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Nursing and human-computer interaction in healthcare robots for older people: An integrative review

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ABSTRACT

Objectives: This study examined the published works related to healthcare robotics for older people using the attributes of health, nursing, and the human-computer interaction framework.
Design: An integrative literature review.
Methods: A search strategy captured 55 eligible articles from databases (CINAHL, Embase, IEEE Xplore, and PubMed) and hand-searching approaches. Bibliometric and content analyses grounded on the health and nursing attributes and human-computer interaction framework were performed using MAXQDA. Finally, results were verified using critical friend feedback by a second reviewer.
Results: Most articles were from multiple authorship, published in non-nursing journals, and originating from developed economies. They primarily focused on applying healthcare robots in practice settings, physical health, and communication tasks. Using the human-computer interaction framework, it was found that older adults frequently served as the primary users while nurses, healthcare providers, and researchers functioned as secondary users and operators. Research articles focused on the usability, functionality, and acceptability of robotic systems. At the same time, theoretical papers explored the frameworks and the value of empathy and emotion in robots, human-computer interaction and nursing models and theories supporting healthcare practice, and gerontechnology. Current robotic systems are less anthropomorphic, operated through real-time direct and supervisory inputs, and mainly equipped with visual and auditory sensors and actuators with limited capability in performing health assessments.
Conclusion: Results communicate the need for technological competency among nurses, advancements in increasing healthcare robot humanness, and the importance of conscientious efforts from an interdisciplinary research team in improving robotic system usability and utility for the care of older adults.

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What is already known about this topic?

- The rising number of older adults requires quality supportive health and nursing services.
- Fourth Industrial Revolution technologies such as robotic healthcare systems have the potential to improve and complement health and nursing care.
- Human-computer interaction is indispensable in ensuring machines' usability, like robotic systems, success, and effectiveness in target end-users.

What this paper adds?

- The integrative review revealed a robust description of the robotic systems and interactions utilized and showcased in previous literature using the components of the human-computer interaction Framework.
- There is a need for studies employing robots to improve care in non-laboratory, real-world settings using probability samples of older adults.
- Nurses need to work within an interdisciplinary team to improve further the robotic system and its usability and utility for the care of older adults.

1. Introduction

Globally, populations are aging (Partridge et al., 2018) due to the increasing life expectancy and fertility decline that produces a global demographic shift favoring older adults (Clegg & Williams, 2018). The number of people aged 60 years and above hit the 1 billion mark in 2019 (World Health Organization, 2021), with numbers expected to increase to more than double by 2050 and more than triple by 2100 (United Nations, Department of Economic and Social Affairs, 2017). These demographic trends represent challenges in advanced age-related chronic diseases and traditional models for healthcare delivery. Now more than ever, the continuous "greying" of the population requires technology-driven nursing services (Sato et al., 2020).

As the healthcare industry gradually enters the Fourth Industrial Age (also, Industry 4.0 and 4IR), the introduction of healthcare robots in health-related services for older adults represents an emerging, viable and promising intervention (Castro e Melo & Faria Araújo, 2020; Tan & Taeihagh, 2021). Industry 4.0 offers an opportunity to address complex problems, advance the health sector (Castro e Melo & Faria Araújo, 2020), and revolutionize healthcare practice (Park, 2016). This enigmatic epoch of progress is characterized by the "merging of physical, digital, and biological systems" (Schwab, 2016), introducing technologies such as robotic systems in health and nursing care settings.

Healthcare robots have long been recognized for their promising roles to complement quality supportive health and nursing services for the growing aging population (Abdi et al., 2018; Wynsberghe, 2015). These applications have been explored previously in diverse areas, such as assistive care (Broekens et al., 2009; Gasteiger et al., 2021; Simou et al., 2015), rehabilitation nursing (Fattal et al., 2020; Flandorfer, 2012; T. Tanioka, 2019), social isolation (Kidd et al., 2006; Shibata et al., 1997), education (Sá et al., 2019), and security (Metzler et al., 2016; Simou et al., 2015). The demand and value of medical and nursing care robots from Japan are estimated at 30 billion yen in 2019 and are expected to rise to 90.5 billion yen in 2026 (Nomura Research Institute, 2021). Although the increasing demand for healthcare robots may complement the way nurses deliver quality and safe patient care, these technology systems face adoption risk due to usability challenges and issues related to human-computer interaction (Clawson et al., 2015; Lazar et al., 2015).

Human-computer interaction plays a pivotal role in ensuring machines' usability, like robotic systems, and its success and effectiveness to target end-users (Gulliksen, 2017; Siek, 2018; Søgaard Neilsen & Wilson, 2019). It encompasses the subsections of user engagement, adaptation, perception, and information generation that occurs between and among the nurse, patient, and machines (Kamin et al., 2017; Oertel et al., 2020). A more specific term, human-robot interaction, is being advanced to describe the field of social robotics focusing on human perception and interaction with robots (Bartneck & Moltchanova, 2020; Henschel et al., 2020; Zou et al., 2020). In human-robot interaction, how a robotic system was built and programmed to interact with humans and the characteristics of its intended users are essential. Previous studies reported that these human-computer interaction and human-robot interaction-related factors are direct antecedents of behavioral intention for technology use and actual use behavior for both nurses (Brandsma et al., 2020) and clients (Singleton et al., 2019).

While the concept of robotics and human-computer interaction are emerging as important areas of scientific inquiry (Hochheiser & Valdez, 2020), it received scant attention from nurse scholars (Oertel et al., 2020). Although previous literature reviews provided an excellent exploration of robotics in nursing in general (e.g., Carter-Templeton et al., 2018; Maalouf et al., 2018), further studies specific to a client cohort and technology concept of interest in this emerging area in nursing are timely and necessary (Gómez Rivas et al., 2021; Kangasniemi et al., 2019). Despite the growing interest in healthcare robots in gerontology, an integrative review focusing on nursing, human-computer interaction, and older adults has not been accomplished. This review aims to occupy the gaps by examining the scientific literature on healthcare robots designed for older people. Specifically, it aspires to: (a) describe the articles based on distribution, bibliometrics, and scientometrics, (b) critically appraise the articles and identify the domains of focus related to health, nursing, and human-computer interaction, (c) analyze the research articles based on attributes of the human-computer interaction framework by Beaudouin-Lafon (1993), the taxonomy of user-healthcare robot interaction by Bzura et al. (2012), and its relevance in nursing, (d) assess theoretical articles in terms of its contribution in advancing the fields of human-computer interaction and nursing, and (e) investigate the features and morphology of healthcare robots found in the literature. A state of the science and the potential of human-computer interaction to contribute to nursing praxis, education, and research are presented.

2. Methods

The method of an integrative review was conducted to evaluate health, nursing, and human-computer interaction attributes in the robotic system for nursing care of older people from the current empirical and theoretical scholarly works. The method of Whittemore & Knafl's (2005) was adopted: (a) problem identification, (b) literature search, (c) data evaluation, (d) data analysis, and (e) presentation. In this paper, robotic systems refer to the "*actuated mechanisms programmable in two or more axes with a degree of autonomy, moving within its environment to perform intended tasks; a robot includes a control system and an interface of the control system*" (International Organization for Standardization, 2012 cited in Tanioka et al., 2017).

A health informationist assisted in developing a search strategy, and the CINAHL, Embase, IEEE Xplore, and PubMed were searched. The keywords used were robotics, robot, human-computer interaction, computer user interface, healthcare, and health to ascertain the volume of published articles about human-computer interaction and robotics in the healthcare field in general. Articles found from database searching (N = 334) with no filter were added to the online review management, Covidence. The title and abstract screening list had only 316 titles after removing duplicates (n = 18), with only 304 articles available as full text. In the full-text screening, both empirical and theoretical sources written originally in English mentioned nurse, nurses, nursing, and older adults were included (n = 47). Hand searching (Richards, 2008) was used for retrieved manuscripts to identify omissions from the search and yielded additional eight articles. During the data evaluation, the articles were assessed using a 6-scale Authority, Accuracy, Coverage, Objectivity, Date, Significance or AACODS checklist (Tyndall, 2010) for theoretical papers, and 0-100% scoring Mixed Methods Appraisal Tool or MMAT (Pluye et al., 2009) for research articles. A total of 55 articles were eligible for the integrative analysis. The PRISMA (Liberati et al., 2009) flow diagram is shown in Fig. 1.

In the data analysis of the eligible articles (n = 55), bibliometrics and scientometrics were used to quantitatively describe them based on their type (e.g., research/empirical, or non-research/theoretical), publication year, geographical origin, number of

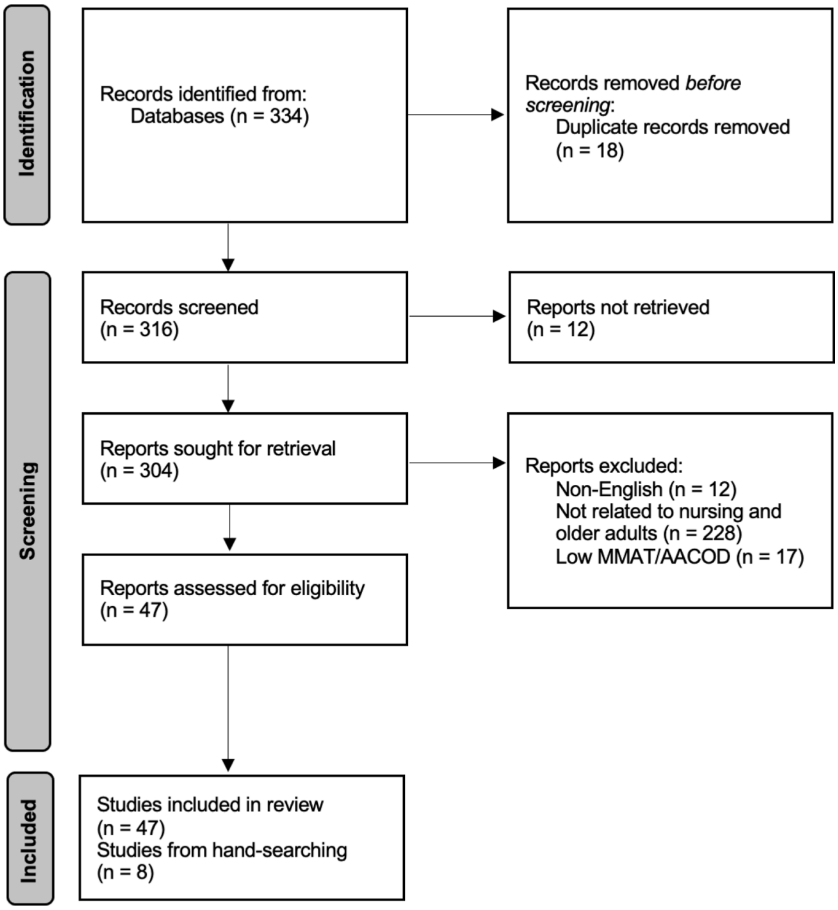

Fig. 1. PRISMA 2020 Flow Diagram

authorships, publication source (i.e., nursing, or non-nursing journal), health domain (i.e., physical, mental, social), nursing knowledge domain (i.e., practice, client, client-nurse, environment) and human-computer interaction domain (i.e., communication, physical task). Afterward, the articles were divided based on type to explore the purpose, methods, outcomes, and result implications to human-computer interaction and the nursing profession. Content analysis was performed using MAXQDA, a qualitative analysis software, to code essential features and details of the articles and extracted crucial themes guided by the literature review inquiries. Trustworthiness was evaluated using critical friend feedback by a second reviewer.

3. Results

3.1. Article Distribution, Bibliometrics, and Scientometrics

The final analysis contained 26 research articles and twenty-nine theoretical papers Table 1. indicates the dominance of articles from multiple authors (65.45%) and countries belonging to the developed Western Pacific (40%), European (34.55%) American (23.64%) regions. A preponderance of articles came from Japanese researchers (f=17; 30.91%). Notably, most of the articles (74.55%) are found in non-nursing publication sources.

3.2. Article Descriptions, Critical Appraisal, and Health, Nursing Knowledge and Human-Computer Interaction Domains

The articles were also evaluated based on critical appraisal, descriptions and health, nursing knowledge, and human-computer interaction domains of focus, as shown in Table 2. Critical appraisal of the articles using established tools (Pluye et al., 2009; Tyndall, James, 2010) revealed acceptable scores. Most of the published works are directed towards describing the technology, testing robot usability, introducing the concepts of caring and empathy, and advancing the role of nurses in the use of healthcare robotics. Data showed that healthcare robots are commonly utilized in the improvement of the clients' physical health domain (43/55 occurrences), mainly under the nursing practice theme (47/55 occurrences), and almost equal in the communication (40/55 occurrences) and physical task performance (43/55 occurrences) domains of human-computer interaction. Theoretical articles encompassed discussions of multiple health, nursing, and human-computer interaction domains per article, while research publications are primarily focused on one domain in health, nursing, and human-computer interaction.

3.3. Research Articles' Outcomes, Human-Computer Interaction, and Relevance to Nursing

Table 3 shows that most of the published research papers are quantitative-experimental (16/26; 61.53%). Only four papers (4/26; 15.38%) utilized the qualitative approach, while the remaining few adopted field-testing, descriptive-evaluative, iterative, and case study approaches. Many of the research papers investigated usability, functionality, and acceptance of the robots and were conducted in the clinical (14/26; 53.85%) and laboratory (10/26; 38.46%) settings with noticeable gaps in testing the robotic technology in natural client-home environments. All studies made use of either purposive or convenience sampling. Most of the studies (20/26; 76.92%) used multiple data gathering tools and measures (e.g., questionnaire, technical data, patient reports), while interviews are the evident tools for studies using the qualitative paradigm.

In the language of human-computer interaction, humans are classified as either primary (direct) or secondary (indirect) utilizers with distinct roles (peer, commander, operator, supervisor) (Bzura et al., 2012). Most articles involved older adults as study subjects and principal robot users, and few included the nurse and healthcare providers as primary robot users. Few (4/26; 15.38%) tested the robots using non-older adult individuals as the pilot. Researchers, for their part, served as robot operators in all laboratory-based studies. Human-computer interaction mechanisms present in the research literature are described as "active controlling

Table 1
Article Distribution

Attributes	*n*	%
Authorship		
Single	10	18.18
Double	9	16.36
Multiple	36	65.45
Type		
Research	26	47.27
Theoretical	29	52.73
Publication Source		
Nursing	14	25.45
Non-Nursing	41	74.55
Region		
America	13	23.64
European	19	34.55
Southeast Asia	1	1.82
Western Pacific	22	40.00

Note. N = 55.

Table 2
Article Bibliometric, Purpose, Critical Appraisal, Health, Nursing, Practice Area and Human-Computer Interaction Attributes

Article Bibliometrics			Critical Appraisal		Health[c]			Nursing Knowledge[d]			Human-Computer Interaction[e]		
Author(s), Year	Country, Region	Category, Type	Purpose/Outcome	Score[a,b]	*P*	*M*	*S*	*PR*	*CL*	*CN*	*EN*	*CT*	*PT*
(Matsumoto et al., 2005)	Japan, Western Pacific	Research, Quantitative	Proposed an “emotion estimation module” based on words for recognizing human emotions	60%			●	●				●	
(Koch, 2006)	Sweden, European	Theoretical, Discussion	Identified trends and new technology developments for an aging society	6	●	●		●	●		●		●
(Carignan & Krebs, 2006)	USA, America	Theoretical, Discussion	Explored current trends, technical challenges and potential solutions to remote diagnostics and treatment through rehabilitation robots	6	●			●	●	●	●		●
(Mukai et al., 2006)	Japan, Western Pacific	Research, Quantitative	Tested a soft areal tactile sensor for human-interactive robots	80%	●			●					●
(Tsai et al., 2007)	China, Western Pacific	Research, Qualitative	Described the development of a telepresence robot for interpersonal communication with the elderly in a home environment	60%			●	●				●	
(Manecke, 2007)	USA, America	Theoretical, Editorial	Introduced articles in robotics and telepresence	6	●	●	●	●	●		●	●	●
(Chung et al., 2007)	USA, America	Theoretical, Discussion	Discussed robotic telepresence in terms of history, present practice, and future directions	6	●	●	●	●	●		●	●	●
(Takacs & Hanak, 2008)	Hungary, European	Theoretical, Discussion	Introduced a prototype and initial experience with home robot to improve drug compliance	6	●			●	●		●	●	●
(Riva & Gaggioli, 2009)	Italy, European	Theoretical, Discussion	Discuss the relevance of “presence” and “interaction”, and the NeuroVR system in enhancing users’ level of experience	6	●	●	●	●	●	●	●	●	●
(Tapus, 2009)	France, European	Research, Qualitative	Showed the benefits of a robot’s physical embodiment in human-robot social interactions	80%	●			●				●	
(Vain et al., 2009)	Japan, Western Pacific	Theoretical, Discussion	Presented a new unsupervised learning algorithm of human-robot interaction for behavior planning unit of a scrub nurse robot	6	●			●					●
(Neven, 2010)	Netherlands, European	Research, Qualitative	Analyzed interactions between robots, users, and developers	80%	●			●				●	
(Moon et al., 2011)	Canada, America	Theoretical, Discussion	Presented synergies between medical robotics and multi-user virtual environments	6	●	●	●	●			●	●	●
(Wood, 2011)	USA, America	Theoretical, Discussion	Described the presence of robots in healthcare	6	●	●	●	●			●	●	●
(Huang et al., 2011)	USA, America	Theoretical, Discussion	Proposed a set of necessary functions of a caring robot and applied nursing care theory as framework for human-computer interaction	6	●	●	●	●		●		●	●
(Mori et al., 2012)	Japan, Western Pacific	Theoretical, Theory Discussion	Described the Uncanny Valley in human-robot interaction (an English translation)	6		●	●				●	●	
(Granata et al., 2013)	France, European	Research, Quantitative	Identified the usability problems of the robot interface for end-users and the human factors affecting technology use	80%		●			●			●	
(Surendran et al., 2013)	India, Southeast Asia	Research, Quantitative	Presented the design and implementation of a low cost and low power context-aware robot to assist the elderly	60%	●			●			●		●

(continued on next page)

Table 2 (*continued*)

Article Bibliometrics			Critical Appraisal		Health[c]			Nursing Knowledge[d]			Human-Computer Interaction[e]		
Author(s), Year	Country, Region	Category, Type	Purpose/Outcome	Score[a,b]	*P*	*M*	*S*	*PR*	*CL*	*CN*	*EN*	*CT*	*PT*
(Okano et al., 2013)	Japan, Western Pacific	Research, Mixed	Proposed a system (reinforcement-learning) for preventive care providing suitable exercise through game playing with robots	80%	●			●					●
(Boman & Bartfai, 2015)	Sweden, European	Research, Mixed	Evaluated usability of a mobile telepresence robot (MTR)	80%	●	●		●		●		●	●
(Sharts-Hopko, 2014)	USA, America	Theoretical, Discussion	Provided an overview of personal care robotics development	6	●		●	●			●	●	●
(Pérez et al., 2015)	Spain, European	Research, Quantitative	Designed and developed a complete robotic agent for the improvement of ADLs	60%	●	●	●	●				●	●
(Wästlund et al., 2015)	Sweden, European	Research, Qualitative	Evaluated the functionality and usability of gaze-driven powered wheelchair and its safety at the home	60%	●			●	●				●
(Whelton, 2016)	USA, America	Theoretical, Discussion	Reviewed technological changes asserting that humans will be united with machines	6	●						●		●
(Ishiguro & Majima, 2016)	Japan, Western Pacific	Theoretical, Theory Discussion	Presented a patient education model using a humanoid robot	6			●	●				●	
(Koceski & Koceska, 2016)	Macedonia, European	Research, Quantitative	Investigated the acceptance of the developed robot system	80%	●	●	●	●				●	●
(Eftring & Frennert, 2016)	Sweden, European	Research, Mixed	Provided an overview on social and assistive robot design for seniors	60%	●	●	●	●				●	●
(Czaja, 2016)	USA, America	Theoretical, Discussion	Highlighted potential role of technology in long-term care support for adults	6	●	●	●	●			●	●	●
(Lepage et al., 2016)	USA, America	Theoretical, Discussion	Presented a tele-homecare telecommunications framework for robot telepresence	6	●		●	●			●	●	●
(Arent et al., 2016)	UK, European	Research, Quantitative	Evaluated the control techniques intended for moving the ReMeDi robot	80%	●			●					●
(Zsiga et al., 2018)	Hungary, European	Research, Mixed	Tested a companion robot supporting older adults	60%	●	●	●	●				●	●
(Broadbent et al., 2013)	New Zealand, Western Pacific	Theoretical, Discussion	Delved into the psychology behind human relationship with robot	6	●	●	●	●	●	●	●	●	●
(Tanioka, 2017)	Japan, Western Pacific	Theoretical, Theory Discussion	Described the development of the Transactive Relationship Theory of Nursing (TRETON)	6	●	●	●	●	●	●	●	●	●
(Tanioka, Osaka, et al., 2017)	Japan, Western Pacific	Theoretical, Discussion	Described recommendations towards the design and development of Humanoid Nursing Robots (HNRs) from the researchers' standpoints	6	●	●	●	●	●	●	●	●	●
(Huang et al., 2017)	China, Western Pacific	Research, Quantitative	Evaluated the developed robot patient that can simulate patients for nursing students' skills development	60%	●			●					●
(Li et al., 2017)	USA, America	Research, Quantitative	Described the development and testing of a telepresence nursing robot TRINA	60%	●			●					●
(Cortellessa et al., 2018)	Italy, European	Research, Quantitative	Assessed the telepresence robot through psychophysiological evaluation	80%	●		●	●				●	●
(Dometios et al., 2018)	Italy, European	Research, Quantitative	Tested a user-adaptive online robot motion planning and interactive control	60%	●			●					●

(*continued on next page*)

Table 2 (*continued*)

Article Bibliometrics			Critical Appraisal		Health[c]			Nursing Knowledge[d]			Human-Computer Interaction[e]		
Author(s), Year	Country, Region	Category, Type	Purpose/Outcome	Score[a,b]	*P*	*M*	*S*	*PR*	*CL*	*CN*	*EN*	*CT*	*PT*
(Moyle et al., 2020)	Australia, Western Pacific	Research, Qualitative	Identified feasibility of the telepresence robot	80%			●	●		●		●	
(Kremer et al., 2019)	Germany, European	Research, Quantitative	Performed an initial testing to assess feasibility of the eye tracking as a measure of workload	60%		●				●		●	
(Tanioka, Yasuhara, et al., 2019)	Japan, Western Pacific	Theoretical, Discussion	Explored disruptive engagement with technologies, robotics, and the caring discipline	6	●	●	●	●	●	●	●	●	●
(Sato et al., 2020)	Japan, Western Pacific	Research, Qualitative	Described rehabilitation care experience with robot among older patients	80%	●	●		●				●	●
(Tanioka et al., 2020)	Japan, Western Pacific	Research, Quantitative	Evaluated changes in the autonomic system activity of elderly patients with schizophrenia	80%	●			●				●	
(Koceska et al., 2019)	Macedonia, European	Research, Quantitative	Tested the software architecture and the robot capabilities for navigation, as well as the robot manipulator.	80%	●			●				●	
(Diño & Ong, 2019)	Philippines, Western Pacific	Theoretical, Discussion	Explored fourth industrial revolution technologies in research, technology, and education	6	●	●	●	●			●	●	●
(Jensen et al., 2019)	USA, America	Theoretical, Editorial	Addressed some considerations in developing and testing robots for older adults	6	●	●	●	●			●	●	●
(King & Barry, 2019)	USA, America	Theoretical, Discussion	Proposed a guide in developing healthcare robots to illuminate caring theories and practices	6	●	●	●	●			●	●	●
(Tanioka, Smith, et al., 2019)	Japan, Western Pacific	Theoretical, Discussion	Framed the development of humanoid healthcare robots within the caring science	6	●	●	●	●			●	●	●
(Kawai et al., 2019)	Japan, Western Pacific	Theoretical, Discussion	Advanced the use of public health nurses as intermediaries for community health care using communication robots	6	●	●	●	●			●	●	●
(van der Putte et al., 2019)	Netherlands, European	Research, Quantitative	Investigated a social robot with data-collection and assessment capabilities	60%			●	●				●	
(Lanza et al., 2020)	Italy, European	Theoretical, Discussion	Proposed a multi-agent architecture for intelligent care	6	●	●	●	●			●	●	●
(Pepito et al., 2020)	Japan, Western Pacific	Theoretical, Discussion	Described the impact of artificial empathy and affective development robotics	6	●	●	●	●			●		●
(Betriana et al., 2021)	Japan, Western Pacific	Theoretical, Discussion	Reviewed Uncanny Valley Theory and its appraisal to examine relations with generating healthcare robot conversational content	6		●	●				●	●	
(Osaka, 2020)	Japan, Western Pacific	Theoretical, Theory Discussion	Described the development of the model for the intermediary role of nurses in transactive relationships with healthcare robot	6	●	●	●	●				●	●
(Tanioka et al., 2021)	Japan, Western Pacific	Research, Qualitative	Explored the developmental issues affecting healthcare robots in compassionate communication	80%	●			●				●	

Note. N = 55.

[a] Research articles scored using Pluye et al.'s (2009) Mixed Methods Appraisal tool (MMATS) in %.

[b] Theoretical articles scored using Tyndall's (2010) Authority, Accuracy, Coverage, Objectivity, Date, Significance (AACODS) in whole number.

[c] Huber et al.'s (2011) Health Domain: P = Physical; M= Mental, S= Social.

[d] Kim's (2015) Nursing Knowledge Domain: PR = Practice, CL = Client, CN = Client-Nurse, EN = Environment.

[e] Vain et al.'s (2009) Human-Computer Interaction Domain: CT = Communication Task, PT = Physical Task

Table 3
Summary of Research Articles

Author(s), Year	Research Attributes				Human-Computer Interaction			Relevance to Nursing
	Purpose/Outcome	Method	Setting	Key Findings	User Role	Robot	Interaction	
(Matsumoto et al., 2005)	Proposed an "emotion estimation module" based on words for recognizing human emotions	Experimental – prototype system was run on 50 statements from blog	Laboratory	Robot emotion occurrence events are successful when the reference sentence patterns are found in the library. There is a need to expand the emotion library.	Researcher – Operator	AIBO and ifBot -Robot equipped with emotion estimation module	Active Controlling interaction	Application of robots in practice requires consideration of potential users' individuality.
(Mukai et al., 2006)	Tested a soft areal tactile sensor for human-interactive robots	Experimental – Tactile sensor was tested for pressure sensing and frequency response	Laboratory	The sensors in the robot were able to detect centroids of a moving object	Researcher - Operator	Experimental robot with tactile sensors	Active Controlling interaction	Technologies in nursing should be safe and operational in real world settings
(Tsai et al., 2007)	Described the development of a telepresence robot for interpersonal communication with the elderly in a home environment	Experimental – Robot usability and functionality were tested on pilot users (n=7)	Laboratory	Users were able to effectively achieve navigational and visual target goals.	Client – Peer Provider - Operator	Telepresence Robot for Interpersonal Communication (TRIC)	Active Controlling interaction	Technological competency is required for nurses using telehealth devices.
(Tapus, 2009)	Showed the benefits of a robot's physical embodiment in human-robot social interactions	Experimental – Participants from a senior living facility (n=3) tested a robot and simulated robot (computer) in cognitive game activity	Clinical	Users prefer robot than a computer for the cognitive game activity	Client – Peer	Socially assistive robotics facilitating a cognitive task performance	Active Controlling interaction	Physical presence rather than simulated technology tool is more preferred by the client.
(Neven, 2010)	Analyzed interactions between robots, users, and developers	Multi-method Qualitative – Interview and observation with researchers and users	Laboratory	Older adult representations are important in user experience.	Client – Peer Researcher - Operator	iRo – robot to enhance cognitive health and later serve as an assistive technology	Active Controlling interaction	Solving negative stereotypes of older adults could help prevent resistance to health technologies.
(Granata et al., 2013)	Identified the usability problems of the robot interface for end-users and the human factors affecting technology use	Experimental, Descriptive, Usability Testing – with 22 older adults	Clinical	Interfaces and contents of the services were deemed usable by the older adult participants with cognitive impairments.	Client – Peer	Kompaï Robot with user-interafce	Active Controlling interaction	Technology usability is an important factor of intention for use among health and cognitively impaired older adults.
(Surendran et al., 2013)	Presented the design and implementation of a low cost and low power context-aware robot to assist the elderly	Experimental –Context aware robotic platform with voice recognition was designed and tested	Laboratory	The system was able to make context aware decisions based on various environments	Researcher – Operator	Context-aware robot with voice recognition	Active Controlling interaction	Technological competency is required for nurses using context-aware biomedical robotic platform.
(Okano et al., 2013)	Proposed a system (reinforcement-learning) for preventive care providing suitable exercise through game playing with robots	Experimental –Subjects (n=49) participated in a demo and answered a self-reported questionnaire related to fatigue	Clinical	The system was proven to be enjoyable and effective in encouraging users to exercise	Researcher – Operator Client – Peer	Oni, Avatar and Rival – gameplaying robots	Active Controlling interaction	Robots are potential tools for health promotion.
(Boman & Bartfai, 2015)	Evaluated usability of a mobile telepresence robot (MTR)	Mixed– Questionnaire and interview data from 38 nurses, 10 assistant nurses and 3 patients (n=51) were	Clinical	Providers and staff can support the patients in their ADLs at a distance using the MTRs	Client – Peer Provider - Operator	Mobile telepresence robot for telehealth	Active Controlling interaction	Nurses can support older people in their ADL performance using mobile telepresence robot.

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Table 3 (*continued*)

Author(s), Year	Research Attributes Purpose/Outcome	Method	Setting	Key Findings	Human-Computer Interaction User Role	Robot	Interaction	Relevance to Nursing
		analyzed after training and exposure to the MTR						
(Pérez et al., 2015)	Designed and develop a complete robotic agent for the improvement of ADLs	Experimental –Thirteen older adults answered the questionnaire after exposure to the robot	Clinical	The robot is prepared to deliver coaching for rehabilitation	Client – Peer	ALECSA robot as exercise coach	Active Controlling interaction	Robots are potential tools to improve ADLs among older adults.
(Wästlund et al., 2015)	Evaluated the functionality and usability of gaze-driven powered wheelchair and its safety at the home	Qualitative Case Study involving three adults with severe motor impairments were investigated	Clinical	Individuals with severe disabilities can obtain higher level of independence using the device.	Client - Operator	EyeGo System – gaze-driven control powered wheelchair	Active Controlling interaction	Rehabilitation program must be adapted to the clients' individual needs and using technology-enabled care are potentially motivating.
(Koceski & Koceska, 2016)	Investigated the acceptance of the developed robot system	Experimental –35 persons (caregivers and older adults) were immersed in training and activities with the telepresence robot	Clinical	Core functionalities were accepted and perceived beneficial by potential users.	Client – Peer Provider – Operator	Assistive Telepresence Robot with linear actuator	Active Controlling interaction	User acceptance is crucial in implementing technology-driven interventions.
(Eftring & Frennert, 2016)	Provided an overview on social and assistive robot design for seniors	Iterative innovation process where potential users (14 older adults) were involved in the development of the robot.	Clinical	Robots can be mentally stimulating, may reduce feelings of loneliness and may raise issues on safety.	Researcher – Operator Client – Peer Provider – Operator	HOBBIT robot intended to promote independent living among older adults	Active Controlling interaction	User-centered development and trials are necessary in implementing technologies in practice.
(Arent et al., 2016)	Evaluated the control techniques intended for moving the ReMeDi robot	Experimental – user studies were carried out involving 66 providers, assistant, and patients in manipulating the robot and assessing client perceptions	Clinical	Safety and usability were achieved and perceived the robot as safe.	Client – Peer Provider – Operator	ReMeDi system medical mobile robot	Active Controlling interaction	User-centered design process is crucial for developing health technology.
(Zsiga et al., 2018)	Tested a companion robot supporting older adults	Field tests were conducted for eight subjects who were asked to evaluate the robot services	Community	The home-deployed care robot was useful and accepted by the older adults.	Client – Peer Provider – Operator	Kompaï companion robot capable of verbal and touch screen interactions	Active Controlling interaction	Most robot functions could be used in case of mild dementia.
(Huang et al., 2017)	Evaluated the developed robot patient that can simulate patients for nursing students' skills development	Experimental – Four nursing teachers participated in the simulation experiment related to patient transfer trial.	Laboratory	Skills were carried out with 85% achievement rate. The robot can reproduce patient categories in patient transfer activities.	Provider – Peer	Robot patient that can simulate various patients for transfer training	Active Controlling interaction	Robots are potentially effective in skills training among nursing students.
(Li et al., 2017)	Described the development and testing of a telepresence nursing robot TRINA	Experimental – Twenty-six nursing tasks were performed by an experienced operator in the simulated hospital room using the telepresence nursing robot	Laboratory	The operators successfully performed 52 out of 71 subtasks at 95x times slower than direct human performance	Provider – Operator	TRINA robot version 1.0, a telenursing robot design to assist providers to perform a variety of clinical tasks	Active Controlling interaction	The use of robot is promising but 1:1 fidelity to the capabilities of the human person requires further research.
(Cortellessa et al., 2018)	Assessed the telepresence robot through	Twenty-five users (n=25) evaluated the capabilities and	Laboratory	The robot was evaluated as usable, and open-minded	Provider – Peer	ROBIN, an enhanced telepresence robot	Active Controlling interaction	Service personalization is

(*continued on next page*)

Table 3 (*continued*)

Author(s), Year	Research Attributes Purpose/Outcome	Method	Setting	Key Findings	Human-Computer Interaction User Role	Robot	Interaction	Relevance to Nursing
	psychophysiological evaluation	new communication services of the robot.		users have a more positive interaction with the robot.				important in technology-driven interventions.
(Dometios et al., 2018)	Tested a user-adaptive online robot motion planning and interactive control	Experimental – the proposed setup was tested using the robot performing a wiping task	Laboratory	The robot executes motion with good tracking performance in challenging task scenarios	Researcher - Operator	ARMAR-III performing a wiping motion task	Active Controlling interaction	Robots can assist in performing ADLs in both clinical and home environments.
(Moyle et al., 2020)	Identified feasibility of the telepresence robot	Qualitative research from semi-structured interviews involving 6 family carers	Community	Family members reported feelings of connectedness and presence when communicating with their family members through telepresence robots.	Provider – Peer	Giraff and VGo telepresence robot as communication tools	Active Controlling interaction	Robots are tools in fostering social connections between patient-provider and patient-relative.
(Kremer et al., 2019)	Performed an initial testing to assess feasibility of the eye tracking as a measure of workload	Experimental simulation with the robots with eye-tracking equipment.	Laboratory	Eye tracking as a feasible measure in assessing mental workload.	Researcher - Operator	Robot and eye tracking devices	Active Controlling interaction	The use of eye tracking is promising in robotics research.
(Sato et al., 2020)	Described rehabilitation care experience with robot among older patients	Qualitative case study involving 9 patients in geriatric health facilities.	Clinical	The robot can elicit simple and individual instructions for simple activities.	Client – Peer Provider – Operator	Pepper robot programmed to interact with patients	Active Controlling interaction	Eliciting communication and physical activities are valuable robot features for older people.
(Tanioka et al., 2020)	Evaluated changes in the autonomic system activity of elderly patients with schizophrenia	Case method analysis of a patient diagnosed with schizophrenia and hypertension.	Clinical	Using image analysis and assessment of autonomic nervous activity is essential for programming robots for physical health interventions.	Client – Peer Provider – Operator	Pepper robot programmed to facilitate a radio exercise.	Active Controlling interaction	Biosphysiologic measures are essential in understanding client response to robots.
(Koceska et al., 2019)	Tested the software architecture and the robot capabilities for navigation, as well as the robot manipulator.	Evaluation study to test the software architecture and the robot capabilities for navigation in an elderly house with 26 elderly and 5 caregivers	Clinical	The proposed paradigm significantly improved the robot's navigation and participants showed acceptance of the robot.	Client – Peer Provider – Operator	Telepresence robot for assisted and independent living	Active Controlling interaction	Robots are tools for nurses to improve healthcare and reduce social isolation among older adults.
(van der Putte et al., 2019)	Investigated a social robot with data-collection and assessment capabilities	Experimental – exploratory design involving 35 patients. Robot was used to conduct patient data collection.	Clinical	Patients and nurses found the robot reasonably acceptable for the assessment role.	Client – Peer Provider – Operator	Pepper robot with autonomous health data acquisition capabilities	Active Controlling interaction	Robots are potential tools in nursing assessment and evaluation.
(Tanioka et al., 2021)	Explored the developmental issues affecting healthcare robots in compassionate communication	Exploratory descriptive case study to examine communication between the patient (n=2) and robot	Clinical	Conversations between robot-patient showed practical usage of technologies with AI and natural language processing.	Client – Peer Provider – Operator	Pepper robot equipped with digital cameras to document communication proceedings.	Active Controlling interaction	Robots are potential communication partners of nurses for older adults.

interaction." Content and thematic analyses of the research article results revealed the prevalence of the following themes related to the practice of nursing: (a) promise and potential of robots as an effective tool for nurses in practice (promotion, rehabilitation, social connection) and training, (b) importance of "user-centered design" and usability as antecedents of robotic technology use, (c) preference of physical robots rather than simulated virtual technology among older adult users, and (d) significance of technological competency and continuing professional development of nurses.

3.4. Theoretical Articles' Outcomes and Their Relevance to Human-Computer Interaction and Nursing

Table 4 shows that most non-empirical articles included in this integrative review are theoretical-discussion papers (23/29; 79.31%) and the least theoretical-editorial type (2/29; 6.90%). Notably, four (4/29; 17.24%) are theory discussions. The purposes of the articles vary in terms of the concepts, trends, issues, and challenges explored in integrating robotic systems in the care of older people under several health, nursing, and human-computer interaction domains.

Content and thematic analyses surfaced the following relevant themes associated with human-computer interaction and relevance to nursing practice. On the one hand, human-computer interaction-related themes include: (a) classification of human-computer interaction in healthcare as physical or psychological processes, (b) importance of the "Uncanny Valley' in understanding user robot preferences and predicting robot use, (c) progressive advancement of robotics technology to include multidimensionality and other advanced features, and (d) central role of AI and natural language processing in the development of empathy, emotion, communication, and expression on robots. On the other hand, the theoretical articles' contribution to the nursing field are summarized in the following themes: (a) feasibility of home-based telerehabilitation of older adults, (b) promise and potential of robots as an effective tool for nurses, (c) inclusion of 'gerontechnology and robotics in the curricula and continuing professional development of nurses, (d) presence of nursing-focused theories and models related to the use of healthcare robots in the nursing field, and (e) importance of recognizing patient uniqueness and individuality in robot-driven nursing interventions.

3.5. Robot Features and Morphology

Using a model and taxonomy framework introduced in previous papers (Beaudouin-Lafon, 1993; Bzura et al., 2012), current and future robotic systems were explored in research and theoretical articles. Robots were summarized based on their appellations, developer, description, and morphology (Table 5 and Fig. 2). An interesting finding relates to robot system morphology. Most of the machines are architected under functional type. Fifteen (15) anthropomorphic, fourteen (14) functional, and five (5) zoomorphic robots are found in the articles included in this review. Furthermore, these robots were showcased in the conceptualized design spectrum of healthcare robots for older adults (Fig. 2).

Robots in the literature are primarily combinations of autonomous and fixed categories. Few studies showed remote-controlled machines by a healthcare provider. The articles described the current robotic systems in healthcare as mostly equipped with visual and auditory sensors and actuators. Few studies described the robots as having the features of physical actuators (e.g., "Hobbit") that allow robots to move objects physically. For example, only one machine from a study (Takacs & Hanak, 2008) can dispense chemical (drug) and elicit a chemical actuator. Several studies (e.g., Koceski & Koceska, 2016) have included sensors in their robots that can evaluate vital signs and health parameters from older adult patients.

4. Discussion

4.1. Article Distribution, Bibliometrics, and Scientometrics

Findings from the review indicate an almost equal number of articles from both research and theoretical sources demonstrating the presence of both empirical and non-empirical exploration of healthcare robots in healthcare for older adults. As the science of robotics advances in nursing, literature from various type and sources are crucial as they serve as currencies in the development of the discipline. Nursing knowledge coming from scientific studies, wisdom, and other forms of scholarship from experts altogether shape and inform the practice and future of the nursing profession (Oermann et al., 2019). In the coming of the fourth industrial age, nurses are enforced to stay informed and maintain a more anticipatory and contemporary stance towards emerging technologies to preserve their relevance in the techno-era (Archibald & Barnard, 2018).

Articles in this review were mostly products of multiple authors from high-income countries, indicating the presence of the digital divide in robotics and potential issues of access to healthcare robot resources in some territories. Evident in the research outcomes is Japanese researchers' extensive presence and influence of Japanese researchers in health robotics for older people. This finding was supported by a lot of literatures claiming Japanese leadership in the production and dissemination of "care robots" due to the country's noticeable and culturally unique "love" for robots (Wagner, 2021; Wright, 2021). Considering the Japanese advancement and advantage in healthcare robots, much must be learned from their best practices.

The digital divide in robotics has long captured the attention of support groups and continues to represent one of the major roadblocks in adopting robotic systems. This concern is evident from the recent initiatives from scholars, funders, and specialty groups to bridge the digital divide in robotics between progressive and less progressive nations (e.g., Diaz-Orueta et al., 2020). A common argument in technology use in the least developed countries is their resource capacity to acquire advanced technology systems. As previously reported, robotic projects are sometimes disrupted because of limited resources and fewer robot units to compensate for the number of clients (Miguel Cruz et al., 2017). Moore's Law, or the expected biannual rise of digital electronic production while

Table 4
Summary of Theoretical Articles

Article Attributes		Purpose/ Outcome	Relevance to Human-Computer Interaction	Relevance to Nursing
Author(s), Year	Category, Type			
(Koch, 2006)	Theoretical, Discussion	Identified trends and new technology developments for an aging society and relate them to current research	Provided recommendations for healthcare technologies: personalized, user-friendly, and context-aware interfaces that are both multi-modal and multi-lingual	Emphasized the importance of informatics and knowledge management skills to healthcare professionals
(Carignan & Krebs, 2006)	Theoretical, Discussion	Explored current trends, technical challenges and potential solutions to remote diagnostics and treatment	Introduce future trends in telerehabilitation system components, such as multidimensionality (e.g., VR, 3D displays, holography) and high-bandwidth interactive robots	Considers high-quality home-based telerehabilitation as a feasible but hazy practice of the future
(Manecke, 2007)	Theoretical, Editorial	Introduced articles in robotics and telepresence	Mentions remote telepresence and robotics caring for ICU patients equipped with mobile, audio-video, assessment, and communication capabilities	Provided an idea that robotics can decrease the required manpower in the ICU by providing robot support to healthcare providers
(Chung et al., 2007)	Theoretical, Discussion	Discussed robotic telepresence in terms of history, present practice, and future directions	Define remote telepresence as wireless mobile robotic technology with two-way audio-video communication features and its uses in clinical practice and education	Provided an example where the physicians are communicating with the nurse through a remote telepresence robot in the ICU
(Takacs & Hanak, 2008)	Theoretical, Discussion	Introduced a prototype and initial experience with home robot to improve drug compliance	Introduce a simple low-cost robot with ambient facial, RFID interface and face recognition	Introduce the idea that home robots can serve as nurses' tool to carry out routine tasks in patients' home
(Riva & Gaggioli, 2009)	Theoretical, Discussion	Discuss the relevance of "presence" and "interaction", and the NeuroVR system in enhancing users' level of experience	Emphasized the importance of "presence" for optimal experiences and empowerment using robotics and virtual reality application	Healthcare providers can provide maximum presence through VR technology by controlling the activity, virtual environment, user intention and action. This highlights the importance of technological competency among nurses.
(Vain et al., 2009)	Theoretical, Discussion	Presented a new unsupervised learning algorithm of human-robot interaction for behavior planning unit of a scrub nurse robot	Robot tasks can be deployed through passive learning algorithms and automation technologies	Routinary nurse tasks can be programmed in robots
(Moon et al., 2011)	Theoretical, Discussion	Presented synergies between medical robotics and multi-user virtual environments	Described human-computer interaction in the healthcare field as both physical (perform task) and psychological (provide expressive behaviors) processes	Robots are potential nurse tools in providing empowerment, education and accommodate patients' needs
(Wood, 2011)	Theoretical, Discussion	Described the presence of robots in healthcare	Discussed remote monitoring and introduced new terms for virtual visits: telementoring, telerounding and teleconsulting. Introduced the future plans of adding more sensing and imaging systems to surgical robots.	Continuing professional development of nurses in practice is possible through telementoring using robots.
(Huang et al., 2011)	Theoretical, Discussion	Proposed a set of necessary functions of a caring robot and applied nursing care theory as framework for human-computer interaction	Advances the importance of natural language processing and facial expression as major composites of a caring and conversational robot	Development of a caring robot requires consideration of the human being's five senses of interaction with outside environment and conversational competence.
(Mori et al., 2012)	Theoretical, Theory/Model Development	Described the Uncanny Valley in human-robot interaction (an English translation)	Robot attributes of human likeness has pattern of relationship to human affinity with robots.	Clients (nurses and patients) have sense of affinity with robots.
(Sharts-Hopko, 2014)	Theoretical, Discussion	Provided an overview of personal care robotics development	Users expressed fear for robots that appeared more human-like. Preferred robots for older adults have the following features: presence of cognitive stimulus, fall detection, automatic help call, communication and mood assessment	Potential integration of gerontechnology in the nursing curricula to address significant trends
(Whelton, 2016)	Theoretical, Discussion	Reviewed technological changes asserting that humans will be united with machines	Robots may exist as machines in human-machine units or hybrids of machines and organisms called "cyborg"	Nursing requires "global awareness". Person-centered practice is important in the global age of technology

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Table 4 (*continued*)

Article Attributes Author(s), Year	Category, Type	Purpose/ Outcome	Relevance to Human-Computer Interaction	Relevance to Nursing
(Ishiguro & Majima, 2016)	Theoretical, Theory/Model Development	Presented a patient education model using a humanoid robot	Users prefer child-like less human-like robots	Robots are potential tools for nurses in health information dissemination
(Czaja, 2016)	Theoretical, Discussion	Highlighted potential role of technology in long-term care support for adults	Developers must consider age-related changes in designing better products. Technology in long-term care services requires balance between technology and human interaction	Importance of technology access and literacy for optimal use of technology in nursing care
(Lepage et al., 2016)	Theoretical, Discussion	Presented a tele-homecare telecommunications framework for robot telepresence	Robot telepresence provides mobility to sensors and exerts physical presence at home	Competence in using telecommunication platforms is essential for nurses utilizing telehomecare
(Broadbent et al., 2013)	Theoretical, Discussion	Delved into the psychology behind human relationship with robot	Head, eye and body movement and orientation among humans are measures and indicators of engagement level with robots. Proxemics, gender, culture, and age influences robot affinity and likeability. Robots can convey and detect emotion through posture and gesture.	Physical embodiment (humans feel closer to actual robots than virtual robots) is important in nurses' relationship with artificial technologies.
(Tanioka, 2017)	Theoretical, Theory/Model Development	Described the development of the Transactive Relationship Theory of Nursing (TRETON)	Programmed HNRs with human-like emotive behaviors can convey emphatic understanding to the patients and their families.	Nursing encounters involving humans and HNRs can advance the practice of transactive engagement. Advances the Transactive Relationship Theory of Nursing (TRETON).
(Tanioka, Osaka, et al., 2017)	Theoretical, Discussion	Described recommendations towards the design and development of Humanoid Nursing Robots (HNRs) from the researchers' standpoints	High-performance speech recognition system for robots, and emotion responses are necessary to foster interaction with older adults	Considerations on nursing attributes, ethical concerns and human safety are recommended for HNR-human relationships.
(Tanioka, Yasuhara, et al., 2019)	Theoretical, Discussion	Explored disruptive engagement with technologies, robotics, and the caring discipline	Artificial intelligence and robotics are envisioned to provide transactional changes between robots and users	Caring is the core of nursing amidst technological changes and advances
(Diño & Ong, 2019)	Theoretical, Discussion	Explored fourth industrial revolution technologies in research, technology, and education	Machine learning and artificial intelligence are crucial factors predicting human-computer interaction	Nurses' engagement in continuing learning and scholarship are valuable in the fourth industrial age.
(Jensen et al., 2019)	Theoretical, Editorial	Addressed some considerations in developing and testing robots for older adults	Supported the idea that social robots might be anthropomorphic or amorphous. Anthropomorphism, animation, likeability, and perceived intelligence of robots predict usability.	There is no "one size fits all" approach in gerotechnology. Nurses must consider patient individuality.
(King & Barry, 2019)	Theoretical, Discussion	Proposed a guide in developing healthcare robots to illuminate caring theories and practices	Robots have no "knowingness", and must be developed to show compassion through silence, calming words, music, videos, or tactile stimulus.	Integrating caring concepts in robotics must include trust, mutuality, confidence, courage, and respect. "Irreplaceable" nurses are central to the integration of technology in healthcare.
(Tanioka, Smith, et al., 2019)	Theoretical, Discussion	Framed the development of humanoid healthcare robots within the caring science	Empathy (with degree and depth), as an expression of caring, must be programmed to HHRs.	Nurses must participate in knowledge development of robots, AI and empathy were caring science is the core.
(Kawai et al., 2019)	Theoretical, Discussion	Advanced the use of public health nurses as intermediaries for community health care using communication robots	Effective client-robot interaction requires (licensed) "intermediaries" (e.g., PHNs).	Nurses may function as "mediator" between patients and communication robots to promote effective robot use and prevent ethico-moral issues.
(Lanza et al., 2020)	Theoretical, Discussion	Proposed a multi-agent architecture for intelligent care	Robots can be programmed to provide more intelligent support/bridge between the healthcare provider and client rather than merely teleoperator tasks	Robots can provide more specialized supports to several nursing areas and scenarios.
(Pepito et al., 2020)	Theoretical, Discussion	Described the impact of artificial empathy and affective development robotics	Robots must possess essential features of emphatic expression to become social agents and effective human-computer interaction. Advancement in	Th willingness of clients to accept HNRs in nursing depends on their ability to interact with humans in the healthcare settings, and advancing artificial empathy is the most

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Table 4 (*continued*)

Article Attributes		Purpose/ Outcome	Relevance to Human-Computer Interaction	Relevance to Nursing
Author(s), Year	Category, Type			
			Affective Developmental Robotics (ADR) and Artificial Empathy.	important aspect. Inclusion of robotics engineering in the curricula.
(Betriana et al., 2021)	Theoretical, Discussion	Reviewed Uncanny Valley Theory and its appraisal to examine relations with generating healthcare robot conversational content	Physical, language and mobility features with natural language processing is integral to robot-human healthcare practice	Clients (nurses and patients) have sense of affinity with robots.
(Osaka, 2020)	Theoretical, Theory/Model Development	Described the development of the model for the intermediary role of nurses in transactive relationships with healthcare robot	Intermediaries are needed in scenarios using low-fidelity robots.	Nurses act as intermediaries between client and robots. Advances the Model for Intermediary Role of Nurses in Transactive Relationships with Healthcare Robots (MIRTH) model.

maintaining production requirements, as explained in various papers (e.g., Shalf, 2020), offers the promise of lower-cost machines and robots in the near future. This prediction will enable older adults from resource-challenged countries to equally benefit from robotic systems in healthcare and for scholars to participate equitably and be represented in future studies. However, technology adoption in less developed nations must also consider other non-resource-related factors to integrate and acculturate users in healthcare robotics constructively. In this case, the healthcare sector can benefit from practical, theoretical frameworks such as the Universal Theory of Acceptance and Use of Technology (Venkatesh et al., 2003), widely explored in different healthcare and resource settings.

Most articles examined are published in non-nursing journals. There seems to be an understanding that the application of robotic systems for the care of older adults is a concept that will interest nurses and the healthcare and computer engineering sectors. This finding might also imply that scientific discourse in robotic systems are inherently multidisciplinary and interdisciplinary. Successful intellectual exchange in healthcare robotics shall include the multidisciplinary members of the healthcare team and the non-health, information technology, and engineering professionals. A worthy exemplar is the Fondazione Don Carlo Gnocchi foundation from Italy. A multidisciplinary team successfully established and deployed a robotic and sensor-based rehabilitation strategy in 28 centers across the Italian territory (Jakob et al., 2018).

4.2. Article Descriptions, Critical Appraisal, and Health, Nursing Knowledge, and Human-Computer Interaction Domains

Healthcare robots in the literature were primarily used chiefly in the practice setting domain as a tool for health intervention covering mostly rehabilitation activities, physical task performance, and communication for older adult healthcare. For instance, telepresence robots are linked as an essential tool for the feasibility of home-based physical and neurological telerehabilitation among older adult clients in the near future (Carignan & Krebs, 2006; Deutsch et al., 2007; Popescu et al., 2000). Additionally, robots are crucial in promoting communication and interaction between and among the client, healthcare provider, and significant others, emphasizing nursing caring and empathy as evident in both research and theoretical sources. This networking feature of healthcare robots led to the advancement of "social robots" in the field (Flandorfer, 2012; Henschel et al., 2020; Song et al., 2021). The development of emphatic behaviors in healthcare robots is a key to realizing authentic communication (Asada, 2015), the ability of robots to interact intuitively and socially with humans (Wiese et al., 2017), and eventually serve as an instrument to provide quality nursing care (S Huang et al., 2011.).

Noticeably from the published papers, healthcare assessment was not a typical function deployed through robotics but an area with the most promising benefits. Robots were seen to potentially provide easy, objective, and quantifiable metrics in evaluating sensory, motor, and cognitive functions (Scott & Dukelow, 2011) which are routinely done in older adult cohorts. This scenario can be made possible through the advancements in machine programming, machine learning, and artificial intelligence (AI) embedded in robotic systems to carry out specific assessment tasks. The possibilities in patient assessments are endless, for it will significantly depend on the number and type of sensors and actuators attached to the robot. These advancements were expected to be featured in future articles in healthcare robots for older adults.

4.3. Research Articles' Outcomes, Human-Computer Interaction, and Relevance to Nursing

To date, most healthcare robotic systems are being tested in the laboratory, mainly involving a convenience sample of essentially healthy older adults. Before actual use among older adults, there is also a trend to pilot robotic systems for healthy and younger individuals. The pilot testing of robotic systems in the laboratory is an acceptable practice to ensure safety. Outcomes of reviewed studies may not be generalizable to the older adult population due to the non-randomized nature of the study samples. Still, the initial findings may provide a reliable groundwork to inform research methods in robotic systems. Additionally, the diversity and robustness of measures utilized and shown in the research articles reassure future robot study tools are calibrated to produce valid and reliable results. The inclusion of biophysiological measures (e.g., muscle movement, eye-tracking) is promising.

In terms of human-computer interaction, the research articles presented the older adult clients as the primary users of healthcare robots. This finding is concurrent with the expectation that robotic systems and related devices will play a unique role in the healthcare

Table 5
Robot Features and Morphology from the Literature

Robot	Organization/Developer	Description/ Hardware	Morphology	Appeared in the Article(s)	Reference
JavaTherapy System	(Reinkensmeyer et al., 2001) University of California	Unilateral rehabilitation system featuring a force-feedback joystick attached to the patient's wrist through an orthopedic splint. Force-feedback joystick, custom clip-on splint, mobile arm support, and custom support based are the mechanical components used in the system.	Functional	(Carignan & Krebs, 2006)	F1
Rutgers Master II (RMII)	(Popescu et al., 2000)	Teletherapy robotic exoskeleton worn on the inside of the patient's hand that provides resistive forces to the three fingers and the thumb through the action of pneumatic pistons. Infrared Sensors and Noncontact Hall-effect integration is one key feature of Rutgers Master II (Bouzit et al., 2002)	Functionsal	(Carignan & Krebs, 2006)	F2
vInMotion2 (MIT-Manus)	Massachusetts Institute of technology (MIT) Bionik Laboratories Corp.	Robot for interactive and cooperative bilateral rehabilitation. It also allows patients to perform reaching movements in a horizontal plane. MIT-Manus can assist and monitor arm positions of the patients. (Hidler et al., 2005)	Functional	(Carignan & Krebs, 2006)	F3
"Home robot with ambient facial features"	(Takacs & Hanak, 2008)	Simple low-cost robot with ambient facial, RFID interface, face recognition and tablet dispenser for medication compliance. This robot can also monitor the food intake of the user. Face display feature provides an assessment that is comprehensible for the elderly.	Functional	(Takacs & Hanak, 2008)	F4
NeuroVR	(Riva & Gaggioli, 2009)	Robot that provides 14 pre-designed non-threatening virtual environments for rehabilitation activities. It is offered as open-source software and a platform that enables users to access virtual environments helpful for clinical settings.	Functional	(Riva & Gaggioli, 2009)	F5
Robotic Nursing Assistant		It is a robot designed with Mecanum wheels and can turn in any direction. Its stability and security in lifting patients reduce the number of recorded injuries both from patients and employees. A Robotic Nursing Assistant can lift patients weighing 300 pounds or more.	Humanoid	(Wood, 2011)	A1
TUG Automated Robotic Delivery System	Aethon	Independent, speaking robot used to transport supplies, linens, meals, and medications to patient units or remove trash and food trays. TUG employs sensors and a built-in map to make rounds in the hospital. It is also connected with fire alarms, electronic doors, and even elevators through Wi-Fi.	Functional	(Wood, 2011)	F6
Pepper	Softbank Robotics	Known as the first emotional robot assigned to be an assistant. It is a humanoid robot with multiple capabilities (e.g., Exercise). Pepper can also understand and react to primary human emotions. The robot is up for 12 hours when continuously active, and Pepper will automatically navigate its way to the charging station when his battery level is low.	Humanoid	(K. Ishiguro & Majima, 2016) (Broadbent et al., 2013) (T. Tanioka, Yasuhara, et al., 2019) (Sato et al., 2020) (R. Tanioka et al., 2020) (van der Putte et al., 2019) (T. Tanioka et al., 2021)	A2
Alice/ "Eva"	Santa Monica Intelligent Technology Co., Ltd.	A 60 cm tall Humanoid robot with multiple capabilities. Equipped with communication skills to assist the elderly and capable of reporting to a medical staff about health records.	Humanoid	(Ishiguro & Majima, 2016.)	A3
IRL-1	(Lepage et al., 2016)	Interactive robotic testbed platform used in a research study. Designed with orientable and expressive face, 8-microphone array, grippers and two arms partnered with omnidirectional mobile platform (Michaud et al., 2010)	Humanoid	(Lepage et al., 2016)	A4

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Table 5 (*continued*)

Robot	Organization/Developer	Description/ Hardware	Morphology	Appeared in the Article(s)	Reference
iRobi	Yujin Robot	Social robot made with single-board computer, Intel Pentium processor, 40 GB Hard disk, and equipped with Bumblebee camera. (Lee et al. 2016). This robot is considered both a home and educational robot as it can teach English, say Nursery Rhymes to children and dance and sing.	Humanoid	(Broadbent et al., 2013)	A9
Nao	Aldebaran	It is a humanoid robot equipped with sensors that enables face recognition. Nao can perform activities done by humans aligned to academics, research, and different industries (Michieletto, 2013)	Humanoid	(Broadbent et al., 2013)	A5
Paro	Intelligent System Co.	It is a Pet-like social robot used in elderly care. Coping up with anxiety and reducing stress are the main functions of Paro. Addressing the psychosocial needs of Dementia patients are the main feature of this robot (Hung et al., 2019.)	Zoomorphic	(Broadbent et al., 2013) (Jensen et al., 2019)	Z1
Pleo	Innvo Labs	A social robot designed like a small dinosaur covered with rubber consists of 14 gears and force-feedback features. It can move its neck, tail, and even the eye-lid. The hardware components include two infrared sensors, a CMOS Camera, and push-buttons. (Fernaues et al., 2010)	Zoomorphic	(Broadbent et al., 2013)	Z2
Telenoid R1	Osaka University and ATR Hiroshi Ishiguro Laboratory	Designed as a minimalist robot with 9 degrees of freedom that allows its vertical and horizontal movement. Measured as 80 cm and weighs in at 6kg. Telenoid can greet and hug its users.	Humanoid	(Broadbent et al., 2013)	A6
Philip K. Dick	Hanson Robotics	Humanoid social robot designed by Hanson Robotics that employs 36 servomotors to be able to perform wide range of facial expressions. This robot serves in Apollo Mind initiative.	Humanoid	(Broadbent et al., 2013)	A8
Hiroshi Ishiguro geminoid	ATR Hiroshi Ishiguro Laboratory	Humanoid social robot that is designed to resemble or function as a duplicate of an existing person. Behavior and actions of this robot is controlled by computer network powered by Android Science. 3 core elements run this robot 1.Robot 2. Server 3. Teleoperation interace (Nishio et al., 2007)	Humanoid	(Broadbent et al., 2013)	A7
Joy for All	Hasbro	It is an interactive life-like robotic cat specifically designed for older adults. Its interactivity and playfulness are unique are the key features of Joy for all (Bradwell et al., 2019). The primary function of this robot is to serve as a companion to humans.	Zoomorphic	(Jensen et al., 2019)	Z3
HOBBIT	EU's 7th Framework Programme	It is a functional, localized, individual robot with visual, physical, and auditory sensors and actuators. Well-equipped with the required hardware and software components, this robot navigates in a domestic environment that prevents and detects falls of the elderly.	Humanoid	(Jensen et al., 2019) (Eftring & Frennert, 2016)	A10
ElliQ	Intuition robotics	It is an empathetic digital companion robot, a voice-activated Smart device for older adults designed to reduce loneliness and isolation in older adults. ElliQ can connect the elderly with family and friends.	Functional	(Jensen et al., 2019)	F7
Moxie	Diligent Robotics	Robots with harmonious interactivity capabilities are designed to assist children with MBDDs (Mental Behavioral Developmental Disorders.) Sense-react loop of the Moxie system is the most crucial in building connection and trust with its users (Gratch et al., 2006.)	Humanoid	(Pepito et al., 2020)	A11
AIBO	Sony	It is a robot equipped with an emotion estimation module. The personality and behavior of the robot develop over time. Employed with sensors, it has a face-recognition feature, detects smiles, and learns new tricks.	Zoomorphic	(Matsumoto et al., 2005)	Z4
ifbot	Business Design Laboratory (Japan)	Social robot for communication with emotion detection/ estimation features. Many users are	Humanoid	(Matsumoto et al., 2005)	A12

(continued on next page)

Table 5 (*continued*)

Robot	Organization/Developer	Description/ Hardware	Morphology	Appeared in the Article(s)	Reference
		entertained to communicate with the ifbot with its capabilities to show various facial expressions.			
Experimental robot with tactile sensors	(Mukai et al., 2006)	Experimental robot with tactile sensors. It has the ability to detect tangential stress and be used in grasping force control.	Functional	(Mukai et al., 2006)	F8
Telepresence Robot for Interpersonal Communication (TRIC)	(Tsai et al., 2007)	It is a functional, localized, individual robot with visual, physical, and auditory sensors and actuators. It uses Virtual reality implementations, communication technologies, robotics, and human-system interfaces. Its primary function is to assist the elderly in connecting with family and caregivers, which can be implemented in a home environment.	Zoomorphic	(Tsai et al., 2007)	Z5
Kompai	Robosoft	It is a humanoid robot that is designed to assist the elderly and persons with disabilities. Kompai is employed with its hardware that allows the robot to understand speech and talk and navigate autonomously.	Humanoid	(Granata et al., 2013) (Zsiga et al., 2018)	A13
Oni Robot	(not specified)	Game-playing robot with emotions	Humanoid	(Okano et al., 2013)	A14
Giraff/ROBIN	Camanio Care AB	It is designed to assist the elderly in their homes as well as connect them to family, friends, and healthcare professionals. ROBIN uses a Mobile telepresence robotic (MTR) system. Equipped with devices and sensors, it aims to monitor the activities and health of the elderly.	Functional	(Boman & Bartfai, 2015) (Moyle et al., 2020) (Cortellessa et al., 2018)	F9
ALECSA	LEGO Mindstorms NXT	It is an exercise coach robot that consists of 4 main sensors: A touch sensor, Sound sensor, light sensor, and Ultrasonic sensor. It is also being run by the brain of the education robot called "NXT Brick."	Humanoid	(Pérez et al., 2015)	A15
EyeGo System	(Wästlund et al., 2015)	Gaze-driven control-powered wheelchair robot. It is designed in order to assist patients with severe cognitive impairments. The EyeGo system is an optical line navigation system that allows patients to control it safely and independently.	Functional	(Wästlund et al., 2015)	F10
VGo	VGo Communications	It is a robot that can act as a proxy in a different location. VGo replicates a person in a distant place. Controlled via Net, it can see, talk, hear, and move around just like an average person. This robot is commonly used in healthcare setting.	Functional	(Moyle et al., 2020)	F11
ReMeDi	(Arent et al., 2016)	It is a medical mobile robot that provides a platform for doctors to examine and check patients over long distances. ReMeDi's main features are the two standard examination techniques: palpation and ultrasonographic examination.	Functional	(Arent et al., 2016)	F12
Tele-robotic Intelligent Nursing Assistant (TRINA)	(Li et al., 2017)	It is a telenursing robot designed to assist providers in performing a variety of clinical tasks. These tasks include handling contaminated materials and protective gear and assisting in patient-caring tasks. Equipped with sensors and telepresence technology, it effectively collects information from its patient and the environment.	Functional	(Li et al., 2017)	F13
Telepresence Robot	(Koceska et al., 2019)	It is designed for assisting the independent living of the elderly. Telepresence Robot supports the patients' daily activities by addressing loneliness and social isolation concerns through the provision of virtual presence.	Functional	(Koceska et al., 2019)	F14

of older adults as the population continuously greys (Shalf, 2020). Previous literature reported the successes of robots in fulfilling the needs of older adults in the performance of daily routines, keeping their independence, and promoting life quality (National Research Council (US) Steering Committee for the Workshop on Technology for Adaptive Aging, 2004). Most articles have centered on nurses and care providers as secondary users of the technology acting as operators and supervisors. This finding communicates the apparent

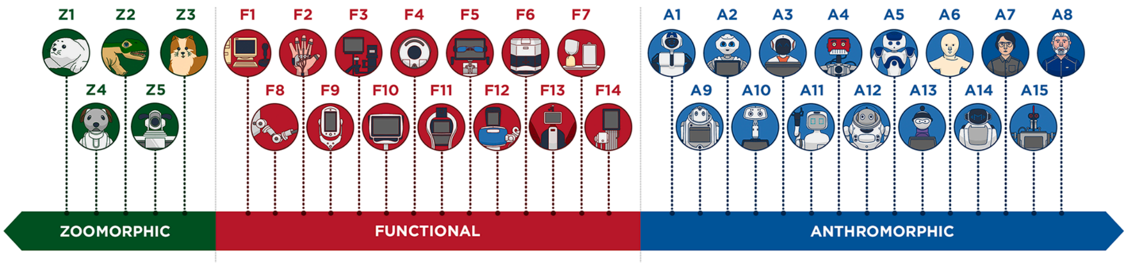

Fig. 2. *Design Spectrum of Healthcare Robots for Older Adults. Note*. Zoomorphic: *Z1* = Paro, *Z2* = Pleo, *Z3* = Joy for All, and *Z4* = AIBO; Functional: *F1* = JavaTherapy System, *F2* = Rutgers Master II (RMII), *F3* = InMotion2 (MIT-Manus), *F4* = Home robot with ambient facial features, *F5* = NeuroVR; *F6* = TUG Automated Robotic Delivery System, *F7* = ElliQ, *F8* = Experimental robot with tactile sensors, *F9* = Giraff/ROBIN, *F10* = EyeGo System, *F11* = VGo, *F12* = ReMeDi, *F13* = Tele-robotic Intelligent Nursing Assistant (TRINA), and *F14* = Telepresence Robot; Anthromorphic: *A1* = Robotic Nursing Assistant, *A2* = Pepper, *A3* = Alice/“Eva”, *A4* = IRL-1, *A5* = Nao, *A6* = Telenoid R1, *A7* = Hiroshi Ishiguro Geminoid, *A8* = Philip K. Dick, *A9* = iRobi, *A10* = HOBBIT, *A11* = Moxie, *A12* = Ifbot, *A13* = Kompai, *A14* = Oni Robot, and *A15* = ALECSA.

separation of technology’s actual users, on-site supervisors, and developers. It was less frequent for published research articles to involve nurses as real-time virtual commanders of robots but more direct operators of these machines and patient advocates, as evidenced by their perceptions assessed in research studies.

The research articles highlighted the uniqueness and importance of usability testing for older adult clients due to their vulnerable and compromised (mobility, sensory) status. Findings also revealed the older adults’ preferences for physical robots rather than the simulated/virtual versions (Tapus, 2009; Zsiga et al., 2018), suggesting the importance of physical embodiment in human-robot interactions. These ideas advance the usefulness of human-centered design (HCD) in healthcare robotics development in nursing. HCD is an emerging and innovative approach that brings clients and developers together in developing usable products and technologies (Bazzano et al., 2017), with a promise of improving the usability of healthcare innovations and technologies (Beres et al., 2019). In HCD, both human capabilities and limitations improve user experience and produce outstanding results (Kasdaglis & Stowers, 2016).

The findings of the studies also communicate the need for technological competency while maintaining a caring attitude among nurses. This outcome concurs with the concepts of Technological Competency as Caring in Nursing (Locsin, 2017) in explaining the dynamics and coexistence of technology and caring in nursing. In this theory, competence in technology is reflected in shared nursing process dimensions of technological knowing, mutual designing, and participative engaging, focusing on the nursing practice within the human caring perspectives (Locsin, 2017).

4.4. Theoretical Articles’ Outcomes and their Relevance to Human-Computer Interaction and Nursing

Reconciling the humanism of nursing and the technology of robotics is an important focus for the future. Many of the theoretical articles are discussion papers covering various topics valuable in understanding healthcare robots and human-computer interaction and their implications to nursing. Notable findings were the categorization of human-computer interaction in healthcare as either a physical or psychological process, the call for integrating gerontechnology and robotics in the nursing curricula, and consideration of the older adults’ uniqueness in nurse-patient and robot-nurse dyads.

This literature review has successfully uncovered the supporting articles on the healthcare robot preferences among older adults - the classic Uncanny Valley Theory by Masahiro Mori et al. (2012). Furthermore, this theory introduces an interesting concept to consider in developing humanoid robotic systems (Betriana et al., 2021; Tay et al., 2018). Mori has observed that human affinity to robotic systems increases when its human-like features increase until a certain point where people begin to feel strange towards robots that are almost human in physical characteristics and behavior. Therefore, future developments of effective robotic systems for the aging cohort require emphasizing the science of anthropomorphism. Furthermore, the manner and extent of realism on how robots are displayed as human-like will undoubtedly impact interaction and actual use.

Advancements in natural language processing and artificial intelligence were essential in "humanizing" healthcare robots. In this line, deep learning (DL) might be most applicable to ensure the progress and development of healthcare robots’ automation capabilities. DL is a popular and modern paradigm for machine learning using modern optimization techniques with more efficient yet straightforward methods (see Wu et al., 2020). Furthermore, applying DL in natural language processing will make healthcare robots more intelligent and intuitive in conversation and communication tasks (Tsuruoka, 2019), for instance, with the nurse and clients’ significant others.

It is interesting to note that discussions on nursing-focused theories and models in healthcare robotics (Betriana et al., 2021; K Ishiguro & Majima, 2016.; Osaka, 2020; T. Tanioka, 2017) were discovered in theoretical sources of this literature review. These models highlight nurses’ intermediary role in human-computer interaction, user-preference prediction, and the transactive relationship between and among the older adult client, nurse, and humanoid machines. As literature in healthcare robotics expands, the presence of these models was expected to be found in scientific discourses in nursing and health informatics.

4.5. Robot Features and Morphology

The review found that robotic systems possess more auditory and visual sensors and actuators than physical actuators. This result runs parallel with the observation that *hard* (moving rapidly to apply physical force) robots are possibly dangerous to humans (Whitesides, 2018), more so for patients in the healthcare settings. Consequently, developers are now advancing the concept of *soft* robotics to describe robotic systems with similar utility but are safer to work with human beings (Gariya & Kumar, 2021). The soft robotic hand (Shi et al., 2021) tested for hand rehabilitation among chronic stroke survivors is a good benchmark.

Robots featured in the studies are less human-like in physical structure. Robots usually appear non-anthropomorphic in early development (Broadbent et al., 2013). Then and now, the perception of an external agent as human-like is strongly believed to influence how individuals positively behave, communicate and empathize with robots (Dennett, 1971; Song et al., 2021). A more humanoid machine elicits a greater sense of agency (Barlas, 2019; Ciardo et al., 2018), trustworthiness, and a positive attitude (Spatola & Agnieszka, 2021) among users to a certain extent (Mori et al., 2012). Human beings are accustomed to understanding external objects with human features and behaviors (H Ishiguro & Nishio, 2007.) and have tendencies to anthropomorphize objects in the environment (Reeves & Nass, 1998).

Patterns from the literature reviewed challenges the healthcare sector to redefine the meaning of presence in human-computer interaction by introducing innovative modes of interaction between man-machines. Compared to other industries, the adoption of robots in the health sector has been low due to ethical, resource, and user attitudes. Apart from the expected prevalence of real-time direct control for robots in research and non-research literature, remote monitoring, telepresence, and virtual reality (VR) appear in published works. The majority of the robotic systems being used currently require the physical presence of the user and machine in the exact location. Still, the scholarly examination of remote healthcare delivery is underway. For instance, immersive VR in robotics is a promising complement to physical robots to engage older adults and induce feelings of being present in a realistic healthcare environment when used correctly (Bergmann et al., 2018; Tieri et al., 2018). VR technology can also offer the benefit of showcasing a telepresence robot that is significantly cheaper than live physical robots. In remote monitoring, older adults can also perceive the presence of their providers showcased through robot screens and be more open to their health partners due to the online disinhibition effect (Stuart & Scott, 2021).

5. Limitations

Despite several strengths of this review paper, there are significant limitations that should be considered. The articles extracted for examination came from scholarly databases and hand searching techniques. This approach ensured the quality of the data corpus and averted the inclusion of the growing robotic systems literature found in web pages (i.e., blogs). The inclusion of articles tagged with 'nursing' and 'human-computer interaction' in the databases may have potentially excluded relevant themes that are also valuable in discussing humans and robots in the nursing practice. Article linguistics has been considered a barrier in ensuring the representation of articles written in a non-English language. An interdisciplinary team with bi-lingual members may be conceived for prospective projects. Future review studies are hoped to acknowledge these limitations to illustrate a more precise portrait and show literature patterns of robotic systems for older people in healthcare.

6. Conclusions

Technology literature in the nursing sciences has increased remarkably, and the presence of healthcare robots in the industry has already captured the interests of scholars and scientists within and beyond the healthcare sphere. This integrative review has uncovered the dynamic and overlying concepts in health, nursing, and human-computer interaction in healthcare robotics for older adults. Robots' slow but sure assimilation in mainstream healthcare delivery is timely and relevant as global challenges act as catalysts of healthcare transformation. The integration of robotics in healthcare has gradually introduced powerful tools for nurses and healthcare personnel. Considerable benefits in this integration are the promise of access to technology-driven, usable, efficient, safe, client-specific, and quality care services. Amidst the advancements in healthcare robotics, there is a constant exploration of authentic, care-driven, and empathic nursing care discernable in nursing-focused models and frameworks intersecting healthcare and technology. Nurses' participation in knowledge development in these fields is an expression of caring, and they can create rather than predict the future of nursing.

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M.J.D., P.M.D., K.W.D., S.L.S., and I.L.O. conceived the review and developed the search strategy. M.J.D. and I.L.O. retrieved the literature and undertook the data extraction. M.J.D., P.M.D., K.W.D., S.L.S., and I.L.O. undertook data analysis. M.J.D., P.M.D., K.W.D., S.L.S., and I.L.O. contributed to the development of the review, interpretation of the findings, and drafting of the final version of the manuscript. All the authors read and approved the final draft.

Declaration of Competing Interest

The authors declare no conflict of interest.

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