A Systematic Review of the Literature Examining the Use and Application of Robots and Artificial Intelligence for Assisted Living for Persons Living with Dementia

By

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The above review committee determined that the major paper is acceptable in form and content and that a satisfactory knowledge of the field was covered by the work submitted. A copy of the Certificate of Approval is available from the School of Graduate and Postdoctoral Studies.

Abstract

Introduction: This review aims to examine how artificial intelligence (AI) and robotic technologies can enhance quality of life (QOL) outcomes in persons living with dementia (PLD).

Methods: A systematic literature search was conducted in Medline via Ovid, ProQuest Nursing and Allied Health, and IEEE Xplore was performed in November 2020.

Results: Ten articles were found to be eligible for inclusion. To date, the most well studied application of robots and AI for improvement of QOL outcomes for PLD are robotic pets.

Discussion: The use of AI and robots for improving QOL outcomes in PLD offer promise as they are non-invasive, cost-effective, and can be deployed in a variety of clinical and community settings.

Keywords: Systematic review; dementia; artificial intelligence; robots; quality of life

Author's Declaration

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Statement of Contributions

This project has been externally peer reviewed and edited by Dr. Karima Velji.

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Glossary of Key Terms

Key Terms	Definitions	Reference
Alzheimer's Disease (AD)	AD is the most common form of dementia. AD is a set of symptoms involving memory function, cognitive thinking, and behavior. Symptoms progress overtime and get severe enough to affect the daily tasks and function.	Alzheimer's Association, 2019
Creutzfeldt-Jakob Disease (CJD) related Dementia	A rare, fatal infectious brain disorder caused by prion accumulation. There are more than 50 variations of CJD that have been identified.	Bartfay, 2016
Deep Learning	Deep learning is a form of machine learning which allows computers to understand and learn from their environment based on their experience using a hierarchy of concepts.	Kim, 2016
Dementia	Dementia is defined as the deterioration in memory, behavior, cognitive thinking, and the inability to conduct everyday basic activities. It is a chronic progressive neurological disorder. Dementia is associated with emotional and behavioral problems which also decrease the quality of life.	WHO, 2019
Frontotemporal Dementia (FD)	FD is a form of dementia which causes progressive nerve cell loss in the frontal lobe or temporal lobe of the brain. This leads to a deterioration in behavior, personality issues and difficulty in comprehending language.	Alzheimer's Association, n.d.
Lewy Bodies (LB)	LB has features of AD and PdD. LB is associated with a protein known as alpha-synuclein. An abnormal deposit of alpha-synuclein in the brain leads to problems with movement, mood, behavior and thinking.	Bartfay, 2016
Machine Learning	Machine learning involves the use of an algorithm system which identifies patterns in data.	Erickson, 2017
Parkinson's Disease related Dementia	PdD has been linked to abnormal microscopic deposits of alpha-synuclein. These deposits are known as Lewy bodies.	Bartfay, 2016
Vascular dementia (VD)	VD is the second most common form of dementia. VD is a set of symptoms that include memory loss, cognitive issues, and issues with problem solving/language. This is caused by brain damage as a result of a stroke and blocks the blood flow to the brain. When blood flow is impaired, it is possible for the blood vessels to be damaged with reduced circulation.	Mayo Clinic, 2019

List of Abbreviations

AD	Alzheimer's Disease
ADL	Activities of Daily Living
AI	Artificial Intelligence
BPSD	Behavioural and Psychological Symptoms of Dementia
CBI	Cambridge Behavioural Inventory
CDC	Centers for Disease Control and Prevention
CJD	Creutzfeldt-Jakob Disease
CSDD	Cornell Scale for Depression in Dementia
DLB	Dementia with Lewy Bodies
MARIO	Managing Active and healthy aging with the use of CaRing servIce robots
MMSE	Mini Mental State Examination
MNA	Mini Nutritional Assessment
NPI	Neuropsychiatric Inventory
PARO	Personal Robot
PdD	Parkinson's Disease related Dementia
PHAC	Public Health Agency of Canada
Pick's Disease	Frontotemporal Dementia
PLD	Persons Living with Dementia
QOL	Quality of Life
QOL-AD	Quality of Life in Alzheimer's Disease
RS-14	Resilience Scale
SPMSQ	Short Portable Mental Status Questionnaire
VD	Vascular Dementia
WHO	World Health Organization

Chapter 1. Introduction

1.1 Background and Significance

Dementia is defined as a chronic and often progressive neurological disorder that results in a progressive deterioration of mental processes. Dementia is clinically characterized by memory disorders, personality and behavioural changes, emotional and mood disturbances, and impaired cognition, concentration, judgment and/or reasoning (Bartfay & Bartfay, 2020). The cognitive decline which results from dementia exceeds the decline which is expected from normal ageing processes (WHO, 2020). Behavioural and psychological symptoms of dementia (BPSD) can be grouped in many ways. The simplest method of grouping BPSD is by behavioural and psychological symptoms. Behavioural symptoms include agitation, cursing, hoarding, physical aggression, sexual disinhibition, restlessness, shadowing, swearing, and wandering. Psychological symptoms include anxiety, delusions, depressive mood, and hallucinations (IPA, 2012). As dementia progresses it begins to interfere with functions of daily living, such as eating, dressing, bathing, paying bills, and travelling outside of one's home (Alzheimer's Association, n.d.).

There are over 100 different types of dementia, which include Alzheimer's Disease (AD), Vascular Dementia (VD), Dementia with Lewy Bodies (DLB), Parkinson's Disease related Dementia (PdD), Frontotemporal Dementia (Pick's disease), Creutzfeldt-Jakob Disease (CJD) related Dementia, and mixed or multifactorial dementias (Bartfay, 2016; Bartfay & Bartfay, 2020). AD is the most common form of dementia and contributes to 60-70% of cases worldwide (WHO, 2020). In 2019, the global prevalence of individuals affected by dementia was 47 million (Chan, 2019). It is projected that 82 million people globally will be living with dementia in 2030, and 151 million people in 2050 (Alzheimer's Disease International, 2020). In Canada, there are currently over 747,000 Canadians living with dementia (Alzheimer's Association, 2020). It is projected that from 2011 to 2031 there will be a 1.6-fold increase in prevalence, a 1.7-fold increase in deaths, and a 1.98-fold increase in the number of people living with dementia in Canada (Manuel, 2016).

The impact of dementia can be seen beyond an individual's health and has impacts socially and economically. Dementia requires a large amount of support from family, healthcare workers, professionals, and decision makers as the disorder progresses. This is often one of the largest challenges in dementia care as there are finite resources for assistance, in particular, when focusing on quality of care and life outcomes. The current global cost of dementia is estimated to be $800 billion USD per year and is predicted to increase to $2 trillion USD by 2030 (Livingston, 2017). In Canada, the annual cost of care to Canadians for those living with dementia is over $12 billion. Informal care providers for seniors living with dementia spend 11 more hours per week (26 hours total) than informal care providers for other seniors (CIHI, 2016). Additionally, 45% of those unpaid caregivers are more likely to experience distress than caregivers of other seniors (26%). Furthermore, the estimated total out-of-pocket cost for caregivers of individuals living with dementia in Canada was $1.4 billion in 2016 (CIHI, 2016). The use of medications in treating dementia is also costly as the cost to implement a dementia-treating drug into the market is $359 million (Alzheimer Society, 2020). Without effective and constant efforts in the field of dementia research, the growing burden of dementia will have severe personal, socioeconomic, and health related impacts in Canada and abroad.

1.2 A Dementia Strategy for Canada

The National Strategy for Alzheimer's Disease and Other Dementias Act was passed by Parliament in 2017 (Alzheimer's Society Canada, 2019; CAHS, 2020). This national dementia strategy is needed to provide a compelling central vision, which provides direction for mobilizing resources needed to meet the needs of the increasing number of person's living with dementia (PLD), their caregivers, and clinical staff. Caregivers for persons with dementia, in comparison to caregivers for individuals with other illnesses, were found to have greater negative health consequences such as frailty, financial constraints, and an increased risk for depression and anxiety (CAHS, 2020). It is noteworthy that primary caregivers of PLD face large financial challenges associated with caring for an individual with dementia, which are not well addressed in legislation. Such challenges include, out-of-pocket costs, lost income, and employment consequences (CAHS, 2020). In May 2018, the Federal Health Minister held a national conference in which dementia related challenges were critically examined. Opportunities were also identified, and collaborative action plans were shared to create ideas for an improved national strategy. The aim of this strategy is to bring Canada closer to "a Canada in which all people living with dementia and caregivers are valued and supported, quality of life is optimized, and dementia is prevented, well understood, and effectively treated" (Public Health Agency of Canada [PHAC], 2019).

To achieve this vision, 5 principles were outlined in order to guide governmental; non-governmental; community organizations, and other individuals' efforts in successfully implementing the pan-Canadian strategy as follows:

(i) Prioritize quality of life for both the individuals living with dementia and their caregivers;

(ii) Understand and respect diversity and create an inclusive approach;

(iii) Respect human rights, and support autonomy and dignity of individuals living with dementia;

(iv) Engage in evidence-informed decision making, and

(v) Use a results-focused approach in order to track progress (Public Health Agency of Canada [PHAC], 2019).

Based on these aforementioned principles, 3 national objectives were subsequently formulated: (i) prevent dementia; (ii) advance therapies and attempt to find a treatment or cure, and (iii) improve the quality of life (QOL) for individuals living with dementia and their caregivers (PHAC, 2019). This strategy highlights the need to focus on groups who are at a high risk of developing dementia, as well as those who are faced with barriers accessing and utilizing equitable care. The successful implementation of a national plan such as the dementia strategy for Canada, will require significant advancements in research. Advancements will be required within the field of dementia care, as well as complimentary fields. These fields include the use of artificial intelligence (AI) and assistive robotics, which shall be the focus of this systematic review of the literature and major thesis project. Accordingly, this systematic review focuses on the 3rd national strategy of improving QOL for PLD.

1.3 Robots, AI, and Dementia

The term robot refers to any machine which is automatically operated and replaces human effort (Peter, 2020). The word “robot” comes from the Czech word “robota” meaning “forced labour". It originated for use in a play titled Rossum's Universal Robots (R.U.R) written by Karel Čapek (Moravec, 2020). The field of robotics is concerned with the design and construction of these robots. Robotics and artificial intelligence (AI) are commonly perceived to be the same, however this is not the case. Robotics is concerned with the form and structure of the robot, whereas, AI refers to the ability of a computer or computer-powered robot to perform tasks that are associated with intelligence (Copeland, 2020). Simply put, robotics is the form, and AI is the function. Although intelligence is a general term in nature, AI studies and applications are primarily focused on learning, problem solving, perception, language, and reasoning. The learning component of AI is done through machine learning, where computer software that can learn autonomously is implemented (Hosch, 2020).

When working in the field of robotics there are three fundamental rules outlined by Isaac Asimov. The three laws of robotics are as follows:

(i) A robot may not injure a human being, or, through inaction, allow a human being to come to harm. (Moravec, 2020).

(ii) A robot must obey the orders given to it by human beings except where such orders would conflict with the First Law. (Moravec, 2020).

(iii) A robot must protect its own existence as long as such protection does not conflict with the First or Second Law. (Moravec, 2020).

These laws have set a standard for robot development, particularly in the field of robot intelligence and behaviour.

The use of advanced technologies such as robotics and AI have the potential to assist and enhance dementia care that is provided by clinical staff, caregivers in the community, and improve the QOL of PLD. The use of technology in dementia is not a new concept per se but has primarily been employed for diagnostic and assessment purposes (Astell, 2019). By contrast, the use of AI technologies is a much newer concept in the field of healthcare, which commonly involves the application of intelligent technological systems to understand and/or perform behaviours that are associated with human intelligence. These behaviours include inter alia deep learning, reasoning, problem solving, and planning, amongst others.

The most common focus and use of AI in dementia care today, is in the early clinical detection and diagnosis of these neurocognitive disorders. The current literature suggests that the early detection of dementia is the most critical and valuable stage in treating and preventing the disorder (Astell, 2019; Jammeh, 2018; Razavi, 2019). Research findings suggest early diagnosis results in earlier treatments, which has positive outcomes in QOL for PLD as well as decreased associated primary caregiver burden and stress.

The use and application of AI and assistive robotics for PLD has great clinical and community potential in Canada and abroad. Indeed, the current and predicted exponential growth rate of individuals with dementia globally, requires efforts beyond early detection and diagnosis. Nonetheless, there is a depth of studies to date which have critically examined the use and application of these aforementioned technologies for the management of PLD in both clinical and community settings. Accordingly, this review seeks to fill these noted gaps in the empirical literature by examining:

(i) The use of robot assistants and care providers in both clinical and community settings;

(ii) the employment of robotic pets (e.g., cats, dogs, seals) for improving QOL outcomes in clients with various forms of dementia, and

(iii) virtual applications, such as motion capture and sensory input to monitor clients for behavioural and psychological symptoms of dementia (BPSD) (e.g., aggression, agitation, hallucinations, wandering); improve client safety; predict their needs, and provide personalized care and/or interventions employing remotely based machine learning outcomes.

1.4 Quality of Life for PLD

QOL is a broad concept that includes subjective evaluations of both the positive and negative aspects of life (Centre for Disease Control and Prevention [CDC], 2018). However, there is still no definitive consensus with regards to the definition of QOL in the empirical literature. Various groups and individuals may have different ideas about what makes certain aspects positive or negative. This can create a challenge for many researchers and health care workers as they aim to improve QOL for individuals. The WHO (2020), for example, defines QOL "as an individual's perception of their position in life in the context of the culture and value systems in which they live and in relation to their goals, expectations, standards and concerns".

QOL has become the focus and objective of modern health care in Canada and globally (PHAC, 2016). Aging population trends in Canada and globally are resulting in increased prevalence of various forms of dementias. This poses a significant challenge for families, caregivers, and the health care system (Bartfay & Bartfay, 2020; PHAC, 2016 & 2020). Recognizing the importance of developing and implementing an effective strategy to address this growing health care challenge, the Federal Minister of Health through the PHAC asked the Canadian Academy of Health Sciences (CAHS) to provide an evidence-informed and authoritative assessment on the state of knowledge to help advance federal priorities under the National Strategy for Alzheimer's Disease and Other Dementias Act.

For decades researchers and health care professionals have been analyzing and measuring various QOL outcomes, and how it changes in relation to chronic noncommunicable diseases such as dementia (CAHS, 2019). There a variety of QOL scales employed by researchers in dementia care (See Table 1).

Table 1. Examples of QOL scales employed by researchers

Scale	**Strengths**	**Weaknesses**	**Reference**
Addenbrooke's cognitive examination (ACE-III) test	- Test-retest reliability (0.92) - Evaluates a broader range of cognitive functions	- Lack of sensitivity to executive dysfunction - Does not perform well on non-Alzheimer's dementias (eg, frontotemporal dementia, Parkinson's related dementia)	(Takenoshita, 2019)
Clock-drawing test	- Effective in identifying mild to moderate dementia - Quick and easy to conduct	- Lowly educated individuals may score lower due to educational effects - Less sensitive in detecting early dementia than many other tests - Clock-drawing may be affected by other cognitive dysfunctions and should not be used alone	(Palsetia, 2018)
Cornell Brown Scale for Quality of Life in Dementia (CSB)	- Interrater reliability (r = 0.90) - Internal Consistency (Cronbach's alpha = 0.81) - Incorporates caregiver and patient perspective	- Lacks sensitivity for early stage dementia - Lacks empirical evidence for validity in severe dementia - Relies on conceptualization of QOL	(Ready, 2003)
Mini-Mental State Examination (MMSE)	- Test-retest reliability (0.80-0.95)	- Lacks sensitivity to early sings of dementia	(Baek, 2016) (Simard, 1998)

	- Acceptable specificity and sensitivity for mild to moderate stages of dementia	- Difficulty assessing severely impaired patients - May provide false negatives - Does not assess executive function	
Quality of Life-Alzheimer's Disease (QoL-AD)	- Internal Consistency (Cronbach's alpha = 0.84-0.88) - Test-retest reliability (0.76 patients, 0.92 caregivers) - Quick and easy to conduct	- Relies on conceptualization of QOL	
The Neuro Psychiatric Inventory (NPI)	- Test-retest reliability (0.84 – 0.94)	- Terminology may be general and unclear at times	(Kaufer, 2000)

Although each intervention and outcome has its strengths and weaknesses, certain tests are best noted for their ability to asses various aspects of QOL for PLD. The clock drawing test has been recognized as one of the fastest and simplest methods to assess cognition while maintaining a very good sensitivity and specificity (Sheehan, 2012). The MMSE is one the most widely used scales in measuring cognition and although often seen as the gold standard, it is often employed incorrectly as a diagnostic tool (Sheehan, 2012).

Another well-known aspect of QOL for PLD is behaviour. The Neuro Psychiatric Inventory is a tool which is widely used to assess the frequency and severity of a wide range of behavioural symptoms of dementia. It has been proven to have good test-retest reliability and interrater as well as a strong correlation with other behavioural symptom scales (Velakoulis, 2007).

With regards to overall QOL for PLD, the most extensively validated and widely used scale is the QoL-AD. One of the most important features of the QoL-AD scale is that it is dementia specific, quick to administer and can be completed by either the PLD or their caretaker (Sheehan, 2012).

Depending on the stage and clinical type of dementia, the challenges faced in determining QOL can be exacerbated as PLD are often unable to communicate their thoughts, needs, feelings, and ideas as the disease progresses over time. For example, it has been reported that person's with advanced stages of dementia often revert to their primary language (mother tongue), and are therefore unable to communicate their needs to health care providers (McMurtray et al., 2009; Sanders et al., 2020; UK Alzheimer's Society, 2020). Nevertheless, there have been significant advancements in understanding QOL for PLD. The ability to perform activities of daily living (ADLs), general cognition, and physical functioning status have been identified to positively correlate with QOL outcomes. Conversely, severity (i.e., staging) of dementia, anxiety, depression have been identified to be negatively correlated with QOL (Kim, 2019). Furthermore, neuropsychiatric symptoms including behavioural and BPSD such as hallucinations, delusions, wandering, agitation, and aggression have also been identified to be negatively correlated with QOL (Kim, 2019). Current findings also suggest that factors which have a direct effect on social environmental factors and individual functioning status, have the greatest effect on QOL (Cerejeira et al., 2012; Chiu et al., 2016; Kim, 2019).

Understanding dementia progression is a key component of understanding QOL and potential interventions which may improve QOL. Several different staging tools may be used to determine an individual's dementia progression. Some of the most common clinical scales employed include 7-stage scales, a 5-stage scale, and a 3-stage scale (Dementia Care Central, 2020). The 7-stage scales that are commonly employed include the FAST scale and the Global Deterioration Scale. The 5-stage scale is known as the Clinical Dementia Rating scale (Dementia Care Central, 2020). The 3-stage scale is the easiest to comprehend of the common clinical scales employed in dementia staging and is the scale that has been adopted in this article.

1.5 Statistics and Trends

Dementia is one of the leading causes of dependency and disability amongst older individuals across the globe (WHO, 2020). The world's aging population continues to grow exponentially each year. In 2016, 8.5% of the world's population (617 million) was over the age of 65 (National Institute of Health, 2016). By 2020, 17% of the world's population was over the age of 60 (He, 2016), and by 2030 this number will be projected to reach over 44% (UN, 2015). In Canada, approximately one in six Canadians (5.8 million) are 65 years or older, and this age group is growing four times faster than the overall population (PHAC, 2016). This presents a large concern as dementia is a disease which is most commonly found in individuals over the age of 65. Somewhere in the world an individual is diagnosed with dementia every 3.2 seconds (Alzheimer's Disease International, 2020). In fact, there were over 50 million persons living with dementia worldwide in 2020 alone. Currently, 60-70% of all dementia cases are Alzheimer's Disease (WHO, 2020). Vascular dementia is the second most common type of dementia, accounting for 15-20% of all dementia cases (Wolters, 2019). Lewy Body dementia is the third most common type of dementia, accounting for 5 to 10 percent of cases (Alzheimer's Association, 2020). Lewy Body dementia is believed to be largely underdiagnosed or misdiagnosed with PdD (Kane, 2018). Mixed dementias remain a diagnostic challenge for health care professionals and their prevalence is unclear due to the difficulty involved in identifying multiple dementias (Custodio, 2017).

In Canada, there were more than 402,000 individuals aged 65 and over living with dementia (excluding Saskatchewan) (Government of Canada, 2017). There are 76,000 new cases of dementia diagnosed in Canada each year, which indicates an incidence rate of 14.3 per 1000 individuals age 65 and over (Government of Canada, 2017). Furthermore, the prevalence was found to be higher in women than men, with two-thirds of Canadians aged 65 diagnosed with dementia being women.

1.6 Economic Cost of Dementia

As discussed earlier, dementia has both significant social and economic impacts. This can be seen through costs of informal care provided by unpaid family members, social care, and direct diagnostic and healthcare services. In 2015, the global societal cost of dementia was $818 billion USD, which is 1.1% of the global gross domestic product (GDP) (WHO, 2020). The cost as a proportion of GDP was found to vary based on the income ranking of each country. It is worth noting that the cost as a proportion of GDP was found to be 0.2% in low as well as middle income countries. The costs as a proportion of GDP for high-income countries was 1.4% (WHO, 2020). The combined Canadian health care system costs, as well as out-of-pocket caregiver costs, were $10.4 billion in 2016 (Government of Canada, 2017). This figure is projected to increase to $16.6 billion by 2031(Government of Canada, 2017).

1.7 Objectives

To my knowledge, there have been no systematic reviews of the empirical or grey literature examining the use and application of assistive robots and AI for PLD. Accordingly, this review seeks to fill this noted gap and also seeks to examine how these technologies can enhance QOL outcomes in PLD and enhance client care management in both clinical and community settings.

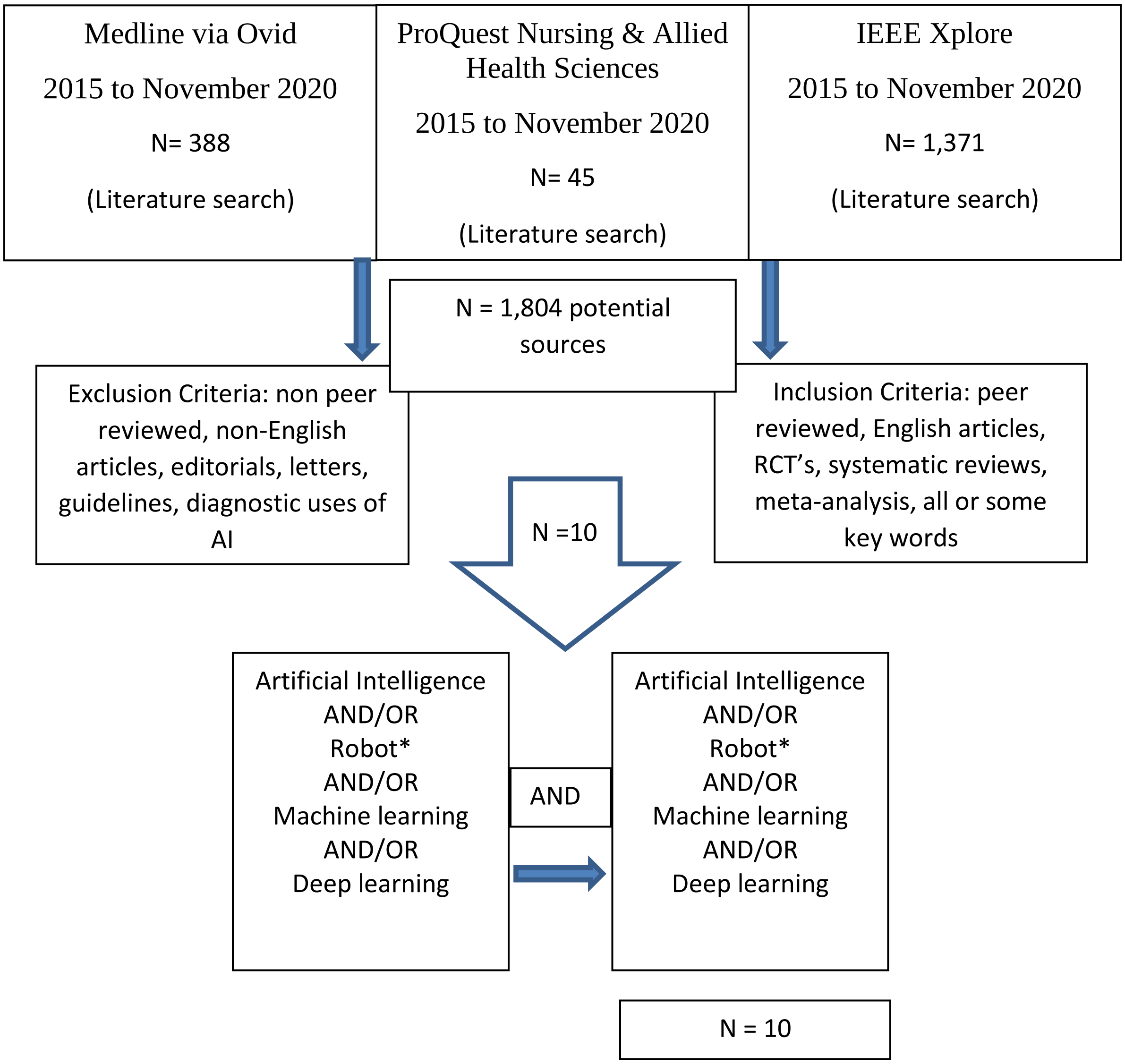
Chapter 2. Systematic Review of the Literature

2.1 Methods

A systematic review of the empirical literature was undertaken to identify articles related to the use and application of assistive robotics, AI, and dementia, employing the following 3 electronic databases: (i) Medline via Ovid; (ii) ProQuest Nursing and Allied Health, and (iii) IEEE Xplore. The search terms used in the databases include "artificial intelligence," "robot" "machine learning," "deep learning," "dementia," and "Alzheimer*". The literature search targeted articles from January 2015 until November 2020. The studies selected for the inclusion criteria consisted of peer reviewed articles and full text articles published in English only. Articles published in other languages (e.g., Russian, French, German) were excluded. The inclusion criteria also included articles which focused on the application of robots and AI for improvement of the QOL outcomes and quality of care for PLD. The grey literature was also searched for additional information on dementia, incidence and/or prevalence rates, as well as other associated statistics related to dementia care services. The websites employed for grey literature searches consisted of the World Health Organization, Alzheimer's Associations, Canadian Institute for Health Information, Centres for Disease Control, Alzheimer's Society of Canada and the Government of Canada and Minister of Health and Long-term Services (MOHLTC), Ontario. The exclusion criteria of the search strategy consisted of non-English and non-accredited or recognized agencies, affiliations, and/or reports. Editorials, letters, guidelines, client testimonials and/or reports focusing on the diagnostic applications of robots and AI within dementia care were also excluded.

Figure 1

Flow Chart of Literature Process



Titles were first examined for key word matches and identifiers. Abstracts were then reviewed and if deemed appropriate, full articles were subsequently retrieved and critically reviewed. A data extraction template was employed for consistency of approach and also to organize data. The data extraction template comprised of the Author(s) name, country of origin, design and methods, major outcomes and findings, article ranking, and implications. This data was extracted and included in the summary of major studies chart (see Appendix A). References from the primary articles located were also examined to identify potential secondary sources.

A ranking system comprised of 7 levels was employed to assess the strength of each publication retrieved. Level I is the highest rank and consists of systematic reviews of randomized control trials (RCT), and non-randomized clinical trials. Level II includes RCT's and non-randomized trials. Level III is comprised of systematic reviews of observational and/or correlational studies. Level IV consists of single observational or correlational studies. Level V includes systematic reviews of descriptive or qualitative studies. Level VI consists of a single descriptive or qualitative study. Level VII is the lowest ranking and includes expert opinions, panels, or committees (Bartfay & Bartfay, 2016).

2.2 Results

2.2.1 Sample Size

The results of the initial search can be seen in Figure 1. The screening located 1,804 potential sources of which 38 were redundant. A total of 10 articles met the inclusion criteria and were included in this review. The sample size of the studies was between 4 and 415 participants. Barret et al. examined the effects of MARIO intervention for PLD with a sample size of N = 10 (Barret, 2019). Bemelmans et al. examined the therapeutic effects of PARO using a sample size of N = 91 (Bemelmans, 2015). Gustafsson et al. examined the effectiveness of using a robotic cat for improving QOL in PLD, where N = 4 patients were included in the case study and N = 14 professional caregivers and family members were included in the interview study (Gustafsson, 2015). Hung et al. conducted a scoping review which identified and analyzed 29 papers (Hung, 2019). Kim and coworkers (2020) evaluated a sensor based deviant behaviour detection system using generated data and therefore provides no sample size for the study. D'Onofrio et al. (2019) compared pre- and post-MARIO interaction QOL for PLD using a sample size of N = 20. Leng et al. (2018) conducted a systematic review which critically analyzed and synthesized literature from 8 articles. Lv et al. (2020) examined the effectiveness and accuracy of a teleoperating robot and did not have a sample population for this study. Mervin and coworkers (2018) conducted an RCT to test PARO's cost effectiveness and effects on QOL with a sample size of N = 415. Lastly, Petersen and associates (2016) examined the viability of PARO as a tool to improve QOL for PLD using a sample size of N = 60.

2.2.2 Articles by Country

The articles included in this review all came from unique locations. 1 article was from Ireland (Barret, 2019), 1 from the Netherlands (Bemelmans, 2015), 1 from Sweden (Gustafsson, 2015), 1 from Korea (Kim, 2020), 1 from Italy (D'Onofrio, 2019), 1 from Canada (Hung, 2020), 2 from China (Leng, 2018; LV, 2020), 1 from Australia (Mervin, 2018), and 1 from the U.S.A (Petersen, 2016).

2.2.3 Study Designs

Additionally, the major types of study designs utilized by the articles included in this review have also been identified. This includes 1 qualitative article written by Hung et al. (2019) which undertook a scoping review on the benefits and barriers of PARO in care settings. Furthermore, 4 of the articles included in this review were mixed method studies (D'Onofrio, 2019; Gustafsson, 2015; Leng 2018; Petersen 2016). Five articles were identified as different types of quantitative studies (Barret, 2019; Bemelmens, 2015; Kim, 2020; Lv, 2020; Mervin, 2018). Two of these quantitative studies were quasi-experimental studies (Barret, 2019; Bemelmens, 2015). Another 2 studies were experimental studies (Kim, 2020; Lv, 2020), and 1 study was a randomized control trial (RCT) (Mervin, 2018).

2.2.4 Article Ranking

Using the Conventional evidence-based medicine (EBM) and evidence-based practice (EBP) strength ranking hierarchy for published research articles, we evaluated the strength of the articles in this review. Two Articles were ranked at level I as they were both systematic reviews of RCT's and non-randomized trials (Hung, 2019; Leng, 2018). Four articles were ranked at level II with one being an RCT (Mervin, 2018) and 3 being non-randomized trials (Bemelmans, 2015; D'Onofrio, 2019; Petersen, 2016). Four articles were single observational or correlational studies and therefore ranked at level IV (Barret, 2019; Gustafsson, 2015; Kim, 2020; Lv, 2020). No articles were ranked at level III, V, VI, or VII.

2.2.5 Summary

This chapter provided an overview of the search methods employed to conduct a systematic review of the literature, which included inter alia data bases searched, inclusion and exclusion criteria and key words employed. A total of 10 peer-reviewed articles were located and their main findings have been summarized along with the associated ranking. In the subsequent Chapter 3, we shall critically discuss the implications of these findings and implications for future research. We shall also discuss various possible clinical and community-based applications.

Chapter 3. Discussion and Conclusion

3.1 Discussion

The main objective of this systematic review of the empirical literature was to examine how these noted technologies can enhance QOL outcomes in PLD, and also identify potential applications of these technologies in clinical and community-based settings. There is a growing incidence and prevalence of PLD, which creates urgent needs for better management and QOL improvements for PLD and their families. The studies included in this review can be grouped into three distinct areas of AI and robot application for improving QOL for PLD: (i) Service robots; (ii) robotic pets, and (iii) virtual care.

3.1.1 Current Applications of AI and Robots in Dementia

These preliminary findings suggest that the use of AI and robots may have positive effects on QOL outcomes for PLD. This supposition was derived from a comprehensive systematic review of the empirical literature that was conducted (see Chapter 2). This finding is consistent with those reported in the literature. For example, the robot MARIO was shown to be capable to create significant improvements in QOL outcomes for PLD (D’Onofrio, 2019). Mario was also found to be well received by PLD and was found to help foster a level of social inclusion (D’Onofrio, 2019; Barret, 2019). MARIO may also be an effective tool for managing the stress placed on the health care system and the rising direct and indirect health care cost associated with caring for PLD (D’Onofrio, 2019). Indeed, MARIO may be an effective tool for fostering social inclusion, providing support, improving long term care management, and improving QOL for PLD (MARIO, 2015; D’Onofrio, 2019). Further research with greater sample sizes and more statistical power is warranted in order to further elucidate how MARIO could be utilized for both clinical and community-based applications.

To date, the most well studied application of robots and AI for improvement of QOL outcomes for PLD are robotic pets (Bemelmans, 2015; Petersen, 2016; Mervin, 2018; Hung, 2019; Gustafsson, 2015; Leng, 2018). Findings from the systematic review of the literature suggest that PARO improves QOL for PLD by supporting psychosocial needs and improving care experiences (Bemelmans, 2015; Petersen, 2016; Mervin, 2018; Hung, 2019). It is notable that PLD who underwent PARO-based interventions were reported to have a reduction in agitation and BPSD's and saw a decrease in behaviour medication, pain medication, anti-anxiety medication, and anti-depression medication (Petersen, 2016; Mervin, 2018). However, it is important to note that the client perspective and robot-human interaction of PARO remains largely unexplored in the current literature base (Hung, 2019). Nonetheless, the robotic pet JusttoCat's effects on QOL for PLD remain to be determined clinically. It is critical to note that the statistical power in these investigations were marginal at best, based on the limited sample sizes employed (Gustafsson, 2015). Lastly, the majority of studies reviewed were descriptive in nature, lacked clear control and/or baseline measures (e.g., BPSDs). Further prospective and preferable long-term studies are determined to further valid the clinical and community-based applications of AI and robotic technologies for PLD.

Virtual care applications are an extremely new field in dementia care which may be partially achieved via the application of robots and associated AI applications (Kim, 2020; Lv, 2020). Results from the systematic review of the literature conducted suggest that virtual dementia care has the potential to lessen the burden on the health care system by reducing the demand on care staff, as well as reducing direct and indirect (e.g., unpaid care by primary caregiver) costs of care and primary caregiver burden as well (Kim, 2020; Lv, 2020). It is interesting to note that virtual care was found to provide quality care in a faster time frame, which in turn was also shown to improve QOL outcomes for PLD (Kim, 2020; Lv, 2020). Although these preliminary findings related to virtual dementia care appear promising, future research is warranted to examine how best these new technologies can effectively be employed in both clinical and community-based settings (e.g., home care).

3.1.2 Stages of Dementia

As described earlier in Chapter 1, this systematic review of the literature adopted a 3-stage dementia scale consisting of (i) early; (ii) middle, and (iii) late stage dementia. Various treatments and tools for improving QOL in PLD may depend upon the stage of dementia and also personal preferences by the patient and ease of comfort and willingness of primary care providers to adopt these noted technologies also (Alzheimer’s Association, 2020; Logsdon, 2007). Indeed, the effectiveness of noted treatments and/or interventions are often effected by the stage of dementia for the targeted client (Logsdon, 2007). Clinical staging of the various forms of dementia can be difficult and unclear as presenting clinical signs and symptoms for the various stages often overlap (Alzheimer’s Association, 2020).

In fact, only 3 out-of-10 articles included in this systemic review of the empirical literature actually provided data as to the stage of dementia for their sample population (Barret, 2019; Bemelmans, 2015; Gustafsson, 2015). Barret and coworkers (2019), for example, examined MARIO’s effects on early and middle stage dementia; whereas Bemelmans et al., (2015) focused on the therapeutic effectiveness of PARO on middle and late stage clients with dementia (Bemelmans, 2015). Lastly, Gustafsson et al., examined the effects of JusttoCat on late stage clients with dementia (Gustafsson, 2015). Hence, drawing direct comparisons between these various studies becomes problematic due to the lack of staging information and/or different types of sample staging populations utilized. This creates a noted gap in the empirical literature as the effectiveness of each intervention has not been explored to its full potential. Furthermore, without this information it is rather difficult to determine which intervention and/or technology is best for each of stage and type of dementia. Based on the limited data surrounding AI and robot effectiveness in each stage, a conclusion cannot be drawn until further research with an emphasis on effects as per dementia staging is conducted. Moreover, there is a need to develop a theoretical basis for the application of these noted technologies and empirically evaluate them in a variety of settings, clinical stages of dementia, and settings. Indeed, it is anticipated that the use of affordable and low-cost AI and robotic technologies may be deployed in a variety of settings including hospitals, day clinics for dementia care, and home-based community settings. For example, the cost of the AI robot "Little Sophia" by Hansen Robotics in Hong Kong is approximately $200 (USD) (Hanson Robotics, 2021).

3.1.3 Major limitations in the Literature

I wish to acknowledge that the studies included in my systematic review have several limitations and challenges. As noted previously, the literature often failed to acknowledge what clinical stage and specific type of dementia were being included in the reviewed studies. This made it difficult to identify the potential effectiveness of these technologically based interventions (Logsdon, 2007). Indeed, there are over 100 different forms of dementia (Bartfay & Bartfay, 2019). Hence, clients living with Alzheimer's disease may respond differently to an robotic and/or AI -based intervention than those living with frontotemporal, vascular or Parkinson-related dementias to name but a few. There was also a noted lack of baseline measures in these reviewed investigations (e.g., pre and post-test BPSD) and/or use of control groups to validate the effectiveness of technology-based interventions for PLD.

Another major limitation identified was the small sample sizes employed and lack of statistical power to prevent the occurrence of type 2 errors in these investigations (Barret, 2019; Gustafsson, 2015; D'Onofrio, 2019; Leng, 2018). Hence, it is difficult to extrapolate these findings to larger target populations (e.g., clients living in dementia at home). It is also difficult to ensure a representative distribution and find significant relationships within the data based on small sample sizes (e.g., N < 10 per study). Lastly, some studies were unclear as to which setting their intervention was deployed in. For example, a long-term care nursing home located in a community versus a clinical setting. Despite these noted limitations found within the empirical literature, these preliminary finding show promise and application for AI and robotic-based technologies to manage PLD.

3.2 Conclusion

The main objective of this review was to critical examine the empirical literature for the current uses and application of AI and robotic-based technologies for the management of dementia in both clinical and community-based settings. Indeed, there is a growing prevalence of dementia in Canada and globally, which creates urgent needs for exploring new and cost-effective strategies for managing BPSD associated with various forms of dementia, and also help to maintain and/or improve QOL outcomes in clients living with dementia and their primary caregivers. The utilization of robotic and AI-based technologies appears to offer promise to fill this need. In particular, the following three distinct areas have been identified by this critical review of the literature: (i) Growth of robotic assistants as care providers in clinical and community settings; (ii) implementation of robotic pets, and (iii) virtual applications, such as motion capture and sensory input.

It is evident that many of these technologies are still in their infancy and require further research and development before they can be widely implemented into standards of care and/or clinical practice. Furthermore, aside from the varying technologies and interventions outlined within the current literature, the variation amongst intervention type, intervention frequency, and intervention administration makes it increasingly difficult to draw conclusions systematically. Findings surrounding the application of service robots in dementia care are inconclusive and contradictory. Further research incorporating stringent intervention type, frequency and administration will allow for better analysis and conclusions regarding this technology in the future. Additionally, although virtual application demonstrates great promise for the future, there are few virtual applications with little practical application at the time of writing this review. This is an area of robotic and AI-based technologies which should be carefully studied and followed in the near future using well-outlined intervention type, frequency, and measurement scales to ensure accurate and timely implementation of these technologies into dementia care. Based on the current literature, the greatest and most practical application of robots and AI in dementia care is robotic pets, in particular, PARO. This is not to say that other forms of robots and AI are not practical applications, rather they have not been studied as rigorously and applied into practical settings enough to warrant a further comparison at this point in time.

The use of AI and robots for improving QOL outcomes in PLD offer promise because they are regarded as non-invasive, non-pharmacological, and cost-effective technologies that can be deployed in a variety of clinical and community settings. Future research employing carefully designed clinical trials with control groups and large-scale prospective studies on the use of AI and robots for improving QOL in PLD are certainly warranted. These investigations should take care to include the specific clinical stage and type of dementia investigated. These studies should also aim to have a higher number of subjects to increase the statistical power and generalizability of these studies. In addition, there is a need to develop and test theories related to robots and AI-based technologies with PLD as their target population. This would allow for a more refined and faster integration of technologies into the rapidly growing realm of dementia care and management. It is argued that the future use of AI and robotic-based technologies will ultimately result in improved QOL outcomes for PLD, as evidenced by the preliminary findings of the systematic review of the literature conducted.

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Appendix A

Summary of Major Studies Located

Author(s) and Country of Origin	**Design and Methodology**	**Rank**	**Major Outcomes and Findings**	**Implications**	**Stage**
Barrett et al. 2019 Ireland	A pre-post pilot study was performed on a single group in a purposively selected nursing home. N = 10 Participants engaged with MARIO 3 times per week for 4 weeks. Quality of Life- Alzheimer's Disease (QOL-AD), Cornell Scale for Depression in Dementia (CSDD), and Multidimensional Scale of Perceived Social Support (MSPSS) questionnaires were used to collect data. The data was analyzed using non-parametric tests.	IV	This study found no notable improvements in questionnaire outcomes. This could be due to the small sample size and power of the study	MARIO has the potential to foster a social inclusiveness within PWD.	Early and middle

D'Onofrio et al. 2019 Italy	N = 20 clients were screened for eligibility based on the inclusion and exclusion criteria in the study. Neuropsychiatric symptoms, cognitive status, affective status, social aspects, and QOL-AD were assessed. A questionnaire was administered to the PWD and a questionnaire was answered by the person who supervised the trial session	II	Post-Mario interaction was found to create significant improvements in MMSE, NPI, CSDD, Quality of life, RS-14, CBI, SPMSQ, and MNA. Mario was well received by PWD and caregivers, and was found to foster a level of social inclusion MARIO is an effective tool for creating social inclusion, supporting PWD and their caregivers, and improving long-term care management	MARIO has the potential to aid the medical community and decision makers in improving the quality of care while managing the stress placed on the health care system and the rising cost of dementia care	Not specified

Bemelmans et al. 2015 Netherlands	A multicenter quasi-experimental time series ABAB study was conducted. 3 care organization in 6 different locations participated in the study with N=91 participants During the A phases the participants received standard care and were measured 5 times using the IPPA and mood scale During the B phases the participants received Paro intervention 5 times	II	The therapeutic effectiveness of Paro was found to have a strong positive effect. However, it's effect on care support was found to have no significant effect. The effectiveness of therapeutic interventions with Paro is attributed to the user-centred programming of Paro Paro was found to be perceived as an additional load by nurses and requires additional training however, it is believed that as caregivers gain experience with Paro these perceptions and feelings may change	Paro should be used an additional care tool for caregivers but not as a direct replacement for care.	Middle and late

Hung et al. 2019 Canada	This scoping review involved five stages: Conducting broad searches, refining selection criteria, reviewing search results, mapping literature, and summarizing results. Articles that reported the benefits and barriers to using PARO in care settings were searched for and identified. All relevant literature was included regardless of methodological quality.	I	PARO provides many benefits in supporting psychosocial needs and care experiences. Three gaps were highlighted within the literature: The client perspective remains unexplored The effective use and training of PARO lacks investigation There is a need to apply theory to create a better understanding of the robot-human interaction.	Future research should focus on the gaps outlined in the article in order to create a better understanding of PARO and improve its uses in dementia care.	Not specified

Mervin et al. 2018 Australia	Data was used from the described cluster-RCT which included N = 415 participants from 28 long-term care facilities. Facilities were blindly randomized into 1 of 3 groups and the PARO intervention group received individual 15-minute sessions with PARO 3 times per week. The value for money of PARO was assessed using the CMAI-SF and was particularly focused on change in agitation relative to cost. A staff member from the facilities filled out an item measure at baseline, week 10, and week 15 where the frequency of agitated behaviour was rated.	II	There was no significant difference between the study groups when comparing cost-effectiveness outcome of agitation. However, there was a noted reduction in agitation by week 10 in the PARO group and plush toy group Medication usage also did not significantly change for any of the groups, nor were there any significant differences between the groups	Paro is not a cost-effective tool in reducing agitation. A plush toy provides a slightly better value for money than PARO with regards to agitation improvement. However, Paro does create a greater reduction in agitation than the plush toy alternative.	Any diagnosis

Petersen et al. 2016 U.S.A	A randomized block design with repeated measures was used for this study. Before and after outcome measures such as Rating for Anxiety in Dementia (RAID), Cornell Scale for Depression in Dementia (CSDD), Global Deterioration Scale (GDS). Pulse rate, pulse oximetry, galvanic skin response (GSR) and medication utilization were analyzed in this study. The sample size was calculated to be N = 60 using Cohen's d.	II	PARO proved to be a viable alternative to anti-anxiety medication and anti-depression medication. It also had positive effects on pulse rate, oxygen saturation levels, GSV, RAID, CSDD, and medication use, thus indicating improved symptom control.	Robotic pet therapy provides a cost effective, modern solution to the issue with current care methods.	Not specified

Gustafsson et al. 2015 Sweden	This study used a mixed-methods approach that was divided into 2 stages. 1 was a quantitative single-case study (n=4) 2 was a qualitative interview study (n=14). Participants included individuals with dementia (N=4) for the single case stage, and professional caregivers and family members for the interview stage. Data collection included using the CMAI to measure occurrence of BPSDs and quality of life measurements using the Quality of Life in Late Stage Dementia (QUALID) scale after JusttoCat intervention. The interview stage data was collected through qualitative descriptions by the caregivers and relatives. Data analysis was performed via result plotting of CMAI and	IV	CMAI results showed no obvious trend throughout the phases. The QUALID scale showed a decrease in the mean scores thus signifying a better quality of life in all cases. It is not possible to draw any conclusions as the sample size is very limited and requires further exploration. The interview findings were congruent with other robotic pet research and found that integration of social robots was helpful for clients with BPSDs	This study has an extremely small sample size and provides minimal implications for future research.	Late

	QUALID scale for visual analysis.				
Leng et al. 2018 China	A systematic review and meta-analysis were conducted by following the PRISMA guidelines. Two electronic literature searches of 6 databases were conducted by two independent reviewers. The quality of the included studies was assessed following the Cochrane Handbook for systematic review of interventions.	I	The meta-analysis demonstrated a significant decrease in BPSD, particularly depression and agitation in those treated with PRI. There was no significant increase in the quality of life or cognitive function in clients who were treated with PRI.	Pet robots may be an extremely viable option for BPSD reduction when introduced appropriately.	Not specified

	The total number of articles included was n=8. The meta-analysis used the standardized mean difference and the mean difference where articles used the same outcome scales and included n=7 articles.				
Kim et al. 2020 Korea	Sensors were attached to 5 objects: door, window, refrigerator, drawer, and auxiliary bed. The deviant behaviour was then used to map the learning model. 2 models were then used to detect deviant behaviour: (1) uses unsupervised learning (autoencoder) and (2) uses LSTM. The collection of sensor data was in consultation with the nurses therefore, the data was generated through the pre-	IV	The model demonstrated a high level of performance. The autoencoder was able to identify normal behaviours and the LSTM model was able to create a more sophisticated set of results from the autoencoder. The single layer autoencoder performed the best out of all of the autoencoders. The more data that was collected the better trained the system	This application of deep learning in dementia care shows great promise for the future. Further research must be done in a practical setting	Not specified

	designation of the objects the sensors would be attached to and the defining of behaviours.		and therefore, the more accurate the behavioural detection.		
Lv et al. 2020 China	A motion capture suit is worn by the operator and connected via Wi-Fi to a laptop. The laptop is then connected to a robot which is controlled by the suit. The rosbag was used in order to record the real-time positioning and orientation data of the operators end coordinate system and the robot's tool central point during the experiment.	IV	The teleoperating robot had such a small deviance in trajectory that it was able to pick up a medicine bottle as well as assist an elderly woman get a cup during the demonstration.	This application has the potential to make health care resources that would otherwise be in use available while providing at home care and comfort for individuals with dementia.	Not specified

	A dynamic time warping (DTW) algorithm was then applied to the final data in order to calculate the distance between operator and robot trajectories.				

Legend: I = systematic reviews of RCT and non-randomized trials; II = RCT and non-randomized trials; III = systematic review of observational and correlational studies; IV = single observational or correlational studies; V = systematic reviews of descriptive and qualitative studies; VI = single descriptive or qualitative study; VII = expert opinions, panels, or committees