments brought up are indeed more beneficial for the future development of the design project.

This is apparently the principle motivation of UCD and UT combined, where the users are positioned in the heart of design development process, and the evaluation allows the collection of data in identifying usability problems [316]. The recognition of usability problems from this test will be used for futher evolvement of the design concept, while simulatenously enhancing the design process by means of diminishing the unnecessary and recurrent issues occurred. Therefore, the study can summarize that the proposed design project does not end here. In point of fact, both critics and credits attained from this second UT contribute the weights and provide motivation for further work on this project. However, at the same time, the study should also bear in mind the limitations of any developing research, which are due to the restrictions of time and resources. For this reason, the study suggest to put a hold on the further development of this project and to conclude all the collected findings as a complete research at present time.

The next chapter eventually summarizes the study in compliance with the present phase of the design project and presents all the required aspects for if it were to be further developed and commercialized. It then concludes the research and provides the recommendation for future works.

CHAPTER **SEVEN**

7 Conclusion and Recommendation

7.1 General Reflections

The study has revealed many findings from this thesis writing, starting with its theoretical constructs and ending it with the series of conducted evaluations for the proposed design project. The main research question – how to explore the possible ways to improve the wayfinding ability or lessen the difficulties in outdoor navigation faced by the older adults with cognitive impairment, through the design and technological standpoints – has been justified, by accomplishing the corresponding objectives.

The synthesized conceptual framework that exemplifies the collective reviews of related works helps to strategize the subsequent research plans. In the beginning of the performed reviews, the study exposes the significance to focus on the research topic, mainly due to its pressing needs. The increasing number of ageing population each year and the accompanying implications are not uncommon and have been addressed in many existing bodies of works. However, the specific issue that is emphasized in this study is still lacking.

Based on the reviews of related literatures, there were not many studies focusing on the amalgamated issues caused by the cognitive impairment in elderly, especially for their decline in mobility domain. Even if there were, the numbers were insufficient and more importantly, there were no great attention given to the knowledge of design and technology in providing the possible solutions. As discussed profoundly in Chapter Two, the mobility issues are prominently associated with several other factors – navigation ability and spatial skill, as well as the sensory acuity. If the study were to highlight them again, all these allied factors are increasing more obviously in accordance with the age and the progression of the disease, namely dementia of AD type. What makes the condition aggravated is when the two most requisite sensory faculties for wayfinding, i.e. vision and also hearing are the most affected in these individuals. This is one of those critical points that amplify the need to expeditiously find the alternative solutions.

From here, the study introduces and explores the uncommon sensory for navigational purposes, which is the sense of touch. One of the biggest motivations that boosts the study to go further on finding out more on the potentials of haptic modality for wayfinding is mainly on the fact that the older adults (with or without dementia) may not be able to rely on these two most impaired sensory faculties. Apart from that, it is founded on the distinctive characteristics of haptic/tactile sensory system itself. These impulses have been profoundly vindicated throughout the integral review of the correlated existing literatures.

The potential of haptic stimuli as a form of wayfinding signals has apparently been studied by several previous scholars, and has been recognized to give an encouraging outcome of interventions. However once again, the previous studies did not target on the specific population and due to this, the issues touched were diverse. Here, many of the existing bodies of works were focusing on using haptic to help the wayfinding of visually impaired persons and a very limited number of studies that essentially focused on those with cognitive dysfunction.

In addition to this, the implemented approach in seeking the solutions to the raised issues explicitly from the angle of design and technology is not ordinarily encompassed for this field of research. This makes the current study even more judicious and stands on its own firm novelty. On that account, the study exerted this knowledge and outlined a design project to befit into a form of (therapeutic) intervention for the probed case study. The proposed project that was evolved along with the several phases of development was also used as a tool for the series of assessments. This flow was clearly presented starting from its initial conception in Chapter Four, first prototype development in Chapter Five and the its further development in Chapter Six.

The conducted series of assessments were by some means a way to clarify the questions and to materialize the linked objectives of the study. The design project needed to be developed and assessed periodically or by phases according to its level of readiness /completion. Also, these assessments served dissimilar purposes or aims, and for this reason different strategy was used in each one of them. For instance, the first assessment performed in this study was a survey and it was aimed to evaluate its early concept. The investigation on the feasibility of the proposed concept was important to determine the further actions and the continuations of this project. Due to the difficulties to require persons with dementia to answer the set of complex questions structured in the survey, the researcher envisioned to receive the feedbacks on the conceptual design by the individuals who mostly understand them.

The researcher received the overall constructive responses and comments from the medical/clinical experts as well as professional and non-professional caregivers of dementia over the proposed concept from the survey. But, the most significant indication was on the viability of using haptic-feedback as a modality of assistive navigation to help the wayfinding of people with dementia. This encouraged the researcher to further perfecting the conceptual design and developing the functioning prototype.

After the first prototype was completed with reference to previous findings, the actual assessment grounded on the principles of Usability Testing (UT) was carried out. It was the very first time the researcher managed to conduct an experiment on the subjects that represented the target group of the intervention. Evaluating the whole usability aspects with the actual users provided truly useful information on how the assistive technology that was conceptualized might help their wayfinding in an outdoor environment.

This first UT also allowed the researcher to observe the navigational performance of the subjects with the device and at the same time gathered the important feedbacks directly from them. From the assessment, most of the participants demonstrated the acceptable performances and gave positive appraisals on the concept, despite some concerns largely affiliated to the wearable aspects of the device. The subsequent design development was intended to improve and concurrently rectify what was lacking in the design of the first prototype.

Founded on this basis, the study endured the design project with the second prototype development and conducted another assessment of usability, again with the subjects who represented the real users. Notwithstanding, this UT was concentrated more on the qualitative analysis than from its subjective assessment, as additional navigation test was not performed due to some limitations. Then again, the subjective assessment was apparently even more critical and reasonable. This was because the key objective here was to evaluate the wearability of the device prototype, while the previous navigation tests had already verified that the subjects with dementia could accept the use of haptic signal for navigation.

The second prototype development and its measurements brought the study even closer to the point where strategies on the actual production of the assistive navigation device could begin, provided that several other concerns were redressed. The study obviously needed to put an end to the current study based on the provided availabilities and ungovernable obstructions, but it did not mean the design project stopped here. Likewise, the entire series of performed assessments expounded the potential of it to be further explored and finally commercialized. Therefore, for the commercialization and mass-production purposes, it is appropriate to deliberate its potential markets as accounted in the next section.

7.2 Commercialization

In terms of market segmentation, the study has previously mentioned about the stakeholders of the proposed intervention, to be precise in Chapter Four, which comprise of different levels of users. These stakeholders are apparently the direct and indirect users of the device: (1) direct or primary users are the older adults with dementia and (2) indirect or secondary/tertiary users are the caregivers, managers of nursing homes and medical experts of dementia.

What has been proposed for the design project in fact resembles the whole intact structure of intervention that involves these stakeholders. This structure requires the members to complement each other and it may not be efficient if any of the stakeholders does not adequately contribute or play the role. As an example, even though the primary users of the device are the persons with dementia, they may not have the purchasing power. Instead, the secondary/tertiary users are expected to do the buying of the device on their behalf.

Besides, the study has stressed that this intervention is quite uncommon for the people with dementia. Due to this and also from the results of the first and second UTs, it is convinced that familiarization is absolutely an essential criterion in determining the attainment of the intervention. Here, the study proposed that before the dementia patients can use the device on regular basis, they should be given a proper training. The training could be provided from the institutions level (nursing homes, hospitals or even from homes) by their caregivers. This supports the necessity of contributive collaboration among all the members of the said stakeholders.

The use of this device is very likely to be extendable to a larger market or bigger groups of users. One essential point is that the device does not require any visual and auditory interactions; hence, it may also be appreciated by the users with visual and/or hearing disabilities. Secondly, the device is purposely designed to have a simple interface, so that even the real target users need not take long to learn how to use it. Thus, the uncomplicated functionality of the device could also be valued by the normal/healthy elderly and those who are not really into gadgets and current technologies or the ‘non-techie’ persons.

The main stakeholders of the said structure that consist of the primary/secondary/tertiary users, aside from the extended users as preceded above typify the market segmentation of the device and the proposed intervention strategy altogether. The study has previously deliberated on the importance of the aesthetic aspect of the device, which is also one of the main aims for the device’s further development, as presented in detail in chapter 6. Nonetheless, the more crucial aspect that justifies the rationality to commercialize the device lies upon the features it offers.

At present, the evolution in the trend of applications for the navigation systems in particular for the pedestrian is evident and consistent with the universal rapid enhancement of technology. Also, the inexpensive current wayfinding methods make them even more pervasive and allow almost everyone to have the possibility to choose any mode/system of navigations they prefer; from the variety of GPS devices to the numerous mobile navigation applications. Against this background, the primary intention of the proposed project is not to utterly replace these existing and already established wayfinding strategies, but it is more on providing another practical option. As what the study has emphasized earlier on the functions of this device, it does not wish to compete with the current indoor or outdoor navigation interfaces, since this device offers different purposes.

First, the users rely neither on visual displays/cues such as maps nor audio signals such as voice commands, like the ordinary wayfinding methods. Instead, the approach still allows the users to be alert to the (outdoor) surroundings within the route of navigations. The complete and vital concentrations to travel specifically in a complex outdoor environment will not be distracted with the obligation to simultaneously focus on visual/audio signals. The haptic signals given to the users are intuitive and may result in an affective wayfinding.

Secondly, the study has presented critical justifications on the practicality for the device to be wearable. The device already has a simple-yet-intuitive interaction, yet having it in a wearable form could even minimize its complexity level as low as possible, which is purposely made compatible for our target users. One of the additional advantages is that the users do not have to carry this device like the mobile phones or other everyday gadgets, since they can comfortably wear it like an accessory. This at the same time reduces the potential to misplace or lose it.

On a different note, the device is a stand-alone product by itself, which means it does not require the integration with another product. However, the caregivers of dementia patients for instance, may need to monitor them for some safety reasons. For this reason, the device may be connected to a mobile application that tracks their current location and activities, in order to assure their safety when travelling and being in an open outdoor environment unaccompanied.

Furthermore, to keep up with the current trend and also for the commercialization purpose, this invention is called “We HAND” (pronounced as we-hand), named after the acronym of ‘Wearable Haptic Assistive Navigation Device’. This name visualizes its real goal where it is intended as a 'helping hand' by means of aiding the outdoor navigation. Nonetheless, before any product or device can make it into the retail market, a comprehensive analysis of market research and planning need to be performed beforehand.

The concerning aspects include the advancement strategy and manufacturing, production cost, supply chain, and time of release. This is to realize the goal for mass-production, while at the same time ensuring that the device can be sold at a low price so that it can reach a wider range of consumers. In its development stages, the project was given a limited financial aid of approximately 500 Euro for the prototyping purposes (this was considered as the entire direct and indirect costs for both prototype developments). Then again, the study hopes that the manufacturing cost can be drastically reduced, due to the larger volumes of production, and making the retail price lower than 100 Euro for one unit.

Finally, during the completion of this thesis writing, the researcher is already in the process of filling the patent for this project. Thus, after a legitimate analysis of potential market and commercial value, the device is expected to be ready for retail within the following 3 to 5 years. Nevertheless, even after all the above-mentioned thoughts of the potential markets, there are always countless challenges along the way. This is not unusual in any design project or product design and development processes. Thus, the next section discusses on the challenges and the possible solutions to all the surfaced problems and limitations in general on finishing the present study and in particular on establishing the design project.

7.3 Challenges and Possible Solutions

Designing a product is completely an intricate yet iterative process, but as the development gets closer towards its goal, then only the requirements and clarifications of the artifact can be well-refined. In addition, having a proper design determines many of the prospective production configurations, since it is one of the primary measures before any conception can be forwarded into the manufacturing phase [329].

Undoubtedly, there are many sensible physical and virtual platforms in today's world that are available to the designers and can aid them in making the effective decisions even from its initial stage. The awareness of design problems early in design process greatly influence the succeeding aspects in the later stages that include manufacturing, costing, market placement and so forth, while at the same time reduces the unnecessary reiterations. These are the fundamental keys in achieving the successful design project, since the whole design process could be more proficient and seamless, as agreed by the earlier scholars who mentioned about the product design principles [329] [330][331].

This study does acknowledge and espouse this evidence into the research. That being said, the present study mostly follows other design principle that is akin, namely UCD since the study goal meets its recommended guidelines. The first and foremost criterion of UCD is placing the actual users in the core of design process [1]. But then again, this is where the biggest challenge of this design project emerges. This matter has been disclosed in the earlier chapter, to be precise during the discussion on criteria and limitations of UCD (Chapter Five: 5.3.1). Even in that subsection, the issues and restrictions encountered during the assessment were highlighted more, but the fundamental challenge remains, which concerns the participants or the target population of the study.

Firstly, the studies on the people with dementia or those with the deterioration of cognitive domain in general, are too often being administered by the scholars in pharmaceutical and its correlated backgrounds most of the time. Nevertheless, the founded approach the study proposed is perceptibly peculiar towards this area of research. With that said, it concurrently triggered off the primary conflicts or struggles the study had to run into, since the topic is seemingly out of the norm for the researcher as industrial designer.

Due to this reason, the study needed to borrow many of the contributive facts from the health-related fields, mainly regarding the statistics, methodologies and even the previous interventions to complete the present study. However, looking on the bright side, this challenge is apparently reversible for its own unique advantage. Conducting a study on the similar topic by different fields may result in providing the alternative and equally significant finding but with different perspective. Also, it is in some way augmented the importance to carry out /perform this study because of its inventiveness quality as well as the noticeable dearth on the topic.

The second most apparent challenge linked with investigating on this specific population is due to their known inabilities. Older adults usually will experience the gradual decreasing capabilities to communicate appropriately [163], and in rational thinking and also to remember things [332], as a biological result of ageing, sensory loss, and memory declines. However, due to the cognitive impairment, older adults with dementia manifest the declining memory and behavioural changes and ability to think clearly because of the neurons failure. Thus, the incapability to communicate, aside from the decline in verbal memory, inductive reasoning, numeric and verbal abilities became even more obvious. This causes the first-hand data gathering, mainly on the subjective and verbal assessments from these individuals, to be very formidable and almost inconceivable.

This matter can be a real challenge especially during the assessment phases, where the assessment was conducted on the actual population without any intervention. In this study, there were three main phases of assessments performed in total. Due to the aforementioned issues, the first (or preliminary assessment) was executed without the direct engagement of people with dementia. The reason being was principally due to its complex questioning structure, which required the respondents to not only rate their answers but with adequate solid reasoning. This is exactly the incapability and difficulties of people with dementia. For this purpose, the survey was answered by the individuals who mostly deal with them instead, as was revealed during the explanation of its procedure in Chapter Four.

On the contrary, the second and third assessments became slightly smoother. The tests were equipped with the functioning device prototypes that were used by the subjects as the apparatus. Even there were also subjective or qualitative measurements involved in these assessments, but in the second UT especially, the precedence was on its quantitative data and analysis with regards to the navigational performances with the device prototype. Besides, the questions asked to the subjects were not as intricate as in the first assessment. Likewise, having the prototype exceptionally helped the observations by the experimenters towards the reactions, performances and acceptability of the subjects; in addition to the whole usability aspects of the design concept. Therefore, the involvements of actual target population in these two assessments were highly plausible and appropriate.

Another related challenge is on the recruitments of participants for the assessments. The study had hard times to recruit and find the adequate number of, firstly, the respondents for the survey (preliminary assessments) and secondly, the subjects for both the UTs. What the researcher could suggest from his experience of conducting these several phases of assessments was the networking and connection with the responsible institutions or organizations. Having strong connections and established networks from the higher level (such as the national/state association of dementia), to the medium level (for instance nursing homes, therapy centers or the hospitals), and finally the individual level (like medical experts, physiologists or therapists) could smoothen the assessment processes, making it more productive, while at the same time reduced its overall time and energy tremendously.

Then again, even with the appropriate networking and connections, the other factor that adds to the problem of recruitment is probably due to the hesitation on: (1) the relevancy of the proposed project and (2) the expected level of comprehension of dementia patients and their reactions. What the study proposed in the design project is the use of alternative modality for wayfinding is rather new and unconventional for most of the people. Yet, the persons with dementia are presumed to not perceive it but they reacted well to this type of intervention. Therefore, the proposal should be accompanied with concrete justifications, grounded with sturdy facts from the existing achievements on similar interventions and promising expected outcomes for the target population. This way, the prospective institutions could be more interested to collaborate in the project proposed.

On a different standpoint, the external challenges the researcher faced in completing the study are the time and resources factors. These are the common disputes experienced by most of the researches. The research process was expected to flow effectively and steadily, to meet the limited time allowance so that the allocated financial support could be well-organized and utilized. But, keeping the productive-yet-constant research momentum was not an easy task, since the study also dealt with human factor. Therefore, acquiring the excellent strategies with the alternate provisions along the duration of the study could help to systematize the research progress and maintain the flow. In Table 7.1, the challenges/issues and the possible solutions for both of the design project and the entire study as debated earlier are summarized.

Overcoming these challenges by means of providing and following the plausible recovery plans allow the researchers to carry on with the following research conducts. For this study, the following activities founded on this reflection somehow bring the study closer to achieving the research goals. This aspect is indeed discussed in the next section, on how the aims of the study are accomplished.

Table 7.1: Summary of Challenges Emerged and the Possible Solutions

	CHALLENGE	POSSIBLE SOLUTIONS
1.	Research topic and studies on the people with cognitive impairment are greatly allied with health-related fields.	Adopt the knowledge from existing studies and propose different approach in seeking the compatible significant findings.
2.	Incompetency to adequately communicate and project solid reasoning by older adults with dementia.	Firstly, target on different group of respondents (who understand/deal with them the most) to answer the more complex questionnaire. Secondly, provide the functioning prototypes for the tests, so that observations and quantitative data can be gathered.
3.	Recruitment of the participants for the assessments.	Firstly, establish good networking and connection with the prospective institutions/organizations. Secondly, equip the proposal with solid justifications, sturdy facts from the existing achievements and the plausible beneficial outcomes.
4.	Limited time and resources.	Provide the dynamic general and specific schemes/strategies to structure the research progress and maintain the productive flow.

7.4 Achievement of the Objectives

The current study is unquestionably more than about designing and developing a product/device that is planned/calculated/premeditated to cater to the critical issues of wayfinding encountered by the target population. As highlighted several times along the thesis writing, the design project is seemly the tool or platform to either authenticate or falsify the hypotheses and research questions manifested in line with the intensive analyses of previous works. Yet, these queries could not be countered without fulfilling the objectives of this study. Necessarily, the fitting strategies should be carefully framed, so that the required activities can be well-executed afterwards.

Research objectives are important because they are apparently the bridges to answer the research questions and provide the necessary list of tasks to accomplish the overall goal. For this reason, objectives should be clearly defined and assertive, so that they can guide the identification, investigation, and measurement of several variables in a study. In a nutshell, objectives visualize what and how aims could be accomplished. This is the reason why they are stated early, in the beginning of the research conduct [333].

For the present study, the principal objective is to seek for possible ways to improve or assist the wayfinding disability of older adults with dementia by means of analyzing the interrelated causes of this specific deficit. And certainly, the study was looking at this subject matter from the view of design and technology. Hence, critical decisions on selecting the appropriate methods/strategies to achieve this main objective are unambiguous. The study has initially presented the in-depth review and analysis on the worrying impacts of the increasing number of older persons affected by this neurodegenerative disease in general, and the fact that the disability to navigate independently as one of the most obvious problems faced by them, as well as it is known to be the early indication for having the disease.

Besides, the interconnected problems under the domain of deterioration in mobility experienced by people with dementia resulted in a number of destructive connotations. It does not solely impair the spatial navigation skill, but also towards their daily life that include the poor performance of ADLs, low quality of life, poor social functioning and increasing of burden and expenditure which lead to institutionalization. On top of that, most of the dementia patients are among the elderly, but this study still stressed on the expression of 'older adults' because this study covets to associate and emphasize on the issues of cognitive and spatial skill deteriorations with the ageing factor. This is because, aside from the worsening of cognitive decline, age is a comparatively significant factor for the mobility problems. Yet, the changes of sensory faculties are also the consequences of being old, making the underlined issues even more noticeable and worth investigating.

Once the background problem had been addressed, the research moved further into the analysis of previous works that partially touched on the strategies under the keyword of wayfinding/navigation/orientation. Again, the priority was still within the scope of design and technological approach. As expected, none of the reviewed literatures focused exactly on the said issues . For this reason, the analyses were systematized into several phases and based on their relevancies. In Chapter Two, the reviews started with the existing wayfinding strategies in general, and went specifically into the related assistive technologies.

Prior theoretical analysis from deliberation of various available literatures on this theme gave the reseacher a clearer view to execute the necessary actions in the research investigation. But, another strategy was needed in accomplishing the overall goal. This was where the sub-objective delivered the task, since it was aimed to realize the plausible solution to the issues raised. From the performed reviews, the study unveiled the dearth that needed to be concentrated on and finally filled. From this point, scrutinizing deeper on the potential of haptic modality for navigation, device wearability and both in combined began. The disclosed gap from the previous works by some means initiated the exploration of the aforementioned potentials and at the same time piloted this design project proposal.

Here, the exact goal of the sub-objective, which is to conceptualize a new form of navigational assistance to assist the wayfinding of older adults with dementia, becomes even justifiable. The design project is certainly a part of the methodology of the present study. It is a medium to verify the theories founded - a tool for the series of assessments and finally the strategy to accomplish the overall goal. The project has also confirmed that the design and technology domain carry the comparable weight to overcome the issues that are often tackled by the more common field of research i.e. health-related discipline.

Having a clear defined objective is extremely crucial in order to achieve the appropriate solution to a targeted problem, since it accentuates and better schematizes the strategies and actions that the researcher needs to follow. Accomplishing the research objectives is certainly the principal criterion to produce promising results for the evidence-based practice. In some manner, the objectives of this study are fulfilled by meeting both the theoretical and practical compulsions. Therefore, this study can claim that the main objective and its sub-objectives projected as the goal of the present research have been entirely achieved.

Usually, in between the understanding of the prospective plans and the acceptance of these conducts, there are nonobservances or noncompliance of routines / actions of any study or project, and gives a perplexing time to those directly and indirectly involved. For this reason, the stakeholders, funders and decision makers who are engaged in a study should be aware of the feasible results of intervention and what the study may ultimately contribute. Essentially, there is a fair connection between the goal establishment and the contributions of research, since the subsidiary intention for achieving the goal is to contribute to the existing knowledge. The research contributions for this study are therefore demonstrated in the succeeding section.

7.5 Research Contributions

It is the truth that there is no absolute formula to succeed in fulfilling the requirement of any innovation. For this study, however, the expected outcomes of intervention could be accomplished by realizing the general and specific aims. In a broader view, it could be stated that the conducted research has bestowed the additional knowledge to the area of assistive technology and design for disability through the research goal establishment, in conformity with the design principles formerly mentioned – UCD, ID, UD and DFA. Again, this is feasible through the intervention the researcher projected in the present study.

Setting aside the mortality aspect, every one of us will get old sooner or later. Here, the tendency for older adults to experience the decline of cognitive function and finally being diagnosed with dementia are known to be relatively high. Hence, anyone of us has equal possibility of having the disease; especially those who are exposed to the risk factors of dementia are even more vulnerable. The common risk factors aside from age include the genetics make up, medical conditions, lifestyle choices and all of these in combination.

AD or dementia in general causes tremendous negative implications to someone's life and the people around them. The fact that there is no definite remedy available makes the situation even more severe. However, as previously discussed in the first chapter, even if the disease cannot be completely cured, its progressions are likely to be decelerated, both with therapeutic (pharmacologically or not) interventions and preventive approaches. This can reduce its damaging affects to the sufferers at the same time.

In view of this, the feasibility to delay the development and minimizes the consequences of dementia is imminent. Then again, the approach used is reasonably different, because first, the study is are looking at the non-pharmacological approach and secondly, the intention is more on reducing the life dependency and burden of caregiving. From the principle of assistive technology, this is indeed the key component of what it serves customarily.

Like the previous successful non-pharmacological intervention strategies, this approach in a rightful manner, may provide the beneficial outcomes compatible to the pharmaceutical method. The weakening of spatial skill or wayfinding ability as a whole, is one of the most reported, conspicuous and usual deficits in dementia cases. The present study takes the opportunity to highlight on this issue, mainly due to the noteworthy eventual impact of intervention.

This study widens the applicability of the non-drugs approach from the non-medical perspective, and at once proves its relevancy to cater to the manifested issue. Here, the leading contribution is consummated through the design project. The development of wearable haptic-feedback assistive navigation device, grounded from the performed series of assessments, offers a tool to assist the wayfinding of the target population. Although there are still handful of research works to be done to perfect both the project and the entire intervention, the current study portrays the encouraging likelihood of this exploration.

In terms of the field of interest, the study accomplished the design project schemes via the valuable strategy to augment the independence of people with dementia, aside from minimizing the habituation of intensive caregiving. The contributions are extended to not only the individuals with dementia, but also the social system. This is primarily because spatial navigation skill is interrelated with the mobility and eventually the autonomy.

Improving the ability to navigate leads to maintaining the good mobility, while simultaneously allows these persons to execute and preserve the performance of ADL independently for as long as possible. This is in some way resulted in keeping their good quality of life, an important factor of survival for those affected by this disease. However, as preceded above, even with the promising outcomes and the remarkable overall research contributions, the proposed intervention is not completely prepared to be implemented in the real life without further and deeper evidence-based studies/investigations. The presentation of this thesis ends with the reports on the recommendations for future works, in relation to the present research topic.

7.6 Recommendations

The undertaken study puts emphasis on several issues and subject matters that may be profitable for future research. There are many insufficient evidences and information where the study found deficiencies in the previous studies that have been partly featured in this thesis, but some other related matters remain lacking. Therefore, in this section, several recommendations that would encourage more researches in the related topics are being offered.

From the research perspective, the study would absolutely encourage more future works on the field of design and technology, mainly under the themes of design for disability or design for disabled people, as well as the assistive and wearable technologies. This present study highlights these research themes to provide the alternative-yet-compatible approaches to the commonly performed studies in the topics associated to elderly, disabilities, therapeutic, health and promoting wellbeing in general.

Then again, the goals of this study could not be achieved by solely taking into account the perspective of design and technology. The need to refer to the studies that stressed on the target population (elderly with dementia) and the associated subject matters from the health-related field of research was pertinent before the proposal of intervention strategy could transpire. Thus, though the study has conducted sequence of validations to authenticate this alternative approach, more evidence-based research works that could possibly blend both fields should be further promoted.

To establish these multi-disciplinary studies, the researches should embrace the knowledge and exercise the investigations from both the respected disciplines. For instance, the data on the number of physically disabled persons and the most reported daily life's circumstances would help the designers to plot the design solutions. Likewise, in this study, precisely in Chapter Two, the study has presented the profile of changes in the most important sensory faculty for wayfinding in older adults with and without dementia. This information was gathered mainly from the previous literatures in medical and neuro sciences, physiology, gerontology and so forth. Then, it was adopted by this study to propose the design project and it also may help future works in the non-medical disciplines.

In addition to this, what the study found lacking in order to promote the multi-disciplinary studies in this topic is on the factual and direct comparison between the declines of wayfinding ability due to: (1) the age and severity of dementia and (2) the sensory changes or impairments. As an example, the study has managed to find some literatures concerning how the persons' spatial skill is affected due to age and cognitive decline individually, but not combined together.

And again, there is no direct relationship that shows the graph of increasing age and dementia progression, as well as sensory changes, with the patients' wayfinding decline. The profile of sensory changes mentioned above is somewhat generic and not specifically illustrates its connection towards the level of deterioration in wayfinding. The in-depth studies that highlight the said associations, among other things, would help future researches to specify the intervention of what works in which level of cognitive impairment (or dementia stages) and to strategize the interventions for the persons with multiple impairments that combine both cognitive and sensory.

In relation with this recommendation, the study would also promote more studies that equate the navigational performances of people with cognitive impairment in both physical and virtual environment. One of the established works in this theme is by Cuhsman et al. [132], that validates the comparable navigational skills by normal elderly and those with AD in both settings. Then again, the comparison was made in the indoor environment which was known to be less complex and challenging as compared to the outdoor navigation.

This study remarkably advocates that the experiments of navigational performance to be carried out in a more controlled condition using the virtual environment. Based on the researcher's experiences conducting the tests with the dementia patients, they tended to be more reluctant and easily agitated when they were asked to begin the outdoor navigation test, not long after they were introduced to the device. But, in the virtual setting, the intervention strategies (either with the prototype or not) could be tested before they were brought outside for the actual outdoor navigation tests. In some way, when the subjects could be properly trained and mentally prepared before the outdoor tests, their caregivers would be more confident to allow these patients to participate in the tests, and the needless repetitions and time wastage could be eliminated. At the end, the whole process of developing the intervention strategy could be more effective because the undesirable distractions were being curtailed.

Finally, the evolution of the design project until its ameliorated version (as shown in the second prototype development) to where the device is at the present stage had come from a long and challenging journey. While the results of the conducted assessments are convincing, further manifestations could be exerted in order to provide more selections of wearable devices that serve the similar purpose - aiding the wayfinding. The numbers of studies that centralize on wearable device/technology are continuously growing, in line with the abundance of technological advancements available these days. However, there is still a dearth of exploration with respect to the topics that have been mentioned earlier (elderly, disabilities, therapeutic and health/wellbeing) and the integration with assistive technologies. Therefore, due to their distinctive advantages, the combination of device wearability and assistive technology aspects should be refined so that it may be employed on varied applications within the health and disability scopes.

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APPENDIX

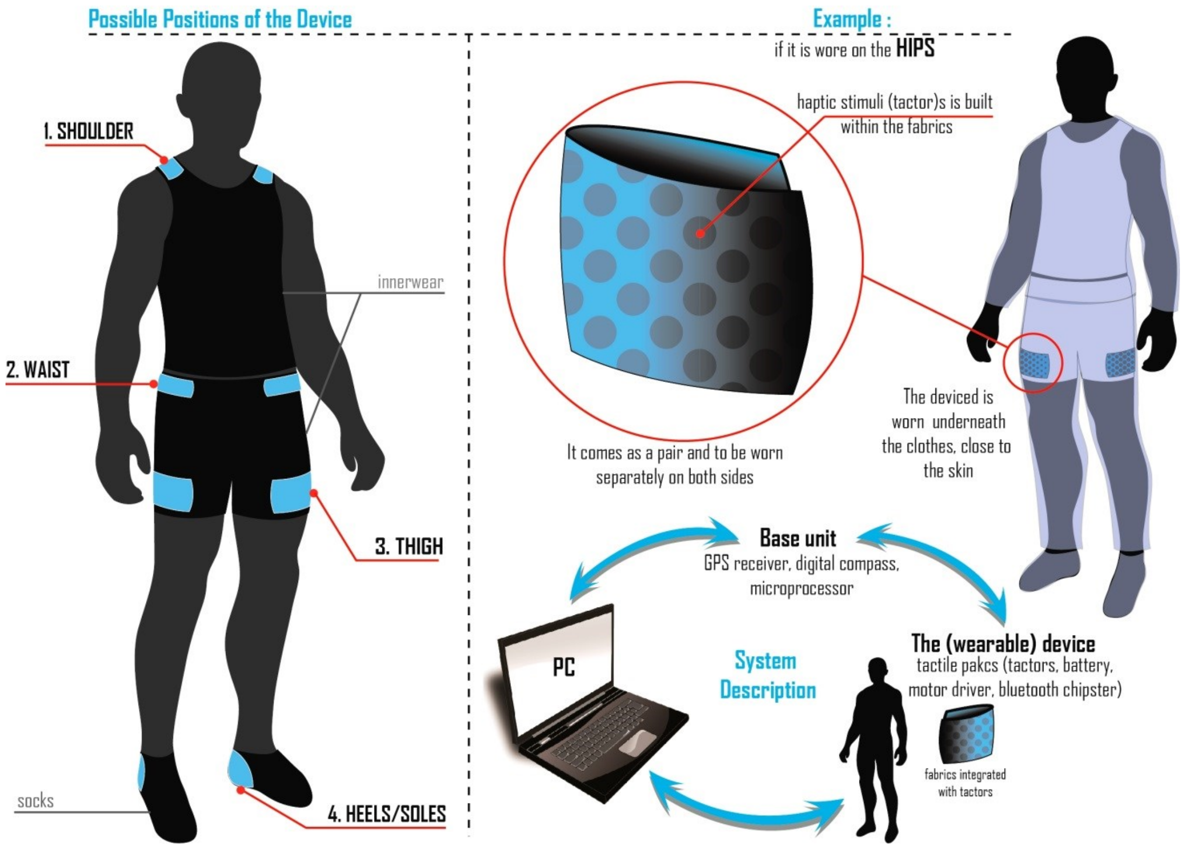
PRELIMINARY ASSESSMENT: SURVEY

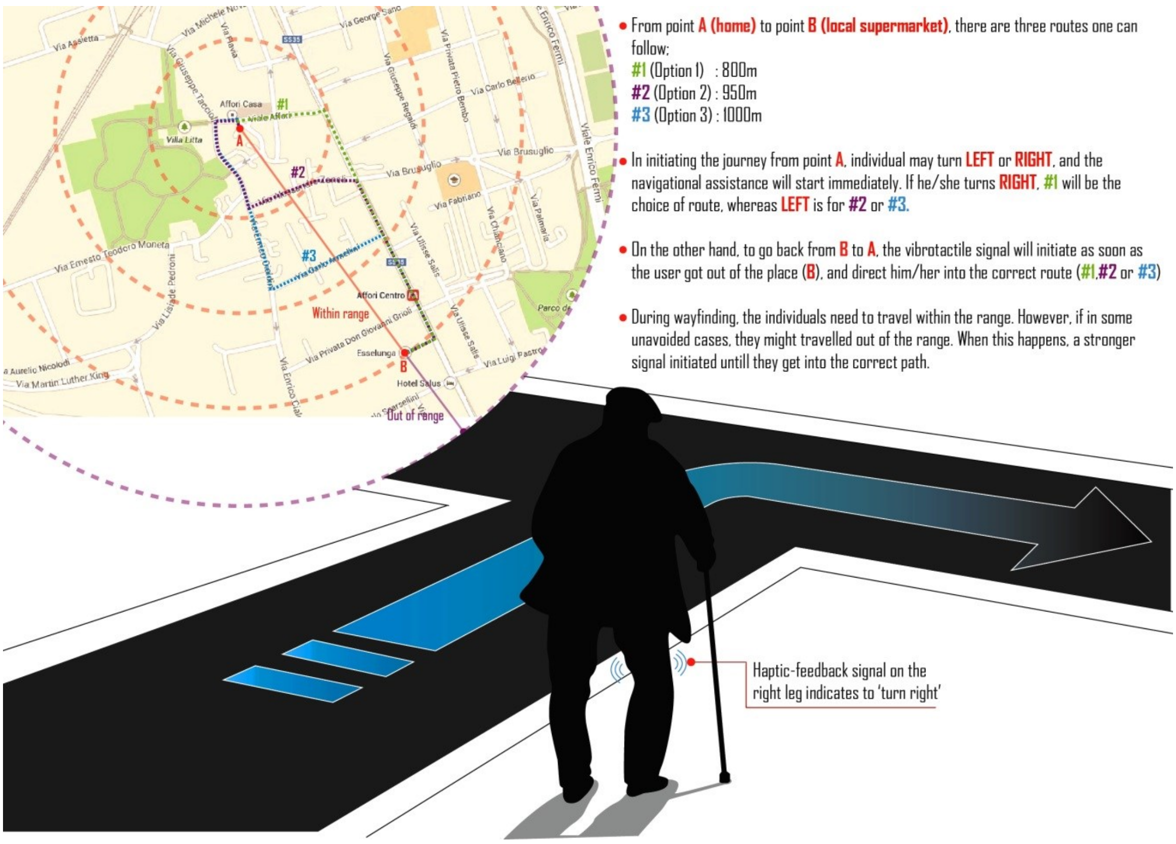
Description of Intervention

The haptic-feedback navigational tool is intended to support the wayfinding deficit in AD patients. This non-visually and non-intrusively tool uses haptic stimuli as the signals, instead of reading map or listening to speech instruction in the course of navigation. The signal given by the device provides the simplest possible information, which is to go to left or right. The uncomplicated feature is crucial as it should support the remaining abilities of the users (AD patients) and also to avoid distraction and confusion during wayfinding. For the ease and practicality of use, this tool is meant to be wearable.

The built-in haptic signal will work efficiently for the users if it directly touches their skins. Also, since this device provides the left and right inputs, it is designed to be worn as a pair on both sides of (chosen) body parts, so that they will not confuse with the signals. This is important, as even a minor interference may cause confusion to them. The concept of this navigational tool may lessen their risks being in an open space, as it permits them to keep their eyes and ears on the surroundings. With regard to this concept, since it is a new technique of wayfinding even for many of us, it requires the constant use for familiarization and therefore delivers the promising outcomes of intervention.

Design Concept: How it works





QUESTIONNAIRE

DEMOGRAPHICS OF RESPONDENTS

Name and Institution

____

____

Gender

Mark only one square.

- [ ] Male
- [ ] Female

Age

Mark only one square.

- [ ] 21 and below
- [ ] 22 to 34
- [ ] 35 to 44
- [ ] 45 to 54
- [ ] 55 to 64
- [ ] 65 and above

Highest academic qualification

Mark only one square

- [ ] Primary School
- [ ] Secondary School
- [ ] Bachelor Degree
- [ ] Master's Degree
- [ ] Doctorate
- [ ] Other:

Occupation

Mark only one square

- [ ] Professional
- [ ] Nonprofessional

What is your qualification as a respondent?

- [ ] Medical doctor/student
- [ ] Therapist
- [ ] Neurophysiologist
- [ ] AD Caregiver
- [ ] Nursing Homes Manager/Staff
- [ ] Family member/spouse of AD patient
- [ ] AD subject
- [ ] Others: ____________________

Have you been dealing with AD patients or individuals with dementia?

Yes ☐ No ☐

Do you have anyone close or related to you who have AD?

Yes ☐ No ☐ I don't know ☐

ACCEPTABILITY

Current navigational devices require the users to view a map and/or listen to speech instruction. Do you think AD subjects would use this new concept of navigation?

Mark only one square

- ☐ Most unlikely
- ☐ Unlikely
- ☐ I don't know
- ☐ Likely
- ☐ Most likely

Please add your comment to support the above answer

____

____

Since this new navigational device requires continuous use to get familiarized with its functions, would they comply and cope with it?

Mark only one square

- ☐ Most unlikely
- ☐ Unlikely
- ☐ I don't know
- ☐ Likely
- ☐ Most likely

Please add your comment to support the above answer

____

____

Do you think this new navigational device is acceptable by AD subjects?

Mark only one square

- ☐ Highly unacceptable
- ☐ Unacceptable
- ☐ Neutral
- ☐ Acceptable
- ☐ Highly acceptable

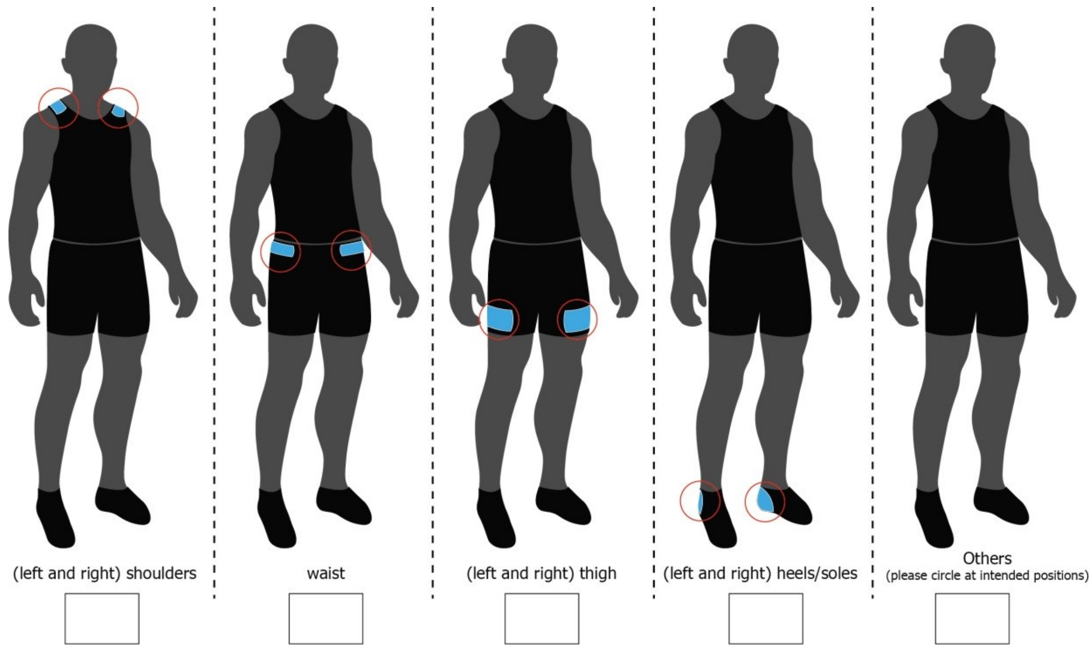
Please add your comment to support the above answer

____

____

WEARABILITY

Based on the illustration shown below, which one of these positions is the most appropriate to place the device?



Based on the above positions (and if you have your own choice), please rate them according to the suitability

Mark only one per row.

	Highly unsuitable	Unsuitable	Neutral	Suitable	Very suitable
Shoulders					
Waist					
Thighs					
Heels/soles					

Please add your comment to support the above answer

____

____

This device is meant to be wearable and may function at its best if it has the direct contact with the users' skin. What do you think if it integrates with underwear or clothes? *
(1 as very negative and 5 as very positive)

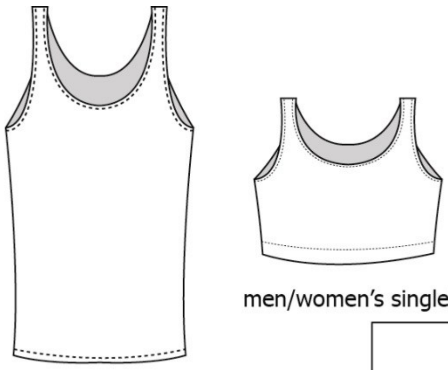
☐	☐	☐	☐	☐
1	2	3	4	5

Please add your comment to support the above answer

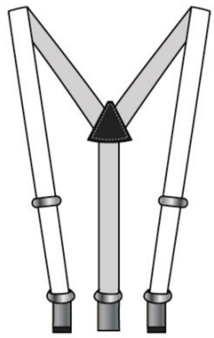
____

____

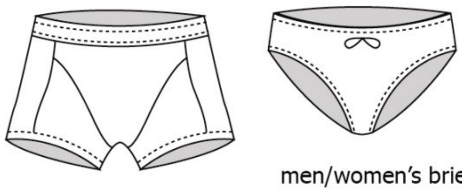
Which one of these is suitable to be integrated with the device?
(You may choose more than one answer)



men/women's singlets ☐



suspender ☐



men/women's briefs ☐

socks ☐

bra ☐

____
(please state your idea)
others ☐

Please add your comment to support the above answer

____

____

To cope with the continuous practice and as it is designed to integrate with the clothes; do you agree if this device should be worn in long hours?
Mark only one square

☐	☐	☐	☐	☐
Strongly agree	Agree	Not sure	Disagree	Strongly disagree

Please add your comment to support the above answer

____

____

SETTING SUITABILITY

Based on its functionality, do you agree if this navigational device is designed to be used mainly in an outdoor environment?
Mark only one square

☐	☐	☐	☐	☐
Strongly agree	Agree	Not sure	Disagree	Strongly disagree

Please add your comment to support the above answer

____

____

This navigational tool could be used to facilitate AD patients to find their ways…
(You may choose more than one answer)

- ☐ Inside their homes
- ☐ Within their neighborhoods
- ☐ To use public transportations
- ☐ Inside the nursing homes
- ☐ To the nearest parks, markets, churches
- ☐ Others:____________________________

Would you recommend AD subject to travel alone with the assistance of this device?
Mark only one square (1 as very negative and 5 as very positive)

☐	☐	☐	☐	☐
1	2	3	4	5

Please add your comment to support the above answer

____

____

What is the relevance range (of distance) AD subjects should be allowed to travel with this device?

Mark only one square

- ☐ Less than 1 km
- ☐ 2 - 4 km
- ☐ 5 - 6 km
- ☐ 7 - 8 km
- ☐ 9 - 10 km
- ☐ Above 10 km
- ☐ Other: _____________

Please add your comment to support the above answer

____

____

Do you think this tool may also work in an indoor environment?

Mark only one square

- ☐ Yes, mainly inside the home
- ☐ Yes, mainly inside the building
- ☐ No

USABILITY

Do you think this new concept of navigation could be helpful for AD subjects in wayfinding?

Mark only one square

- ☐ Very unhelpful
- ☐ Unhelpful
- ☐ Neutral
- ☐ Helpful
- ☐ Very helpful

Please add your comment to support the above answer

____

____

Do you prefer this device to be a standalone device (without any integration with another electronic device, such as mobile phone or GPS device)?

Mark only one square

- ☐ Absolutely no

- [ ] No
- [ ] I don't know
- [ ] Yes
- [ ] Absolutely yes

Please add your comment to support the above answer

____

____

Based on its concept, the (left and right) directions are guided only by the built-in haptic stimuli. Do you need additional features, such as visual and auditory instruction?

Mark only one square

- [ ] Absolutely no
- [ ] No
- [ ] I don't know
- [ ] Yes
- [ ] Absolutely yes

Please add your comment to support the above answer

____

____

If you think you need the additional feature to be added into this device, what it would be? Please ignore this question if it is not related.

Mark only one square

- [ ] Visual instruction (similar to current mobile GPS application)
- [ ] Speech instruction (similar to current mobile GPS application)
- [ ] Both of the above speech and visual instructions
- [ ] Other:____

Please add your comment to support the above answer

____

____

How this device may be benefited by AD subjects? *

Check all that apply

- [ ] Increased mobility
- [ ] Improved wayfinding ability
- [ ] Reduced dependency
- [ ] Good performance of activities of daily living (ADLs)
- [ ] Other:____

Please add your comment to support the above answer

____

____

Do you think this device is easy to use by AD subjects? *

Mark only one square

- ☐ Absolutely no
- ☐ No
- ☐ I don't know
- ☐ Yes
- ☐ Absolutely yes

Please add your comment to support the above answer

____

____

How practical this new concept of navigation to be implemented

Mark only one square (1 as very impractical and 5 as very practical)

☐	☐	☐	☐	☐
1	2	3	4	5

Please add your comment to support the above answer

____

____

GENERAL CONCEPT

Considering the whole concept of this new navigational device, how strong do you believe it could be useful to assist the wayfinding of individuals with AD?

- ☐ Mark only one oval.
- ☐ Very negative
- ☐ Negative
- ☐ Neutral
- ☐ Positive
- ☐ Very positive

Do you agree if this device may substitute or provide an alternative for current navigational devices?
Mark only one square

☐	☐	☐	☐	☐
Strongly agree	Agree	Not sure	Disagree	Strongly disagree

Do you agree if this concept of navigational tool helps to promote active lifestyle among AD subjects?
Mark only one square

☐	☐	☐	☐	☐
Strongly agree	Agree	Not sure	Disagree	Strongly disagree

Please write down if you have any comment or recommendation on how this conceptual design can be improved.

____

____

FIRST USABILITY TEST: FIRST PROTOTYPE

DEMOGRAPHICS OF PARTICIPANTS

Participants	Name	Age	Gender	MMSE Score	MMSE Test Date
1	Nugnes Vanda	76	Female	17	16/04/2015
2	Pat Luisa	76	Female	21	17/10/2013
3	Gino	76	Male	27	02/07/2015
4	Giancarlo	81	Male	21	05/11/2013
5	Aldo	78	Male	21	02/04/2015
6	Leonetta	80	Female	20	17/07/2014
7	Anita	86	Female	23	29/10/2015
8	Rosa	80	Female	17	03/07/2014
9	Brunilde	78	Female	20	16/01/2014
10	Carla	74	Female	-	19/03/2015

ORIENTATION/ FAMILIARIZATION

Participants	Session 1		Session 2		Preferred Position
	Yes	No	Yes	No	
1	✓		✓		*Waist*
2	✓		✓		*Shoulder*
3	✓		✓		*Shoulder*
4	✓		✓		*Shoulder*
5	✓		✓		*Waist*
6	✓		✓		*Waist*
7	✓		✓		*Waist*

8	✓		✓		Waist
9	✓		✓		Waist
10	✓		✓		Shoulder
11					
12					

ROUTE: 1									
Participants	Walking Speed (m/s)	Control time (s)	Time taken to make the turns (s)						Time taken to finish the route (s)
			Turn 1	Turn 2	Turn 3	Turn 4	Turn 5	Average	
6 Waist	0.79	7.56	8.69	29.10	28.52	19.71	8.21	18.85	776.43
8 Shoulder	0.68	8.86	9.45	9.21	33.71	30.82	34.54	23.55	956.43
4 Waist	0.78	7.74	7.80	24.22	25.75	21.33	8.98	17.62	733.81
9 Waist	0.51	11.08	12.02	11.73	34.45	12.24	11.45	16.34	682.27
3 Shoulder	1.08	5.53	5.60	7.32	6.61	6.03	5.65	6.24	337.82
10 Shoulder	0.73	8.15	9.12	23.41	29.51	11.27	9.49	16.56	602.05
ROUTE: 2									
Participants	Walking Speed (m/s)	Control time (s)	Time taken to make the turns (s)						Time taken to finish the route (s)
			Turn 1	Turn 2	Turn 3	Turn 4	Turn 5	Average	
6	0.79	7.56	11.40	8.81	7.86	21.33	8.21	11.52	567.01

Waist									
8 Shoulder	0.68	8.86	8.92	27.22	26.57	9.43	9.02	16.23	797.92
4 Waist	0.78	7.74	7.90	8.71	18.65	8.92	7.89	10.41	526.07
9 Waist	0.51	11.08	11.34	25.33	12.71	11.84	12.13	14.67	647.72
3 Shoulder	1.08	5.53	5.57	8.41	5.22	6.11	5.63	6.19	321.434
10 Shoulder	0.73	8.15	8.57	21.73	10.11	9.43	9.21	11.81	512.45

FOLLOWING TEST													
Participants	Walking Speed (m/s)	Time taken to make the turns (seconds)											Time taken to finish the route (seconds)
		Turn 1	Turn 2	Turn 3	Turn 4	Turn 5	Turn 6	Turn 7	Turn 8	Turn 9	Turn 10	Average	
Leonetta Shoulder	0.79	9.06	14.84	7.58	9.72	8.40	17.72	17.40	9.54	7.69	8.01	11.00	614.71
Rosa Waist	0.68	8.98	9.60	18.90	9.56	9.64	9.65	23.69	20.77	35.21	8.90	15.49	767.47
Carla Waist	0.73	8.57	10.73	15.11	8.43	19.21	9.97	19. 57	8.62	9.12	8.16	10.88	701.14

Numero	**Hai sentito bene la vibrazione?**		**Dove senti meglio la vibrazione?**		**L'apparecchio che hai indossato è comodo?**		**Vorrei avere/ usare questo apparecchio, vorresti usarlo?**		**Quanto e'stato utile questo apparechio?**		**Avresi bisogno di un po di tempo per imparare (a usarlo)?**		**Se lo usassi tutti i giorni saresti piu bravo?**	
6	Poco		Spalla		Poco		Poco		Poco		Poco		Poco	
	Un po		Vita	✓	Un po		Un po	✓	Un po	✓	Un po		Un po	✓
	Molto	✓	Eguale		Molto	✓	Molto		Molto		Molto	✓	Molto	
	Commento:		Commento:		Commento:		Commento:		Commento:		Commento:		Commento:	
8	Poco		Spalla		Poco		Poco		Poco		Poco		Poco	
	Un po		Vita	✓	Un po		Un po	✓	Un po	✓	Un po		Un po	
	Molto	✓	Eguale		Molto	✓	Molto		Molto		Molto		Molto	
	Commento:		Commento:		Commento:		Commento:		Commento:		Commento:		Commento:	
4	Poco		Spalla	✓	Poco		Poco	✓	Poco		Poco		Poco	
	Un po	✓	Vita		Un po	✓	Un po		Un po	✓	Un po		Un po	
	Molto		Eguale		Molto		Molto		Molto		Molto	✓	Molto	✓
	Commento:		Commento:		Commento:		Commento:		Commento:		Commento:		Commento:	
9	Poco		Spalla		Poco		Poco		Poco		Poco		Poco	
	Un po	✓	Vita	✓	Un po		Un po	✓	Un po		Un po	✓	Un po	
	Molto		Eguale		Molto	✓	Molto		Molto	✓	Molto		Molto	✓
	Commento:		Commento:		Commento:		Commento:		Commento:		Commento:		Commento:	
3	Poco		Spalla	✓	Poco		Poco	✓	Poco		Poco	✓	Poco	
	Un po		Vita		Un po		Un po		Un po		Un po		Un po	

	Molto	✓	Eguale		Molto	✓	Molto		Molto	✓	Molto		Molto	✓
	Commento:		Commento:		Commento:		Commento:		Commento:		Commento:		Commento:	
10	Poco		Spalla		Poco		Poco		Poco		Poco		Poco	
	Un po		Vita	✓	Un po		Un po	✓	Un po	✓	Un po		Un po	
	Molto	✓	Eguale		Molto	✓	Molto		Molto		Molto	✓	Molto	✓
	Commento:		Commento:		Commento:		Commento:		Commento:		Commento:		Commento:	

SECOND USABILITY TEST: SECOND PROTOTYPE

PHASE 1

Participants	**Acceptance of the device**					**Reactions of the haptic stimuli**					**Understanding the meaning haptic signals**					**MMSE Score**	**Institution**
	1	*2*	*3*	*4*	*5*	*1*	*2*	*3*	*4*	*5*	*1*	*2*	*3*	*4*	*5*		
ROSSANA					X			X					X			17	Genera Onlus
FIORINA					X					X					X	20	Genera Onlus
BRUNO					X					X					X	19	Genera Onlus
ANGELA					X		X					X				14	Genera Onlus
ANTONIA					X				X						X	16	Rsa San Giuseppe
LUCIA					X					X					X	15	Rsa San Giuseppe

PHASE 2

Questions	Participants	Scale					Comments
		1	*2*	*3*	*4*	*5*	
1. Do you properly sense the vibration?	ROSSANA			X			
	FIORINA				X		
	BRUNO					X	
	ANGELA		X				
	ANTONIA				X		
	LUCIA					X	
2. Do you think the device is useful?	ROSSANA			X			
	FIORINA				X		
	BRUNO					X	
	ANGELA						*She did not properly understand the use and the meaning of the device*
	ANTONIA					X	
	LUCIA					-	*She doesn't know. She was not collaborative.*
3. Do you need more time to learn to use it?	ROSSANA					X	
	FIORINA					X	
	BRUNO					X	
	ANGELA					X	
	ANTONIA	X					
	LUCIA						*No*
4. If you are given more time to use it, will you perform better?	ROSSANA					X	
	FIORINA					X	*She asked for more time to better understand*
	BRUNO					X	

	ANGELA					X	
	ANTONIA					X	
	LUCIA						*She doesn't know. She was not collaborative*
5. Are you comfortable wearing the device?	ROSSANA					X	
	FIORINA					X	
	BRUNO					X	
	ANGELA					X	
	ANTONIA					X	
	LUCIA					X	
6. How comfortable is the device related to the material?	ROSSANA					X	
	FIORINA					X	
	BRUNO					X	
	ANGELA					X	
	ANTONIA					X	
	LUCIA					X	
7. How comfortable is the device related to the shape of the hard-case	ROSSANA				X		
	FIORINA					X	
	BRUNO					X	
	ANGELA					X	
	ANTONIA					X	
	LUCIA					X	
8. Attachment: How much do you perceive the device on the body?	ROSSANA	X					
	FIORINA	X					
	BRUNO	X					
	ANGELA	X					
	ANTONIA	X					
	LUCIA	X					

9. Movement: Do you sense if the device moving around your abdomen area?	ROSSANA	X					
	FIORINA	X					
	BRUNO	X					
	ANGELA	X					
	ANTONIA	X					
	LUCIA	X					
10. Harm: Is the hard-case device hurt your back?	ROSSANA	X					
	FIORINA	X					
	BRUNO	X					
	ANGELA	X					
	ANTONIA	X					
	LUCIA	X					*If I sit, it hurts my back*
11. Would you like to have the device and use it?	ROSSANA			X			
	FIORINA				X		
	BRUNO					X	
	ANGELA					X	*No useful answer*
	ANTONIA					X	
	LUCIA					X	