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Robots, AI, and Cognitive Training in an Era of Mass Age-Related Cognitive Decline: A Systematic Review

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ABSTRACT Developing countries world-wide are witnessing historical growth in their elderly populations, and with it, importantly, a steady rise in the number of people experiencing age-related cognitive decline. This reality has the potential to produce an unprecedented strain on affected families, healthcare systems and taxpayers in the very near future. This study: a) examines the present limits and predicted capacity of Artificial Intelligence (AI) as they relate to the various and complex needs of those hoping to optimize the positive benefits of cognitive training, and b) systematically reviews the efficacy of Human Robot Interaction (HRI) as an intervention strategy for elderly individuals confronting cognitive challenges along the spectrum from Mild Cognitive Impairment (MCI) to Advanced Cognitive Impairment (ACI). The results of this systematic review suggest that, overall, the utilization of humanoid and pet robots, such as NAO and PARO, respectively, produce improvements in cognition and markers of social and emotional health and engagement; however, when embedded with AI with the capacity for Deep Learning the potential of robotic technology to aggressively meet the needs of individuals experiencing age-related cognitive decline will be significant.

INDEX TERMS Artificial intelligence, cognitive decline, elderly cognitive training, robotics.

I. INTRODUCTION

More than at any time in history, the prevalence of age-related dementia has never been so great. Since the second world war, the population of Western Europe and eastern Asia has grown and *grown older*. As a result of improvements in medicine, nutrition and workplace safety standards, and with the help of a precipitous drop in infant mortality rates, the average life span of these countries has continued to rise [1]. In 2015, people over 60 years of age in Western Europe represented 21% of the population [2]. Presently in countries such as Japan, according to Haruaki Deguchi of The Japan Times [3], those individuals 65 years of age or older have come to represent up to 28% of the population. All of this, despite the dropping infant mortality rate.

And these figures have not peaked. Indeed, they are predicted to grow, perhaps considerably [2]. By 2030, 33% of the population of Western Europe is expected to be above 60 years of age [2]. In contrast, in Japan, by 2060, one in every 2.5 people will be 65 years old, or older [3]. Following this trend, the elderly may comprise up to 38.4% of the population by 2065 [4]. Worldwide, by 2050 it is predicted that more people will be older than 60 years than under 15 [2].

More important, concomitant with exploding elderly populations of affluent countries is the prevalence of age-related cognitive decline. This impairment appears along a continuum from Mild Cognitive Impairment (MCI) or possibly pre-dementia to Alzheimer's disease. With the loss of cognition comes the decline in Activities of Daily Living (ADL). A loss in cognition initially can mean the momentary delay in access to common words in a commonplace conversation and progress to the inability to place a familiar face in the street or to identify a family member, and the

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disintegration of short-term memory. Along this continuum irritation turns to concern and rising anxiety. But in the initial stages the centrality of cognition in human locomotion produces additional reason for concern. Cognitive decline has been shown to effect sensory motor control. Early stages of cognitive decline are in fact detectable in changes of gate and coordination. The deleterious reality increases the incidence of injuries like burns and falls [5].

Worldwide, according to recent estimates, one person every seven seconds is identified with dementia. By the age of 65, 10 to 20% of seniors can be found to experience MCI [6]. While those grappling with MCI may find their symptoms unchanged over time or discover the integrity of their cognition returning to an earlier state, for those experiencing cognitive decline in their mid-60s and beyond, there is a high chance it will progress towards full-blown dementia, at a rate between 10 to 15% per year. This serious concern is compounded by the growing numbers of seniors manifesting symptoms of pre-dementia or Alzheimer's Disease. References [7], [8]. By 2050 it is estimated that 9, 200,000 people will be afflicted by Alzheimer's disease around the world [9]. Furthermore, while cognitive decline is devastating for those it touches, it further impacts the physical wellbeing of those suffering from cognitive decline [10]–[12] and, as mentioned, increases the likelihood of physical injury. Consequently, this rise in cognitive decline is projected to place a seemingly insurmountable strain on the medical profession, social services, and taxpayers. For example, while it has been estimated that for every elderly person in 2015, seven health workers were available, by 2030 it is expected that this number will drop to slightly under five [2].

However, as has been noted by Calhoun [13] and Thorndike [14], and is known as the Flynn Effect, I.Q. scores, as calculated using such tools as the Wechseler Intelligence Scale for Children (WISC), have been rising for decades, and not only with children. In fact, in the last five decades measurable I.Q. scores, have risen by 15 points, on average. Similarly, measures of semantic and episodic memory, have also risen, according to Ronnlund [15]. Since evolution cannot be at play this change can only be explained by environment and diet [16]. This would suggest that human intervention can play a role in rehabilitation or mitigation of dementia symptoms.

In fact, non-pharmaceutical approaches to combat age-related cognitive decline have been explored and the results provide reason for optimism. These forms of intervention include therapist-patient cognitive training, physical exercise, animal therapy, and Human Robot Interaction (HRI). Early studies have shown that HRI has the benefit of improving mood, social relationships among patients and emotional expression of individual dementia sufferers [17]–[19]. Furthermore, unprecedented developments in artificial intelligence (AI), robotics and the field of cognitive psychology have demonstrated to be effective, at the very least, at delaying the symptoms for those suffering various levels of age-related cognitive decline [20].

The primary aim of this systematic review will be to examine the efficacy of HRI as an intervention for elderly individuals experiencing age-related cognitive decline and investigate the growing potential for AI to maximize the effect of cognitive training. Additionally, recognizing that other differences among elderly participants may be at play in the successful adoption of new technology, gender and age and response to robotics will be examined. Moreover, we will identify and explore concerns or questions that may arise during this review process and provide recommendations for improvement when possible. Ultimately, we aim to provide researchers and engineers, who are developing robots for cognitive training, a direction through which they can optimize the impact of AI in this field.

II. METHODS

A. SEARCH STRATEGY

This systematic review followed the guidelines for the preferred reporting items in systematic review and meta-analysis (PRISMA) guidelines [21]. The databases were searched using the following keywords: *elderly, old, cognitive impairment, age-related cognitive decline, cognitive training, cognitive intervention, robot, robotics, socially assistive robots, SAR, artificial intelligence,* and *AI.* All selected publications underwent a selection process with the following sequence: titles were reviewed, followed by each abstract, and finally, the full text of each publication was examined. All research was limited to papers published after and including 2007. The main thrust of the search was conducted in May and June of 2019, and through Google Scholar and ResearchGate. Only English publications were considered.

B. INCLUSION AND EXCLUSION CRITERIA

Based on the results of the inclusion and exclusion criteria, selected papers were formulated for three categories. The two primary categories included studies which examine the impact of robotic interventions on cognition and well-being in the elderly, and papers which investigate advances in AI. A third, more general category, included response to robots vis-a-vis gender and across the ages, and recent papers which explore possible issues to be addressed in the implementation of robots for cognitive training as they relate to the elderly. For the primary category addressing robots vis-à-vis cognitive training for individuals experiencing age-related cognitive decline, a study met the inclusion criteria if it: a) was published within the last twelve years, b) included a sample of older adults (whether deemed healthy, or along the spectrum from MCI to extreme), c) included participants 59 years or older, and d) used only robots (either humanoid or pet) as intervention. Cognitive intervention studies that used computer-based trainings but not robotics were excluded. There were a very limited number of systematic reviews which examined the impact of pet robot or robot intervention; however, these were excluded

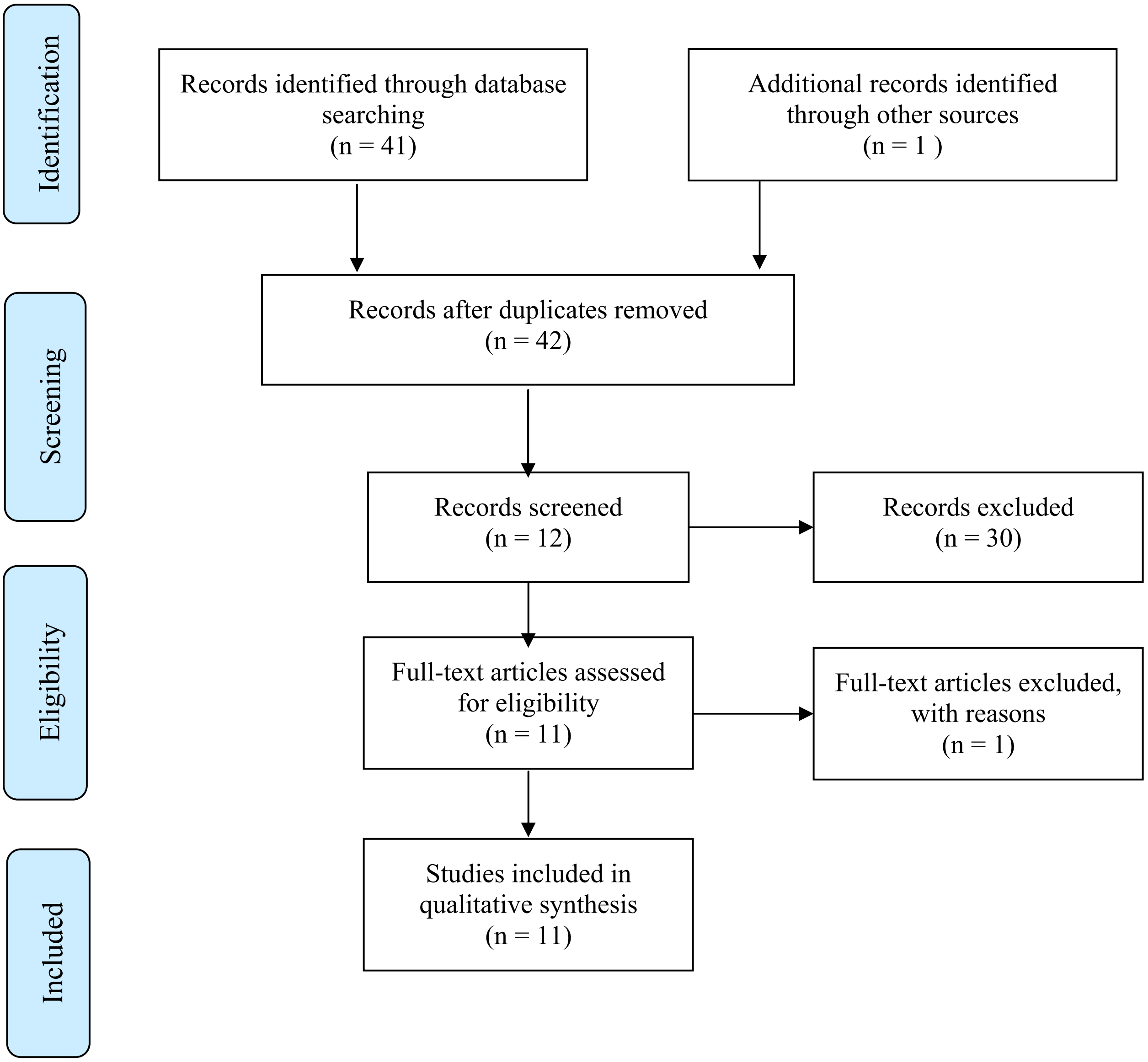


FIGURE 1. Flow diagram of search results.

because they were outside the focus of this paper or for reasons of methodological quality. For example, “Pet robot intervention for people with dementia: a systematic review and meta-analysis of randomized controlled trails” [8], examined behavioral and psychological symptoms of dementia (BPSD). “Psychosocial Health Interventions by Social Robots: Systematic Review of Randomized Controlled Trials” [73] generalized from interventions with children, people with autism and older adults. Finally, the systematic review “Robotics to Enable Older Adults to Remain Living at Home” [74] was excluded due to methodological weakness identified by its researchers. In contrast, this systematic review addresses, specifically, the potential impact on the cognition of elderly individuals experiencing age-related decline using the most recent findings as they relate to robot interventions. One systematic review and meta-analysis, “The Effectiveness of Social Robots for Older Adults: A Systematic Review and Meta-Analysis of Randomized Controlled Studies” [75] examined the impact of robot human intervention on well-being. This general but excellent systematic and meta-analysis used subjective measures to determine cognitive improvement and metrics of cortical neural activity to infer the potential of this form of intervention to delay cognitive impairment. but was excluded to avoid overlap; instead, specifically related studies were mined for this review. Studies which focused on robot human interventions were divided generally into two groups, those which examined strictly cognitive measures, and those examining additional socio-emotional measures as a result of exposure to robots, Fig. 1.

In addition, contrasted separately were those studies which explored the impact and implications of humanoid and non-humanoid robots. The first studies placed their focus on robots resembling humans which served as Socially Assistive Robots (SARs) or service type robots. A SAR is defined as an artificial agent possessing the features or characteristics of either a human or an animal [22], [23]. These robots are used to assist the elderly in independent living activities. The latter studies examined those robots with the main function of alleviating negative emotions and conditions, such as depression. Designed to serve the function of providing companionship, these robots resemble animals, such as cats, dogs and seals. Interestingly, few studies exist currently which examine the impact of robots as tools to provide cognitive training for the elderly. Because of this, all studies which explored the effects of HRI that had the potential to enrich the findings related to robot cognitive training for those experiencing age-related cognitive challenges were considered eligible for review. Consequently, all studies which focused on HRI and elderly people with samples of individuals along the spectrum from healthy to severely cognitively impaired were included. Studies using physically or surgically assistive robots were excluded. Also, studies which did not provide a specific outcome were excluded.

III. RESULTS

In total, 42 experimental papers were initially selected based on their titles. After a reading of each abstract, studies were categorized into 'high relevance', 'medium relevance' and 'low relevance' to the research objectives. Study design and sample characteristics such as intervention, age, cognitive status, outcomes, and researcher-identified limitations were analyzed. Of the 42 papers 11 were selected based on the eligibility requirements (mentioned above) and for addressing key researcher questions and concerns. In fact, during this search no paper met all the targeted criteria. There was, however, one strongly related randomized controlled study of the effects of a 12-week cognitive training program on changes of cortical thickness in *healthy* elderly participants. (This study [25], conducted in Korea in 2016, matched all search key words except for 'AI' and 'illiterate'). It examined multimodal stimulation via robot intervention and its effects on cognition. Several quality research papers were excluded for such reasons as: a) too closely resembling another selected paper, and b) being a systematic review and meta-analysis. One paper, for example, written by the Korean researchers above presented a compelling conference paper in the same year, with an identical sample size, which addressed *single* mode stimulation, rather than multi-modal stimulation. It additionally provided limited information to distinguish it from the previous study. Consequently, this second paper was excluded despite meeting the eligibility criteria and being closely related to this study's objective. The few partially related systematic reviews and meta-analysis that were found were not included because - due to the limited quality studies examining the use of robotics for cognitive intervention of older adults – these studies often overlapped in the research and findings used to support conclusion. Outside of the targeted criteria, but of potentially significant relevance, were: two studies that examined gender and age group response to SARs. In addition to the nine papers which examine the general impact of robotics (whether cognitive, social or emotional) and the two exploring gender and age, 11 were examined which provided additional perspective on potential concerns vis-à-vis the integration of robotics into the field of cognitive training for the elderly and, finally, eight papers explored recent developments in AI, Machine Learning (ML) and Deep Learning (DL) generally as they relate to healthcare.

Table 1 shows the methodological quality of the 11 studies examining the impact of robotics vis-à-vis cognitive training and response related to age and gender. Table 2 summarize the findings of each individual study. Each was reviewed and key information pertaining to study design was extracted, including: *study title*, *author* and *year of study*, *type of intervention / study*, *number of subjects*, *type and trial period*, *cognitive or social domain observed / statistical methods*, *findings*, and *limitations / challenges*.

Those which were found to be significantly related were: three randomized controlled trials (RCT), one controlled trial (CT), two randomized block design studies (RBDS), one controlled study, one pilot study with a pre-post design, one observational study, one experimental study, and one qualitative usability study.

A. QUALITY ASSESSMENT

Table 1 presents an assessment of the methodological quality of the included robotic experimental studies. The quality assessment ranged from four to nine, with an average of 6.5 out of nine. All included studies have a 'good' methodology. A study by Liang *et al.* [29] had the highest methodological quality. The score of item one was low among the included studies because all of the studies, except Liang *et al.* [29] and *et al.* [24], had a small sample size, below 200. All studies clearly mentioned the age range or mean age group of their sample, except for the studies by Liang *et al.* [29] and Schermerhorn et al. [27], identifying their sample only as 'young adults' and 'old adults' with the former, and 'undergraduates' in the latter. All studies which measured change over time had a duration of longer than four weeks; only one study by Sung *et al.* [30] was identified as having a very short duration at just 28 days. Two studies measuring initial impressions and preference, Polak *et al.* [31] and Schermerhorn *et al.* [27], respectively, were conducted in one session.

B. PARTICIPANTS, SAMPLE SIZE, AND DURATION OF INTERVENTION

As you can see from Table 2, among the 11 studies exploring the impact of robotics, nine included participants which were exclusively older adults [24]–[26], [19], [28]–[30], [32], [33], while two used subjects who were either 'older' and

TABLE 1. Scores of methodological quality.

Authors	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Total Score (max = 9)
Tanaka et al. (2012) [24]	Y	Y	Y	Y	N	N	Y	Y	N	6
Kim et al. (2015) [25]	N	Y	Y	Y	Y	Y	Y	Y	Y	8
Pino et al. (2019) [26]	N	Y	Y	Y	Y	Y	Y	Y	Y	8
Sabanovic et al. (2013) [19]	N	N	Y	Y	Y	Y	N	N	N	4
Schermerhorn et al. (2008) [27]	N	N	N	N	Y	Y	Y	N	Y	4
Petersen et al. (2016) [28]	N	Y	Y	Y	Y	Y	Y	Y	Y	8
Liang et al. (2017) [29]	Y	Y	Y	Y	Y	Y	Y	Y	Y	9
Sung et al. (2014) [30]	N	Y	Y	Y	Y	Y	Y	N	Y	7
Polak et al. (2018) [31]	N	Y	N	N	Y	Y	Y	N	Y	5
Valenti-Soler et al., (2015) [32]	N	Y	Y	Y	Y	Y	Y	N	Y	7
11 Takayanagi et al., (2014) [33]	N	Y	Y	N	Y	Y	Y	Y	N	6

Q1. Sample size > 199; Q2. Age mentioned and relevant; Q3. Duration > 3 weeks; Q4. Cognitive or socioemotional domains > 2, or preference Q5. Supervised intervention; Q6. Carried out at center; Q7. Similar baseline; Q8. Subjects similar at baseline; Q9. Statistically significant.

Y: Yes – The study met the criteria. N: No – The study did not meet the criteria.

'younger' [31], or undergraduate students whose age was not specified [27]. Of these nine studies using older adults, three included healthy older adult participants [24], [25], [30]. Five studies included participants with some level of age-related cognitive decline, identified along a spectrum from mild cognitive impairment (MCI) to advanced dementia [25], [19], [28], [29], [32]. One study used participants specifically with MCI [26]. Two studies included participants who possessed general dementia symptoms [26], [27]; one study included only participants identified as possessing "advanced"

TABLE 2. Robots used in elderly care.

Author & Year of Study	Type of Intervention / Study	No of Subjects, Type & Trial Period	Cognitive and social domain observed / Statistical methods	Findings	Limitations / Challenges
Tanaka et al., (2012) [24]	- Randomized controlled trial (RCT) - Humanoid robot resembling a 3-year-old boy: *Kabochan Nodding Communication robot* – non-adaptive, pre-programmed speech and activities, without touchpads; commercially available for home use) - Individual intervention: living with in home setting, with questionnaire	- 34 healthy elderly women, living alone - Age range: 66 – 84 years old - Those identified predementia or dementia excluded - Length: 8 weeks, with pre, and posttest followed 4 – 8 weeks	A variety of cognitive functions, plus bio markers: saliva cortisol and sleep, subjective fatigue, motivation and healing Tools: Cognistat, Mini-Mental State Examination (MMSE) score, questionnaires, the Geriatric Depression Scale (GDS-15), The Tokyo Metropolitan Institute of Gerontology Index of Competence	- Improvement: Mini-mental State Examination (MMSE) score, judgment and verbal memory; in particular: executive and memory functions	- Moderately small sample size - Limited time with robot (too short to evaluate effect confidently on cognition)
Kim et al. (2015) [25]	- Randomized controlled trial (RCT) - Humanoid robot: *Silbot* and *Mero* - programmable, interactive; responsive and adaptive, with touchpads, speech and facial recognition: available for clinical use only - Individual intervention: 44 blocks for memory training, 14 for language, 12 for calculation, 16 for visuospatial function and 34 for executive function	- 85 without cognitive impairment - 48 IG: 24 received traditional cognitive training (T-IG), 24 Robot (R-IG). 37 CG - Age range: 60 years or older individuals - Length: 12-week study	Cognitive thinning and a range of cognitive functions, including visual memory and executive function Tools: Alzheimer's Disease Assessment Scale, with cognitive subscale (ADAS-cog), 7 subsets of Cambridge Neuropsychological Test Automated Battery (CANTAB): 3 visual memory tasks of Delayed Matching to Sample (DMS), Pattern Recognition Memory (PRM), Paired Associates Learning (PAL), 2 Executive function or working memory tests: Spatial Working Memory (SWM), Stockings of Cambridge (SOC); 2 attention tests: Reaction Time (RTI), Rapid Visual Information Processing (RVIP)	- IGs diminished rate of thinning of global structural network topology, specifically in heteromodal association cortexes responsible for information integration of monomodal association cortexes which facilitates learning - "Significantly reduced" cortical thinning in right and left anterior cingulate cortex (ACC), plus small areas of R inferior temporal cortex robot intervention vs TIG. - Improvements in RIG executive function and visual memory - Greater improvement of visual memory in TIG - Greater improvement in executive function (using SOC) of IG positively correlated to changes in left temporoparietal junction and inferior temporal gyrus. Suggest can mitigate age-associated structural brain changes. - RIG improved motivation of goal-directed behavior - Multi-domain training improves reasoning and processing speed (exec. functions) - CG experienced greater general cognitive scores (ADAS-cog) and visual memory (PRM task)	- Daily cognitive activity of participants outside lab not controlled - Larger percentage of women (note: women tend to have increased cognitive thinning with age) - Robot group had increased amount of physical activity - possibly affecting rate of thinning in anterior cingulate cortex (ACC)

symptoms [32], and two studies identified its participants as being along the spectrum of individuals possessing attributes from MCI to "advanced" [19], [33]. The age range of older individuals used in all intervention studies (when provided) was from 45 to 101 years old. Only one study [19] did not include an age range or medium age, only identifying its participants as 'nursing home residents'. With the exception of two studies [27], [31] which were one-time 'response' experiments, the duration for each intervention was between 28 days and three months, with sessions occurring between one and three times a week.

C. IMPACT ON COGNITIVE AND SOCIAL-EMOTIONAL FUNCTION, AND RESPONSE

Social and emotional well-being have been shown to strongly impact cognitive function and, hence, quality of life. Social

TABLE 2. ***(Continued.)*** **Robots used in elderly care.**

Pino et al. (2019) [26]	• Controlled study, facilitator non blind • Individual intervention • Humanoid robot: *NAO* – programmable, interactive; responsive and adaptive; fully open and developable platform, without tablet: available for clinical use only • Human–robot interaction to reinforce therapeutic behavior and treatments adherence for improved memory	• 21 individuals with mild cognitive impairment (MCI) • Groups of 6 – 8 subjects • Age range: 45 – 85 years • Mean age: 73.45 years • Mean education level: 9.9 years • Length: 90-minute group sessions / 8 weeks	Memory Tools: Anna Pesenti Test, Digit Span, Attentional matrices, MAC-Q (Memory Assessment Clinics-Questionnaire), PFL, HADS (Hospital Anxiety and Depression Scale), STAI-X (State-Trait Anxiety Inventory), and customized software to quantify smile and visual attention. SPSS 21.0 (IBM Corporation)	• Increased visual gaze and reinforced therapeutic behavior: significant change prose memory and verbal fluency measures, also depressive symptoms • Researchers conclusion: can be one of the most important and cost savings technologies for health care system	• Performed at single center with non-blind "interested" in purpose of study • Small sample size (though study of feasibility, not generalizability)
Sabanovic et al. (2013) [19]	• Observational study • Pet seal robot: *PARO* - zoomorphic therapeutic robot; programmable, interactive, responsive and adaptive; without touchscreen: available for clinical and home use • Group intervention: adapted to multi-sensory behavioral therapy (MSBT) – widely used for dementia – held at facility	• 10 participants with cognitive impairment from minor to severe; nursing home residents from rehabilitation wing • 3 excluded from final analysis • Age range: N/A • Length: 7 weeks, once a week for 30-45-minutes group session mediated by therapist	Observational: codification and tracking of behaviors: visual (looking), verbal (speaking, singing, making other noise such as cooing), physical (petting, hitting, holding, kissing, taking or sharing PARO)	• Direct: increased verbal communication with PARO • Indirect: increased interaction with other participants • Steady growth over duration of study: suggest not just novelty effect	• Limited sample size • Limited intervention period
Schermerhorn et al. (2008) [27]	• Randomized, controlled trial (RCT) • Humanoid robot: • *ActiveMedia Peoplebot* – limited - adaptability, programmable, interactive, locomotes via wheels: available for experimental use only • Individual intervention: survey, arithmetic task, 2nd survey, 'within-subjects' design; gender	• 47 healthy participants: 24 males and 23 females (undergraduates from Engineering and Psychology) • Age range: N/A • No exclusion	Gender differences in response to robot Tools: a 6-point Likert scale to respond to 25 statements, 30 'true-false' statements from the Marlowe-Crowne Social Desirability Scale, and researcher observation	• Men view robots as more human-like, provide more social facilitation • Woman, more as machine-like, less engaged in arithmetic tasks	Challenges: • Distinguishing effect of robot (in general) from voice, specifically • Documenting and quantify gender difference • Explaining why differences exist

TABLE 2. ***(Continued.)*** **Robots used in elderly care.**

	condition (male vs female); difficulty ordering (easy to difficult and difficult to easy)				
Petersen et al. (2016) [28]	- Randomized block design (RBD) with pre-post test - Pet seal robot: *PARO* - zoomorphic therapeutic robot; programmable, interactive, responsive and adaptive; without touchscreen: available for clinical and home use - Intervention: IG: robotic pet therapy CG: standard care, including physical activity, music, and mental stimulation	- 61 participants with dementia: IG: 35 and CG: 26 - Mean age: 83. 4 +/- 5.8 & 83.3 +/- 6.0 - Length: 12-week study, exposed once a day for 3 weeks to lessen novelty effect. - Excluded: physical limitations and pre-existing psychiatric diagnosis	Stress and anxiety Rating for Anxiety in Dementia (RAID), Cornell Scale for Depression in Dementia (CSDD), Global Deterioration Scale (GDS)	- Decreased stress and anxiety; reductions in psychoactive and pain medication	- Not specified
Liang et al. (2017) [29]	- Randomized trial (RT) - Pet seal robot: *PARO* - zoomorphic therapeutic robot; programmable, interactive, responsive and adaptive, without touchscreen: available for clinical and home use - Group intervention: IG: robot pet seal Intervention *PARO*, i.e. stroking etc. CG: conventional therapy	- 24 participants with dementia: (NA) IG 13, CG 11 - Age range: 67 – 98 years - In 2 daycare centers - Length: 6 weeks, 30 min sessions, home/6 weeks; 2-3x/week with follow up 6 weeks and 12 weeks	Behavior, affect and social response; blood pressure and saliva cortisol; hair cortisol (at baseline and at 6 weeks and 12 weeks) Addenbrooke's Cognitive Examination, Cohen-Mansfield Agitation Inventory Short Form, the Neuropsychiatric Inventory Brief Questionnaire Form, and the Cornell Scale for Depression in Dementia	- Improved emotional and social function (affect and staff/participant interaction) - Higher cognitive capacity = greater response - No significant difference of behavior and physiological measures	- Small sample size due to lack of comprehension and inability Challenges - Thinning or very thin hair producing produced less cortisol levels - Recruiting and maintaining participants
Sung et al. (2014) [30]	- Pilot Study with pre-post design of robot-assisted therapy for older adults - Non-random assignment (assumed) - Pet seal robot: *PARO* - zoomorphic therapeutic robot; programmable, interactive, responsive and adaptive, without touchscreen: available for clinical and home use - Group intervention: Pet robot interaction: stroking, cuddling etc.	- 16 physically healthy participants with seal robot - 9 males, 3 females - Mean age: 77.25 - Length: 4 weeks, twice a week of 30-minute sessions residential care facility - 12 completed	Communication and interaction skills as a result of robot-assisted therapy for older adults Tool: Assessment of Communication and Interaction Skills (ASIS-C) & Activity Participation Scale (APS)	- Significant improvement in communication and interaction skills and activity participation	- Group setting with only one PARO - Small sample with one group - Extraneous variables: impact of contact with research assistance and staff - Hawthorne effect (awareness of participation in test)

TABLE 2. ***(Continued.)*** **Robots used in elderly care.**

Polak et al. (2018) [31]	• Qualitative Usability Study • Humanoid robot: *Pepper* - programmable, interactive; responsive and adaptive: available mainly for clinical and profession use only • Individual intervention: Non-embodied computer and humanoid robot tasks, followed by preference survey	• 60 (evidently) healthy participants: 30 "older" & 30 "younger" • Age range: 'old': 10 age 65 to 77 years, 20 63 – 75 years, 'young': 22 – 28 years, and 23 – 28 years	Age-related (young or old) differences of response to humanoid robot and computer screen Tool: custom-built preference questionnaire, and statistical analysis using the SPSS Statistics Toolbox	• Significant preference for robot over computer screen for both age groups. Stronger pref. by young. Both: robot more interesting and human-like	• Slow response time of robot
Valenti-Soler et al. (2015) [32]	• Randomized (in blocks) controlled trial. (RTC) • Pet seal robot: *PARO* humanoid Humanoid robot: *NAO* – programmable, interactive; responsive and adaptive; fully open and developable platform, without tablet: available for clinical use only; vs live animal (2 black Labrador Retrievers) • Group and individual intervention: introduction of 2 types of robots and trained dog into conventional therapy / interactions & therapeutic activities: identifying numbers, words, and colors using flash cards	• 71 participants with advanced dementia: IG 33 and CG 38, • Total study age range: 58 - 101 years • Nursing home • Phase 1 Age range: 58 - 100 years Mean age: 84.68 • Phase 2 Age range: 59 - 101 years Mean age: 84.7 years • Day Care Center • Phase 1 Age range: 68 - 87 years Mean age: 77.9 years • Phase 2 Age range: 69 - 87 years Mean age: 79 • Length: 3 months/2 days per week, 30-40 minutes sessions	Social and emotional markers Tools: Global Deterioration Scale (GDS), the sMMSE, the MMSE, the Neuropsychiatric Inventory (NPI), the Apathy Scale for Institutionalized Patients with Dementia Nursing Home version (APADEM-NH), and the Apathy Inventory (AI) and the Quality of Life Scale (QUALID)	• Improved healthy (lower stress), mood (feelings of loneliness), communication; lessened severity of dementia on specific scales • Phase 1 improvement apathy in robot group • NAO (robot group) decline in cognition in MMSE (increased delusion), but not sMMSE; and increased irritability • Phase 2 QUALID scores increased in PARO; increased hallucinations and irritability in both robot/animal vs CG • Phase 1: improvement in NPI irritability	• Small sample size; in nursing home • Randomization done by unit, not individuals

isolation strengthens feelings of depression and diminishes cognitive focus [16]; anxiety can impede the capacity for abstract thought [43]. Because of this, both cognitive and social-emotional measures as a result of exposure to or direct cognitive training with robots were examined. Of studies exploring these themes, five examined the impact of cognitive training [24]–[26], [29], [32], while an additional six focused on social and emotional impact [19], [28]–[30], [32], [33]. Of the five which examined cognitive function, four found impact in specific areas [24]–[26], [32], including judgement [24], verbal scores [24], [26], executive function, memory function (in general) [24], visual memory (specifically), motivation [25] and prose memory [26]; and one focused on general markers of dementia and quality of life [32]. Of the

TABLE 2. ***(Continued.)*** **Robots used in elderly care.**

Takayanagi et al., (2014) [33]	• Experimental study • Pet seal robot: *PARO* - zoomorphic therapeutic robot; programmable, interactive, responsive and adaptive; without touchscreen: available for clinical and home use: intervention condition (IC) • Stuffed toy lion: control condition (CC) • Coded behavior video-taped; frequency of was calculated and analyzed • Individual intervention: Pet robot interactions: petting, talking with, cuddling etc.	• 30 elderly men and women in private rooms of nursing home • M-group (mild/moderate dementia): 19 members, with mean age: 84.9 + 9.1 years • S-group (severe dementia): 11 members with mean age 87.5 + 12.8 year • Hasegawa's Dementia Scale (similar to the MMSE) used to determine participant inclusion: M-group mean score: 16.8; S-group mean score: 8.8 Length: 18 months, every 3 to 6 months, 15-minute sessions	Interactions video-taped and behavior (smiling, looking at, touching and talking to) coded and analyzed Mean value of observed frequency of coded behavior calculated Frequency of coded behavior examined using Wilcoxon signed-rank test Statistical analysis carried out with IBM SPPSS Statistics 22.	• With PARO (relative to Lion): Higher observed frequency of positive expression, including laughing (marginally significantly) Reduced subjective reporting of loneliness Spoke more frequently (with PARO than Lion) • PARO popular among all, including those who do not like animals • Both PARO and Lion groups: greater frequency of communication with staff • M-group with Lion: More frequently talked with staff, possibly due to disinterest Greater frequency of touching/stroking Greater observed frequency of negative emotions and need for staff to initiate conversation • S-group: Greater frequency of neutral expression	• Moderately small sample size • No limitations were identified by researchers • Participants not blind to experiment • Information not collected on gender preference or response

six which explored social and emotional function and well-being, five identified impact in the following general marker of social health: social engagement, communication, social response, interaction within group activity, connectedness, general health and quality of life [19], [30], [29], [32], [33]; whereas, one observed the specific markers related to verbal communication [19]. Of the two which explored emotional measurements [28], [29], changes were noted on specific physical measurements, such as saliva and hair cortisol levels as they pertain to stress, behavioral agitation, and blood pressure, and general markers, including, neuropsychiatric symptoms [29], depressive symptoms [28], [29], and stress, anxiety and global deterioration [28]. Two experiments individually explored preference or response as they pertain to robot presence in the lab; one examined impact of gender [27] and the other the role of age, i.e. being 'younger' or 'older' [31].

D. THE USE OF ROBOTS IN ELDERLY CARE

Nine studies [24]–[26], [19], [28]–[30], [32], [33] which highlighted attributes which suggested the potential positive impact of the introduction of robots into elderly care were shortlisted (Table 2). Of these, five studies [24]–[26], [28], [32] examined the impact on cognition as a result of robot use in therapy; whereas, three specifically utilized humanoid or pet robots in cognitive training with the elderly [25], [26], [32]. From this group only two focused on cognitive training of elderly individuals experiencing age-related cognitive decline, specifically [26], [32]. Most of the studies examined the effect of robots used predominantly as a companion or explored their role in affective therapy [24], [19], [27]–[31], [33]. All robotic studies found evidence of a positive impact of the robot presence relative to traditional therapy and interventions, with only one noting some mixed findings [32].

E. ARTIFICIAL INTELLIGENCE (AI), MACHINE LEARNING (ML) AND COGNITIVE TRAINING

Research in educational psychology shows that instruction is most impactful when it is geared to the level of the student and meets her immediate needs, rather than a particular standard or institutional objective. Specifically, instruction needs to be, as education theorist Lev Vygotsky observed, within a zone of proximal development (ZPD) [34]. This is a level of instructional challenge that is precisely within a range or zone where student learning is optimized. And, this is a dynamic zone. It changes with time and instruction, and the emotional and physical state of the learner. At the most fundamental level, if instruction is effective the student will, in a sense, change, and this change will require an adjustment in the focus, approach and difficulty of instruction. To keep the impact of instruction optimal, therefore, it is imperative that the individual receiving cognitive training be continuously monitored. If there is decay in the participant's cognitive faculty, instruction will need to be altered to reflect this. Should an improvement or learning occur, instruction consequently must reflect the changing need.

Advances in AI suggest that this optimization is possible. AI can be understood as an ''intelligent agent'' that perceives its environment, or collects data, and uses this new data to take appropriate actions to create maximum impact towards a particular goal [35]. When working with human beings this data collection requires many steps, a variety of information modes (audio, visual, text, etc.) and is highly variable. It is consequently less deterministic, more stochastic. Because of this, an intelligent agent would need to demonstrate the capacity to process, and make meaningful, highly complex data to optimize its effectiveness. This would only be possible if the intelligent agent could *learn* continuously, or, in other words, rewrite its own code [35].

This changing data gathered from human subjects is by necessity highly complex and so unprecedented computational power is required. Steady developments in computational power suggest that this need can be met. In 1965, Intel founder Gordon E. Moore predicted that the capacity of integrated circuits, which are responsible for the computer's computational power, could be expected to double at a rate of every two years, approximately [36]. In 1971, his Intel 4004 possessed in the neighborhood of 2300 transistors; by 2016, the world had produced the fastest chip with 10 billion transistors [33]. This has translated into super computational power. The computational power of 1970 was just 10 per second; presently, we are capable of 10 billion computations. As a result of this shift in computational power health care service providers are able to meet certain demands, and the capacity for Machine Learning (ML), a subset of AI in which the intelligent agent learns from experience and improves performance [35], has been demonstrated [37].

There are certain challenges, however. The quality of the potential computing is dependent upon the actual data collected. In addition, it must be meticulously organized into ''training data'' so that the ability to learn is possible. To be effective, the quality of the data must be high, and the quantity significant. The term ''big data'' is used to describe the latter. The gathering of this large quantity of data and its necessary formatting into ''structured data'' to enable processing is, at present, highly time consuming. Additionally, programmers, while necessarily highly skilled, are not experts in the relevant fields, in this case human cognition, if not also neuropsychology, psychiatry and psychology. This creates longer developmental cycles which have the potential to delay the delivery of much-needed health services, such as cognitive training for the elderly.

One solution is the development of new computational models which scientists note approximate the way learning occurs in the human brain. These models loosely utilize a neurological paradigm. This paradigm has data processed in a multileveled network of neuromorphic chips that allows information to grow exponentially more complex and ''meaningful'' by assigning a logical construct to the information at each step. Instead of utilizing a conventional Von Neumann architecture which separates memory and processing and has data moving back and forth between the two like a standard computer, the neuromorphic chip stores and processes data in the same chip or node before passing it on to the next node, thereby optimizing information processing. Scientists refer to this network as Artificial Neural Networks (ANNs). When these networks are combined the process grows progressively more complex, producing the capacity for what scientists call Deep Learning. The possibilities of Deep Learning provide great optimism for the medical community.

Already scientists believe AI has reached the point of rivalling the effectiveness of trained pathologists on particular tasks. An example of this is the use of Computer Assisted Diagnosis (CAD) which utilizes Machine Learning. Of the analysis using CAD of mammograms of woman who later developed breast cancer, cancers were identified as early as a year before official diagnosis by human technicians and doctors [38]. Likewise, similar pattern recognition capabilities have been shown to be very accurate at reading radiographs [35].

All healthcare professionals know that engagement in one's treatment is paramount, and AI has been shown to improve this. From a survey of 300 leaders and healthcare executives, 42% of respondents noted that of those patients *without* AI support just 25% were ''highly engaged'' with their treatment. If patients are unable to move beyond diagnosis, the prognosis is dire [39]. Fortunately, AI has demonstrated the ability to nudge patients towards engagement and effective treatment pathways via the various ubiquitous information gathering and delivery routes, such as smartphones, watches, and conversational interfaces [40]. The increasing computational capacity of AI, coupled with concurrent developments in ambient intelligence (AmI), such as of natural language processing (NLP), eye and face tracking, gesture and speech processing, which can be embedded in robotic agents, will produce a steadily increasing quantity of data [41]. This increase in intelligence will allow AI cognitive training systems to more effectively identify and *respond* to the individual's cognitive and emotional needs. This will optimize the capacity of cognitive training since not only will instruction be placed squarely in the elderly individual's zone of proximal development (ZPD) but the robots, programmed to produce appropriate human emotional responses, will communicate a recognition of the patient's humanity, strengthening engagement [42]. This humanizing potential, when embedded in an appropriate robotic form, may allow, finally, the potential impact of cognitive training to be realized. Rather than identifying an approximation of the elderly individual's needs and providing cold and standardized training to an imagined patient, AI will never stop gathering information and, consequently, training will remain closely aligned to the needs of the *whole*, ever-changing individual.

IV. DISCUSSION

This review a) summarizes the experimental human robot interventions being explored to meet the cognitive needs of an aging population, b) examines both age and gender response to this emerging technology, c) discusses concerns this technology raises that require address by the healthcare profession and caregivers, and finally, d) explores recent developments in AI and how these have the potential to optimize the impact of SAR interventions.

Based on this review, the research findings of 11 papers can divided into three streams: 1) those that explore the potential impact of human robot intervention on the cognition of elderly individuals who may be vulnerable to age-related cognitive decline, 2) those papers which explore the social-emotional impact of human robot intervention; and, finally, 3) those which explore the response to humanoid robot of individuals categorically defined under gender and age. In general, the use of humanoid and pet robots for both cognitive training and as an assistive element in daily activities and to support therapeutic objectives has been shown to have a positive impact on the cognition and social-emotional aspects of its users. There is one minor exception, however. In the case of research performed by Sung *et al.* [30], though overall quality of life markers rose while markers of dementia dropped, with the humanoid group researchers noted increased delusion in the Mini Mental State Exam (MMSE).

Five studies (235 participants) examined the impact on cognition of SAR, both humanoid and pet robot, for example the pet robot seal PARO. These studies can be broadly divided into two categorical approaches, 1) group intervention designs with the SAR, and 2) individual, one-on-one interactions with SARs. The aspects focused on in this cognitive training included executive function and working memory. Included in this were two studies (119 participants) with elderly individuals identified as healthy and three studies (116 participants) with elderly individuals with dementia. Although a wide array of markers was gathered across the five studies it can be concluded that four studies explored here using the cognitive intervention strategies with SAR technology produced improvements in cognition. One study produced [25] mixed findings. Due to the heterogeneity of robot types (humanoid, pet robots of several varieties) however, while extensive generalizations from these studies may be made, caution might be warranted regarding the superiority of any individual robot model.

A. COGNITIVE IMPACT

A significant number of trials have been conducted to determine the effectiveness of an array of conventional and cutting-edge methods of cognitive interventions available to address the growing needs of those with age-related cognitive decline. Overall, though the findings allow for mixed interpretation, evidence suggests a meaningful impact on cognitive markers of symptoms, with a more confident positive conclusions regarding the impact on social and emotional measures - reason for optimism - in regard to age-related cognitive decline.

Two of the studies, both randomized control trials (RCT), used standardized tools to assess the cognitive states of its research participants. The first trial, a randomized control block trial (RCBT) conducted by Soler *et al.* [32] in 2015, compared the impact of humanoid robot, animal shaped robot, an actual dog and conventional cognitive therapy as treatment for individuals with advanced dementia. Subjects were organized into a Phase 1 or a Phase 2 group. Phase 1 had 101 participants (30 with the NAO humanoid robot, 33 with PARO the robot seal, and 38 in the control group). Phase 2 had 110 participants (42 with PARO, 36 with the dog group, and 32 in the CG. NAO is a 58 cm tall white humanoid robot. It is capable of speech recognition and dialogue and includes cameras that allow it to identify shapes, objects and its subjects [76]. PARO, designed to resemble a seal, has 12 sensors beneath its white soft fur exterior which allow it to respond to patting and cuddling, in addition to the human voice, by moving its tail and closing its eyes. It can also respond to the human voice. Additionally, it remembers faces, learns actions to produce positive reactions from its users, and actively seeks eye-contact [77]. All participants interacted with the therapists, animals and robots while performing such therapeutic activities as identifying words and colors with flashcards, performing ADL, and sensory stimulation. In this experiment, both groups included only those with advanced dementia and researchers observed a lowering of markers of dementia severity on specific measurements in both Phases. However, while with the Phase 2 PARO group, researchers noted a rise in quality of life scores, participants in the Phase 1 NAO group displayed, interestingly, signs of cognitive decline - though due to the extremity of the participants' dementia this is to be expected. Of the latter, these included increased delusion in MMSE, though not in the sMMSE [32]. (See Table 2 for intervention details.)

In the second RCT, conducted in 2012 at Osaka City University Graduate School of Medicine, findings were not mixed. Researchers used the Kabochan Nodding Communication Robot (speaking humanoid) and the same robot as the control robot (but without communication elements of speaking and nodding). The Kabochan Nodding Communication Robot is a humanoid robot designed to resemble, in form, speech and motion, a three-year-old boy. This 8-week trial, which included a pre and post-test, placed the intervention robot or the controlled robot in the homes of 34 elderly participants with dementia or predementia. With the intervention group (IG) researchers found an improvement in judgement, verbal scores, and in areas of executive and memory function [24].

Another RCT [25], conducted over a 12-week period, used a two-level diagnostic approach to measure robot-assisted cognitive training. Understanding that cognitive thinning occurs naturally with age and is associated with cognitive decline, the focus of the study was to test the hypothesis that multidomain cognitive training would both delay the progress of cognitive thinning and improve cognition. Conducted in 2015 at the Samsung Medical Center in Korea, researchers hoped to distinguish the impact of traditional cognitive training from cognitive training with a humanoid robot.

Kim *et al.* 25] used 85 individuals, aged 60 and older, without cognitive impairment and measured cortical thickness and cognitive function before and after intervention. In this study 24 individuals received traditional cognitive training, 24 received cognitive training with a humanoid robot (Silbot or Mero), and 37 individuals were members of the CG receiving no cognitive training. Both humanoid robots used 17 cognitive training programs. Except for three programs which monitored and evaluated subject movement, participants responded to all instruction via the Galaxy tab 10.1 smart pad accompanying the robots. These robots provided immediate feedback and encouragement upon completion of individual tasks. For those receiving cognitive training there were 44 blocks of exercises. 14 were devoted to language. 12 focused on mathematical calculations. 16 aimed to improve visuospatial function. The final block attempted to strengthen executive function. As a result of the robot intervention, [25] were able to demonstrate attenuation of cortical thinning in a variety of regions. While the traditional IG experienced greater general cognitive scores and improvement of visual memory, robot training produced greater increases in executive function on the SOC. Additionally, according to Kim *et al.* [25], this improved executive function was positively correlated with attenuation of thinning in the inferior temporal gyrus and the left temporoparietal junction and suggests robot cognitive training can be used to produce meaningful structural brain changes.

Two additional studies which examined the effects on specific aspects of cognition were published by Pino *et al.* [26] in 2019 and Liang *et al.* [29] in 2017.

In the first study, researchers led by Pino [26] of the University of Parma conducted a non-blinded control study examining cognitive interventions performed in conjunction with conventional therapy. Five tasks were employed using NAO: story reading, content questions, associated or not associated words, and associated and not associated word recall. Pino and associates found that HRI not only reinforced therapeutic behavior and an adherence to treatment but had seemingly additional benefits. These possible benefits included, importantly, significant change in prose memory and verbal fluency. The authors of the paper state that identification of the cause of these possible benefits cannot be confirmed as a result of the research design. They suggest the implementation of a larger sample distributed across independent groups [26] to improve generalizability.

A related but small pilot randomized study was performed in 2017 at the University of Auckland. In this study by Liang and associates [29], researchers focused on cognitive function, generally. Conducted at two daycare centers in New Zealand using 24 elderly participants with dementia, 13 people members were allocated to the IG which incorporated multi-sensory behavioral therapy (MSBT) with pet robot seal PARO into the therapy, while 11 were placed in the CG receiving conventional therapy. Researchers found after six weeks of 30 minutes sessions two to three times a week, with a further follow-up six- and 12-weeks post trial, participants in the IG showed higher cognitive capacity and greater response in general. Researchers noted, importantly, that significant differences in cognitive scores were demonstrated by those with greater cognitive capacity compared with those who were more greatly cognitively impaired. It is asserted by researchers that this is due to the fact that those with higher cognitive capacity are more able to engage in meaningful interactions as they draw more significantly on their background information and access their cognitive resources.

B. SOCIAL AND EMOTIONAL IMPACT

In addition to the overall cognitive benefits, social and companion robot intervention has demonstrated meaningful social and emotional impact for elderly individuals with symptoms of age-related cognitive decline.

Six studies (212 participants) explored both the social and emotional impact of introducing SARs into group therapy [19], [28]–[32], [33]. These studies compared the changes in respect to various interventions (conventional, trained animal and robot, whether pet robots such as CuDDler, PARO, or humanoid, such as NAO). The emotional and social aspects explored included anxiety and stress, and increased patient-staff interaction and improved facial expression. Included in these six studies was one (16 participants) with elderly individuals who were identified as healthy [30]; and five studies (196 participants) with elderly individuals possessing dementia [19], [28], [29], [32], [33]. Of the remaining five, one (40 participants) had individuals along a spectrum from MCI to ‘‘severely’’ cognitive impaired [33]; one study (71 participants) included individuals with ‘‘advanced’’ or ‘‘severe’’ dementia [32]. The last two studies (85 participants) included individuals simply identified categorically with dementia [29], [28]. One paper [28] focused exclusively on markers of emotional impact; three studies [29], [32], [33] identified emotional and social effects; three papers studies [19], [30], [33] examined social impact. All studies noted an improvement in markers of emotional wellbeing, such as improvement in measures of apathy, a significant rise in emotional function, and increased interactions with staff and group members.

Petersen *et al.* [28] of Jilin University compared the impact of robotic pet therapy and conventional therapy. Using an RCBT of 61 participants researchers placed 35 individuals in an IG and 26 in the CG. During this 12-week study in 2016 elderly individuals with dementia, averaging in age 83 years of age, were either exposed three-times a week to 20-minute session of physical, activity, music and mental stimulation, or therapeutic robotic pet (PARO) interactions. (To lessen the novelty effect, prior to the study the IG was daily exposed for three weeks to the robotic pet.) Researchers found that participants within the IG had lower measurements of stress and anxiety and demonstrated a lowered need for psychoactive and pain medication [28]. These findings are consonant with those of the research team led by Pino of the University of Bari. According to Pino *et al.* [26], which used a non-blind controlled trail with a humanoid robot, these benefits also include not only an increase in visual gaze but also an alleviation of depressive symptoms.

The three following studies examined both emotional and social markers of robot intervention.

In 2014, Takayanagi *et al.* [33] of Nippon Medical School, in Japan compared the social and emotional response of elderly individuals to the pet seal PARO (intervention condition) and a stuffed lion (controlled condition). Using an experimental design, researchers divided 30 volunteers in two groups: an 'M-group' of in 19 participants with mild to moderate dementia in the general ward of a nursing care facility; and an 'S-group of 11 participants with severe dementia in the dementia ward of the same facility [33]. During the study participants were exposed to either PARO or the Lion for fifteen minutes, every three to six months for an 18-month period. Video-taped behavior of interaction was codified and analyzed. Researchers found with PARO that all participants demonstrated reduced self-reporting of loneliness, and a greater frequency of initiated communication and positive expression, such as laughter. With the M-group there was a marginally significant increase in the latter. With the S-group participants showed less frequency of positive engagement with the lion [33].

In an RCT conducted by Liang employed the companion seal robot PARO as the tool of intervention with 24 elderly individuals with dementia. Using measurements gathered at baseline, then at six and 12 weeks, researchers found participants demonstrated an improvement in emotional and social function, including affect and increase in patient-staff interaction. No behavior or physiological measures, however, reached a statistically significant range [29]

The study by Soler *et al.* [32] (discussed above on cognitive impact) which compared interventions with NAO, PARO and a trained dog showed comparable positive social and emotional response. Specifically, researchers noted improvement on social emotional markers. Soler *et al.* [32] also identified improved health and mood, including lower measures of stress and feelings of loneliness, and enhanced communication. It is likely that the treatment with the PARO, previously shown to decrease stress and anxiety [28], contributed to the ability of participants to focus outward and engage socially, thereby improving communication. Noteworthy, however, with the Phase 1 NAO humanoid robot group, researchers noted improvement in apathy, though with a noted increase in irritability. The latter was also noted with the PARO robot seal group. In Phase 2, while researchers observed a rise in quality of life scores, they were offset by increased hallucinations in all groups, including the CG [32].

Of the five studies, two examined the social impact on elderly individuals in group therapy employing a non-verbal pet robot. The first, a pilot study, led by Sung *et al.* [30] from Tzu Chi University of Science and Technology in Taiwan in 2014, used a pre-post design with the PARO seal robot and identified the impact on social interaction of healthy institutionalized elderly adults. During this study 16 participants were exposed to the pet robot for 30-minute sessions, twice a week, for a period of 12 weeks. Researchers found that participants experienced significant improvement in interaction skills and communication.

A related observational study conducted by Sabanovic *et al.* [19] at Indiana University and the Centerstone Research Institute in the United States identified both direct and indirect benefits of exposure to the pet seal robot PARO. In this study, published in 2013, seven residents with mild-to-severe cognitive impairment underwent multi-sensory behavioral therapy (MSBT) with PARO for 30 to 45-minute therapist-mediated group sessions. During the seven-week period researchers gathered baseline information on visual behaviors towards PARO and vocalization behaviors with PARO, but also other participants and staff. Measures were then taken of the behaviors in the final session and the difference was calculated to quantify impact. These behaviors included the visual (looking), verbal (speaking, singing, or generating other sounds such as cooing) and any physical behavior such as petting, kissing, or sharing the robot pet. A direct benefit observed by the researchers was an increase of verbal communication with PARO (more than doubling verbal communication over the study period), and an indirect benefit was an increase in interaction among group members during sessions (more than tripling the interactions of group members not directly engaged with PARO). Of note was an observed increase in both of these benefits throughout the seven-week period, which suggests to the researchers that the benefits of exposure to the PARO robot were not simply a consequence of the 'novelty effect' [19]

C. USER PREFERENCE

Interestingly, there seem to be both differences and similarities concerning gender and age as they relate to response to robot assistants. In 2008, researchers from the University of Notre Dame and Indiana University published findings from a controlled trial (CT) which examined the responses of men and women to the presence of a robot while performing math equations. The ActiveMedia Peoplebot used in this trial, only nominally humanoid due to lack of aesthetic exterior design considerations, communicated to participants through a pre-programmed script. During this trial 47 subjects, 24 males and 23 female Psychology and Engineering undergraduate students, were tasked with completing arithmetic equations that progressed from easy to difficult, or difficult to easy, in the presence of the ActiveMedia Peoplebot. Researchers found that men tended to view the robot as more human-like while females identified it as more machine-like with the consequence that the latter were engaged less in the arithmetic tasks. Researchers concluded that the robot presence did not facilitate the mathematical tasks [27]. Confidence in this study's findings, however, is undermined by the fact that the distribution of the gender of the participants from each department is not made clear. Without confirmation that gender is evenly distributed, the subjects' affinity and interest pertaining to robots cannot be ruled out as a factor of influence.

In contrast, a study published by Polak of Ben Gurion University in 2018 [30] explored the responses of young adults in their early twenties and older individuals, aged 69 and older, as they relate to a robot. This qualitative usability study (QUS) included 60 individuals, evenly divided between ‘older’ and ‘younger’. Pepper, the white humanoid robot used in this study, stands at 1.2 meters [78] and recognizes faces and basic human emotions. It also is capable of multimodal interactions (including speech) and has a touchscreen mounted on its chest [78]. During this study subjects were required to reproduce a sequence of colored cups presented on the touchscreen and, upon completion of the task, to either touch the robot’s hand or the screen. Findings indicated both age groups had significant preferences for Pepper, a robot humanoid, as expressed in a personal preference questionnaire, while the younger group preference was meaningfully stronger (80% compared to 50%). Both reported finding the humanoid robot more human-like and interesting [31]. This might be explained by the mechanism within the Uncanny Valley Effect as each participant would naturally have attempted to compare and contrast the humanoid with herself, with the robot manifesting aspects meaningfully different, but similar enough to not illicit rejection [44].

D. LIMITATIONS TO FINDINGS OF INTEGRATION OF SAR ROBOTS INTO THERAPY OR ASSISTANCE FOR ELDERLY INDIVIDUALS EXPERIENCING COGNITIVE DECLINE

There were several limitations acknowledged by the individual researchers, and which existed across the research in general. First, most researchers stated that generalizability or reproducibility was compromised by sample size. Except for four [25], [27], [28], [32], all were limited by sample size. Similarly, two [1], [4] with their short duration periods, recommended caution as it pertained to generalizing - and confidence in its reproducibility. One paper pointed to its heterogeneity of focus (quality of life and cognitive) function as a limitation, while another to its levels of dementia. One study [25] highlighted its uneven distribution of women in the study, an inability to limit participants cognitive activity outside of the experiment, and the increased physical activity of its robot group, relative to the traditional cognitive intervention and CG, noting that exercise can affect the rate of cortical thinning in the anterior cingulate cortex (ACC). Finally, two studies [26], [30] identified as a limitation the lack of a single- or double-blind aspect of its study; while another [32] stated that generalizability was hindered because randomization occurred at the block level, rather than the individual level.

E. POTENTIAL ISSUES OF INTEGRATING AI AND ROBOT INTERVENTIONS INTO REGULAR THERAPEUTIC PRACTICE

Despite the proven and potential benefits of Artificial Intelligence and SARs as tools of intervention to mitigate the symptoms of age-related cognitive decline, there are a number of concerns which arise related to user attachment and social neglect, possible practitioner disinterest, the technical requirements of health service providers and the prohibitive costs of robots.

Interventions for elderly individuals experiencing age-related cognitive decline necessarily means that subjects will lack various degrees of incapacitation that make ethical participation in such an interaction contentious. Put simply, participants may not understand the actual capacities of the machines they interact with. Humanoid robots are designed, significantly, to mimic human behavior; they follow conventional social scripts while responding to the individual or asking questions to ease the flow of an interaction or to gather information for assessment. As a result of the seeming naturalness of the interaction, disoriented individuals suffering from cognitive decline may genuinely feel they have developed a relationship with their machine [45]. This too may happen with pet robots such as PARO. While it seems that the creators, manufacturers, and suppliers of these robots and their associated practitioners may intend to make clear that their products/tools are not human, or otherwise, and therefore incapable of developing relationships, the potential issue may not be avoided [46]. Of tremendous relevance is the fact that it has been observed that the mirror neuron network in the cerebral cortex, which is responsible for the experience of human empathy, is active during HRI [47]. The sensation of empathy normally occurs when a pattern of synaptic firing (associated with an observed facial expression and emotion) is mirrored in the observer’s own cortex. When this occurs, the observer experiences a similar, if less intense, version of the emotion expressed by the first person [43]. This can only strengthen an individual’s connection to the robot and has a number of implications.

Clearly, human beings of an advanced age who suffer from cognitive decline will come to view SARs as real companions. Because of this, they are capable of developing, at least in their minds, relationships with these machines [47]. Consequently, attachment should be expected [48]. As a result, despite a possible clear and formal notification beforehand, the complications that can evolve and the user distress that may ensue, for instance with the disruption of technical breakdown, model obsolescence and upgrades of SARs, should be expected and consequence of this for the user could be traumatic [49].

On a related note, because of the engaging nature of SAR combined with overwhelming pressures we can expect on future health services, as elderly populations grow exponentially, these tools designed to meet the needs of this vulnerable people could be at risk of becoming a substitute for real social interaction. While the cognitive benefits and positive impact of increasing users’ social engagement with caregivers and others as a result of interacting with the SARs has been established, these instruments are designed specifically to enrich cognition and human interaction, not to replace human relationships [50]. Still, with the engaging nature of this modern technology, especially when coupled with the discussed potential of AI, we should be cautious not to allow SARs to replace genuine human contact.

All cutting-edge technologies naturally provide technical challenges to those first tasked to utilize them. SARs do not represent an exception. In fact, even with time, the skill set required to effectively utilize this new technology may be beyond that of the average practitioner or medical staff in the field of elderly care. While the latter may understand the benefits and the wisdom of the methodology, they may simply lack the skills to effectively meet the objectives of the instrument. Furthermore, if this technology is indeed effective, or if the needs of the individual receiving treatment change due to deterioration, it will be imperative that the original application of the SARs evolve to meet the altered needs. Consequently, while progressively more user-friendly robots will surely come on the market, in the meantime, a theoretical and practical understanding of the individual SARs programming will be required [51]. Until this occurs, the ability to keep up with this change may not be financially reasonable [52], [53] and it may ignite employment anxiety in health services.

In addition to the absence of adequately skilled professionals capable of comfortably and effectively utilizing robots to improve cognition and social-emotional health, there may be, simply, a lack of genuine vigor by present practitioners to embrace this new, powerful technology. There may be resistance, in fact, for a number of well-considered reasons. The most obvious concern is that the history of technological innovation has shown that individual and organizational adaptation is required both within the field and outside as workers have consistently found themselves displaced. Innovations particularly as they relate to robots and automation, for example in the auto sector and manufacturing, have shown that new technology creates worker uncertainty and unemployment as human workers are replaced by robots [54]. Recent events have demonstrated, however, that while resistance should be expected, at least initially, over time new technologies tend to be embraced [55]. In additional, importantly, according to Rabbitt *et al.* [56], SARs are not, in fact, designed to replace practitioners of cognitive intervention of the elderly, but more specifically to augment and extend their effect. For example, once an individual user can work independently on a particular task, the health practitioner would then be freed up to assist others requiring her attention. This allows the practitioner's highly specialized skills to have greatest impact exactly when they are needed most, rather than be bogged down with repetitive, rudimentary tasks [56].

All new technologies present the challenge of affordability, and this is most pronounced when first introduced. Indeed, with robot technology there are the various costs of not only purchasing, maintaining and the programming, but of also training if the general knowledge of the clinical staff fails to meet the requirements. Certainly, if the object of modern cognitive training is to truly benefit from the most up-to-date robot hardware and software, with staff optimally equipped to employ best practice, the potential high cost of regular upgrades and staff training must be calculated and soberly considered, that is, at until the Deep Learning potential of AI is ultimately realized.

Finally, while the possible benefits of AI, robotics and big data have been discussed and seem certain as computing power increases, concern has been expressed in the public sphere regarding the ethics of information collection and the possible abuse or error as it pertains particularly to medical insurance coverage. Large insurance companies such as John Hancock have recently employed the use of biosensors and behavioral economics apparently in an effort to nudge the public to embrace evidence-based healthy practices [57]. These efforts have been coupled with a reward system that identifies individuals who embrace these best practices [57]. This raises the concern of what the consulting firm McKinsey calls 'personalized pricing' [58]. On the surface, the concept seems innocuous, but insurance recipients of Idaho's Medicaid program who have used biosensors have in fact, found their premiums rise by as much as 30 % [59]. Certainly, if a SAR were to identify symptoms that indicated that a desired improvement, or an attenuation of symptoms, was not occurring, a similar response by insurance providers might be predicted. In short, a sensor embedded in a robotic device that continuously monitored a patient's progress could also be used to flag an individual whose future treatment could be predicted to grow more expensive. This might not only produce a discontinuation of a much-needed SAR cognitive or socio-emotional intervention but also affect general medical coverage. Additionally, while the issue of eliminating unconscious bias in AI algorithm is an ongoing challenge, researchers point to the unfortunate practice of 'proxy discrimination [58]. 'Proxy discrimination' occurs when a particular bias is inserted in an algorithm to prevent its easy detection. Examples of this include the identification of gender of a job applicant based on the choice of wording in a resume, and a possible pregnancy inferred from keywords used during an internet search. Equally troubling would be substitution of ZIP code for race [59]. In fact, research conducted by ProPublica found that individual residents of a minority neighborhood were required to pay considerably higher car insurance premiums than those from white neighborhoods with the same level of risk [60]. Though this latter issue concerns data collection in a general sense, it might be imaginable that considering the high cost of providing individualized treatment via a SAR this could occur for particular minority groups. In fact, individuals residing in lower income and lower educated neighborhoods may find – as a result of the statistically higher prevalence of chronic diseases in these populations [1] – that those SARs designed to meet their very needs are just out of their reach due to the cost-benefit analysis of an insurance company, if these residents have been granted coverage at all. It might be concluded that such categorical identification and discrimination would more likely occur prior to the commencement of cognitive training via a SAR; still, as data collection continues during

HRI we can assume that additional discriminatory categories might also be created.

F. POTENTIAL LIMITATIONS OF THIS REVIEW

There are limitations to consider with this review. One limitation is that only English language studies were included. It is feasible and likely that quality RCTs have been conducted which we have not included here. Additionally, this review has used studies with a plurality of approaches, for example, there were varying degrees of intervention duration, group and individual interventions, and both an RCT and a qualitative usability study was used. Because of this, generalizability cannot be certain.

G. RECOMMENDATIONS

In light of this review's findings, the researchers would suggest the following recommendations:

1. *Future research should focus on SARs in the home environment.* Since, ultimately, this technology should optimize the attenuation of cognitive decline, or even to halt or prevent it, user-friendly and effective treatment should be explored in the home environment to provide intervention as early as possible.

2. *Affordability of SAR should be made an aim.* The NAO humanoid robot used in several of the studies is presently commercially available; however, at close to 10 thousand dollars for the standard model [80]. it is prohibitively expensive. To maximize to potential of these tools they need to be thus made affordable for home use.

3. *A thorough consideration should be made of many of the practical and ethical issues discussed in this review.* This new technology seems to demonstrate significant positive potential; however, as with all new technologies, strategies to prevent misuse and abuse, while addressing its shortcomings, should be identified.

4. *A new engineering approach must be embraced which addresses the misguided nature of humanoid robot and AI development.* As the research on preference suggests, interest and connection with the robot support engagement during HRI [25], [29]. This engagement naturally strengthens the impact of cognitive training [60]. Because of this, as engineers move forward, designs that strengthen this sense of connectiveness need to be realized. For decades the development of robots has focused significantly on the task of strengthening the similarity of apparent robot movement and general appearance to the human form [61]. Early images of humanoid robots emphasized this association, often, as in the case with Honda's Asimov, shown running, climbing stairs, and hopping on one foot. This has been presented as an indication of progress while, in contrast, for example, the use of wheels for locomotion has been perceived by engineers as "almost cheating" [61]. A list of the robots receiving the greatest fanfare in 2019 include *Atlas* from Boston-based Waltham, China's UBTech *Walker*, Toyota's *T-HR3*, Agility Robotics *Cassie*, and the Honda *E2-DR*. All are humanoid. With its research and development costs projected to reach 3,962.5 Million by 2023, the humanoid robot industry, like the *Asimov* robot which was discontinued in 2018 - appears to demonstrate conspicuous progress [81] while appearing in search of a purpose beyond emulating human capability.

In fact, the embodiment of the humanoid robot introduces a significant hurdle to HRI connectiveness [60], and this requires further consideration. An individual's acceptance or rejection of a humanoid robot form as it progresses along the continuum from 'somewhat resembling human' to 'very strongly resembling human' has been described by [62] with the 'uncanny valley' hypothesis. This description does not address causality. One possible explanation has been provided by ethoroboticists [60] who draw insight from ecology and ethology. Miklósi et al. suggests that because animals possess the life-preserving skill to instinctively place other living agents into various categories ranging from qualities of 'sameness' to 'difference', both a sense of 'appropriate' attraction and the apprehension of threat is experienced by humans when interacting with highly human-like robots, possibly because they fall within the multiple categories [60]. Additional evolutionary [63]–[65], and competing mental representation paradigms [66], [67] have been employed in an attempt to explain the 'uncanny valley' hypothesis.

Recent developments in neuroimaging technology have allowed the human reaction described by the 'uncanny valley' hypothesis to be further understood from an enriched cognitive neuroscience perspective, one which may additionally point the way to overcoming this problem. According to [68], in an effort to maximize efficiency, the mind constructs cognitive models of the world which it uses to organize and predict information gathered from the sense. Perception, understood this way, is a process of inference beginning in the cerebral cortex and extending down to the lower regions of the brain and the sensory organs. While error does occur, it is minimized by employing all levels of processing. What is perceived, in fact, is a consequence of "joint minimization of predictive error" [69]. In other words, since we employ mental models to understand the world, we are only really conscious when our predictions fail [68], [69]. Perception, understood this way, is "controlled hallucination" [69]. Consequently, because this process is beneath the level of consciousness, this researcher suggests that the experience of repulsion identified by the 'uncanny valley' hypothesis may be the continued unsettling condition of the mind which results from being jolted from the comfort of the mental model to the uncertainty of conscious perception when the sense of 'difference' in the robot is perceived repeatedly during HRI. Further research is suggested to confirm this.

The objectives of perfect human embodiment in robots and cognitive intervention are therefore in conflict. The crux of this problem as it relates to HRI is that the efforts of engineers to embody robots with human form will ultimately create greater hurdles to connectedness until those elements constituting 'difference' are completely eliminated. This is unlikely in the foreseeable future.

To overcome this problem, engineers must minimize the negative aspects associated with the 'uncanny valley' while additionally maximizing the positive socioemotional effects of robots that strengthen the individual's experience of connectedness and enhance the efficacy of HRI interaction [60].

Again, cognitive neuroscience points in the direction of a solution. Previously mentioned was the possibility that a lonely and intellectually compromised elderly individual aided by the activation of the mirror neuron system in the cerebral cortex may develop the inability to distinguished reality from fiction and may come to feel a strong and genuine connection to their SAR. This individual's experienced 'theory of mind' of their humanoid robot should not be discredited by that fact that her judgement has been compromised by dementia [70]. The experience of empathy is, for the average person, an unconscious and automatic neurological phenomenon that occurs - as mentioned previously - in the mirror neuron network system of the cerebral cortex and the limbic system of the observer [43]. In addition to the creation of an understanding emotional life of others, our understanding of the intention of others has its roots in phenomenon of 'goal coding' associated with the firing of mirror neurons in the parieto-frontal lobe [71]. When a 'motor act', a movement with a specific motor goal, is observed, the sensory information gathered from observing this behavior is transformed into a representation of the same behavior in the brain of the observer [71]. This creates cognitive empathy and helps us understand the actions of the other individual 'from the inside'. Evidence would suggest that these are building blocks of a 'theory of mind' [72]. Furthermore, research has shown that the mirror neuron system is activated during HRI [47]. While the individual or robot may exist, our sense of their realness, and a 'theory of mind', is clearly substantiated by our neural firing.

Because of this, engineers of the humanoid robot form, and software developers, should a) utilize cognitive neuroscience by considering those mirror neuron patterns which directly contribute to an individual's experience of 'theory of mind' which consequently strengthen preference and a sense of connection that an individual can feel with the robot [60], and b) further optimized the efficacy of SAR by considering design elements which prioritize the specific function of the HRI over the objective of perfectly emulating human form and capacity [60].

V. CONCLUSION

This systematic review has explored the cognitive and socioemotional effect of HRI on the elderly, preferences for these tools as they relate to age and gender, and a number of issues to be addressed by mental health service providers and caregivers. It has also examined the growing potential of Deep Learning by AI, and related technologies, to positively impact robot cognitive training for those individuals experiencing age-related cognitive decline. With regards to AI and Deep Learning, importantly, this review has noted that intelligent agents may have the capacity to make human robot interaction and cognitive training highly patient-centered, thereby significantly raising the value of training. Additionally, this review has demonstrated that, with the exception of one study which showed mixed results, controlled integration of humanoid and pet robots into conventional interventions or ADL, produces benefits for elderly who are healthy *or* along the spectrum of those experiencing age-related cognitive decline. In this review these benefits have been organized into the categories of *cognitive* and *social and emotional*. In general, the cognitive measurements have suggested an improvement in such functions as executive function and memory function. One study found that focused multi-model training attenuated the rate of age-related cortical thinning, both in global structure network topography and specific regions, for example in the right and left medial prefrontal cortex. The latter finding is noteworthy for cognitive training because this region is both instrumental in learning and consistently associated with the cortical thinning that comes with age [25]. Requiring consideration, however, is the study by Valentí-Soler et al. which noted decreased measures in cognition, for example increased delusion. In contrast, all studies which identified markers of social and emotional impact of the utilization of robots (exclusively PARO) found improved social engagement, and the lowering of measurements of stress and anxiety. These findings are meaningful for the objective of improving cognition since it has been shown that both stress and anxiety diminish cognitive performance. In regard to individual preference, this systematic review has noted that both young and old participants appear to respond more positively in experiments to humanoid robots than to the pet robots; whereas men seemed to find the humanoid most acceptable in general. Importantly, the most significant benefits appeared to be conferred upon those participants who responded most agreeably to the robots as this may have strengthened engagement. Additionally, this review has identified some future challenges of both pet and humanoid robot integration into cognitive intervention strategies that need to be considered by society and service providers if we are to effectively meet the needs of the growing elderly population. Furthermore, it has explored the phenomenon of the 'uncanny valley' hypothesis and proposed two recommendations: a) to utilize cognitive science to strengthen the subjective experience of connectiveness with the SAR and, b) to prioritize function of the HRI over the objective of emulating human form and capacity. Finally, this systematic review has acknowledged that the confidence to employ future strategies or to make confident generalizations based on the findings of this review are diminished by the heterogeneity of the study designs and objectives, robot design and function, and sample size and sample duration. While some studies used healthy participants, others included participants experiencing advanced cognitive decline. To strengthen confidence in the findings, by improved reproducibility and generalizability, these elements will need to be addressed.

REFERENCES

[1] S. Pinker, *Enlightenment Now: The Case for Science, Reason, Humanism, and Progress*. New York, NY, USA: Viking, 2018.

[2] J. Abdi, A. Al-Hindawi, T. Ng, and M. P. Vizcaychipi, "Scoping review on the use of socially assistive robot technology in elderly care," *BMJ Open*, vol. 8, no. 2, Feb. 2018, Art. no. e018815, doi: 10.1136/bmjopen-2017-018815.

[3] *National Institution of Population and Social Security*, National Inst. Population Social Secur. Tokyo, Japan, Jan. 2012.

[4] R. Hayashi, M. Beppu, F. Ishii, S. Kamano, M. Kishi, K. Kojima, Y. Korekawa, W. Kureishi, R. Moriizumi, M. Nakagawa, M. Nakamura, K. Toma, K. Watanabe, and K. Yamamoto, "National institute of population and security research," Nat. Inst. Population Social Secur. Tokyo, Japan, Res. Rep. 85, Jul. 2019, ch. 1, pp. 1–16.

[5] G. Leisman, A. A. Moustafa, and T. Shafir, "Thinking, walking, talking: The development of integratory brain function," *Frontiers Public Health*, vol. 4, p. 94, 2016, doi: 10.3389/fpubh.2016.00094.

[6] S. Gauthier, B. Reisberg, M. Zaudig, R. C. Petersen, K. Ritchie, K. Broich, S. Belleville, H. Brodaty, and D. Bennett, "Mild cognitive impairment," *Lancet*, vol. 367, no. 9518, pp. 1262–1270, 2006, doi: 10.1016/S0140-6736(06)68542-5.

[7] G. Magyar, J. Magyar, P. Sinčák, and F. Cavallo, "Using social robots as cognitive stimulation therapy coaches in an elderly care facility," *Researchgate*, Dec. 2017.

[8] M. Leng, P. Liu, P. Zhang, M. Hu, H. Zhou, G. Li, H. Yin, and L. Chen, "Pet robot intervention for people with dementia: A systematic review and meta-analysis of randomized controlled trials," *Psychiatry Res.*, vol. 271, pp. 516–525, Jan. 2019, doi: 10.1016/j.psychres.2018.12.032.

[9] J. P. Vital, M. S. Couceiro, N. M. M. Rodrigues, C. M. Figueiredo, and N. M. F. Ferreira, "Fostering the NAO platform as an elderly care robot," in *Proc. IEEE 2nd Int. Conf. Serious Games Appl. Health (SeGAH)*, May 2013, pp. 1–5.

[10] G. Pichierri, P. Wolf, K. Murer, and E. D. de Bruin, "Cognitive and cognitive-motor interventions affecting physical functioning: A systematic review," *BMC Geriatrics*, vol. 11, no. 1, p. 29, 2011, doi: 10.1186/1471-2318-11-29.

[11] P. Choi, M. Ren, T. G. Phan, M. Callisaya, J. V. Ly, R. Beare, W. Chong, and V. Srikanth, "Silent infarcts and cerebral microbleeds modify the associations of white matter lesions with gait and postural stability: Population-based study," *Stroke*, vol. 43, no. 6, pp. 1505–1510, Jun. 2012, doi: 10.1161/strokeaha.111.647271.

[12] M. Iosa, A. Fusco, G. Morone, and S. Paolucci, "Development and decline of upright gait stability," *Frontiers Aging Neurosci.*, vol. 6, p. 14, Feb. 2014, doi: 10.3389/fnagi.2014.00014.

[13] D. Calhoun, *The Intelligence of a People*. Princeton, NJ, USA: Princeton Univ. Press, 1973.

[14] R. L. Thorndike, "Mr. Binet's test 70 years later," *Educ. Res.*, vol. 4, no. 5, pp. 3–7, May 1975, doi: 10.3102/0013189x004005003.

[15] M. Rönnlund and L.-G. Nilsson, "Flynn effects on sub-factors of episodic and semantic memory: Parallel gains over time and the same set of determining factors," *Neuropsychologia*, vol. 47, no. 11, pp. 2174–2180, Sep. 2009, doi: 10.1016/j.neuropsychologia.2008.11.007.

[16] A. Duckworth, *Grit: Passion, Perseverance, and the Science of Success*. New York, NY, USA: Scribbner, 2016.

[17] H.-M. Gross, C. Schroeter, S. Mueller, M. Volkhardt, E. Einhorn, A. Bley, T. Langner, C. Martin, and M. Merten, "I'll keep an eye on you: Home robot companion for elderly people with cognitive impairment," in *Proc. IEEE Int. Conf. Syst., Man Cybern. (SMC)*, Oct. 2011, pp. 2481–2488.

[18] F. Martín, C. Agüero, J. M. Cañas, G. Abella, R. Benítez, S. Rivero, M. Valenti, and P. Martínez-Martín, "Robots in therapy for dementia patients," *J. Phys. Agents*, vol. 7, no. 1, pp. 48–55, 2013.

[19] S. Sabanovic, C. C. Bennett, W.-L. Chang, and L. Huber, "PARO robot affects diverse interaction modalities in group sensory therapy for older adults with dementia," in *Proc. IEEE 13th Int. Conf. Rehabil. Robot. (ICORR)*, Jun. 2013, pp. 1–6.

[20] R. Nouchi and R. Kawashima, "Improving cognitive function from children to old age: A systematic review of recent smart ageing intervention studies," *Adv. Neurosci.*, vol. 2014, pp. 1–15, Aug. 2014.

[21] D. Moher, A. Liberati, J. Tetzlaff, and D. G. Altman, "Group Preferred reporting items for systematic reviews and meta-analyses: The PRISMA statement," *PLoS Med.*, vol. 6, Jul. 2009, Art. no. e1000097.

[22] J. Broekens, M. Heerink, and H. Rosendal, "Assistive social robots in elderly care: A review," *Gerontechnology*, vol. 8, no. 2, pp. 94–103, 2009, doi: 10.4017/gt.2009.08.02.002.00.

[23] F. Hegel, C. Muhl, B. Wrede, M. Hielscher-Fastabend, and G. Sagerer, "Understanding social robots," Presented at the 2nd Int. Conf. Adv. Comput.-Hum. Interact., Cancun, Mexico, 2009.

[24] M. Tanaka, A. Ishii, E. Yamano, H. Ogikubo, M. Okazaki, K. Kamimura, Y. Konishi, S. Emoto, and Y. Watanabe, "Effect of a human-type communication robot on cognitive function in elderly women living alone. Medical science monitor," *Int. Med. J. Exp. Clin. Res.*, vol. 18, no. 9, 2012, Art. no. CR550, doi: 10.12659/MSM.883350.

[25] G. H. Kim *et al.*, "Structural brain changes after traditional and robot-assisted multi-domain cognitive training in community-dwelling healthy elderly," *PLoS ONE*, vol. 10, no. 4, Apr. 2015, Art. no. e0123251, doi: 10.1371/journal.pone.0123251.

[26] O. Pino, G. Palestra, R. Trevino, and B. Carolis, "The humanoid robot NAO as trainer in a memory program for elderly people with mild cognitive impairment," in *Proc. Int. J. Social Robot.*, 2019, pp. 1–13, doi: 10.1007/s12369-019-00533-y.

[27] P. Schermerhorn, M. Scheutz, and C. R. Crowell, "Robot social presence and gender: Do females view robots differently than males?" in *Proc. 3rd Int. Conf. Hum. Robot Interaction-HRI*, 2008, pp. 263–270, doi: 10.1145/1349822.1349857.

[28] S. Petersen, S. Houston, H. Qin, C. Tague, and J. Studley, "The utilization of robotic pets in dementia care," *J. Alzheimer's Disease*, vol. 5, no. 2, pp. 569–574, 2016, doi: 10.3233/JAD-160703.

[29] A. Liang, I. Piroth, H. Robinson, B. Macdonald, M. Fisher, U. M. Nater, N. Skoluda, and E. Broadbent, "A pilot randomized trial of a companion robot for people with dementia living in the community," *J. Amer. Med. Directors Assoc.*, vol. 18, no. 10, pp. 871–878, Oct. 2017, doi: 10.1016/j.jamda.2017.05.019.

[30] H. Sung, S. Chang, M. Chin, and W. Lee, "Robot-assisted therapy for improving social interactions and activity participation among institutionalized older adults: A pilot study," *Asia–Pacific Psychiatry*, vol. 7, no. 1, pp. 1–6, 2014, doi: 10.1111/appy.12131.

[31] R. Feingold-Polak, A. Elishay, Y. Shahar, M. Stein, Y. Edan, and S. Levy-Tzedek, "Differences between young and old users when interacting with a humanoid robot: A qualitative usability study," *J. Paladyn Behav. Robot.*, vol. 9, no. 1, pp. 183–192, Jul. 2018, doi: 10.1145/3173386.3177046.

[32] M. V. Soler, L. Agüera-Ortiz, J. O. Rodríguez, C. M. Rebolledo, A. P. Muñoz, I. R. Pérez, E. O. Ruiz, A. B. Sánchez, V. H. Cano, L. C. Chillón, S. F. Ruiz, J. L. Alvarez, B. L. Salas, J. M. C. Plaza, F. M. Rico, G. A. Dago, and P. M. Martín, "Social robots in advanced dementia," *Frontiers Aging Neurosci.*, vol. 7, p. 133, Sep. 2015, doi: 10.3389/fnagi.2015.00133.

[33] K. Takayanagi, T. Kirita and T. Shibata, "Comparison of verbal and emotional responses of elderly people with mild/moderate dementia and those with severe dementia in responses to seal robot," *PARO. Frontiers Aging Neurosci.*, vol. 6, p. 257, Sep. 2014, doi: 10.3389/fnagi.2014.00257.

[34] L. S. Vygotsky, *Mind in Society: The Development of Higher Psychological Processes*. Cambridge, MA, USA: Harvard Univ. Press, 1980.

[35] S. A. Bini, "Artificial intelligence, machine learning, deep learning, and cognitive computing: What do these terms mean and how will they impact health care?" *J. Arthroplasty*, vol. 33, no. 8, pp. 2358–2361, Aug. 2018.

[36] K. Rupp. *Moore's Law: Transistors per Microprocessor*. Accessed: Nov. 2, 2018. [Online]. Available: https://ourworldindata.org/grapher/transistors-per-microprocessor

[37] M. Buchanan, "The law of accelerating returns," *Nature Phys.*, vol. 4, no. 7, p. 507, Jul. 2008, doi: 10.1038/nphys1010.

[38] B. Marr. (2016). *The Top 10 AI and Machine Learning Use Cases Everyone Should Know About*. Forbes. [Online]. Available: https://www.forbes.com/sites/bernardmarr/2016/09/30/what-are-the-top-10-use-cases-for-machine- learning-and-ai/#3fa9d29794c9

[39] T. H. Davenport, T. Hongsermeier, K. A. McCord. (2018). *Using AI to Improve Electronic Health Records*. Harvard Business Review. [Online]. Available: https://hbr.org/2018/12/using-ai-to-improve-electronic- health-records

[40] T. Davenport and R. Kalakota, "The potential for artificial intelligence in healthcare," *Future Healthcare J.*, vol. 6, no. 2, pp. 94–98, Jun. 2019, doi: 10.7861/futurehosp.6-2-94.

[41] D. D. Luxton and L. D. Riek, "Artificial intelligence and robotics in rehabilitation," in *Handbook of Rehabilitation Psychology*, 3rd ed. American Psychological Association, 2019, pp. 507–520.

[42] S. N. Yoon and D. Lee, "Artificial intelligence and robots in healthcare: What are the success factors for technology-based service encounters?" *Int. J. Healthcare Manage.*, vol. 12, no. 3, pp. 218–225, Jul. 2019. doi: 10.1080/20479700.2018.1498220.

[43] D. Goleman, *Emotional Intelligence*. New York, NY, USA: Bantam Dell, 2005.

[44] P. Jonell, J. Mendelson, T. Storskog, G. Hagman, P. Östberg, I. Leite, T. Kucherenko, O. Mikheeva, U. Akenine, V. Jelic, A. Solomon, J. Beskow, J. Gustafson, M. Kivipelto, and H. Kjellstrom, "Machine learning and social robotics for detecting early signs of dementia," Tech. Rep., Sep. 2017. [Online]. Available: https://arxiv.org/pdf/1709.01613

[45] A. Sharkey and N. Sharkey, "Granny and the robots: Ethical issues in robot care for the elderly," *Ethics Inf. Technol.*, vol. 14, no. 1, pp. 27–40, Mar. 2012.

[46] G. F. Melson, P. H. Kahn, A. Beck, B. Friedman, T. Roberts, E. Garrett, and B. T. Gill, "Children's behavior toward and understanding of robotic and living dogs," *J. Appl. Developmental Psychol.*, vol. 30, no. 2, pp. 92–102, Mar. 2009.

[47] V. Gazzola, G. Rizzolatti, B. Wicker, and C. Keysers, "The anthropomorphic brain: The mirror neuron system responds to human and robotic actions," *NeuroImage*, vol. 35, no. 4, pp. 1674–1684, May 2007, doi: 10.1016/j.neuroimage.2007.02.003.

[48] Kalvi Foundation. *Recipe for a Robot: What it Takes to Make a Social Robot*. Accessed: Jan. 19, 2020. [Online]. Available: https://www.kavlifoundation.org/science-spotlights/recipe-robot-what-it-takes-make-social-robot#.XiQf48gzZPY

[49] J. Forlizzi, "How robotic products become social products: An ethnographic study of cleaning in the home," in *Proc. ACM/IEEE Int. Conf. Hum.-Robot Interact.-HRI*, 2007, pp. 129–136.

[50] C. J. Calo, N. Hunt-Bull, L. Lewis, and T. Metzler, "Ethical implications of using the Paro robot with a focus on dementia patient care," Presented at the 25th Assoc. Advancement Artif. Intell. (AAAI) Conf. Artif. Intell., Hum.- Robot Interact. Eldercare, San Francisco, CA, USA, Aug. 2011.

[51] N. Giullian, D. Ricks, A. Atherton, M. Colton, M. Goodrich, and B. Brinton, "Detailed requirements for robots in autism therapy," in *Proc. IEEE Int. Conf. Syst., Man Cybern.*, Oct. 2010, pp. 2595–2602.

[52] J. A. Atherton and M. A. Goodrich, "Supporting clinicians in robot-assisted therapy for autism spectrum disorder: Creating and editing robot animations with full-body motion tracking," Presented at the Robot. Sci. Syst. Workshop Hum.-Robot Interact., Perspect. Contrib. Robot. Hum. Sci., Los Angeles, CA, USA, Jun. 2011.

[53] J. F. Gorostiza and M. A. Salichs, "End-user programming of a social robot by dialog," *Robot. Auto. Syst.*, vol. 59, no. 12, pp. 1102–1114, Dec. 2011.

[54] E. Ackerman. (Aug. 2011). *Foxconn to Replace Human Workers With One Million Robots*. [Online]. Available: http://spectrum.ieee.org/automaton/robotics/industrial-robots/foxconn-to-replace-human-workers-with-one-million-robots

[55] C. M. Christensen, J. H. Grossman, and J. Hwang, *The Innovator's Prescription: A Disruptive Solution for Health Care*. New York, NY, USA: McGraw-Hill, 2009.

[56] S. M. Rabbitt, A. E. Kazdin, and B. Scassellati, "Integrating socially assistive robotics into mental healthcare interventions: Applications and recommendations for expanded use," *Clin. Psychol. Rev.*, vol. 35, pp. 35–46, Feb. 2015, doi: 10.1016/j.cpr.2014.07.001.

[57] *A. Senior. John Hancock Leaves Traditional Life Insurance Model Behind to Incentivize Longer*, Healthier Lives, 2005.

[58] S. Jeong. (Apr. 10, 2019). *Insurers Want to Know How Many Steps You Took Today*. The New York TImes. [Online]. Available: https://www.nytimes.com/2019/04/10/opinion/insurance-ai.html

[59] J. Stanley. (Jun. 2, 2017). *Pitfalls of Artificial Intelligence Decision Making Highlighted In Idaho ACLU Case*. ACLU 100 Years. [Online]. Available: https://www.aclu.org/blog/privacy-technology/pitfalls-artificial-intelligence-decisionmaking-highlighted-idaho-aclu-case

[60] A. Miklósi, P. Korondi, V. Matellán, V.and M. Gácsi, "Ethorobotics: A new approach to human-robot relationship. frontiers in psychology," *Frontiers Psychol.*, vol. 8, p. 958, Jun. 2017, doi: 10.3389/fpsyg.2017.00958.

[61] S. Crowe. (2019). *Humanoid Robots: Five to Watch in 2019*. The Robot Report. [Online]. Available: https://www.therobotreport.com/humanoid-robots-watch-2019/

[62] M. Mori, "Bukimi no tani the uncanny valley," *Energy*, vol. 7, pp. 33–35, 1970. [Online]. Available: https://spectrum.ieee.org/automaton/robotics/humanoids/the-uncanny-valley

[63] K. F. MacDorman and H. Ishiguro, "The uncanny advantage of using androids in cognitive and social science research," *Interact. Stud.*, vol. 7, no. 3, pp. 297–337, 2006, doi: 10.1075/is.7.3.03mac.

[64] M. M. Moosa, and S. M. M. Ud-Dean, "Danger avoidance: An evolutionary explanation of uncanny valley," *Biol. Theory*, vol. 5, no. 1, pp. 12–14, 2010, doi: 10.1162/BIOT_a_00016

[65] D. J. Lewkowicz, and A. A. Ghazanfar, "The emergence of multisensory systems through perceptual narrowing," *Trends Cogn. Sci.*, vol. 13, no. 11, pp. 470–478, 2009, doi: 10.1016/j.tics.2009.08.004.

[66] H. Chen, R. Russell, K. Nakayama, and M. Livingstone, "Crossing the 'uncanny valley': Adaptation to cartoon faces can influence perception of human faces," *Perception*, vol. 39, no. 3, pp. 378–386, 2010, doi: 10.1068/p6492.

[67] A. E. Ferrey, T. J. Burleigh, and M. J. Fenske, "Stimulus-category competition, inhibition, and affective devaluation: A novel account of the uncanny valley," *Frontiers Psychol.*, vol. 6, p. 249, Mar. 2015, doi: 10.3389/fpsyg.2015.00249.

[68] D. Eagleman, *Incognito: The Secret Lives of the Brain*. New York, NY, USA: Random House, 2011.

[69] A. K. Seth, "A predictive processing theory of sensorimotor contingencies: Explaining the puzzle of perceptual presence and its absence in synesthesia," *Cogn. Neurosci.*, vol. 5, no. 2, pp. 97–118, 2014, doi: 10.1080/17588928.2013.877880.

[70] E. Kalbe, M. Schlegel, A. T. Sack, D. A. Nowak, M. Dafotakis, C. Bangard, M. Brand, S. Shamay-Tsoory, O. A. Onur, and J. Kessler, "Dissociating cognitive from affective theory of mind: A TMS study," *Cortex*, vol. 46, no. 6, pp. 769–780, Jun. 2010, doi: 10.1016/j.cortex.2009.07.010.

[71] G. Rizzolatti and C. Sinigaglia, "The functional role of the parieto-frontal mirror circuit: Interpretations and misinterpretations," *Nature*, vol. 2, no. 4, pp. 264–274, 2010.

[72] Accessed: Dec. 2019. [Online]. Available: https://www.japantimes.co.jp/opinion/2019/07/25/commentary/japan-commentary/real-policy-challenges-facing-japan/#.XiPbq8gzZPY

[73] N. L. Robinson, T. V. Cottier, and D. J. Kavanagh, "Psychosocial health interventions by social robots: Systematic review of randomized controlled trials," *J. Med. Internet Res.*, vol. 21, no. 5, May 2019, Art. no. e13203.

[74] A. J. Pearce, B. Adair, K. Miller, E. Ozanne, C. Said, N. Santamaria, and M. E. Morris, "Robotics to enable older adults to remain living at home," *J. Aging Res.*, vol. 2012, pp. 1–10, 2012.

[75] L. Pu, W. Moyle, C. Jones, and M. Todorovic, "The effectiveness of social robots for older adults: A systematic review and meta-analysis of randomized controlled studies," *Gerontologist*, vol. 59, no. 1, pp. e37–e51, Jan. 2019.

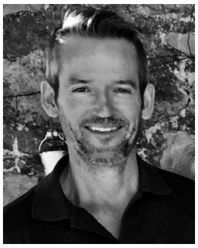
[76] Accessed: Jan. 19, 2020. [Online]. Available: https://www.softbankrobotics.com/emea/index.php/en/nao

[77] Accessed: Jan. 19, 2020. [Online]. Available: http://www.parorobots.com/

[78] Accessed: Jan. 19, 2020. [Online]. Available: https://www.softbankrobotics.com/emea/en/pepper

[79] Accessed: Jan. 19, 2020. [Online]. Available: https://www.robotlab.com/store/nao-power-v6-standard-edition"https://www.robotlab.com/store/nao-power-v6-standard-edition

[80] Accessed: Jan. 19, 2020. [Online]. Available: https://www.marketsandmarkets.com/Market-Reports/humanoid-robot-market-99567653.html



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