Dissertation

Technologies in Dementia Home Care

Expectations – Experiences – Effectiveness

submitted by

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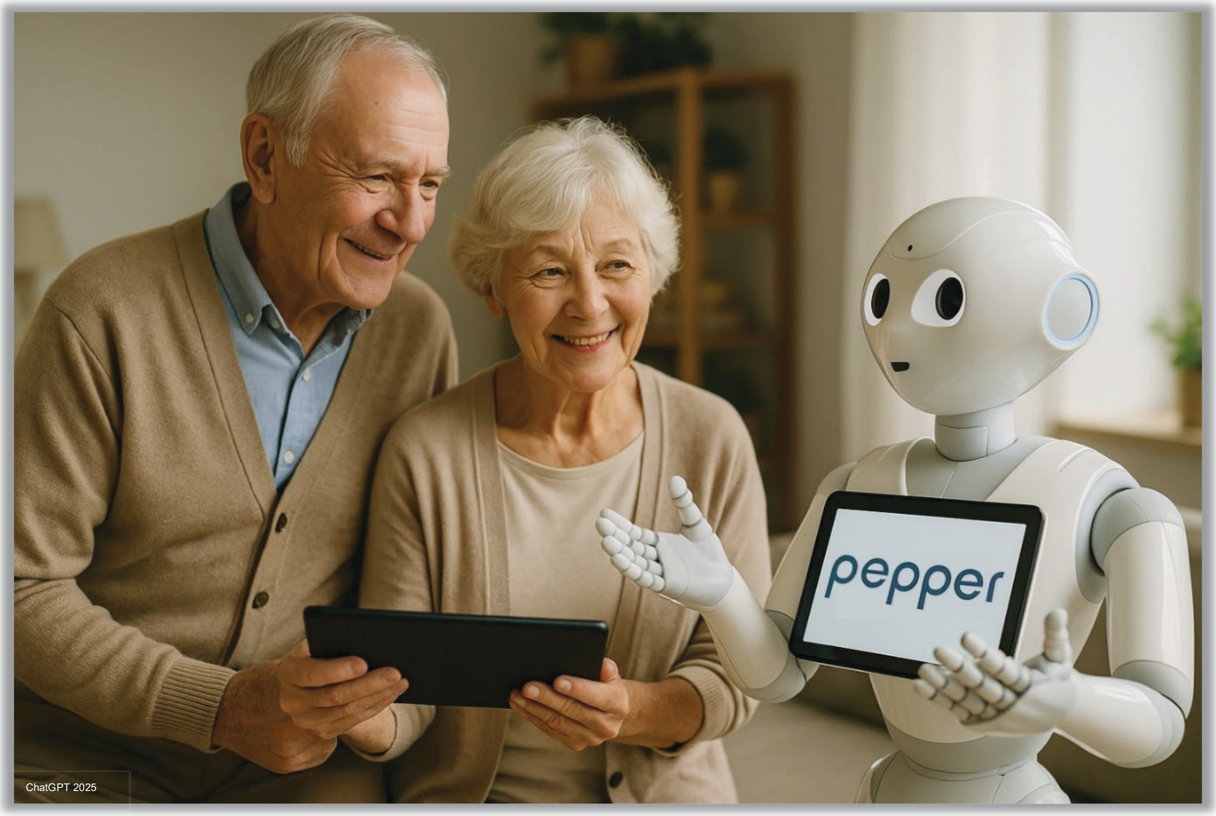
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Graz, April 2025 *Julia Zuschnegg, m.p.*

Disclosures

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Abbreviations and Definitions

ADL	Activities of daily living
AI	Artificial intelligence
BPSD	Behavioral and psychological symptoms of dementia
CCI(s)	Computer-based cognitive intervention(s); Computerbasierte kognitive Intervention/en
CI	Confidence interval
CDS	Care dependency scale
CR	Cognitive rehabilitation
DCB-TS Model	Dementia Caregiver Burden and Technological Support Model
LLM(s)	Large language model(s)
MCI	Mild cognitive impairment
PwD	People with dementia; Personen mit Demenz
QoL	Quality of life
RCT	Randomized controlled trial
SAR(s)	Socially assistive robot(s); sozialassistierende/r Roboter
SCD	Subjective cognitive decline
SMD	Standard mean difference
VR	Virtual reality
ZBI	Zarit Burden Interview

Apathy is the most common behavioral and psychological symptom of dementia (BPSD) and is primarily described as a loss of motivation (1, 2).

Large Language Models (LLMs) are a form of artificial intelligence (AI) designed to comprehend and produce text in a human-like manner by leveraging the extensive data they are trained on. They achieve this by analyzing patterns in text and predicting the probability of word sequences. Consequently, LLMs can deduce meaning from context, produce coherent and contextually appropriate responses, translate languages, summarize texts, answer questions, and assist with creative writing or code generation tasks (3).

Mobile/Wearable technologies include smart watches, bands and rings, sensors in clothes, sensor patches, and smartphones/tablets which enable the noninvasive collection of personalized data of one's physiology (e.g., heart rate, oxygen saturation, sweat, glucose levels) or behavior (e.g., sleep patterns/phases/efficiency, activity level) (4, 5).

Realist Review is a specific literature review approach *"to reviewing research evidence on complex social interventions, which provides an explanatory analysis of how and why they work (or don't work) in particular contexts or settings (6, p. iv)."*

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Zusammenfassung

Hintergrund: Die Demenz, mit globalen Anstiegsraten, führt über die Zeit zu Pflegeabhängigkeit, die primär von Angehörigen durch Pflege und Betreuung kompensiert wird. Diese kann zu Belastung mit negativen Konsequenzen für Angehörige und Personen mit Demenz (PwD) führen. (Nicht-)technologische Interventionen, wie *Emerging Technologies*, haben das Potenzial Belastungen zu reduzieren. Forschungsergebnisse zu Erwartungen, Effektivität und Erfahrungen mit solchen Technologien sind jedoch unzureichend vorhanden.

Übergeordnetes Ziel: Die Erforschung der *Emerging Technology* Coach Pepper (humanoider, sozialassistierender Roboter (SAR), kombiniert mit einem Tabletcomputer als computerbasierte kognitive Intervention (CCI)), als Unterstützung zur Belastungsreduktion pflegender Angehöriger von PwD (3). Berücksichtigt wurden dabei Unterstützungserwartungen von Betreuenden an humanoide SARs (1) und die Effektivität von CCIs für kognitiv Beeinträchtigte (2).

Methode und Ergebnisse der 3 Studien: (1) Die qualitative Studie mittels Fokusgruppen zeigte, dass Pflegende und Demenztrainer*innen (n=52) überwiegend positive Erwartungen für die Unterstützung bei Grundbedürfnissen hatten, besonders bei der Gefahrenvermeidung. (2) Die systematische Übersichtsarbeit mit Metaanalysen (24 Artikel, 8 Datenbanken) zeigte einen positiven Trend in der Gedächtnisfunktion von PwD (4 RCTs). Ergebnisse der Studie 1 und 2 flossen in die Studie (3) mit Mixed-Methods Design ein. Der quantitative Part (RCT) mit 32 Angehörigen zeigte keine Signifikanz einer Belastungsreduktion. Der qualitative Part mittels Interviews (n=16) zeigte eine primär positive Einstellung zu Coach Pepper, jedoch neutrale Gefühle gegenüber der Belastungsreduktion. Positive Erfahrungen zur Unterstützung wurden für 6 von 14 Grundbedürfnissen geäußert, begleitet vom überwiegenden Wunsch nach Optimierungen, z.B. Sprachfunktion, Personalisierung.

Schlussfolgerung: Coach Pepper wurde von Angehörigen gut angenommen, zeigte aber keine signifikante Belastungsreduktion. Optimierungen sind notwendig, besonders der Sprachfunktion, die durch Künstliche Intelligenz verbessert werden könnte. Coach Pepper könnte im häuslichen Bereich als Zusatzleistung von professionellen Service (z.B. Hauskrankenpflege) angeboten werden.

Abstract

Background: Dementia, with its increasing global prevalence, leads to care dependency over time, with care being primarily taken over by informal caregivers. This can result in caregiver burden with negative consequences for both caregivers and people with dementia (PwD). (Non-)technological interventions, including emerging technologies, have the potential to mitigate this burden. However, research on expectations, effectiveness, and experiences with such technologies remain insufficient.

Overall aim: To investigate an emerging technology, Coach Pepper (a humanoid socially assistive robot (SAR) combined with a tablet computer as a computer-based cognitive intervention (CCI)), as support for reducing caregiver burden of informal caregivers of PwD (3), with the incorporation of support expectations from caregivers and dementia trainers regarding humanoid SARs (1), as well as the effectiveness of CCIs for people with cognitive decline (2).

Methods and Results of the 3 Studies: (1) The qualitative study using focus groups showed that caregivers, nurses, and dementia trainers (n=52) had predominantly positive expectations regarding support in human needs, especially in avoiding danger. (2) The systematic review with meta-analyses (24 articles, 8 databases) revealed a beneficial trend in memory function for PwD (4 RCTs). Findings from Study 1 and 2 were incorporated into Study (3), which followed a mixed-methods design. The quantitative part (RCT) with 32 caregivers showed no significant effects on caregiver burden. The qualitative part, using interviews (n=16), revealed a primarily positive attitude toward Coach Pepper but neutral feelings regarding caregiver burden. Positive experiences regarding support were expressed for 6 out of 14 human needs, accompanied by a predominant desire for optimizations (e.g., speech function, customization).

Conclusion: Coach Pepper was well received by caregivers but had no significant effect on caregiver burden. Optimizations are necessary, particularly regarding the speech function, which could be enhanced through artificial intelligence. Coach Pepper could be offered as an additional service in the home setting through professional services (e.g., home nursing care).

Introduction

Every three seconds, someone is diagnosed with dementia (7). Worldwide, over 55 million people live with this condition, with nearly 10 million new cases each year and between 139 and 153 million cases predicted by 2050 (8, 9). This alarming trend makes dementia a serious global health concern, as it is not only the seventh leading cause of death but also a significant contributor to disability and care dependency[1] among older adults (9-11).

Dementia is an overarching term used to describe a range of neurological conditions that affect the brain, characterized by a progressive cognitive decline. The underlying cause varies depending on the type of dementia (e.g., Alzheimer's disease, vascular dementia) (11). However, the spectrum of cognitive decline can begin earlier with conditions such as subjective cognitive decline (SCD) and mild cognitive impairment (MCI) (11). SCD refers to self-perceived cognitive worsening over time, even when clinical assessments reveal no objective abnormalities (11-13). In contrast, MCI already represents objective evidence of cognitive impairment (with the absence of dementia) and, unlike dementia, is characterized by essentially normal functional activities (14). Both conditions increase the risk of developing dementia over time (11, 15-18).

Dementia progressively affects cognitive abilities, resulting in various health problems and increased care dependency[1] regarding various physical and psychosocial human needs[2] (e.g., hygiene, communication, learning ability) (9, 11, 19). People with dementia (PwD) begin to lose their ability to live independently at home, which may ultimately require institutionalization (e.g., nursing homes), particularly in the later stages of dementia (11, 20). In this regard, public healthcare systems worldwide face significant challenges, as the number of available healthcare professionals, such as geriatricians, and especially nursing staff, is declining while the demand for dementia care continues to rise (11, 21, 22). Concerning this, informal caregivers (e.g., relatives, friends; mostly women) play a key role in dementia care and in supporting healthcare systems by providing unpaid, regular care and/or supervision. They often assume the primary care responsibility for PwD, particularly in the early stages of the disease, facing significant challenges and, therefore, are often referred to as *"the invisible second patients"* (11, 20, 23, p. 217). On the one hand, caring for PwD is highly demanding, requiring significantly more care than caring for older people without dementia (11, 19, 21). This can lead to caregiver burden[3], with dementia caregivers facing a higher risk compared to non-dementia caregivers, potentially resulting in health-related consequences, and influencing

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[1] defined on page 22
[2] defined on page 21
[3] defined on pages 16, 18

the decision to institutionalize the person with dementia (11, 24). On the other hand, many PwD express a strong desire to age and live (independently) at home for as long as possible (20, 25). Living at home benefits the quality of life (QoL) of PwD (26), as it can provide comfort, freedom, and a sense of being 'anchored' due to long-term connections (27). Considering all these aspects, solutions are needed to address these challenges in dementia home care by supporting informal caregivers and PwD.

In this context, beyond conventional support options for informal caregivers (e.g., hourly formal home care, education in caregiving skills) (11), the development and application of emerging technologies[4] (e.g., humanoid socially assistive robots (SARs)[5]) are considered a promising solution to support future dementia home care (28-32). In particular, due to their human-like appearance and social interaction capabilities, humanoid SARs have great potential to support caregiving for PwD by addressing their physical and psychological human needs[6], for instance, learning abilities[7] (28-31, 33-35). Such support can include cognitive training for PwD aiming to preserve cognition, which can be delivered through computer-based cognitive interventions (CCIs)[8] conducted on a tablet computer (hereafter called 'tablet') (36, 37) accompanied by a humanoid SAR (28, 31, 33). These technological support options create opportunities for emerging technologies to serve as caregiving support, potentially reducing the burden of informal caregivers of PwD (29-31).

Definitions and theoretical framework

Caregiver burden can be seen as a result of complex and dynamic interactions primarily related to care responsibilities arising from caring for a loved one, as well as the self-perceived negative impact of these responsibilities on the informal caregiver's life over time (38, 39). To better represent this complexity and these dynamics in the context of dementia, this doctoral thesis introduces the *Dementia Caregiver Burden and Technological Support Model,* also illustrated in Figure 1 on page 17.

Dementia Caregiver Burden and Technological Support (DCB-TS) Model

The *DCB-TS Model* is primarily based on the *Stress Process Model of Caregiving* by Pearlin, Mullan (38), along with the version by Zarit (39) and encompasses both parties involved in

[4] defined on page 19
[5] defined on page 20
[6] defined on page 21
[7] defined on page 22
[8] defined on page 20

caregiving: informal caregivers and PwD. It outlines factors related to dementia caregiving that can contribute to caregiver burden, potentially leading to various consequences for both informal caregivers and PwD (38, 39). Furthermore, the model explains how interventions in the form of (non-)technological support can impact caregiver burden, either positively or negatively. The support component in the model was extended with constructs of the *Almer Model* by Heerink, Kröse (40) (i.e., attitude, perceived usefulness) and with the underlying concept of the *Care Dependency Scale (CDS)* by Dijkstra, Buist (41) (i.e., physical and psychosocial human needs) to enhance acceptance and, consequently, the use of the investigated emerging technology (i.e., humanoid SAR combined with a CCI) as a support device for informal caregivers in dementia home caregiving, aiming for a beneficial impact on caregiver burden.

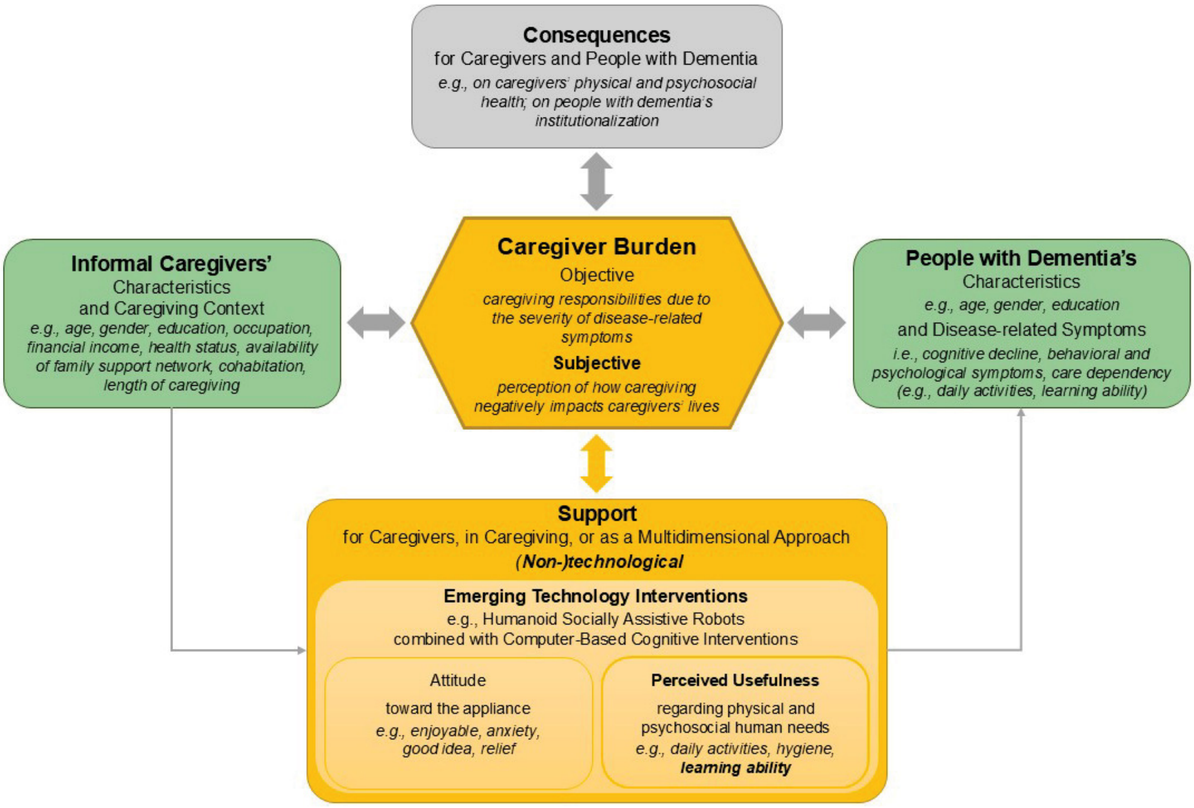

Figure 1: Dementia Caregiver Burden and Technological Support Model based on Pearlin, Mullan (38), Zarit (39), Heerink, Kröse (40) and Dijkstra, Buist (41).

The *DCB-TS Model* presents the characteristics and caregiving context of **informal caregivers** (hereafter called 'caregivers') as a component that can influence the development of caregiver burden (38). In the literature, several risk factors have been identified, including age (42-44), gender (42-45), education (43, 46, 47), occupation status (43, 44), financial income (48), health status (42, 43, 48), marital status (43), relationship to the person with dementia (e.g., spouse or child) (42, 47, 49), cohabitation with the person with dementia (42-

44), the availability of a family support network (46, 47), and the length of caregiving (42, 45, 47). While these factors are associated with caregiver burden, evidence for some remains inconsistent (e.g., specific age or gender, employment or non-employment) (42-44, 50).

PwD also have identified risk factors related to their characteristics, such as gender (46), age (43), education (43, 44), and retirement pension (43). However, the component in Figure 1 specifically highlights disease-related symptoms typically associated with dementia, namely cognitive decline, care dependency, and behavioral and psychological symptoms of dementia (BPSD) (e.g., apathy, agitation, sleep impairment, hallucinations, anxiety, eating disorders (51)). These symptoms often initiate the process of caregiver burden development (38, 39).

Caregiver burden, which is defined on page 16, can be distinguished into an objective and subjective type.

Objective caregiver burden refers to the measurable caregiving responsibilities of caregivers (e.g., care hours, required supervision) which result from the severity of disease-related symptoms in PwD including cognitive decline, care dependency, and BPSD (23, 38, 39, 52, 53). Both the extent of caregiving responsibilities (e.g., care hours per day/week (53-55), daily care (56)) and the severity of individual disease-related symptoms (i.e., cognitive decline (54, 56, 57), BPSD (44, 45, 49, 56), care dependency (42, 45, 48, 56)) are further associated with (higher) subjective caregiver burden. In this doctoral thesis, objective caregiver burden is considered only descriptively, as the main focus is on subjective caregiver burden.

Subjective caregiver burden refers to the self-perceived negative impact that caring for a person with dementia has on the life of a caregiver over time (58, 59). The subjective evaluation of the objective burden by caregivers, shaped by their characteristics and the caregiving context, plays a critical role in determining how intensely the caregiving role is experienced as burdensome (38, 39, 53, 59). Although this type of burden is ‘subjective’, it can be evaluated quantitatively using instruments such as the well-known Zarit Burden Interview (ZBI) (58, 59). The ZBI examines subjective caregiver burden by assessing the perceived impact of caregiving on caregivers’ lives in terms of psychological, social, health, and financial aspects (e.g., whether their social life suffers due to caregiving, the feeling of not having enough money for care, and the challenges of fulfilling other obligations such as family and work) (58-60). Subjective caregiver burden is widely used as an outcome in studies, as it provides important information about how caregivers cope with their caregiving situation (52). In this regard, researchers (38, 39, 61) emphasize its relevance by arguing that, even among caregivers in the same nursing context, the level of subjective burden can vary despite the associations between objective and subjective caregiver burden.

Caregiver burden can subsequently lead to considerable negative **consequences** for both the caregivers and the PwD (11, 38, 39, 61-63). This, in turn, can either decrease or intensify the caregiver burden due to interaction effects, such as poorer health status of the caregiver (43, 48) or the institutionalization of the person with dementia (64, 65). Recent reviews (62, 63) and a report (11) identified the following negative consequences for caregivers in this context: physical (e.g., pain, heart problems, hypertension, impaired immune function, increased mortality) (11, 38, 62, 63), psychological (e.g., depression, burnout, anxiety, sleep disturbance, cognitive decline) (11, 38, 62, 63), social (e.g., isolation, loneliness) (11, 63), and financial consequences (e.g., unemployment) (11, 63). Furthermore, caregiver burden can negatively impact PwD by affecting their received quality of care, worsening BPSD, increasing their risk of hospitalization, and potentially leading to the caregiver's decision to move the person with dementia from their familiar environment to a nursing home (11, 65). To prevent these negative consequences of caregiver burden, caregiving support can be incorporated (38, 39).

The **support** component can play a mediating role in the *DCB-TS Model* in relation to caregiver burden (38). Depending on the support's usefulness in addressing objective caregiver burden factors and whether caregivers perceive it as beneficial or disruptive, support can impact caregiver burden positively, negatively, or not at all (23, 38, 66). The decision to seek support can result from the caregiver burden component, where a high subjective burden may even hinder the decision due to feeling overwhelmed (67). Otherwise, it can depend on the caregivers' characteristics and caregiving context, such as gender (23), education (11), or their relationship with the person with dementia (e.g., adult-aged child to parent) (67). However, these associations are complex (23). The landscape of interventions supporting caregivers in dementia care is also complex and diverse, reflecting the mixed evidence on their effectiveness in providing relief (11, 23, 38, 39, 68-70). Most interventions focus directly on caregivers (e.g., psychoeducational programs to manage stress and cope with everyday situations, psychological therapy) (11, 38, 39, 68-70), while others provide caregiving support (e.g., helping with daily activities), offering respite for caregivers (e.g., hourly formal home care, adult care centers) (11, 23, 38, 39, 70), or utilize multidimensional approaches (11, 70). Furthermore, these support interventions can be distinguished as non-technological and technological approaches, with an increasing trend toward applying emerging technologies as caregiving support in dementia home care (11, 28-31, 68-70).

The term '**emerging technology**' is widely used in the literature but with varying meanings (71). Following Rotolo, Hicks (71) in this doctoral thesis, an emerging technology is defined by the following five attributes: It is 1) a radically novel/new and, 2) relatively fast-growing technology, 3) characterized by a certain degree of coherence persisting over time,

4) potentially considerable in its impact on socio-economic domain(s) (e.g., recognized through the composition of actors, institutions, and the knowledge produced), and 5) mainly impacting the future, accompanied by uncertainty and ambiguity. These attributes can vary from 'low' to 'high' levels throughout the process. However, the definition encompasses technological advancements that have seen relatively little prior development (e.g., virtual reality (VR), robotics (72)) and that apply to technologies used in new domains or 'niches', different from the original purpose (e.g., the use of VR and humanoid SARs in dementia care (72)) (71). In this context, emerging technologies can also involve combinations of technologies (e.g., humanoid SARs combined with tablets). However, to be considered radically novel (attribute 1) within a 'niche', emerging technologies must differentiate themselves to some degree from the original domain (71). In dementia care, the application of emerging technologies is of great interest, particularly in supporting PwD and caregivers through humanoid SARs and CCIs (29, 31, 33).

In general, **SARs** are an intersection of assistive robots and socially interactive robots. They are intended to support and assist a human user by fostering close and effective social interaction (73). SARs often resemble a human or an animal, with varying degrees of realism (74, 75). While research on SARs has steadily grown over the past decade (30, 76), humanoid SARs have garnered particular interest for their role in dementia home care and their potential to address the predicted challenges (29, 31, 77). Humanoid SARs, characterized by a recognizable but non-realistic human-like appearance (74), are designed to facilitate human-robot interaction comparable to human-human interaction (35). They aim to foster a stronger sense of social presence compared to purely functional robots (e.g., an industrial robotic arm) and to build companionship with the human user(s) (35, 78). Furthermore, their appearance plays a crucial role in shaping user expectations and influencing their assistive capabilities (34), as, unlike animal-like robots, humanoid SARs are intended to assist with various physical and psychosocial human needs (29-31, 78). In particular, for PwD in the early stages, humanoid SARs are intended to primarily provide direct verbal support for various human needs due to cognitive decline (e.g., through reminders), with physical support if necessary (e.g., picking up objects) (29, 31, 77). Given these potential support possibilities, humanoid SARs are increasingly seen as promising technologies for integration into intelligent homes and as personal assistive devices for supporting dementia home care, including cognitive intervention applications such as cognitive training for PwD (28-33, 40).

In recent years, cognitive interventions have increasingly relied on technologies commonly referred to as **CCIs**, including emerging technologies (e.g., virtual, augmented, or mixed reality) or already established standard technologies (e.g., smartphones, tablets, personal computers (PCs), game consoles), with cognitive training (characterized by structured tasks) being the most common approach (72, 79-81). CCIs aim to preserve or improve cognitive abilities (e.g., global or domain-specific cognition like executive functioning) with the assumption that these improvements also positively impact further disease-related outcomes (e.g., everyday activities, BPSD, QoL) (82-85). In this regard, the literature demonstrates a beneficial impact of CCIs on cognition in PwD (36, 37, 86) and those at risk (i.e., SCD (87), MCI (36, 79, 86, 88)) while having minimal side effects and relatively safe usage (36, 80). Some CCIs include physical exercises, as the combination is expected to be more beneficial than cognitive training alone (89, 90). Despite these advantages, training intensity is crucial for effectiveness but may add to caregiver burden, as caregivers might feel responsible for ensuring regular execution (recommended six days per week (91)) (92) while also managing apathy – the most common BPSD symptom (1). The lack of motivation in PwD could potentially be addressed with the support of a humanoid SAR, which could accompany and assist with the training by using its social capabilities (33).

In this **doctoral thesis**, the **support** component and the caregivers' **subjective burden** represent the core elements within the *DCB-TS Model*, as the three studies included in this doctoral thesis fall within the support component, with one (Study 3) demonstrating the effect of an emerging technology (i.e., a humanoid SAR combined with a CCI) on subjective caregiver burden. The objective caregiver burden and factors of the components for caregivers and PwD are described only descriptively. While the consequences of caregiver burden were also not examined in this thesis, they were included in the model to highlight the importance of caregiver burden.

In this regard, the support component of the *DCB-TS Model* was expanded with constructs of the Almere Model by Heerink, Kröse (40) due to its specific focus on the acceptance of social robots by older adults. For the investigated emerging technology intervention, in particular, the constructs' **attitude** and **perceived usefulness** were considered. 'Attitude' is defined as *"positive or negative feelings about the application of the technology"*, and 'perceived usefulness' is defined as *"the degree to which a person believes that the system would be assistive"* (40, p. 364). Both constructs influence the acceptance of a humanoid SAR and, subsequently, its actual use (40). With regard to enhancing the construct of *perceived usefulness* for the intervention, the CDS developed by Dijkstra, Buist (41), based on the nursing theory of Virginia Henderson, was integrated. The CDS incorporates 15 components of physical and psychosocial human needs: *eating/drinking, continence, body posture, mobility, day/night pattern, getting (un)dressed, body temperature, hygiene, avoidance of danger, communication, contact with others, sense of rules/values, daily activities, recreational* *activities, and learning ability*. In this context, care dependency represents a process in which an individual's care demands require (professional) support due to their decreased ability to provide self-care (41, 93). The CDS, originally developed within nursing science specifically for PwD, takes a more holistic and comprehensive approach than other similar instruments by incorporating 15 components of human needs, which encompass various basic activities of daily living (ADLs) (e.g., hygiene) and more complex instrumental ADLs (e.g., learning ability) (41, 93, 94). A special focus within the human needs of the CDS is on **learning ability**, which is defined as *"the ability to acquire knowledge/skills and/or to retain knowledge/skills learned in the past" (19, p. 8, 41)*. Since the preservation of cognition, as previously described, is important for PwD and their caregivers, this doctoral thesis places particular emphasis on this human need. In this regard, enhancing *learning ability* was intended to additionally increase the perceived usefulness of the investigated emerging technology, which in turn may foster its acceptance and usage (40), potentially mitigating caregiver burden according to the *DCB-TS Model*.

Problem statement and research gap

Dementia rates are projected to rise considerably in the future, posing challenges for healthcare systems and especially society, as most PwD are cared for at home by informal caregivers (7-9, 11, 21, 22). They play a key role in dementia home care but often experience caregiver burden, which can adversely affect their health. Caregiver burden can also lead to negative consequences for PwD, as caregivers may decide that the person they care for needs to leave their preferred familiar environment and move to a nursing home (11, 25, 38, 39, 62). For these reasons, a priority in dementia research is to investigate support that can mitigate caregiver burden through (non-)technological interventions, such as support in caregiving, with a growing trend of emerging technologies in this context (e.g., humanoid SARs) (25, 29-32, 69, 70).

Humanoid SARs can potentially support PwD in various physical and psychosocial human needs, including learning abilities (29-31, 33). Combining such a robot with tablet-based cognitive training (i.e., CCI) could specifically support learning abilities and help mitigate disease-related symptoms, as the robot provides social interaction and may enhance motivation in PwD, encouraging more frequent training – an important factor, given that apathy is the most common BPSD symptom (1, 33, 82, 91). Overall, such an intervention may help reduce caregiver burden in dementia caregivers; however, evidence was lacking (95), underscoring the need for further research, as highlighted in the following gaps.

First, although humanoid SARs are predicted to offer potential support in dementia care, specific positive and negative expectations of its potential users (e.g., caregivers, nurses) in this context remain underexplored, as most qualitative studies have focused on robot animals or undefined assistive technologies. Consequently, comprehensive qualitative research on the specific support expected – or not expected – by caregivers, nurses, and dementia trainers from humanoid SARs in dementia care, particularly regarding physical and psychosocial human needs (outlined in the CDS), was lacking. These insights were considered crucial to inform future interventional studies (96).

Second, compared to humanoid SARs, research on the beneficial effects of CCIs targeting cognition in PwD was more available. However, systematic reviews with meta-analyses included only studies that focused on either standard or emerging technologies and did not differentiate between participants living at home or in institutional care and did not consider all three relevant stages across the spectrum of cognitive decline. A comprehensive overview of the effectiveness of CCIs on global and domain-specific cognition was lacking, particularly regarding both standard and emerging technologies for community-dwelling people with SCD, MCI, and dementia, focusing on single-person applications (81).

Third, research on the use of humanoid SARs has primarily been conducted in laboratory settings, with limited research 'in the wild' (i.e., real-world care, such as home settings) focusing more on the technical aspects and operability (33, 97). The first available studies on the effectiveness of humanoid SARs, beyond technical outcomes, were conducted with PwD in long-term care facilities. However, for informal caregivers, no studies were available investigating humanoid SARs (with or without a combined CCI) as caregiving support in dementia home care, highlighting the need for further research, particularly on the critical issue of caregiver burden (95).

In the context of the first and third research gap, the inclusion of PwD was considered equally alongside caregivers but not within this doctoral thesis; rather, it was part of the larger AMIGO project (98).

Aims of this doctoral thesis

The overall aim was to investigate an emerging technology, Coach Pepper (a humanoid SAR combined with a tablet as a CCI), as support in dementia home care for reducing caregiver burden by using a mixed-methods approach (Study 3), with the incorporation of support expectations from caregivers and dementia trainers regarding humanoid SARs (Study 1), as well as the effectiveness of CCIs for people with cognitive decline (Study 2).

The aims of the three studies in this doctoral thesis are described below, with Figure 2 illustrating the outline.

The **first study** aimed to explore the expectations of informal caregivers, nurses, and dementia trainers regarding the support of physical and psychosocial human needs through emerging humanoid SARs in dementia care.

The **second study** aimed to provide an overview of the effectiveness of individually performed CCIs, including standard technologies (i.e., PCs, tablets/smartphones, game consoles) and emerging technologies (i.e., virtual, augmented, or mixed reality), on cognition in community-dwelling individuals with SCD, MCI, and dementia.

The **third study** tested a combined emerging technology intervention involving a humanoid SAR combined with a tablet as a CCI (i.e., Coach Pepper). The primary aim was to examine the effect(iveness) of a humanoid SAR, one equipped with functions such as tablet-based multimodal training (i.e., cognitive and physical exercises) for PwD, on caregivers' subjective burden compared to an intervention involving only tablet-based multimodal training for PwD. Secondary outcomes included QoL, depressive symptoms, affect, and acceptance. Additionally, interviews with caregivers were conducted to gain deeper insights into their attitudes and experiences with such a robot at home.

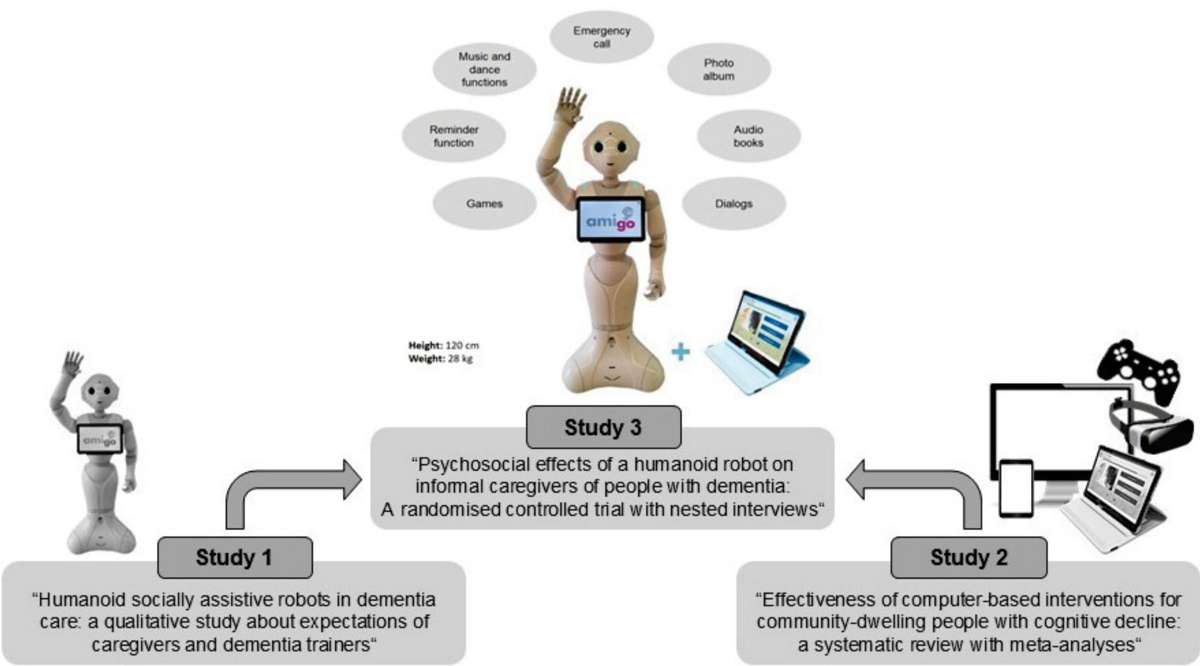

Figure 2: Outline of this doctoral thesis (Socially assistive robot: ©Joanneum Research Forschungsgesellschaft mbH Graz, Institute DIGITAL; Tablet computer: ©Joanneum Research Forschungsgesellschaft mbH Graz, Institute DIGITAL/M. Schwarzl; Other devices: Creative Commons https://pixabay.com/de/)

Discussion

This section provides an overview of the three studies in this doctoral thesis, including their methodologies, main findings, and interconnections. Table 1 presents the methodological aspects. Additionally, this section discusses the main findings, includes methodological reflections, and provides a conclusion.

Table 1: Overview of the study's methodological aspects

	Study 1	Study 2	Study 3
Aim	Examine the expectations of informal caregivers, nurses, and dementia trainers regarding the support of physical and psychosocial human needs through humanoid socially assistive robots (SARs) in dementia care.	Assess the effectiveness of individually performed computer-based cognitive interventions (i.e., personal or tablet computers, smartphones, game consoles, virtual, augmented, or mixed reality) on cognition in community-dwelling people with subjective cognitive decline (SCD), mild cognitive impairment (MCI), and dementia.	Explore the psychosocial effects of the humanoid SAR Coach Pepper (combined with a tablet-based multimodal training for people with dementia) versus a tablet-based multimodal training alone for people with dementia on informal caregivers and examine caregivers' attitudes and experiences with Coach Pepper.
Design	Qualitative descriptive study.	Systematic review with meta-analyses of randomized controlled trials (RCTs).	RCT with a nested qualitative descriptive study.
Sample/ Setting	Informal caregivers (n=16), nurses (n=20), and dementia trainers (n=16) providing dementia care in home settings, adult daycare centers, or nursing homes.	Studies including adults with SCD (n=1), MCI (n=18), and dementia (n=6) living at home.	Informal caregivers of people with dementia (n=32). The study was conducted in private households.
Data collection	11 homogeneous focus groups (3 with informal caregivers, 4 with nurses, and 4 with dementia trainers) using a semi-structured interview guide.	Systematic literature search in MEDLINE, CINAHL, Embase, Cochrane CENTRAL, IEEE Xplore, Web of Science, Scopus, and PsycINFO. Gray literature search and backward citation searching were performed. A checklist was used for study selection.	Data was collected at baseline and after the three-week intervention using standardized questionnaires (primary outcome: subjective caregiver burden). Semi-structured interviews were conducted post-intervention in the Coach Pepper group.
Data analysis	Qualitative content analysis using a concept- and data-driven coding frame.	Two researchers independently assessed the study quality. Meta-analyses were performed using standardized mean difference with a random-effects model. Results were synthesized narratively when pooling was not possible.	Intention-to-treat analysis was performed. Descriptive statistics and statistical tests were used to explore differences between the two groups. Qualitative content analysis with concept- and data-driven coding frame.

Main findings and interconnections

Study 1 illustrates the (positive and negative) expectations of caregivers, nurses, and dementia trainers regarding the 'perceived usefulness' of humanoid SARs in future dementia care, particularly in supporting PwD and themselves by addressing physical and psychosocial human needs. The participants reported positive expectations regarding support by such robots across all human needs based on the CDS, primarily in components such as avoiding danger (e.g., recognizing danger, organizing help), communication/contact with others (e.g., enabling telephone calls, providing company), daily activities (e.g., reminding of appointments, household obligations), recreational activities (e.g., provide music), eating/drinking (e.g., help cook), and mobility/body posture (e.g., give reminders/instructions for physical exercise). Some negative expectations were also expressed, mainly concerning communication/contact with others (e.g., loss of interpersonal interaction) and avoiding danger (e.g., skepticism about handling emergencies) (96).

While the component 'learning ability' was not among the participants' top six positive support expectations – whose ranking was based on the coding frequency of (positive or negative) expectations discussed within each component of human needs – it was recognized across all of them. This was reflected, for example, through reminders, instructions, or cognitive training, which humanoid SARs could support (96). The findings indicated a strong demand for robotic assistance in the cognitive preservation of PwD, aligning with predictions in existing literature (29, 31, 33, 98). Since cognitive training in PwD may help alleviate disease-related symptoms (e.g., cognitive decline, BPSD, care dependency) (11, 36, 37, 82, 84, 86), combining a humanoid SAR with a CCI was considered a way to enhance the perceived usefulness of such robots as dementia caregiving support and potentially mitigate caregiver burden, leading to Study 2.

Study 2 outlined the effectiveness of CCIs on cognition in people with SCD, MCI, and dementia, with most of those interventions being conducted on PCs and tablets. One randomized controlled trial (RCT) involving people with SCD showed significant improvements in memory functions after cognitive training on a PC. Meta-analyses of 12 RCTs demonstrated significant effects of CCIs for people with MCI in memory, working memory, attention/concentration/processing speed, and executive functioning but no significant improvements in global cognition and language. A meta-analysis of four RCTs, combining two studies with PCs, one with a tablet, and one with (non-immersive) VR for PwD, showed a positive trend toward memory improvement but no significant change (SMD 0.33, CI 95% [-0.10, 0.77]) (81).

Based on the positive (non-significant) trend in memory function and the fact that most technologies used in this meta-analysis were non-emerging – called standard technologies, such as PCs and tablets (81) – we decided to combine a humanoid SAR with a tablet as a CCI for the subsequent Study 3. The following three considerations were also incorporated: *First,* the tablet is already widely used in home settings, assuming some familiarity among PwD and their caregivers. In addition, the knowledge and experiences regarding its usability, gained from previous projects investigating tablet-based multimodal training in PwD, were considered for use in Study 3 (e.g., tablet cover for stability; Figure 2 on page 24) (33, 99). *Second,* the tablet was also chosen for its compatibility with the robot, which should support the training through its social-interactive abilities and motivate participants to engage frequently (33), as a high training frequency is intended for a beneficial outcome on cognition (91). *Third,* a tablet connected via web interfaces allows users to maintain a personal distance from a (standing or moving) robot (98, 100), preventing potential damage and ensuring safety during the tablet-based multimodal training. Although the robot in Study 3 had a fixed location within participants' homes (e.g., living room), it could move within its designated radius (33, 98).

Together with the findings of Study 1, where some of the positive participants' expectations were incorporated or adapted into the humanoid SAR functions (e.g., reminder function, emergency call; see Figure 2; and Figure 1 in Study 3) to enhance supportiveness for the utilization in Study 3, and the insights from Study 2 as well as the stated justifications, a tablet with multimodal training (i.e., cognitive and physical exercises) was chosen to be combined with a humanoid SAR called Coach Pepper.

Study 3 explored the effects of the humanoid SAR Coach Pepper on caregivers' subjective burden and additional secondary psychosocial outcomes in comparison to exclusively tablet-based multimodal training for PwD. No significant differences in mean changes between groups were identified in the outcomes of caregiver burden, QoL, depressive symptoms, and affect. Regarding the outcome of acceptance, which was measured only post-interventional, the two domains, usefulness and accessibility, were rated significantly higher by the control group, which received only the tablet-based multimodal training for PwD at home. Qualitative findings about attitudes towards Coach Pepper in dementia care were mostly positive but predominantly neutral regarding caregiver burden. Most caregivers stated that Coach Pepper was neither a burden nor a relief in dementia care during the three-week intervention period, explaining that, on the one hand, PwD required regular support in using the robot for further self-occupation, which, on the other hand, provided them (only) a little free time from caregiving. The perceived usefulness of Coach Pepper in dementia caregiving was already experienced by caregivers in six out of fourteen components of human needs: 'learning ability' (i.e., reminder function, cognitive exercises in multimodal training), ‘recreational activities’ (e.g., jokes, music function), ‘contact with others’ (e.g., Coach Pepper as a contact person for PwD), ‘mobility/body posture’ (i.e., physical exercises in multimodal training), ‘communication’ (i.e. using predefined phrases/dialogs), and ‘avoiding danger’ (i.e., emergency call function). However, they expressed ‘future needs’ as further improvements for such robots in all components of human needs (e.g., advanced emergency and communication functions) (95).

Discussion of the main results

Coach Pepper as an emerging technology for dementia caregiving support

To the best of our knowledge, **Study 3** was the first to investigate the effectiveness of a humanoid SAR as a supportive device for dementia home caregiving (95). While caregivers in both the intervention and control group already exhibited caregiver burden at baseline (101), no significant changes in caregiver burden or other psychosocial outcomes were observed (95). This could be due to the short duration of the three-week intervention period, as well as the relatively broad range of caregiving duration among caregivers, which varied from one month to more than seven years (95), given that caregiver burden tends to increase with the duration of care (42). The quantitative results align with the qualitative findings in that Coach Pepper was neither a burden nor a relief. However, it should be highlighted that some caregivers have already expressed relief from caregiving due to the robot (95).

For Coach Pepper to be a dementia caregiving support, findings on positive expectations regarding potential support from **Study 1** were incorporated into the functions of Coach Pepper within the given constraints (e.g., time and technical resources) of the overall project AMIGO. Additionally, caregivers (and PwD) in Study 3 were involved in customizing Coach Pepper (i.e., reminder functions, dialogs, a photo album) before the start of the intervention so that it could provide support tailored to the needs of PwD and their caregivers (95). Furthermore, a multimodal tablet-based training, based on **Study 2**, was intended to enhance cognition in PwD, thereby contributing to the perceived usefulness of this emerging technology in terms of learning ability. However, for PwD who participated alongside their caregivers in Study 3 and were also considered within the larger AMIGO project (98), no significant change in the outcome ‘cognition’ was observed after the three-week Coach Pepper intervention (102). In addition, ‘motivation’ also remained non-significant in PwD (102), which did not align with the original intention of combining a SAR with a CCI to motivate PwD to engage more frequently in cognitive training for potential positive effects (33, 82, 91), reducing caregiver burden. Interestingly, the QoL for PwD in the Coach Pepper group significantly increased, which was also reflected in their qualitative findings, such as describing the robot as having become like a friend (102). This raises the question of whether the intervention for caregivers in Study 3 was too indirect, as it only provided caregiving support without direct support for themselves (e.g., relaxation exercises) (95). Coach Pepper primarily aimed to support and 'be there' for PwD (95), which is not unusual, as currently, most emerging technologies focus on directly supporting the health and lifestyle of PwD (28, 103). Indeed, some caregivers in Study 3 also reported growing close to Coach Pepper, highlighting their positive attitudes toward the robot (95). However, integrating direct caregiver support functions into humanoid SARs might make a difference in terms of caregiver outcomes, such as caregiver burden. In this regard, the authors of the original *Stress Process Model of Caregiving* (38), on which the *DCB-TS Model* of this doctoral thesis is based, among others (39-41), also incorporated 'coping' alongside 'support' as a mediator for caregiver burden. The authors described three relevant coping strategies for caregivers: managing the stressful situation, managing its meaning to lessen the threat, and managing the resulting stress symptoms (38). Regarding these points, psychotherapeutic (e.g., cognitive behavioral therapy), and psychoeducational approaches (e.g., communication skills, problem-solving, managing BPSD, relaxation exercises, self-care strategies) to help caregivers respond more effectively to the needs of PwD while maintaining their emotional balance could be considered (11, 38, 39, 68, 69). In this context, humanoid SARs could support caregivers by analyzing threatening situations on-site (e.g., those caused by BPSD), helping them manage stress from disease-related symptoms, and providing education on these symptoms to better handle caregiving challenges. Additionally, they could monitor stress-related symptoms (e.g., through mobile/wearable technologies), set prompts when unhealthy limits are reached, suggest breaks, appointments (e.g., psychotherapy), or relaxation exercises, and offer guidance (32, 95).

Caregivers' expectations, perceived usefulness, and future needs regarding humanoid SARs like Coach Pepper

Overall, the results of **Study 1** and **3** demonstrated that caregivers see great potential for support through humanoid SARs in dementia care (95, 96). In addition to the previously discussed issue regarding further support functions for caregivers, the fact that caregiver burden remained unchanged in Study 3 may also be due to caregivers having higher prior expectations of Coach Pepper's usefulness, compared to the perceived usefulness they experienced during the study. The qualitative findings support this, indicating a greater demand for improvements across all components of human needs, compared to the actual perceived usefulness reported in only six components (95). This may also explain why the tablet-based multimodal training in the control group was rated significantly higher in terms of usefulness and accessibility (95, 104). Interestingly, the future needs expressed in Study 3, as well as positive expectations stated by participants in Study 1, led to the conclusion that such robots need considerable advancements to be supportive in dementia care, especially regarding communication (e.g., intelligent speech function, also responding to emotions), mobilization (e.g., specific movements, accompany for a walk), customization (e.g., verbal reminders, music, biography for talking), and the ability to recognize objects, situations, and contexts with appropriate reactions (e.g., emergency situations) (95, 96). In this regard, artificial intelligence (AI) will likely be a game changer (105). Currently, AI in social robotics relies on weak AI, which uses domain-specific algorithms to perform tasks considered intelligent when executed by humans. Examples of such algorithms in SARs include speech recognition, autonomous navigation, gesture and facial recognition, and object and emotion detection (106, 107). Advancements in these areas do not seem far-fetched, particularly when it comes to developing an intelligent speech function, as indicated by participants in Studies 1 and 3, especially given the emergence of Large Language Models (LLMs) (e.g., GPT-4o), which are utilized in applications like ChatGPT (by OpenAI) or Perplexity AI Pro (108, 109). Unlike Coach Pepper, the humanoid SAR 'Navel' from ©navel robotics GmbH has already integrated such LLM for verbal conversations with nursing home residents (110). However, the desired advancements for humanoid SARs, as revealed from the findings of Studies 1 and 3, highlight the need for integrating different algorithms (e.g., walking assistance with conversation and danger avoidance), which aligns with the concept of strong AI – future technologies that are virtually indistinguishable from humans (95, 96, 106). Although some LLMs are highly advanced in their field and can closely resemble human behavior, strong AI, as defined earlier, does not exist yet (106). However, the desire for strong AI in humanoid SARs, enabling them to provide comprehensive support and relief for caregivers, contradicts some ethical findings in both studies – particularly the fear of human replacement and the associated loss of human contact (95, 96), a concern also reflected in further literature (111-113). In this regard, Boada, Maestre (113) highlight the crucial question of whether humanoid SARs will be used as replacements or as collaborative agents in care, which is key to the further development of such robots in dementia care. Considering the ongoing technological advancements, especially in AI (106), continuously involving caregivers and PwD in the research and development of humanoid SARs for use in dementia home care is essential for their perception of the technology, the assessment of its implementation, and shaping its future direction, as was done to some extent from the caregiving perspective in this doctoral thesis.

Learning abilities in the context of CCIs and humanoid SARs like Coach Pepper

The results of **Study 2** showed a positive but non-significant trend for memory function in PwD performing CCIs, while significant effects were found for people with MCI and SCD. This suggests that when considering CCIs, the maxim 'the earlier, the better' may apply (81). Most CCIs relied on standard technologies like PCs or tablets, possibly because emerging technologies such as virtual, augmented, and mixed reality are still in early development for dementia, with limited research, especially in terms of high-level evidence like RCTs (71, 81, 114, 115). Nevertheless, emerging technologies hold great potential as CCIs for dementia, such as leisure-based cognitive training in virtual environments (e.g., beach, city) (116) or (instrumental) ADL training (e.g., grocery shopping, making coffee) (117, 118). However, **Study 3** combined a humanoid SAR with a tablet for multimodal training but showed no significant cognitive results for PwD (95, 102). Participants trained once per week with a dementia trainer and could practice independently (95, 98), while the literature recommends six weekly sessions for beneficial effects (91), which may not have been met. Furthermore, the three-week intervention duration was likely too short to detect significant changes (95, 102). In addition, as mentioned earlier, PwD in the AMIGA project showed that Coach Pepper also had no significant effect on their motivation (102). One further possible reason for these two non-significant outcomes could be that Coach Pepper's motivational strategies, its usability during training, and the combined tablet-based multimodal training need enhancements (95). In another project (i.e., MultimodAAL), the similar tablet-based multimodal training (without a robot) was qualitatively evaluated by participants who suggested introducing (technical) guidance/instructions, motivation/feedback/tips, along with additional written and verbal support (e.g., voice assistant), to improve adherence to the training (92). While the pre-programmed, random praise and motivational statements from Coach Pepper were well-received by PwD according to their caregivers in Study 3, some of these needs were not addressed, as reflected in findings for improvements, such as operating the training via voice command and adding tutorial videos (95). This highlights the need for future enhancement of such robots in guiding cognitive training, particularly for the communication function, AI applications, and customization for tailored feedback and training experiences for PwD (95), which, according to the *DCB-TS Model,* could potentially improve motivation for regular training, benefit cognition, and reduce caregiver burden.

The perceived usefulness of 'learning ability' was also considered in terms of a reminder function in Coach Pepper for PwD in **Study 3** (95), which was expressed before, through findings in **Study 1,** as a positive expectation embedded in all physical and psychosocial human needs (96). The reminder function was intended to support dementia caregiving at home, as also outlined in the literature (29, 31, 77). In addition, this function also holds the potential to promote cognition through a cognitive rehabilitation (CR) approach. This approach involves individualized, goal-oriented strategies developed with caregivers and healthcare professionals to support daily tasks and aims to improve or maintain cognitive performance by building on strengths and compensating for impairments (37, 82, 119, 120). To some extent, this was already considered in Study 3, where caregivers and PwD were asked what should be integrated into the reminder function based on human needs (95). However, future needs for advancing this function were far greater than the perceived usefulness, to the point where one could already speak of CR through Coach Pepper – something that certainly holds potential, considering the technical advances desired by participants in Study 1 and 3 (95, 96).

Methodological reflection – main strengths and limitations

Studies 1 and **3** employed a descriptive qualitative approach with qualitative content analysis by Schreier (121), using a concept- and data-driven coding frame to analyze transcripts from homogeneous focus groups (Study 1) and individual interviews (Study 3). This approach allowed for an open exploration of expectations (Study 1), attitudes, and perceived usefulness (Study 3) of humanoid SARs, which predefined quantitative items that might not have been captured. Nevertheless, both studies employed a semi-structured interview guide to ensure comparability, identifying similarities and differences within findings and target groups. This structure within the interview guides also served as a basis for concept-driven categories, which were again reflected in the structure of the findings in both studies. Data-driven categories are revealed from the transcripts to provide an in-depth description of the material. One difference between the two studies was the data collection method: Study 1 used focus group discussions (96), while Study 3 relied on individual interviews (95). Compared to individual interviews, focus groups can benefit from group dynamics, encouraging participants to reflect on and discuss the experiences and opinions of others, which can generate a broad spectrum of ideas (122). This was particularly useful in Study 1 for exploring various support expectations oriented on the CDS items regarding humanoid SARs in dementia care. While focus groups foster dynamic discussions, they also risk, for example, dominance by certain participants or fabricated responses, which were considered and mitigated using specific strategies according to Krueger and Casey (122). In contrast, individual interviews in Study 3 provided a more intimate atmosphere but lacked the advantages of group interactions. However, they were considered appropriate as they were conducted at home on the day Coach Pepper was picked up, allowing for fresh insights into participants' attitudes and experiences.

For **Study 2**, a systematic review with meta-analyses was deemed appropriate to assess the effectiveness of CCIs on cognition in people with SCD, MCI, and dementia, following the Cochrane Handbook for Systematic Reviews of Interventions (123). However, relevant secondary disease-related outcomes for PwD (e.g., BPSD, care dependency) were not considered. This was due to the already broad eligibility criteria, which included global and domain-specific cognition as outcomes, three target groups, and a wide range of CCIs (81). Additionally, exploring factors that could enhance adherence to CCIs in PwD would have been valuable for further consideration in Study 3. This was actually planned as a combination of: *first*, a systematic review to assess the effectiveness of CCIs; and *second*, a realist review to identify beneficial and hindering key characteristics of these technologies that enhance the adherence, acceptance, compliance, and usability of these technologies for people with SCD, MCI, and dementia (124). Due to the unexpectedly significant effort required, the research team prioritized only the effectiveness of CCIs. However, the tablet used in Study 3 was not newly developed, as mentioned earlier; rather, it had been applied in an earlier project with PwD, in collaboration with a non-profit project partner from a dementia service center, whose experiences were integrated into the tablet application in Study 3 (99). Along with the observed beneficial trend in a meta-analysis of memory function in PwD, mostly using standard technologies as CCI (Study 2) (81), the involvement of qualitative findings regarding such trainings (e.g., motivational statements from a robot) (Study 1, and findings of PwD in the AMIGO project) (96), efforts by the research team (e.g., intervention training on delivery day, a hotline), and the detailed RCT study protocol (e.g., weekly supervised training for PwD) (95, 98), all aimed to achieve those outcomes planned in the realist review (124).

In **Study 3**, an RCT was conducted to investigate the effectiveness of Coach Pepper on subjective caregiver burden (primary outcome) (95). As RCTs generate the highest level of evidence among original studies in evidence-based practice, this was an appropriate design to determine whether the intervention was effective (114, 115). The CONSORT Statement and Checklist (125), with its explanation and elaborations (126), was used to guide and report the study. Additionally, their recommendations for a prior trial registration (ClinicalTrials.gov, NCT03818217) as well as to publish a study protocol (98) were followed to reduce the likelihood of undeclared post hoc changes to the trial methods and selective outcome reporting (125, 126). All caregiver outcomes were reported per protocol and registration. In this context, the registered and defined outcomes of care dependency and BPSD for PwD might also have been of interest within this thesis, as they can play a major role in caregiver burden development, according to the *DCB-TS Model*. However, they also showed no significant changes for PwD (102). Lastly, the mixed-method approach of Study 3 should be highlighted, as it made it possible to evaluate the Coach Pepper intervention and also gain qualitative feedback and a better understanding (127).

Conclusion

Caregiver burden arises from complex and dynamic multifactorial interactions in dementia caregiving, affecting both caregivers and PwD. (Non-)technological interventions as support, including emerging technologies, may help mitigate this burden. In this doctoral thesis, Coach Pepper – a humanoid SAR with a tablet as a CCI – was investigated for dementia home care but showed no significant effects on caregivers' subjective burden or other psychosocial outcomes; however, suggestions for future improvements were identified. Before testing Coach Pepper, a qualitative study explored the support expectations of caregivers, nurses, and dementia trainers regarding humanoid SARs, while a systematic review with meta-analyses assessed the effectiveness of CCIs for SCD, MCI, and dementia, with the findings of both studies considered for Coach Pepper.

Considering the willingness of PwD and caregivers, Coach Pepper, in its current form, can (theoretically) be used at home as a complement to conventional care, albeit with its currently limited functions and with limited continuous (technical) support available. Humanoid SARs like Coach Pepper require advancements for dementia home care, particularly in communication/speech, mobility, customization, and pattern recognition with appropriate reactions (e.g., emergencies) in line with developments in AI. For caregivers, caregiving support in stressful situations (e.g., due to BPSD) or direct support (e.g., through mobile/wearable technologies or integrated sensors for stress detection and prompts for breaks) should be integrated, allowing the robot to also serve the caregiver as the 'client'. Nevertheless, future use of such (advanced) robots requires considerations about accessibility (e.g., through home care services), financial aspects (e.g., rental options, monthly costs, insurance subsidies), and support (e.g., remote, on-site).

CCIs should be regularly offered to people with cognitive decline, as they have minimal side effects, provide a low-threshold option in a stigmatized field, and can complement existing (non-)pharmacological treatments.

Future research should involve potential users in the development process of emerging technologies (e.g., humanoid SARs), utilizing mixed-methods designs for continuous feedback, to address their needs and preferences regarding acceptance, usability, support, and ethical considerations. In this regard, potential users should be open-minded and seize opportunities to contribute to the development of these technologies.

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AI-based cover image

Prompt in German: *Bitte erstelle mir ein Bild mit Roboter Pepper. Im Bild soll ein älteres Pärchen sein (Mann und Frau), dass den Roboter liebevoll ansieht. Im Tablet vom Roboter Pepper soll der Name Pepper stehen. Eine Person soll ein Tablet horizontal in den Händen halten. Es soll eine Trainingssituation darstellen. Der Roboter Pepper soll sich rechts im Bild befinden. Der Fokus soll eher auf den Personen liegen.*, ChatGPT-4o, OpenAI, 02.04.2025; https://chatgpt.com

Appendix

The following publications are appended (in order of appearance):

Zuschnegg J, Paletta L, Fellner M, Steiner J, Pansy-Resch S, Jos A, Koini M, Prodromou D, Halfens RJG, Lohrmann C & Schüssler S. Humanoid socially assistive robots in dementia care: a qualitative study about expectations of caregivers and dementia trainers. Published by Taylor & Francis Group in Aging & Mental Health on March 29, 2021, available online: https://wwww.tandfonline.com/10.1080/13607863.2021.1913476. (Accepted Manuscript)

Zuschnegg J, Schoberer D, Häussl A, Herzog SA, Russegger S, Ploder K, Fellner M, Hofmarcher-Holzhacker MM, Roller-Wirnsberger R, Paletta L, Koini M & Schüssler S. Effectiveness of computer-based interventions for community-dwelling people with cognitive decline: a systematic review with meta-analyses. BMC Geriatrics. 2023;23(1):229. doi: https://doi.org/10.1186/s12877-023-03941-y. (Published article)

Zuschnegg J, Häussl A, Lodron G, Orgel T, Russegger S, Schneeberger M, Fellner M, Holter M, Prodromou D, Schultz A, Roller-Wirnsberger R, Paletta L, Koini M, & Schüssler S. Psychosocial effects of a humanoid robot on informal caregivers of people with dementia: A randomised controlled trial with nested interviews. International Journal of Nursing Studies. 2025;162:104967. doi: https://doi.org/10.1016/j.ijnurstu.2024.104967. (Published article)

Humanoid socially assistive robots in dementia care: a qualitative study about expectations of caregivers and dementia trainers

Julia Zuschnegg, Lucas Paletta, Maria Fellner, Josef Steiner, Sandra Pansy-Resch, Anna Jos, Marisa Koini, Dimitrios Prodromou, Ruud JG Halfens, Christa Lohrmann, Sandra Schüssler

This is an ‘Accepted Manuscript’ of an article published by Taylor & Francis Group in Aging & Mental Health on March 29, 2021, available online: https://wwww.tandfonline.com/10.1080/13607863.2021.1913476.

Abstract

Objective: To examine the expectations of informal caregivers, nurses, and dementia trainers regarding the support of (physical and psychosocial) human needs by humanoid social assistive robots (SARs) in dementia care.

Methods: A qualitative study was conducted with 11 homogeneous focus groups of informal caregivers, nurses and dementia trainers providing dementia care at home, in adult daycare centers, or in nursing homes. A qualitative content analysis was performed using a concept- and data-driven coding frame.

Results: Focus group discussions with 52 individuals were held. Participants reported mostly positive expectations and stated that SARs could offer potential support in all components of human needs, especially in avoiding danger (e.g., recognise danger, organise help), communication/contact with others (e.g., enable telephone calls, provide company), daily activities (e.g., remind of appointments, household obligations), recreational activities (e.g., provide music), eating/drinking (e.g., help cook), and mobility/body posture (e.g., give reminders/instructions for physical exercise). Participants also mentioned some negative expectations in all human needs, predominantly in communication/contact with others (e.g., loss of interpersonal interaction) and avoiding danger (e.g., scepticism regarding emergencies).

Conclusion: Participants stated that SARs had great potential to provide assistance in dementia care, especially by reminding, motivating/encouraging and instructing PwD. Informal caregivers and nurses also considered them as useful supportive devices for themselves. However, participants also mentioned negative expectations, especially in communication/contact with others and avoiding danger. These findings demonstrate the support caregivers and dementia trainers expect from humanoid SARs and may contribute to their optimisation for dementia care.

Keywords: dementia, robotics, informal caregivers, nurses, activities of daily living

Introduction

Dementia is a worldwide public health concern, significantly impacting healthcare systems and society (Alzheimer's Association, 2018; Patterson, 2018). PwD demonstrate higher levels of care dependency regarding physical and psychosocial human needs (e.g., hygiene, social contact) than those without dementia and therefore must receive intensified care to maintain their independence for as long as possible (Alzheimer's Association, 2018; Schüssler et al., 2016).

Dementia care is largely provided by informal caregivers and nurses (Alzheimer's Association, 2018; WHO, 2012) as well as other healthcare professionals like dementia trainers (hereafter called 'trainers') (Schulz et al., 2012; WHO, 2012). Due to disease-specific symptoms, dementia care presents significant challenges, increasing the caregivers' (i.e., informal caregivers and nurses) stress levels and burden (Alzheimer's Association, 2018; Evripidou et al., 2019). With regard to future care, it is also necessary to consider the declining worldwide availability of healthcare professionals like nurses or informal caregivers (European Commission, 2020; OECD, 2011; WHO, 2019).

New technologies, such as socially assistive robots (SARs), could address these future challenges by delivering additional support (Korchut et al., 2017; Koutentakis et al., 2020; Pino et al., 2015; Wang et al., 2017). SARs can be defined as an intersection between assistive robots (aiding a human user) and socially interactive robots (communicating with a human user through social and non-physical interaction) (Feil-Seifer & Mataric, 2005). Present-day SAR designs include mechanoids with a machine-like appearance; humanoids with an unrealistic human-like appearance; androids with a realistic human-like appearance; and robot animals, SARs that look like animals (Pino et al., 2015; Walters et al., 2009).

Generally, SARs are not yet commonly commercially available. A review by Bedaf et al. (2015) identified 6 out of 107 commercially available robots focusing on older people. Buhtz et al. (2018) identified 3 (an animal robot, a box-like robot with an display and a telepresence robot) of 13 commercially available SARs for older people living at home. Currently, the best-known commercially available SAR is the animal robot 'Paro', resembling a baby harp seal (Bioethics Commission, 2018; PARO Robots U.S., 2014). While humanoid SARs are still mostly in the (early) development phase, and have a predominantly machine-like appearance, there already exists an industrially produced humanoid robot called 'Pepper' (Buhtz et al., 2018; Pandey & Gelin, 2018; Zamalloa et al., 2017).

There is already a body of work suggesting that SARs can effectively improve the lives of PwD (e.g., depression, agitation), although much of the research has been conducted using animal robots (Leng et al., 2019; Pu et al., 2019). Since interaction with animal and humanoid SARs happens on different levels (emotional vs. verbal communication level) (Campa, 2016), the SAR´s appearance not only influences its assistive capabilities, but also the expectations for its support potential (e.g., giving verbal reminders), which further affects research results (Powers & Kiesler, 2006). These robot designs must therefore be considered in a differentiated way when conducting research on expectations of support by SARs among potential users (Buhtz et al., 2018; Campa, 2016).

According to the 'Almere Model' of Heerink et al. (2010), expectations towards SARs form a construct that could considerably influence the future use of SARs in practice. Based on Heerink et al. (2010) and further literature (Dijkstra, 2017; Dijkstra et al., 1996; Lohrmann et al., 2003), this study defines 'expectations' as individuals' expectations of potential assistive applications of humanoid SARs regarding various components of (physical and psychosocial) human needs.

Previous scoping reviews (Hirt et al., 2019; Papadopoulos et al., 2018) and one narrative review (Koutentakis et al., 2020), referring to literature about expectations to any SAR designs, reported that informal caregivers and healthcare professionals considered SARs as potentially supportive in dementia care with respect to some components of human needs. However, only two qualitative (Darragh et al., 2017; Wang et al., 2017) and two mixed-methods studies (Broadbent et al., 2016; Pino et al., 2015) cited in these reviews (Hirt et al., 2019; Koutentakis et al., 2020; Papadopoulos et al., 2018) referred to humanoid SARs, whereas most qualitative studies referred to robot animals or non-defined assistive technologies. According to the classification of Hirt et al. (2019) on support possibilities of SARs with a humanoid design in subthemes of activities of daily living, the caregivers' expectations in the two qualitative studies as well as in the qualitative parts of the two mixed-method studies were as follows: 'reminding' (Darragh et al., 2017; Wang et al., 2017), 'interaction' (Wang et al., 2017), 'personal care/nutrition/mobility' (Broadbent et al., 2016; Pino et al., 2015; Wang et al., 2017), 'social participation/engagement', 'reminiscence' (Pino et al., 2015), 'housekeeping' (Wang et al., 2017) and 'leisure activities' (Broadbent et al., 2016). However, it must be emphasised that the interviews of these four studies were either more open (Broadbent et al., 2016; Pino et al., 2015; Wang et al., 2017) or very specific regarding support options (Darragh et al., 2017) and that, in one qualitative study (Darragh et al., 2017), the description of the results did not distinguish between groups of participants (e.g., caregivers of PwD or mild cognitive impairment, experts). In the mixed-method study by Broadbent et al. (2016) the qualitative part accounts for only a minor contribution of results.

It is evident that a comprehensive qualitative research of caregivers' expectations of humanoid SARs regarding human needs is required, which is why this qualitative study aims to examine the expectations of informal caregivers, nurses, and trainers regarding the support of (physical and psychosocial) human needs by humanoid SARs in dementia care.

Methods

Study design

This qualitative descriptive study with caregivers and trainers constituted the first step of a larger project, while a further qualitative study about expectations of PwD and a randomised controlled trial will be reported elsewhere.

This study uses a focus group approach described by Krueger and Casey (2015). This interactive technique enables people to ponder, reflect on, and listen to statements made by others, which reveal their attitudes and expectations and collect extensive information (Krueger & Casey, 2015). Information on the potential for humanoid SARs to provide support in dementia care was collected from informal caregivers, nurses, and trainers.

The COREQ-Checklist (Tong et al., 2007) was used to guide the reporting process during this qualitative research.

Sample and participants

The study was performed in Styria, one of Austria's nine federal states. Participants were included by purposive sampling of maximum variation in terms of three different target groups. This specific method was considered suitable to obtain a comprehensive understanding of all participants' expectations and to identify similarities/differences between these target groups (Ames et al., 2019). Informal caregivers, nurses and trainers were recruited in person or by telephone by a non-profit social organisation offering dementia services. No compensation for participation was given. All participants were ≥18 years old and spoke and understood German. Further inclusion criteria were as follows:

- Informal caregivers had to be relatives or significant others (e.g., friends) of a person with dementia at home and/or in an adult daycare center or nursing home, regardless of dementia type and severity. Informal caregivers could live with the person with dementia in a joint household or not and perform care themselves and/or receive professional assistance or not.

- Nurses had to work as registered nurses in home care, in an adult daycare center, or in a nursing home and demonstrate experience in dementia care.
- Trainers had to have performed cognitive and physical trainings with PwD in their home, in adult daycare centers, or in nursing homes. Trainer education varies internationally and is not yet available in all countries. In Austria, it is open to people aged ≥18 who have completed compulsory schooling (Alzheimerakademie, 2021; Schulz et al., 2012). Future trainers have to complete a nine-month training programme consisting of theoretical courses (eight modules including e.g., communication with PwD, stage-appropriate cognitive training, physical exercises), practical trainings (work shadowing and training in a practice setting) and a final examination (Alzheimerakademie, 2021).

Ethical considerations

Ethical approval was obtained from the Medical University of Graz Ethics Committee (30-142ex17/18). Participants received verbal and written information about the study and gave their oral and written informed consent to participate.

Data collection

Data collection took place from January to May 2018. In total, 56 individuals agreed to participate; 11 focus groups with a total of 52 participants were performed separately for informal caregivers, nurses and trainers and lasted 93.9 minutes on average (Table 1). Four individuals did not attend focus groups, as they missed the appointment (n = 2), became ill (n = 1), or cancelled without justification (n = 1).

Focus groups were performed by JZ and trained healthcare professionals from the non-profit organisation. JZ, a nursing scientist and doctoral student, had experience conducting interviews and trained the healthcare professionals, ensuring consistent data collection. Focus groups were led by a moderator (JZ or one trained healthcare professional) and held in quiet meeting rooms at the non-profit organisation or the institutions (e.g., nursing homes). A two-minute video of the humanoid SAR called 'Pepper' was then shown to give participants an impression of a humanoid SAR and demonstrate its features (e.g., dance function, speech). 'Pepper' is 1.20 m tall, weighs 28 kg, can move its head, upper extremities and chest, and is able to engage with people through conversation and its tablet (Softbanks Robotics, 2020). 'Pepper' was chosen as an example because it is the first robot of its kind to be mass-produced and, therefore, can be purchased (Pandey & Gelin, 2018). However, the moderator emphasised in the focus groups that 'Pepper' served as an example only and that the questions referred to humanoid SARs in general.

A co-moderator (one trained healthcare professional) assisted at each focus group, noting the participants' main statements, summarising the discussion at the end, asking participants for clarification, and gathering further comments. At least three focus groups with each type of participants were conducted, following the recommendations of Krueger and Casey (2015) to achieve data saturation for each target group.

Based on literature* and the research team's expert knowledge on dementia, a semi-structured interview guide was developed and used in the focus groups [see Supplementary Material 1*]. To comprehensively examine participants' expectations, the authors had chosen the items of the 'Care Dependency Scale (CDS)' to govern the development of the interview guide. This scale was originally developed to assess the care dependency of PwD and intellectual disabilities and includes 15 (physical and psychosocial) human needs based on the nursing theory of Virginia Henderson (Dijkstra et al., 1996; Lohrmann et al., 2003). Care dependency, in this context, is seen as a process in which an individual's care demands require (professional) support because of their decreased ability to provide self-care in physical and psychosocial human needs (e.g., hygiene, communication) (Dijkstra, 2017; Schüssler & Lohrmann, 2015). The authors considered the components of human needs included in the CDS as appropriate to conduct a comprehensive qualitative examination of expectations regarding support by SARs in dementia care. Additionally, the CDS human needs items were deemed appropriate for this study for including both physical and psychosocial components (e.g., social contact, communication) (Dijkstra et al., 1996; Lohrmann et al., 2003), which also play an important role in dementia care (Schüssler & Lohrmann, 2015).

Furthermore, two pilot-test interviews were conducted (JZ, SS) with target group representatives to adapt the questions (adjusting the order of the questions) and improve comprehensibility.

Data analysis

Audio-recorded focus groups were transcribed (JZ, SS), and a qualitative content analysis described by Schreier (2012) was performed using a concept- and data-driven coding frame. Based on the research question, the components of human needs (Dijkstra et al., 1996; Lohrmann et al., 2003), further literature from the interview-guide*, and expert knowledge, JZ and SS developed a concept-driven coding frame consisting of a main category and subcategories [see Supplementary Material 2*]. Additional data-driven subcategories were created based on the transcripts. Subsumption was used to generate data-driven subcategories, which is an appropriate strategy if concept-driven main categories and ideas for subcategories already exist. For data segments of the transcript not fitting in an existing subcategory, a new subcategory was generated. This process was repeated until saturation point, meaning that no new subcategory could be generated and none remained empty (Schreier, 2012).

JZ and SS independently categorised each transcript, then met, compared all used categories, discussed, and resolved any disagreements. Finally, the categories were summarised and interpreted by JZ, and the results were then discussed with SS.

Results are presented qualitatively (exemplary personal quotes) and quantitatively (coding frequency) (Schreier, 2012).

MAXQDA (2018) was used to manage the data.

Results

Participants' characteristics

In total, 52 individuals, mostly women (92.3%), agreed to participate in focus group discussions (Table 1). The average participant age was 47.1 years; more than half (55.8%) had a medium education level according to the International Standard Classification of Education (UNESCO, 2012).

Table 1. Characteristics of focus group participants

	Informal caregivers	Nurses	Trainers	All
Total, *n*	16	20	16	52
Focus groups sessions, *n*	3	4	4	11
Range of participants in focus group sessions, *n*	4-8	4-7	2-6	2-8
Duration of focus group discussions in minutes, mean	87.5	102.3	93.2	93.9
Age, mean	54.3	41.1	45.9	47.1
Female, *n* (%)	15 (93.8)	17 (85.0)	16 (100.0)	48 (92.3)
Highest educational level*, *n* (%)				
Low education	1 (6.3)	0.0	4 (25.0)	5 (9.6)
Medium education	10 (62.5)	13 (65.0)	6 (37.5)	29 (55.8)
High education	5 (31.3)	7 (35.0)	6 (37.5)	18 (34.6)
(previous) occupation, *n* (%)		-	-	-
Employed	12 (75.0)			
Housekeeper	4 (25.0)			

Place of employment, *n* (%)	-			-
Home care		7 (35.0)	0.0	
Nursing home		9 (45.0)	2 (12.5)	
Home care and nursing home		-	14 (87.5)	
Adult daycare center		4 (20.0)	0.0	
Professional experience in nursing, *n* (%)	-		-	-
0-1 year		0.0		
2-5 years		4 (20.0)		
6-10 years		1 (5.0)		
11-15 years		2 (10.0)		
16-20 years		6 (30.0)		
> 20 years		7 (35.0)		
Professional experience as trainer, *n* (%)	-	-		-
0-1 year			10 (62.5)	
2-5 years			5 (31.3)	
6-10 years			0.0	
> 10 years			1 (6.3)	
Type of relationship between informal caregivers and persons with dementia, *n* (%)		-	-	-
Spouse	2 (12.5)			
Daughter	7 (43.8)			
Daughter-in-law	4 (25.0)			
Son	1 (6.3)			
Acquaintances (e.g., neighbour, friend)	1 (6.3)			
Granddaughter	1 (6.3)			
Setting PwD, *n* (%)		-	-	-
Living at home	12 (75.0)			
Living in nursing homes	4 (25.0)			
Care provided by informal caregivers, *n* (%)	12 (75.0)			
Extent of care provided by informal caregivers† (*n* = 12), *n* (%)		-	-	-
Substantial	1 (8.3)			
High	6 (50.0)			
Moderate	3 (25.0)			
Low	2 (16.7)			
Support of professional care at home (*n* = 12), *n* (%)	8 (66.7)	-	-	-

* according to the International Standard Classification of Education (ISCED) (UNESCO, 2012).
† Extent of care provided, self-assessed by informal caregivers

Expectations

The following results alternately describe the participants’ positive and negative expectations on assistive applications of humanoid SARs in dementia care in the components of (physical and psychosocial) human needs. The categories ‘avoiding danger’ and ‘communication/contact with others’ were most frequently discussed (coding frequency by absolute numbers) by all participants (both positively and negatively) (Figure 1 and 2).

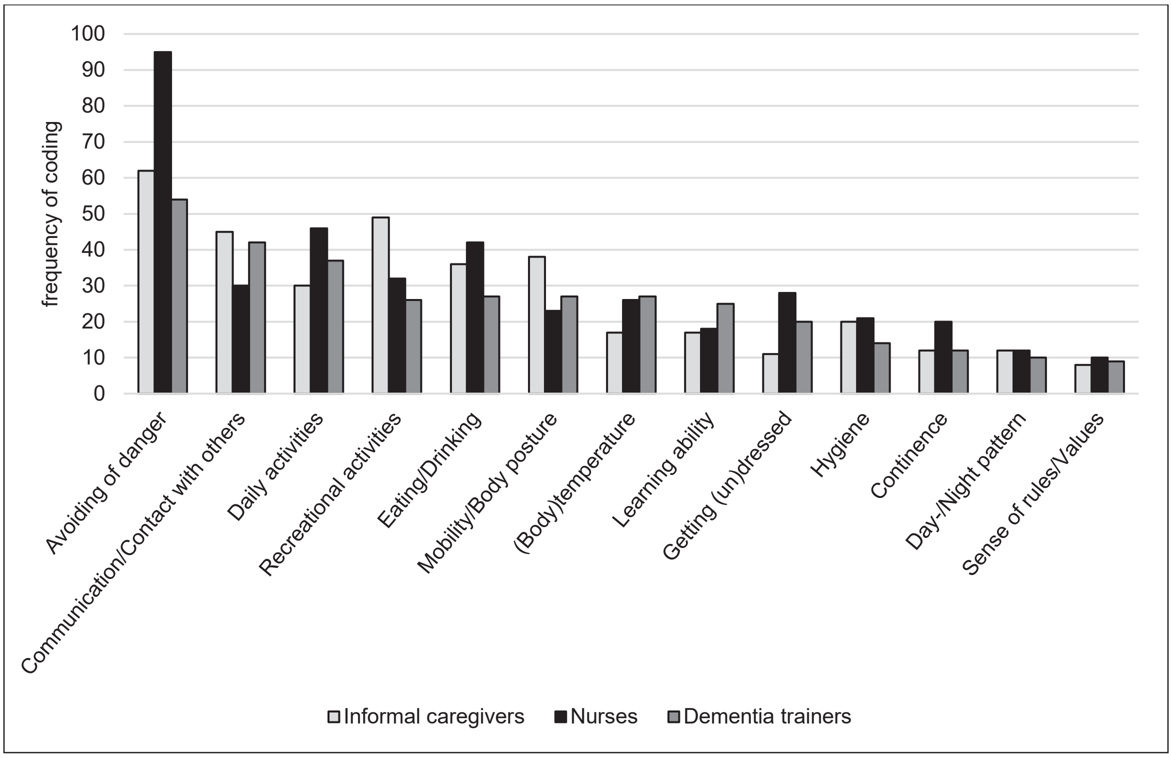

Figure 1. Positive expectations of humanoid SARs per target group

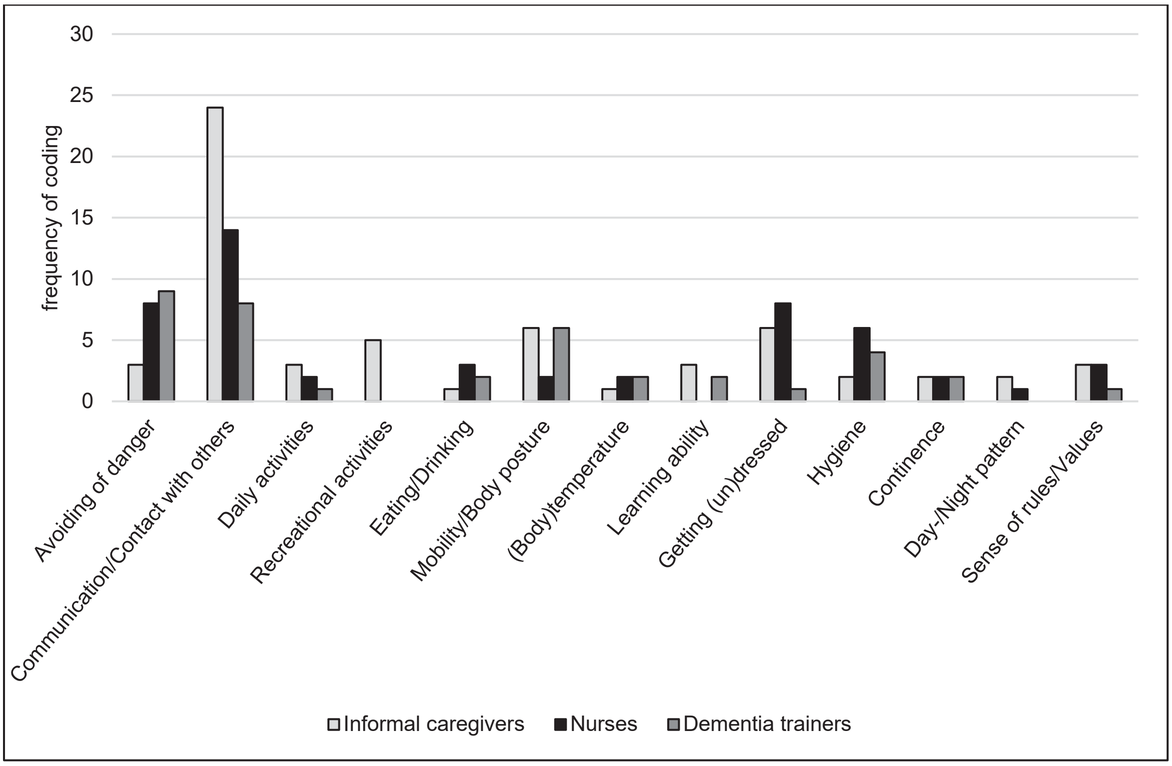

Figure 2. Negative expectations of humanoid SARs per target group

Avoiding of danger

Participants of all three sample groups recognised the highest potential for SARs in this category, stating that SARs needed to be able to identify dangerous situations and raise awareness.

> *'He [SAR] must always be one step ahead of the client [person with dementia]' (DT-FG3:86).*

Nurses and informal caregivers believed SARs could prevent falls and injuries (e.g., give hints inside and outside; offer walking aids, provide company, identify fallen/injured persons). Nurses specifically noted that SARs needed to be able to notify informal caregivers, emergency responders, and healthcare workers if a dangerous situation arose at home or in institutions (i.e., nursing homes, daycare centers).

> *'Of course, he [SAR] should be able to make an emergency call when he notes that he [person with dementia] is lying on the ground' (N-FG3:220).*

However, this theme was controversially discussed, particularly by trainers and nurses who believed that SARs could not help PwD if they fell and could even pose a risk of falling. Some *participants stated seeing no possible application for emergencies.*

> *'What if an emergency occurs? I can´t imagine that the robot acts accordingly' (N-FG2:51).*

In particular in the domestic setting, trainers and nurses frequently mentioned that SARs could help to avoid dangers by detecting temperature changes. They said that SARs should be able to measure and control the stoves'/appliances' temperature, alerting the PwD or switching off appliances if needed.

> *'The person [with dementia] often leaves something on the stove and it switched on. He [SAR] might turn off the stove or alert the person' (DT-FG4:55).*

Participants, especially nurses and trainers, commented that SARs should also be able to measure body temperature and other vital functions (e.g., pulse, blood pressure, blood sugar).

Communication/Contact with others

In particular, trainers suggested that SARs could offer support with making phone calls (i.e., help handle (mobile) phones or make (video) calls by voice command). Informal caregivers and trainers added that SARs should remind the person with dementia to maintain social contacts and initiate conversations with others, especially in the home setting. Informal caregivers suggested that SARs might keep the PwD company (e.g., at home/social events) and communicate with them. To do so and to be able to answer specific questions, SARs would need personal information about the person with dementia and knowledge of current affairs. Informal caregivers also saw this as a potential for relief, as SARs respond to frequently reiterated questions without feeling irritation.

> *'If they [PwD] are already in the phase where they ask the same question 100 times. Because the robot has no everyday stress, it doesn't matter' (IC-FG3:376).*

Informal caregivers and nurses emphasised that interpersonal interaction is crucial when talking to PwD. They stated that SARs could not replace a human in this respect, as they could neither adequately respond to feelings nor even express them. Some also noted concerns regarding spontaneous or slurred speech.

> *'My husband cannot speak so well. He often cannot express himself. And that's where the robot doesn't help' (IC-FG2:168).*

Daily activities

In particular, nurses expressed that SARs should be independently active in the household by keeping order, vacuuming, doing the laundry and support nurses in health institutions by cleaning up and disinfecting residents' rooms.

Participants, and especially trainers, often mentioned how helpful it would be if SARs could provide reminders and step-by-step instructions about appointments (e.g., birthdays), household obligations (e.g., vacuuming), and medication intake.

> *'(…) when taking medication - that he [SAR] says at the time "now you must take it"' (DT-FG2:152).*

Regarding medication, especially informal caregivers expressed distrust toward SARs.

> *'But I think that's where I prefer to do the medicine administration instead of the robot' (IC-FG2:222).*

Recreational activity

Several participants, especially informal caregivers and trainers, stated that SARs should provide music, sing, dance, and even encourage people to join in. Participants also said the SARs should turn the television on/off, switch between channels, and remind the PwD when their favorite programme started.

Informal caregivers mentioned that SARs should be able to play games with the person (e.g., card games) or offer games on their tablet. Nurses and informal caregivers suggested the SARs should read aloud (e.g., newspapers) and take the PwD on walks.

> *'That he [SAR] reminds him [person with dementia] about taking a walk. Of course, it would be nice if he [SAR] could accompany the person' (N-FG2:542).*

But a few informal caregivers, for reasons of dignity and interpersonal interaction, did not welcome the idea of SARs going on walks.

> *'To send someone [with a SAR] for a walk. No, there's no way I could do that' (IC-FG3:276).*

Eating/Drinking

Participants, especially trainers, mentioned that SARs could assist with cooking (e.g., give instructions, use the stove, suggest menus/recipes, prepare food, cook) as well as with shopping and ordering.

Nurses and informal caregivers noted that SARs should encourage the PwD to drink/eat and provide services (e.g., bring a glass of water, set the table). Nurses stated that SARs could document fluid and food intake.

> *'Maybe it would be possible for him [SAR] to record how much someone drank during the day' (N-FG3:67).*

Informal caregivers and nurses were firmly opposed to the administration of food/beverages by SARs, for reasons ranging from possible loss of the ability to eat/drink independently, insufficient consideration of swallowing difficulties, but also the possible impression of dependency from a robot.

> *'I really see the administration of food and beverages as massively problematic' (N-FG4:82).*

Mobility/Body posture

Gymnastic/movement exercises, especially accompanied by music, were mentioned most frequently by informal caregivers. Several participants across all sample groups commented that SARs should provide reminders, instructions, and motivation, but also show exercises and participate.

Furthermore, especially informal caregivers and nurses commented that SARs could accompany the PwD while walking and climbing stairs. Participants stated that such robots should be able to recognise a person's posture (e.g., sitting) and help improve it with encouragement or instructions.

> *'While getting up. That he [SAR] says "Place your legs a little backwards and lean forward, it is easier then"' (N-FG2:174).*

Informal caregivers and nurses also mentioned that SARs should actively mobilise patients.

Due to the unstable appearance of the humanoid SAR 'Pepper', a few informal caregivers and trainers said they could not imagine that such robots could actively assist with mobility.

> *'Climbing the stairs (laughing), I can´t imagine how that would work with a robot' (DT-FG2:119).*

(Body)temperature

In addition to mentioning that SARs should be able to determine temperature, informal caregivers and trainers also stated that SARs should exude heat.

> *'Pepper shouldn´t only feel cold and heat but also radiate it' (IC-FG1:260).*

As sensations of warmth and cold are subjective, some participants in all three sample groups did not wish for support in terms of weather-related clothing.

> *'He [SAR] certainly can´t help judge how cold or hot someone is because each person has to feel this him- or herself' (DT-FG3:76).*

Learning ability

Trainers most often commented that SARs could conduct memory trainings in the form of cognitive exercises, motivate PwD to do these trainings at certain times, but should not emphasise incorrect answers. Nurses and informal caregivers commented that a SAR could perform cognitive trainings more effectively than only a tablet, because the robot, unlike the tablet, could regularly remind and motivate people to do a joint training session.

'Pepper may be better because she encourages you more than a tablet' (N-FG1:34).

Some nurses and trainers stated that SARs should help the PwD maintain their autonomy by first giving reminders before taking over tasks.

In this regard, some informal caregivers and trainers saw less potential for SARs to improve the PwD's learning ability, because they might ignore, forget, or not understand the SAR's reminders.

'I believe that PwD cannot follow what Pepper says' (IC-FG1:207).

Getting (un)dressed

Nurses and trainers mentioned that SARs should be able to identify weather-related clothing and safe shoes, match colors, remember the order of (un)dressing, and indicate when the PwD should change clothes. A few participants, particularly nurses, believed that SARs could actively assist with dressing.

'I could possibly imagine that he [SAR] might be able to help put on stockings, socks, or shoes' (N-FG4:194).

Informal caregivers and nurses most frequently argued against active assistance during dressing, as an intimate act, and some could not imagine it technically possible.

'No, I couldn´t even imagine that a robot would help my mum to remove and put on clothes' (IC-FG3:381).

Hygiene

Participants in all three sample groups commented that SARs should provide step-by-step instructions on body/personal care (e.g., teeth brushing) as well as provide general reminders and motivation.

Active support from SARs was mainly interpreted as assistance in showering/bathing, such as hand-toweling. Some could imagine a SAR washing a person's back and legs, shaving, or combing their hair. Few nurses considered SARs to be unisex, which could be beneficial in assisting people with body care.

> *'In particular, female PwD just don´t want a man to care for them. And that [SAR] would be gender-neutral' (N-FG4:274).*

At this point in the topical discussion, the nurses presented strong opposition to the idea that SARs could completely assume hygiene tasks, due to the sensitivity required for personal hygiene tasks, which they only attributed to human-beings.

> *'But I couldn´t imagine handing over private hygiene care to Pepper' (N-FG4:280).*

Continence

Nurses expressed a wish that SARs would remind and instruct the PwD about personal hygiene (e.g., flushing the toilet, wiping). Nurses and trainers said it would be helpful if SARs performed toilet trainings and, including informal caregivers, stated SARs should also provide active support (e.g., accompaniment to the toilet, preparation of certain products). Nurses frequently wished for SARs to be able to recognise feces, point out the need to change incontinence products or clothing, and draw attention to obstipation.

> *'Remind him [person with dementia] or even recognise if something needs to be changed or not' (N-FG4:404).*

To preserve privacy, some participants in all three sample groups stated that SARs should not take over intimate care and commented that they did not even believe it was technically possible.

> *'If he [person with dementia] wets or soils his pants (...) how should a robot help?' (DT-FG3:108).*

Day-/Night pattern

Participants of all three sample groups mentioned that SARs should act as alarm clocks (e.g., play music, open curtains), remind the PwD of the time, instruct them to go back to sleep if needed, and even act as sleeping aid.

'That he [SAR] sings songs, to [help the person with dementia] fall asleep' (N-FG4:381).

Some nurses considered the idea of the SAR issuing bedtime instructions as paternalistic; especially informal caregivers questioned whether PwD would follow instructions given by a SAR.

'But, if he [SAR] would tell them what to do (...) I don´t know if she [person with dementia] would become aggressive' (IC-FG2:528).

Sense of rules/Values

Participants in all three sample groups emphasised the need for SARs to give reminders, indicate that the person was in the wrong room, set house rules, or lower blinds, especially in nursing homes. Participants commented that the SAR should not invade people's privacy.

'If I want to rest now; Pepper simply shouldn't bother me' (DT-FG2:309).

A few participants, especially informal caregivers and nurses, stated that PwD find rules difficult to follow; they did not expect assistance from SARs in this area.

'Rules are very hard for PwD, because they live in their own world' (IC-FG2:479).

Discussion

In this qualitative study, the authors investigated expectations regarding (physical and psychosocial) human needs expressed by informal caregivers, nurses, and trainers concerning the potential for humanoid SARs to provide support in dementia care. Using the human needs covered by the CDS (Dijkstra et al., 1996; Lohrmann et al., 2003) as a basis for the interview guide and data analysis enabled to gain a comprehensive picture of positive as well as negative expectations, including human needs which had not been addressed before, like '(body)temperature' and 'sense of rules/values', or had only been shown to a limited extent, like 'eating/drinking' (Broadbent et al., 2016; Wang et al., 2017), 'learning ability', 'mobility/body posture' (Darragh et al., 2017), 'getting (un)dressed', 'hygiene', 'day-/night pattern' (Wang et al., 2017), 'continence' and 'recreational activities' (Broadbent et al., 2016) .

Most participants recognised that humanoid SARs could offer support regarding all components of human needs, and especially with respect to 'avoiding danger', 'communication/contact with others', 'daily activities', 'recreational activities', 'eating/drinking', and ‘mobility/body posture’. The first two categories ‘communication/contact with others’ and ‘avoiding of danger’ were discussed the most regarding both positive and negative expectations, followed by ‘getting (un)dressed’, ‘mobility/body posture’, ‘hygiene’, and ‘sense of rules/values’.

Although most participants were open-minded about SARs, it seemed important for the provided support to be supplementary and not replace human care. This finding reflects results reported in Wang et al. (2017), in which one informal caregiver stated ‘Robots are a necessity, but you never replace people’. Mataric (2017), a well-known researcher in the field of robotics, stated that replacing human caregivers with SARs is not the aim; the aim is to fill the gaps where humans are not available, amplify human work, and offer relief for caregivers.

According to the participants, SARs should always ‘keep an eye’ on PwD and provide care. Assistance in ‘avoiding of danger’ by SARs in dementia care is not only of great importance in this study; it is also reflected in the results of qualitative (Darragh et al., 2017; Wang et al., 2017) and mixed method (Pino et al., 2015) studies. However, none of these authors pointed out that participants recognised negative aspects in this area. The results of this study show that some trainers and nurses had concerns about the use of SARs to avoid danger and in emergencies, possibly due to a lack of confidence in the ability of robots to correctly interpret complex care events. Nurses have learned to recognise patients’ nonverbal body language, draw conclusions, and plan/react appropriately, which robots cannot perform yet (Rösler et al., 2018). However, nurses usually expected SARs to identify danger and notify responsible persons.

The second main topical discussion was on ‘communication/contact with others’. The informal caregivers, like those described in Wang et al. (2017), noticed a great potential for SARs to support PwD and to relieve themselves from the PwD’s repeated questions. Some informal caregivers in our study, however, strongly denied that SARs could provide support in this area, expressing concerns regarding human replacement, concerns also mentioned by Pino et al. (2015). The interpersonal relationship that is established during a conversation should not be lost, but the increasing memory loss of PwD requires informal caregivers to provide support in the form of reminders/instructions to address almost all components of human needs. This adds to caregiver burden (Alzheimer's Association, 2018) and may explain why they see SARs as a source of relief.

Participants were not greatly concerned with ‘learning ability’, the feature to preserve a patient’s cognitive function, but this aspect is indirectly present in all components of human needs in the form of reminders and instructions. To support the independence of PwD, nurses and trainers emphasised cognitive preservation, suggesting that SARs should provide activity reminders first before completely taking over an activity. Participants in studies by Pino et al. (2015) and Wang et al. (2017) also suggested compensating for cognitive impairment by SARs as an essential issue. In addition, study participants mentioned the SARs' ability to encourage and motivate PwD to perform activities, regarding almost all components of human needs, presumably due to dementia-specific symptoms like apathy (Robert et al., 2010).

Generally, informal caregivers saw SARs as good companions for PwD and stress relief for themselves. This might be interpreted as their wish to counteract the serious issue of social isolation due to dementia (Hartigan et al., 2019) and the disease-specific higher care burden (Alzheimer's Association, 2018).

Nurses tend to view humanoid SARs more as a practical device for indirect support in their daily work (e.g., reminders, vital function measurement), keeping their core responsibilities for themselves (i.e., direct patient contact). The idea that SARs would take over general nursing activities was also mainly rejected by healthcare professionals in the scoping review of Papadopoulos et al. (2018). Healthcare professionals in this review also expressed the wish to have additional time for patient-centered care, i.e., more time for patients' individual needs (Papadopoulos et al., 2018). This is perhaps why nurses, in this study, expected humanoid SARs to act more as a supportive device for themselves, so that they would have more time to care for the PwD.

Trainers commented most frequently in terms of 'avoiding danger' (e.g., recognition of the temperature of stoves/appliances) and 'communication/contact with others'. However, like nurses, they expressed mistrust regarding a correct response to emergencies. Like informal caregivers, they expected a promotion of communication and social contacts by the SAR, but predominantly by helping maintain social contacts than the sole interaction with the robot itself.

Furthermore, with respect to their profession, they saw support potential regarding learning ability, i.e., to perform cognitive trainings. According to the NICE Guideline (2018), cognitive trainings for people with mild to moderate Alzheimer's disease are not recommended due to current low-moderate-quality of evidence. Bahar-Fuchs et al. (2019) also discussed the low quality of available studies regarding this issue in their systematic review. They stated that further research of high-quality evidence is needed but recommended that the decision for conducting cognitive trainings should not only be based on the current evidence and that further considerations (e.g., PwD's individual preferences, resources) should be included (Bahar-Fuchs et al., 2019).

The results indicate that all participants expect certain functions from humanoid SARs, especially with regard to 'communication/social contact', which play an important role in dementia care (Schüssler & Lohrmann, 2015). Speech systems already exist, but not to the extent that participants expect (Koutentakis et al., 2020). In order to be able to conduct dialogues on a natural conversational basis, this function needs to be developed in a more user-based way, as for example repetitive dialogues can be misleading for PwD (Koutentakis et al., 2020). Other technologies like communication bots (e.g., Alexa) may cover the speech function also, but especially the human-like appearance of a robot can replicate communicative partners better, as the human brain does not react emotionally to artificial objects (e.g. computers, communication bots) (Campa, 2016). In addition, a physical body seems to be crucial for developing trust and attachment to a robot (Koutentakis et al., 2020).

Some scepticism was voiced by the participants, especially informal caregivers and nurses, who did not expect humanoid SARs to recognise feelings and respond/react appropriately. According to Koutentakis et al. (2020), this should become possible in the near future through advances in deep learning and neural networks. The question is, of course, whether this will work satisfactorily for potential users and not increase possible fears of human replacement.

Furthermore, the 'customisability' of humanoid SARs seemed to be important to all participants in this study. Individual adaptations of such robots for persons with dementia (e.g., verbal reminders, biography) are already technically feasible (Schüssler et al., 2020).

The extent of 'mobility-support' that humanoid SARs should offer in the future according to participant's expectations (e.g. accompany on a walk) is currently not yet possible, as Papadopoulos et al. (2020) found in a review about participants who had tested humanoid SARs in health and social care settings identifying limited performance in terms of mobility, describing it as a crucial barrier against the use of such robots.

Furthermore, nearly all participants expected humanoid SARs to be able to recognise objects/situations/connections and react appropriately. Current developments strive to enable artificial intelligence to recognise objects (Koutentakis et al., 2020), but the additional recognition of situations/connections including a suitable reaction is not expected until 2050 at the earliest (KPMG Advisory N.V., 2016).

Strengths and limitations

For confirmability and dependability (Shenton, 2004), all data were blind-coded and subsequently discussed by two researchers (JZ, SS) to ensure the reliability of the coding frame, surpassing the recommendation of Schreier (2012).

To establish credibility, the recommendations of Kidd and Parshall (2000) were followed by summarising the main arguments at the end of each discussion and asking participants for clarification.

One limitation of this study might be that one focus group was performed with only two participants due to a dropout on short notice of three people, while Krueger and Casey (2015) recommended that a focus group should contain at least four participants. The authors decided to hold this focus group, but afterwards recruited an additional focus group for balance.

The fact that only one robot was shown as an example of a humanoid SAR could represent a bias by limiting expectations to this specific robot. However, participants were asked questions during the focus groups, drawing their attention away from 'Pepper'. Since the majority of humanoid SARs are still in the development phase and have a predominantly machine-like appearance (Buhtz et al., 2018; Zamalloa et al., 2017), 'Pepper' was chosen as an example because its development considered previous research of the desired appearance of such robots and a too human-like design had been avoided to prevent an 'uncanny' impression. Furthermore, 'Pepper' is the only humanoid SAR that is currently commercially available and is already being used in different settings (e.g., tourism) (Pandey & Gelin, 2018).

The open approach for the examination of participants' expectations by showing only a humanoid SAR to convey an impression of this technology has led to some results where participants could imagine support by such robot but could not express the realisation further. Showing already existing functions of an SAR and asking more specific questions might have possibly yielded more specific answers. However, pointing out the current technical functions could also have led to limited expectations of support by a SAR, while the expectation of support itself being mentioned by participants, without further explanation, constitutes a vital finding.

Conclusion

The results show that most informal caregivers, nurses, and trainers imagined that SARs could provide support regarding all components of (physical and psychosocial) human needs, and especially with regard to ‘avoiding danger’, ‘communication/contact with others’, ‘daily activities’, ‘recreational activities’, ‘eating/drinking’, and ‘mobility/body posture’. According to the motto ‘helping people to help themselves’, it was especially important to the participants that humanoid SARs would primarily remind, motivate/encourage and instruct PwD instead of taking over tasks completely.

Nurses and informal caregivers also considered SARs as useful supportive devices for themselves. In this respect, most informal caregivers recognised a particular potential for short-term relief by robots supporting persons with dementia. Most nurses could imagine assistance in everyday practice by humanoid SARs, without relinquishing their core responsibilities.

However, participants also mentioned some negative expectations in all components of human needs, predominantly in ‘avoiding danger’ and ‘communication/contact with others’.

These findings provide valuable information, as they demonstrate the kind of support caregivers and trainers expect from humanoid SARs regarding dementia care. Participants showed parallels as well as differences in their expectations, which is why expectations for support should be considered with regard to the respective target group to increase the acceptance and the future use of humanoid SARs. Furthermore, the different settings in which potential users live/work should be considered in more depth and compared with each other.

This research contributes to the development/modification of humanoid SARs for dementia care, guiding the development of these devices for optimal support. The results show that future humanoid SARs should be ‘customisable’ (e.g., biographic information for conversations) and have certain features related to ‘communication/contact with others (e.g., verbal speech), and ‘mobility’ (e.g., walking companion), which are crucial for the future use of SARs in dementia care. Furthermore, SARs should also be able to recognise objects/situations/connections and react appropriately, indicating that further artificial intelligence research is needed.

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Supplementary Material 1. Interview guide for informal caregivers as an example.

QUESTIONS
How could a robot, like Pepper, help you or your family member with dementia* in the following activities? *Questions about expectations were asked for every single component of human needs. As example: How could a robot, like Pepper, help you or your family member with dementia while eating/drinking?* 1) Eating/Drinking 2) Learning ability 3) Mobility/Body posture 4) Daily activities 5) Getting (un)dressed 6) (Body)temperature 7) Hygiene 8) Avoiding danger 9) Communication/Contact with others 10) Sense of rules/Values 11) Day-/Night pattern 12) Continence 13) Recreational activities
A short overview about 2-3 minutes by the co-moderator. Did I properly summarise the discussion? Did I forget something?
Would anyone like to add something that has not been discussed in our discussion yet?

* Nurses and dementia trainers were asked the same questions with slightly adaptions regarding the relation to the person with dementia.

Literature:

Dijkstra, A. (2017). Care dependency. In: S. Schüssler & C. Lohrmann (Eds.), *Dementia in nursing homes* (pp. 229-248*)*, Schwitzerland. Springer Nature.

Dijkstra, A., Buist, G., & Dassen, T. (1996). Nursing-care dependency. Development of an assessment scale for demented and mentally handicapped patients. *Scand J Caring Sci*, 10(3), 137-143.

Heerink, M., Kröse, B., Evers, V., & Wielinga, B. (2010). Assessing Acceptance of Assistive Social Agent Technology by Older Adults: the Almere Model. *International Journal of Social Robotics*, 2(4), 361-375. https://doi.org/10.1007/s12369-010-0068-5

Lohrmann, C., Dijkstra, A., & Dassen, T. (2003). Care dependency: testing the German version of the Care Dependency Scale in nursing homes and on geriatric wards. *Scand J Caring Sci*, 17(1), 51-56. https://doi.org/10.1046/j.1471-6712.2003.00117.x

Schüssler, S., & Lohrmann, C. (2015). Change in Care Dependency and Nursing Care Problems in Nursing Home Residents with and without Dementia: A 2-Year Panel Study. *PLoS One*, 10(10), e0141653-e0141653. https://doi.org/10.1371/journal.pone.0141653

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Supplementary Material 2. Concept- and data-driven coding frame. Demonstration and definitions of the concept-driven main category and subcategories, as well as examples of the data-driven subcategories of the coding frame.

MAIN CATEGORY	SUBCATEGORIES (LEVEL 1)	SUBCATEGORIES (LEVEL 2)	SUBCATEGORIES (LEVEL 3)	SUBCATEGORIES (LEVEL 4)
CONCEPT-DRIVEN	**CONCEPT-DRIVEN**	**CONCEPT-DRIVEN**	**DATA-DRIVEN**	**DATA-DRIVEN**
EXPECTATIONS Individuals' expectations of potential assistive applications in dementia care from humanoid socially assistive robots (SARs) regarding different components of (physical and psychosocial) human needs based on international literature (Dijkstra, 2017; Dijkstra et al., 1996; Heerink et al., 2010; Lohrmann et al., 2003).	EATING/DRINKING Positive/Negative expectations of assistive applications from humanoid SARs to people with dementia (PwD), to eat and drink/prepare food/beverages (Heerink et al., 2010; Lohrmann et al., 2003; Schüssler & Lohrmann, 2015).	*The idea of subdivision into the following subcategories (positive/negative) is based on literature (Wu et al., 2016).* *Example for the following other components of human needs.*	*Example:*	*Example:*
		POSITIVE *Positive* expectations of assistive applications from humanoid SARs to PwD, to eat and drink/prepare food/beverages (Heerink et al., 2010; Lohrmann et al., 2003; Schüssler & Lohrmann, 2015).	COOKING	ROBOT COOKS BY ITSELF ROBOT PROVIDES ASSISTANCE WITH PREPARATION ROBOT GIVES MENU SUGGESTIONS ROBOT GUIDES COOKING
			SHOPPING AND ORDERING	-
			EATING	ROBOT PROVIDES ENCOURAGEMENT ROBOT PROVIDES SERVICE ACTIVITIES ROBOT DOCUMENTS FOOD INTAKE

MAIN CATEGORY	SUBCATEGORIES (LEVEL 1)	SUBCATEGORIES (LEVEL 2)	SUBCATEGORIES (LEVEL 3)	SUBCATEGORIES (LEVEL 4)
CONCEPT-DRIVEN	**CONCEPT-DRIVEN**	**CONCEPT-DRIVEN**	**DATA-DRIVEN**	**DATA-DRIVEN**
			DRINKING	ROBOT PROVIDES ENCOURAGEMENT ROBOT PROVIDES SERVICE ACTIVITIES ROBOT DOCUMENTS FLUID INTAKE
		NEGATIVE *Negative* expectations of assistive applications from humanoid SARs to PwD, to eat and drink/prepare food/beverages (Heerink et al., 2010; Lohrmann et al., 2003; Schüssler & Lohrmann, 2015).	ADMINISTRATION OF FOOD/BEVERAGES	-
	LEARNING ABILITY Positive/Negative expectations of assistive applications from humanoid SARs to PwD, to acquire knowledge/skills and/or to retain knowledge/skills learned in the past (Heerink et al., 2010; Lohrmann et al., 2003; Schüssler & Lohrmann, 2015).	POSITIVE NEGATIVE		
	MOBILITY/BODY POSTURE	POSITIVE		

MAIN CATEGORY	SUBCATEGORIES (LEVEL 1)	SUBCATEGORIES (LEVEL 2)	SUBCATEGORIES (LEVEL 3)	SUBCATEGORIES (LEVEL 4)
CONCEPT-DRIVEN	**CONCEPT-DRIVEN**	**CONCEPT-DRIVEN**	**DATA-DRIVEN**	**DATA-DRIVEN**
	Positive/Negative expectations of assistive applications from humanoid SARs to PwD, to move and to adopt appropriate activity-dependent positions (Heerink et al., 2010; Lohrmann et al., 2003; Schüssler & Lohrmann, 2015).	NEGATIVE		
	DAILY ACTIVITIES Positive/Negative expectations of assistive applications from humanoid SARs to PwD, to manage/structure/perform daily activities (e.g., household, shopping, money, appointments) (Heerink et al., 2010; Lohrmann et al., 2003; Schüssler & Lohrmann, 2015).	POSITIVE NEGATIVE		
	GETTING (UN)DRESSED Positive/Negative expectations of assistive applications from humanoid SARs to PwD, to get (un)dressed (Heerink et al., 2010; Lohrmann et al., 2003; Schüssler & Lohrmann, 2015).	POSITIVE NEGATIVE		
	(BODY)TEMPERATURE Positive/Negative expectations of assistive applications from humanoid SARs to PwD, to	POSITIVE NEGATIVE		

MAIN CATEGORY	SUBCATEGORIES (LEVEL 1)	SUBCATEGORIES (LEVEL 2)	SUBCATEGORIES (LEVEL 3)	SUBCATEGORIES (LEVEL 4)
CONCEPT-DRIVEN	**CONCEPT-DRIVEN**	**CONCEPT-DRIVEN**	**DATA-DRIVEN**	**DATA-DRIVEN**
	maintain body temperature despite external influences (Heerink et al., 2010; Lohrmann et al., 2003; Schüssler & Lohrmann, 2015).			
	HYGIENE Positive/Negative expectations of assistive applications from humanoid SARs to PwD, to maintain personal hygiene and grooming (Heerink et al., 2010; Lohrmann et al., 2003; Schüssler & Lohrmann, 2015).	POSITIVE NEGATIVE		
	AVOIDING DANGER Positive/Negative expectations of assistive applications from humanoid SARs to PwD, to recognise danger and ensure safety (Heerink et al., 2010; Lohrmann et al., 2003; Schüssler & Lohrmann, 2015).	POSITIVE NEGATIVE		
	COMMUNICATION/ CONTACT WITH OTHERS Positive/Negative expectations of assistive applications from humanoid SARs to PwD, to communicate with others (verbally and non-verbally) and to make, maintain, and end	POSITIVE NEGATIVE		

MAIN CATEGORY	SUBCATEGORIES (LEVEL 1)	SUBCATEGORIES (LEVEL 2)	SUBCATEGORIES (LEVEL 3)	SUBCATEGORIES (LEVEL 4)
CONCEPT-DRIVEN	**CONCEPT-DRIVEN**	**CONCEPT-DRIVEN**	**DATA-DRIVEN**	**DATA-DRIVEN**
	social contact (Heerink et al., 2010; Lohrmann et al., 2003; Schüssler & Lohrmann, 2015).			
	SENSE OF RULES/VALUES Positive/Negative expectations of assistive applications from humanoid SARs to PwD, to observe rules and values and assert the protection of privacy (Heerink et al., 2010; Lohrmann et al., 2003; Schüssler & Lohrmann, 2015).	POSITIVE NEGATIVE		
	DAY-/NIGHT PATTERN Positive/Negative expectations of assistive applications from humanoid SARs to PwD, to maintain an appropriate day/night cycle (Heerink et al., 2010; Lohrmann et al., 2003; Schüssler & Lohrmann, 2015).	POSITIVE NEGATIVE		
	CONTINENCE Positive/Negative expectations of assistive applications from humanoid SARs to PwD, to control the discharge of urine/bowel movements and to take appropriate measures in response (Heerink et al., 2010;	POSITIVE NEGATIVE		

MAIN CATEGORY	SUBCATEGORIES (LEVEL 1)	SUBCATEGORIES (LEVEL 2)	SUBCATEGORIES (LEVEL 3)	SUBCATEGORIES (LEVEL 4)
CONCEPT-DRIVEN	**CONCEPT-DRIVEN**	**CONCEPT-DRIVEN**	**DATA-DRIVEN**	**DATA-DRIVEN**
	Lohrmann et al., 2003; Schüssler & Lohrmann, 2015).			
	RECREATIONAL ACTIVITIES Positive/Negative expectations of assistive applications from humanoid SARs to PwD, to make sensible use of free time/participate in leisure activities (Heerink et al., 2010; Lohrmann et al., 2003; Schüssler & Lohrmann, 2015).	POSITIVE NEGATIVE		

Literature:

Dijkstra, A. (2017). Care dependency. In: S. Schüssler & C. Lohrmann (Eds.), *Dementia in nursing homes* (pp. 229-248), Schwitzerland. Springer Nature.

Dijkstra, A., Buist, G., & Dassen, T. (1996). Nursing-care dependency. Development of an assessment scale for demented and mentally handicapped patients. *Scand J Caring Sci*, 10(3), 137-143.

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Schüssler, S., & Lohrmann, C. (2015). Change in Care Dependency and Nursing Care Problems in Nursing Home Residents with and without Dementia: A 2-Year Panel Study. *PLoS One*, 10(10), e0141653-e0141653. https://doi.org/10.1371/journal.pone.0141653

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Effectiveness of computer-based interventions for community-dwelling people with cognitive decline: a systematic review with meta-analyses

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Effectiveness of computer-based interventions for community-dwelling people with cognitive decline: a systematic review with meta-analyses

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Abstract

Background Cognitive deficits arise with age and can increase the risk for subjective cognitive decline (SCD) and mild cognitive impairment (MCI), which may result in dementia, leading to health problems, care dependency and institutionalization. Computer-based cognitive interventions (CCIs) have the potential to act as important counteraction functions in preserving or improving cognition concomitant to available pharmacological treatment. The aim was to assess the effectiveness of CCIs performed individually with a personal or tablet computer, game console, virtual, augmented, or mixed reality application on cognition in community-dwelling people with SCD, MCI and dementia.

Methods A systematic review with meta-analyses of randomized controlled trials (RCTs) was performed. The systematic literature search was conducted in MEDLINE, CINAHL, Embase, Cochrane CENTRAL, IEEE Xplore Digital Library, Web of Science, Scopus and PsycINFO. In addition, a search for gray literature and backward citation searching were carried out. To judge on the evidence, two reviewers independently used the Cochrane Risk of Bias Tool. The standardized mean difference (SDM) for pooling comparable studies using the random-effects model was applied.

Results Twenty-four RCTs were identified, of which 1 RCT examined CCIs in individuals with SCD, 18 RCTs with MCI, and 6 RCTs with dementia. Most interventions were conducted with personal computers. Meta-analyses with 12 RCTs showed significant effects of computer-based cognitive interventions for people with MCI in the domains memory, working memory, attention/concentration/processing speed and executive functioning, but no significant improvements in global cognition and language. Regarding dementia a meta-analysis pooled with 4 RCTs demonstrated a tendency towards, but no significant increase of memory functions (SMD 0.33, CI 95% [-0.10, 0.77]). One RCT regarding SCD reported significant improvements in memory functions for participants conducting a cognitive training on a personal computer.

Conclusions The results demonstrated that CCIs have beneficial effects on domain-specific cognition in people with MCI but no significant effects on people with dementia. In terms of SCD, one study showed significant improvements

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in memory functions. It seems that the beneficial effect for cognitive preservation or improvement due to CCIs occurs at the earliest intervention state. However, more research on SCD is needed.

Trial registration PROSPERO International Prospective Register of Systematic Reviews CDR42020184069.

Keywords Subjective cognitive decline, Mild cognitive impairment, Dementia, Prevention, Non-pharmacological treatment, Cognition, Computerized cognitive training, Computer-based cognitive training, Virtual reality, meta-analysis

Introduction

Aging is associated with cognitive decline [1]. However, when cognitive capacities deteriorate beyond an ageing-associated normal level, cognitive decline can range from subjective cognitive decline (SCD) to mild cognitive impairment (MCI) and finally to dementia [2]. Cognition is responsible for all activities and processes concerned with the acquisition, storage, retrieval and processing of information [3, 4]. It includes different cognitive processes or domains (e.g. memory, attention) [4]. The progressive loss of cognitive capacity leads to various health problems, care dependency and institutionalization over time, particularly in dementia [2].

Dementia is a progressive disease and one of the world's leading causes of disability, associated with high financial, emotional and societal burdens [2, 5]. About 50 million people worldwide live with dementia and this figure is likely to rise to about 152 million people by 2050 [6]. Moreover, the parallel increasing number of people living with SCD and MCI face a higher risk of developing dementia, adding further to the challenges to be faced in the future, as treatment, care dependency and financial costs all rise [2, 7–9]. It is estimated that with a prevalence of between 23.8% and 25.6%, one in four people (above 60 years and older) are affected by SCD, self-experiencing a cognitive decline without an objective cognitive impairment [10]. A meta-analysis indicated a future decline of SCD into MCI of 27% and a 14% decline into dementia [8, 9]. People with MCI already showing impaired cognitive abilities and the prevalence of those aged 60 years and older is estimated between 15% and 20% with an annual rate of between 8% and 15% at which MCI progresses to dementia [7].

Faced with these conditions of cognitive decline, pharmacological treatments currently have a limited effect on the progression of the underlying disease, and this is the reason why non-pharmacological interventions such as cognitive interventions, have moved into the foreground [2, 11, 12]. Cognitive interventions have the aim of preserving or improving cognitive processes or address the impact of impairment in cognitive processes on associated functional abilities in activities of daily living (ADL) (e.g. dressing, personal hygiene) and instrumental ADL (IADL) (e.g. meal preparation, managing medication) [2, 13]. Such interventions usually follow a specific cognitive approach, for which literature definitions often overlap due to their underlying theoretical assumptions and core elements, as well as the context or population for which they were developed [13]. Nevertheless, key defining features exist for the most common approaches, which are cognitive training (CT), cognitive rehabilitation (CR) and cognitive stimulation (CS) [14]. Besides the common goals to preserve or improve (specific) cognitive abilities and processes, there are some differences [14]. CT involves repeated guided practices with standardized, structured tasks, which are usually based on theoretically motivated strategies with a range of (adaptive) difficulties [13, 15–17]. CR typically focusing on a person's need with individualized goals for which patients work together with healthcare professionals and family, following a more compensatory approach to perform individually relevant everyday tasks [13, 15–17]. CS includes a wide range of activities to stimulate thinking and multiple cognitive domains with the involvement of, for example, reality orientation (e.g. relating to time and place) or reminiscence therapy (e.g. telling others about one's past experiences) [13, 15–17].

Cognitive interventions can be delivered as individual or group sessions, with family members or experts as support persons (e.g. nursing scientists, therapists) [14]. They are available in paper form, but also as computer-based cognitive interventions (CCIs) [14]. CCIs have increasingly replaced original paper-and-pencil formats, as they have several advantages over those traditional techniques [18]. For instance, training tasks can be directed to specific cognitive domains (e.g. memory); they can be personalized and adjusted to the performances of an individual; they can be designed in a highly immersive and enjoyable form; and they can incorporate immediate quantitative feedback [18]. Standard devices, such as personal computers (PCs), tablet computers (hereafter called 'tablets') and gaming consoles are already used as technologies for CCIs [17]. More recently, emerging technologies such as virtual reality (VR), which are characterized by novelty, growth and potential socio-economic impact, are on the rise [19, 20].

Systematic reviews with meta-analyses [17, 19, 21, 22] already demonstrated that such CCIs have the potential to improve global cognition and selected cognitive domains in older persons with cognitive decline. However, there were at least three points, which were not sufficient considered in those reviews. First, they only included studies either with standard devices [17, 21, 22] or emerging technologies [19]. For that reason, we decided to include a comprehensive range of technologies used for cognitive purposes in our systematic review, covering both already existing technologies (i.e. PCs, tablets/smartphones, gaming consoles), as well as emerging technologies (i.e. virtual, augmented, and mixed reality). Second, the aforementioned systematic reviews on CCIs [17, 19, 21, 22] did not differentiate between participants living at home or in institutional care settings. Since it is not only the priority of healthcare systems to strengthen home care, but also to maintain independence for living at home as long as possible and to delay institutional care of individuals most affected, it is important to consider closed evidence related to this setting [2, 23]. We thus restricted the setting to people living at home and, in this regard, defined the training format of CCIs to single sessions. Third, the condition of SCD was not considered in those systematic reviews [17, 19, 21, 22], nor could a review focusing on this target group be identified. Consequently, we decided to include this relevant early stage of cognitive decline in our systematic review.

To the best of our knowledge, there has been no systematic review until now, which exclusively considers community-dwelling people with SCD, MCI and dementia in all three cognitive approaches (CT, CR, CS), performed on an individual basis using PCs, tablet/smartphones, gaming consoles, virtual, augmented or mixed reality. Therefore, this systematic review addressed the following research question: How effective are individually performed CCIs for community-dwelling people with SCD, MCI and dementia on cognition?

Methods

Design

This systematic review and meta-analyses, as part of a comprehensive realist review, was reported according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) Statement [24]. The protocol was registered at the International Prospective Register of Systematic Reviews (PROSPERO, CDR42020184069).

Eligibility criteria

The PICO-framework [25] (i.e. Participants, Interventions, Comparison, Outcome) was used to determine inclusion and exclusion criteria for this systematic review. Randomized controlled trials (RCTs) (including conference articles) with the following criteria were included:

Population

We included community-dwelling adults (i.e. people living at home and not in healthcare institutions) over the age of 18 years with SCD, MCI (any type), or dementia (any type or stage). The conditions were defined as follows:

- SCD is a self-perceived decline in any cognitive domain over time, which is unrelated to an acute event or disease, with a normal age-, gender-, and education-adjusted performance on standardized cognitive tests [26].
- MCI manifest through cognitive decline or impairment, with an objective evidence of impairment in cognitive domains, with the absence of dementia and essentially normal functional activities [27].
- Dementia is typically caused by age-related pathophysiological processes related to cognitive functions, which affects a person's ability to perform (I) ADL [2]. Different causes of dementia (e.g. Alzheimer's disease, cerebrovascular disease) are diagnosed by physicians [2].

The studies at least had to describe that the relevant condition was diagnosed and/or had to describe the diagnostic procedure in association with the diagnostic criteria and/or give reference to established clinical or research diagnostic criteria. Data from studies including different groups presenting with cognitive decline, had to be presented in a way to enable data extraction for the group(s) of interest.

Intervention

All interventions that met our defined cognitive approaches of CT, CR, or CS [13, 15–17] exclusively or in combination with physical activity, which were conducted with standard (i.e. PCs, tablets/smartphones, game consoles) and emerging technologies (i.e. virtual, augmented or mixed reality) were included. Robots also constitutes a promising emerging technology [20] and are already tested as CCI [28]. However, the goal of assistance by robots is to create a close and effective interaction with a human user through conversations, emotions, and gestures, which the other chosen emerging technologies do not cover [29]. For reasons of heterogeneity [30], robots were therefore not considered in our review.

Due to our focus on people living at home, only individual sessions of computer-based cognitive interventions were eligible. In this regard, we also consider interventions which were conducted in a lab setting (e.g. adult daycare center, outpatient clinic). No restrictions were made regarding intervention dose, including the overall duration of the intervention or number of intervention sessions. In terms of studies combining computer-based interventions with other kind of cognitive interventions (e.g. paper and pencil forms), the results had to be reported in a way that enabled extracting the data for the intervention(s) of interest. No restriction was set on standard pharmacological treatment.

Control
We included studies with no specific intervention or another kind of (computer-based) cognitive training as control intervention.

Outcome
For this systematic review continuous data of objective outcome measurements on global and domain-specific cognition (i.e. memory, working memory, attention, concentration, processing speed, executive functioning, language, visuospatial, and constructional abilities) was considered.

Information sources and search strategy
In the following databases a systematic literature search was performed by the first author (JZ) to April 2020: MEDLINE via PubMed, CINAHL via Ovid, Embase via Ovid, Cochrane CENTRAL via Ovid, IEEE Xplore Digital Library, Web of Science, Scopus and PsycINFO. Gray literature and additional publications were screened in google scholar and on the social media platform Research Gate (Additional file 1). Finally, the search was completed by checking citations of included studies and identified reviews.

A search strategy, with a combination of keywords and controlled vocabulary terms like MeSH headings using Boolean operators was developed. Following the recommendations of Lefebvre [31], no timeframe, language or document format restriction was set during the databases search to ensure that the search captured as many studies as possible that meet the eligibility criteria. However, only studies written in English or German were finally included.

Study selection
The search hits of each database were inserted into the bibliographic management program EndNote X8 and duplicates were removed. Title-abstract, as well as a full text screening process was based on the inclusion criteria and was conducted independently by JZ, SD, AH at each stage, with JZ assessing all the articles, and the other two authors assessing one half of the articles each. In unclear cases, inclusion was discussed and agreed upon within the research team.

Data extraction
A standardized data extraction form was used to extract general study information (e.g. authors, publication date) and relevant data of the participants' characteristics, interventions and outcomes (see Additional file 2). The process of data extraction was performed by JZ and was checked independently by AH for accuracy. Any disagreements between the authors during this process were solved by discussion and consensus. In case of uncertainty, the authors DS and SS were consulted.

Study risk of bias assessment
The methodological quality of all included studies was assessed independently by JZ and AH using the Cochrane Risk of Bias tool for RCTs [32]. Bias for each study were rated with a high, low, or unclear risk for the following domains: random sequence generation, allocation concealment, blinding of participants and personnel, blinding of the outcome assessment, incomplete outcome and other source of bias. JZ and AH compared and discussed their critical appraisal assessments and disagreements were resolved by consensus or by consulting DS or SS.

Data synthesis
Data synthesis was carried out following the Cochrane Handbook [33] and Borenstein et al. [34] and was discussed within the research team.

Meta-analyses were performed with the statistical software R (version 4.2.2) [35] and meta package (version 6.1–0) [36], using an inverse variance random-effects model with Hartung-Knapp adjustment [37, 38]. The random-effects model was chosen as it is more in line with the actual sample distribution and allows the conclusions to be generalized to a wider array of situations since this gives a better reflection of the 'real world' [39].

Standardized mean differences (SMD) with 95% confidence interval (CI) were applied to pool post-intervention values [30] from studies with similar outcome measures, populations, and technologies. The definition of SMD used in the analysis is Hedges' (adjusted) g, which is similar to Cohens' d, but includes an adjustment for small sample bias [40]. Values of 0.15, 0.40, and 0.75 for Hedges' g are considered of small, medium, and large effect sizes [41], constituting important indicators for clinical significance of statistically significant results, as it reflects the magnitude of the difference in outcomes between groups [42, 43].

Data from the studies included were classified by MK and JZ respectively into global cognition or into the following cognitive domains: memory, working memory, attention/concentration/processing speed, executive functioning, language, and visuospatial/constructional abilities (Additional file 3). If a study reported multiple measures of the same outcome, a simple composite score (i.e. mean of standardized scores) for the measures was created [44] and used for the meta-analysis.

Comparisons between CCIs and control to outcomes immediate post interventions as well as to follow-up (3 to 12 months) were made.

Tests for heterogeneity were performed and assessed by Chi^2-statistics and the associated I^2 statistics, for which an I^2 from 0% to 40% might not be important, 30% to 60% might represent moderate heterogeneity, 50% to 90% might represent substantial heterogeneity and 75% to 100% represented a considerable heterogeneity [30].

If statistical heterogeneity was present, subgroup analyses or sensitivity analyses were performed [30].

When the reported data from the included studies did not allow pooling, their results were synthesized narratively.

Results

Study selection

The literature search retrieved 18,281 records. After removing duplicates, 12,632 records were screened by title and abstract for their relevance. In total, 350 studies were then subjected to a full-text screening, from which 24 studies were finally included in this systematic review. Figure 1 shows the study selection process with the reasons for exclusion of studies at the full-text screening stage.

Study characteristics

All the studies were published in English during the period from 1994 to 2020 (Table 1, Additional files 2 and 3). Studies were predominantly conducted in Europe ($n = 10$) and Asia ($n = 9$), followed by North America ($n = 4$) and Oceania ($n = 1$). Most studies investigated interventions according to the concept of CT, while 4

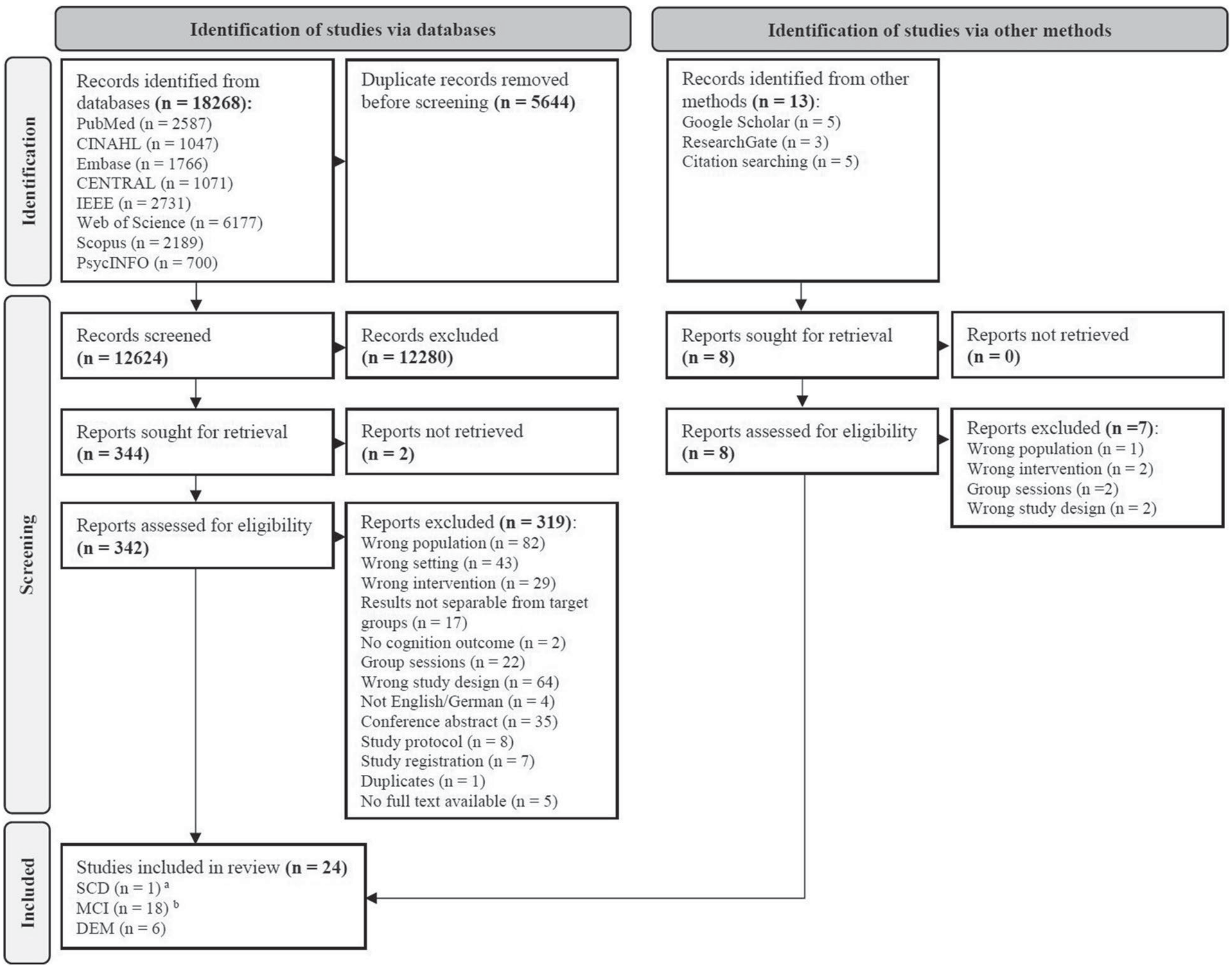


Fig. 1 PRISMA flow chart of study selection of this systematic review [24]. **a** One study [45] examined people with subjective cognitive decline (SCD), as well as people with dementia (DEM). **b** MCI: Mild cognitive impairment

Table 1 Characteristics of the included RCTs ($n = 24$)

Authors; Country	Type of cognitive decline	Sample size (IG[a]/CG[b])	Intervention	Control	Duration in weeks	Sessions/week, (minutes/session)	Setting
Cinar et al. 2020; [45] Turkey	SCD[c]	60 (30/30)	PC[d]	No intervention	12 (or at least 1200 min of training)	about 7 (15–20 min)	Home
Amjad et al. 2019; [50] Pakistan	MCI[e] - not specified	38 (18/20)	VR[f]	Physical exercises (motion, stretching)	6	5 (20–30 min)	Lab
Barnes et al. 2009; [51] USA	MCI - all types	47 (22/25)	PC	Alternative computer-based activities	6	5 (100 min)	Home
Damirchi et al. 2018; [52] Iran	MCI - not specified	44 (11/11/13/9)	IG1: PC IG2: Physical activity group IG3: IG1 combined with physical group activities	Waiting list group	8	3 (30 min in weeks 1–6; 60 min in 7th and 8th week)	Lab
Dimitriadis et al. 2016; [53] Greece	MCI - not specified	158 (53/50/55)	AR[g]	CG1: Alternative computer-based activity CG2: Waiting list group	10	4 (90 min)	Home
Finn et al. 2011; [54] Australia	MCI - amnestic multiple domain	16 (8/8)	PC	Waiting list group	average of 11.4 [h]	4–5 (not reported)	Home
Flak et al. 2019; [55] Norway	MCI - all types	69 (35/34)[i]	PC	Same intervention as in IG but in contrast with fixed low level of difficulty	5	5 (30–40 min)	Home
Hagovska et al. 2017; [46] Slovakia	MCI - not specified	60 (30/30)	PC	Group cognitive training program	10	2 (30 min)	Lab
Han et al. 2017; [56] South Korea	MCI - all types	43 (43/42)[j]	Tablet	Usual treatment	4	2 (30 min)	Lab
Herrera et al. 2012; [57] France	MCI - amnestic multiple domain	22 (11/11)	PC	Cognitive training	12	2 (60 min)	Lab
Hyer et al. 2016; [58] USA	MCI - amnestic and non-amnestic	68 (34/34)	PC	Same intervention as in IG but in contrast with fixed low level of difficulty	5–7	about 5 (40 min)	Lab or Home
Li et al. 2019; [59] China	MCI - amnestic (due to AD[k])	141 (78/63)	PC	No intervention	24	3–4 (about 40 min)	Home
Lin et al. 2016; [60] USA	MCI - amnestic multiple domain (due to AD)	21 (10/11)	PC	Cognitive training	6	4 (60 min)	Home
Nousia et al. 2019; [48] Greece	MCI - all types	46 (25/21)	PC	Usual treatment	15	2 (60 min)	Lab
Park et al. 2019; [49] South Korea	MCI - single and multiple domain	21 (10/11)	Mixed Reality	Computer-based cognitive training	6	3 (30 min)	Lab
Park et al. 2020; [61] South Korea	MCI - amnestic	21 (10/11)	VR	Waiting list group	12	2 (30 min)	Lab
Rosen et al. 2011; [62] USA	MCI - amnestic	12 (6/6)	PC	Alternative computer-based activities	Average of 8 [l]	5 (100 min)	Home
Savulich et al. 2017; [63] United Kingdom	MCI - amnestic (due to AD)	42 (21/21)	Tablet	No intervention	4	not reported (60 min)	Lab
Thapa et al. 2020; [64] South Korea	MCI - not specified	68 (34/34)[m]	VR[n]	Educational program on general health care	8	3 (100 min)	Lab

Table 1 (continued)

Authors; Country	Type of cognitive decline	Sample size (IG[a]/CG[b])	Intervention	Control	Duration in weeks	Sessions/week, (minutes/session)	Setting
Cinar et al. 2020; [45] Turkey	Dementia - AD	60 (30/30)	PC	No intervention	12 (or at least 1200 min of training)	about 7 (15–20 min)	Home
Galante et al. 2007; [65] Italy	Dementia - AD	12 (7/5)[o]	PC	Interviews on current affairs and participants' lives	4	3 (60 min)	Lab
Heiss et al. 1994; [66] Germany	Dementia - AD	70 (18/17/18/17)	IG1: PC IG2[p]: IG1 combined with medication IG3[p]: IG1 combined with medication	Social support	24	2 (60 min)	Lab
Karssemeijer et al. 2019; [67, 68] The Netherlands	Dementia - all types	115 (38/38/39)	IG1: VR (combined with cycling on a stationary bike) IG2: Cycling on a stationary bike	Physical exercises (relaxation, flexibility)	12	3 (30–40 min)	Lab
Lee et al. 2013; [47] China	Dementia - AD	19 (7/6/6)	IG1: Tablet IG2: Cognitive training without Tablet	Waiting-list control group with cognitive activities	6	2 (12–30 min)	Lab
Yu et al. 2015; [69] China	Dementia - not specified	32 (16/16)	Tablet	Cognitive training	4–8	1–2 (30 min)	Lab

[a] IG: intervention group

[b] CG: control group

[c] SCD: subjective cognitive decline

[d] PC: personal computer

[e] MCI: mild cognitive impairment

[f] VR: virtual reality

[g] AR: augmented reality

[h] The authors anticipated 6–10 weeks. Participants completed at least 80% of the sessions

[i] 68 (34/34) participants were included in the final analysis of the respectively study

[j] Cross-over randomized controlled trial

[k] AD: Alzheimer's disease

[l] Participants had to use the program until either achievement of asymptotic performance levels over a several day period or completion of 80% of the training material in a given exercise

[m] 66 (33/33) participants were included in the final analysis of the respectively study

[n] The intervention consists of two parts 1) cognitive training 2) educational program on general health care (as in CG)

[o] 11 (7/4) participants were included in the final analysis of the respectively study

[p] These intervention groups were not considered for analysis, because the medication used consisted of non-commercial substances for the treatment of dementia, as well as non-registered substances of the Austrian Register of Pharmaceutical Specialties

studies [46–49] could be assigned to CR. No study was identified on the concept of CS.

In the context of participant cognitive conditions in the included studies, one study investigated SCD, 18 studies MCI and 6 studies dementia.

The SCD investigation study [45] had a sample size of 60 participants, with a mean age of 67.4 years. The web-based intervention contained not only CT on a PC but also physical exercises (Table 1, Additional files 2 and 3).

The sample size in the 18 MCI-studies ranged from 12–158 participants, with a total number of 924 participants. The mean age ranged from 66.0–76.6 years. One study [50] did not report any participant characteristics and one [52] recruited only women. CCIs were conducted predominantly with PCs ($n=11$) [46, 48, 51, 52, 54, 55, 57–60, 62], followed by tablets ($n=2$) [56, 63], VR ($n=3$) [50, 61, 64], augmented reality (AR) ($n=1$) [53] and one study [49] with mixed reality (MR) ($n=1$), which was a combined intervention of VR and AR with a tablet as device. Two studies [61, 64] used immersive VR-technology, while the third study [50] was non-immersive and based on a gaming console. Most studies had no specific control intervention, a usual or non-cognitive alternative treatment, whereas 3 studies [46, 57, 60] had non-computer-based CT and 3 studies (slightly) different CCIs [49, 55, 58] as control comparator. The longest intervention duration was 24 weeks [59] and the shortest 4 [56, 63] weeks.

The 6 studies focusing on people with dementia encompassed a total of 273 participants with a sample size ranged from 11–115 subjects. The mean age of participants ranged from 66.3–83.0 years and, in 5 studies, global cognition at baseline ranged from 16.6–23.0 points of the Mini Mental State Examination (MMSE) and was 20.0 points in one study [45], utilizing the Montreal Cognitive Assessment (MoCA). Most studies were conducted with a PC [45, 65, 66] or tablet [47, 69], while one study [67, 68] had a non-immersive VR-technology as intervention, consisting of a home trainer which related to a video screen showing a virtual bike tour including cognitive tasks. Only one study [45] reported no alternative treatment for participants in the control group. Duration of intervention ranged from 4–24 weeks.

Risk of bias

Figure 2 provides an overview of the risk of bias for the included studies. Risk of selection bias occurred most frequently in the studies because the method of random sequence generation was not described and was therefore unclear [45, 48–50, 52, 57–60, 62, 63]. Furthermore, the majority of studies [45, 47–50, 52, 57–60, 63, 65, 66, 69] did not mention the procedure of allocation concealment, which was rated with a high risk for selection bias. Overall, only two studies [51, 55], involving people with MCI, were assessed as being at low risk for performance bias. Most of the studies [47–49, 51, 53–57, 59, 60, 62, 65, 67, 69] had a low risk for detection bias by means of blinding the people who measured the outcome data. In contrast the majority of included studies [45, 50–52, 54–56, 58–61, 65, 66] showed a high risk of attrition bias due to insufficient description of the handling of dropouts, as well as missing descriptions of the reasons, inappropriate statistical measures (e.g. last observation carried forward) to compensate missing data, unequal or unclear number of participants between groups, and high drop-out rates. Two-thirds of all studies showed low risk in reporting bias [46–48, 50–52, 54–57, 60, 61, 64–67] and other bias [46, 47, 49, 51–53, 55–58, 61–64, 66, 67, 69], respectively. A high risk of other bias mainly concerned significant differences in one [48] or more [59] relevant baseline characteristics in cognition between the groups, or also due to a significant lack of reporting [50]. Some studies reported cognition baseline data, but were assessed with an unclear risk of bias, due to one [65] or more [54, 60] questionable differences that were not statistically analyzed. One study [45] did not report either statistical information or baseline data regarding a cognitive measurement battery.

Effects of CCIs on cognition of people with SCD

Global Cognition (immediately after Intervention)

Cinar et al. [45] investigated global cognition with the MoCA in people with SCD, which demonstrated a tendency for improvement in the intervention compared to the control group, but with non-significant group differences.

Domain-specific cognition (immediately after Intervention)

For people in the intervention group, memory functioning measured with the Cambridge Cognition CANTAB assessment, revealed significant improvements compared to the control group (delayed matching sample (DMS), percent correct, $p=0.012$; DMS, percent correct, all delays, $p=0.019$; paired associated learning (PAL), total errors (adjusted), $p=0.005$; PAL, total errors, 6 shapes adjusted, $p=0.02$). The pattern recognition memory (PRM), spatial-working memory (SWM) and reaction time (RT) of the CANTAB assessment showed no significant change between the groups [45].

Effects of CCIs on cognition of people with MCI

Global cognition (immediately after Intervention)

The result of the meta-analysis on 6 RCTs (Fig. 3) comparing CCIs vs. a control group post intervention showed a tendency for improvement but had no significant effect on people with MCI regarding global cognition (SMD 0.82, CI 95% [-0.31, 1.94], $I^2=92\%$). Excluding the one

	Random sequence generation (selection bias)	Allocation concealment (selection bias)	Blinding of participants and personnel (performance bias)	Blinding of outcome data (detection bias)	Incomplete data (attrition bias)	Selective reporting (reporting bias)	Other bias
SUBJECTIVE COGNITIVE DECLINE							
Cinar 2020	?	–	–	–	–	?	?
MILD COGNITIVE IMPAIRMENT							
Amjad 2019	?	–	?	–	–	+	–
Barnes 2009	+	+	+	+	–	+	+
Damirchi 2018	?	–	?	–	–	+	+
Dimitriadis 2016	+	+	–	+	?	–	+
Finn 2011	+	+	–	+	–	+	?
Flak 2019	+	+	+	+	–	+	+
Hagovska 2017	+	+	?	?	?	+	+
Han 2017	+	+	–	+	–	+	+
Herrera 2012	?	–	?	+	+	+	+
Hyer 2016	?	–	?	–	–	–	+
Li 2019	?	–	?	+	–	–	–
Lin 2016	?	–	–	+	–	+	?
Nousia 2019	?	–	–	+	+	+	–
Park 2019	?	–	?	+	?	–	+
Park 2020	+	?	–	?	–	+	+
Rosen 2011	?	+	?	+	+	?	+
Savulich 2017	?	–	–	–	+	?	+
Thapa 2020	+	+	?	?	+	+	+
DEMENTIA							
Cinar 2020	?	–	–	–	–	?	?
Galante 2007	–	–	–	+	–	+	?
Heiss 1994	?	–	–	–	–	+	+
Karssemeijer 2019	+	+	–	+	+	+	+
Lee 2013	?	–	?	+	+	+	+
Yu 2015	?	–	?	+	+	–	+

+ Low risk of bias
? Unclear risk of bias
- High risk of bias

Fig. 2 Risk of bias for included studies per target group

study with the AR-intervention [53] with a large SMD, let the heterogeneity drop to $I^2=49\%$, but with an non-significant effect (SMD 0.45, CI 95% [-0.13, 1.03]) (Figure 1 in Additional file 4).

The VR subgroup, including 3 studies, showed a heterogeneity of $I^2=69\%$, which resulted in a trivial heterogeneity ($I^2=34\%$) after excluding the non-immersive

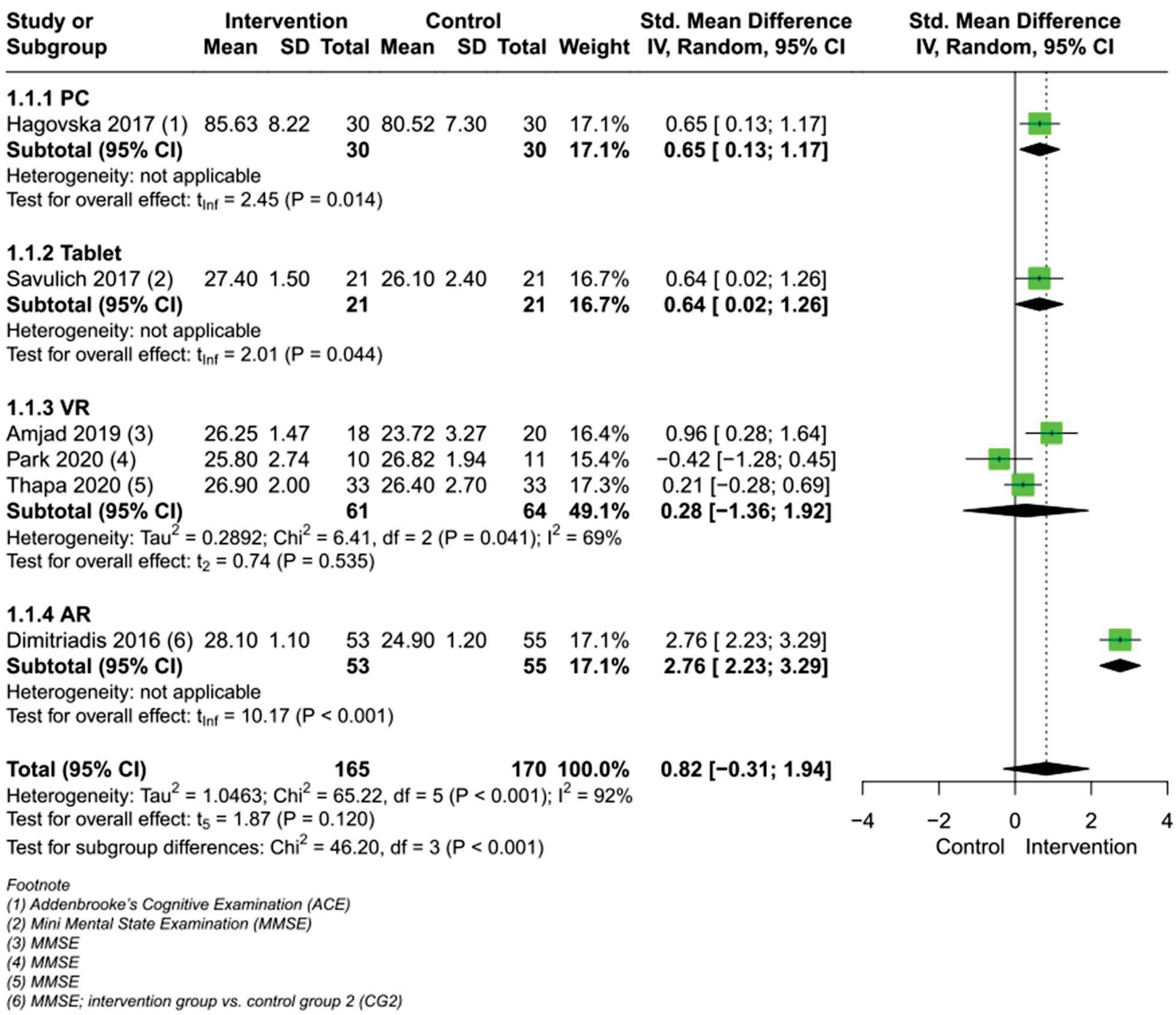


Fig. 3 Meta-analysis of CCIs for people with MCI vs. control immediately post intervention on global cognition

VR-technology study [50], but with a maintained non-significant effect (Figure 2 in Additional file 4).

Three studies [51, 56, 59] provided data on the outcome global cognition in such a way, that pooling was not possible. Two of these studies [51, 56] confirmed the non-significant effect. Li et al. [59] investigated global cognition with two instruments, while one was non-significant and the second showed a significant improvement for the intervention group (MMSE, $p = 0.002$).

Domain-specific cognition (immediately after Intervention)

A meta-analysis (Fig. 4) with a total of 7 studies involving 306 participants was conducted on the outcome memory function, showing a significant effect of CCIs vs. control immediately post intervention (SMD 1.13, large effect size, CI 95% [0.01, 2.25], $I^2 = 93\%$) (for composite scores computation see Figures 3–6 in Additional file 4). When excluding the AR-study [53] with a large SMD, the heterogeneity drops to $I^2 = 59\%$ (SMD 0.64, medium effect size, CI 95% [0.11, 1.18]) (Figure 7 in Additional file 4).

Most studies have been pooled for the subgroup PC ($n = 5$) showing a non-significant effect on memory function with a heterogeneity of $I^2 = 64\%$. Excluding the two studies [46, 57], with a non-computer-based CT as a control group, let the heterogeneity drop to $I^2 = 0\%$, resulting in a significant effect on memory function (SMD 0.89, large effect size, CI 95% [0.56, 1.21]) (Figure 8 in Additional file 4). A meta-analysis with those two excluded studies [46, 57] demonstrated a non-significant effect for the intervention group (SMD 0.36, CI 95% [-7.35, 8.08], $I^2 = 81\%$), but indicated an improvement for both, the CCIs and the non-computer-based CT (Figure 9 in Additional file 4). In one of those two studies [46], the

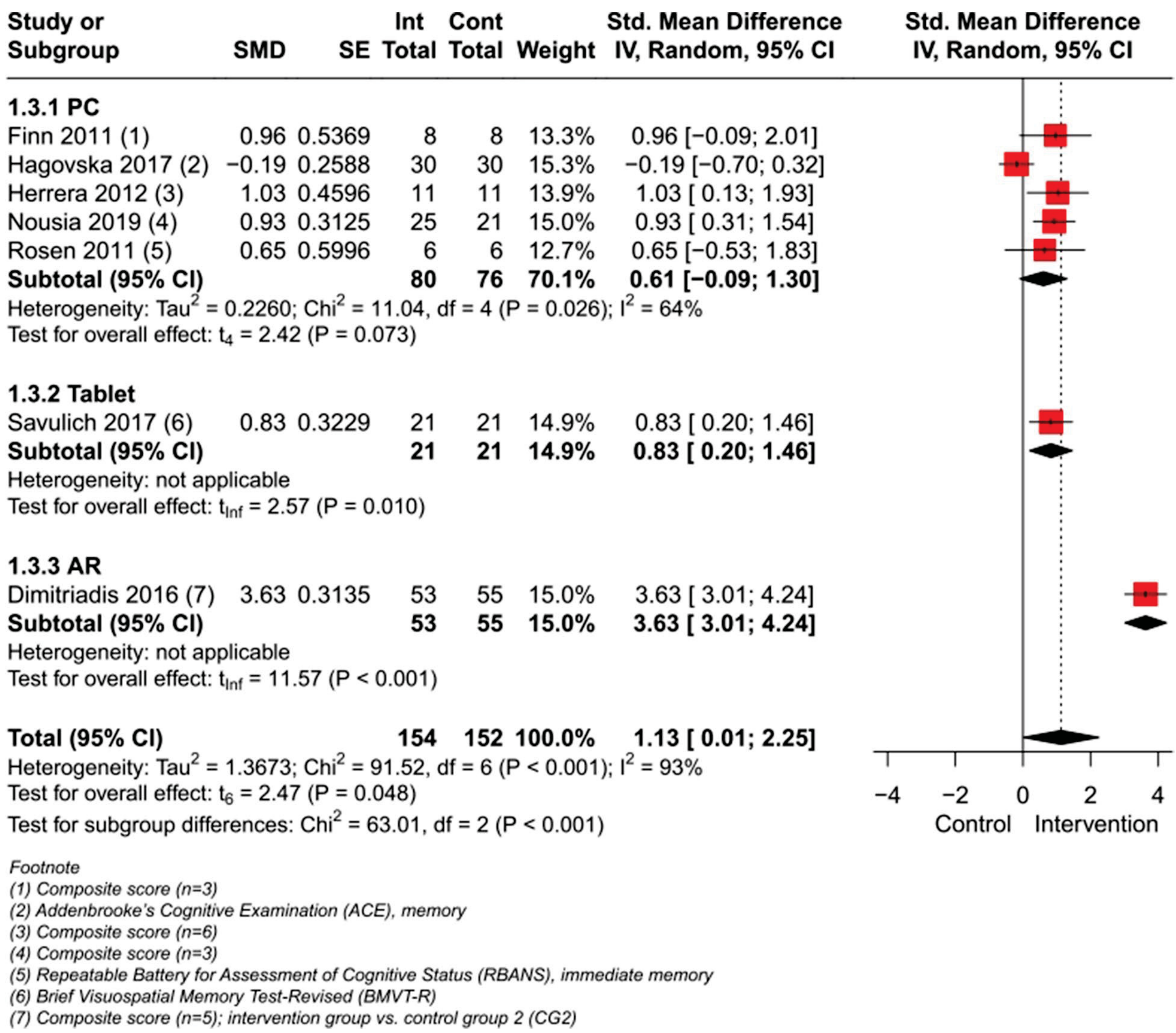


Fig. 4 Meta-analysis of CCIs for people with MCI vs. control immediately post intervention on memory

intervention and control group had CT activities focusing on the memory domain, leading to increased memory function in both groups with a non-significant group difference. In Herrera et al. [57] the CCI was exclusively targeting on recognition, in contrast to the control intervention, resulting in beneficial significantly group differences for participants' memory in the intervention group.

Excluding the AR-study [53] and both above-mentioned studies [46, 57] with the nearly same intervention in both, the intervention and control group, from the main meta-analysis, the significant effect remains (SMD 0.87, large effect size, CI 95% [0.70, 1.03]), but with an heterogeneity of $I^2 = 0\%$ (Figure 10 in Additional file 4).

Meta-analyses on the other domain-specific cognitive outcomes such as working memory, attention/concentration/processing speed and executive functioning showed significant effects for people with MCI and applied CCIs vs. control immediately post intervention. The meta-analysis on the outcome language showed no beneficial effects for participants performing CCIs with a PC compared to control groups (Fig. 5, Figures 11–23 in Additional file 4).

No pooling of studies was possible for the outcome visuospatial/constructional abilities.

Three studies could not be included in any meta-analysis, because of either non-reported, or inappropriate data [51, 56, 59]. In one of these studies [51] working memory increased by participants in the PC-based intervention group (Wechsler Memory Scale 3rd edition, spatial span, $p = 0.003$), but measurement for memory,

Outcome	Technology	Number of studies	N	Effect: SMD (CI 95%)	Effect: p-value	I^2	ES [a]
Working memory							
	PC [b]	4 [40, 43, 47, 50]	109	0.69 (-0.07, 1.44)	0.063	24%	-
	VR [c]	1 [54]	21	0.33 (-0.53, 1.19)	0.454	-	-
	AR [d]	1 [56]	108	1.57 (1.14, 2.00)	<0.001	-	L [e]
	Total	6	238	0.86 (0.25, 1.47)	0.015	68%	L
Attention/ concentration/ processing speed	PC	5 [38, 40, 43, 45, 50]	163	0.59 (0.02, 1.15)	0.045	43%	M [f]
	T [g]	1 [53]	42	-0.27 (-0.88, 0.34)	0.384	-	-
	VR	3 [42, 54, 55]	125	0.55 (0.18, 0.93)	0.024	0%	M
	AR	1 [56]	108	1.58 (1.15, 2.02)	<0.001	-	L
	Total	10	437	0.62 (0.21, 1.02)	0.007	74%	M
Executive functioning							
	PC	4 [38, 40, 45, 50]	143	0.60 (-0.37, 1.58)	0.144	65%	-
	VR	3 [42, 54, 55]	125	0.80 (-0.83, 2.43)	0.170	70%	-
	AR	1 [56]	108	2.65 (2.13, 3.17)	<0.001	-	L
	Total	8	376	0.96 (0.21, 1.71)	0.019	89%	L
Language							
	PC	2 [38, 40]	106	1.63 (-7.66, 10.93)	0.268	90%	-

Forrest Plots

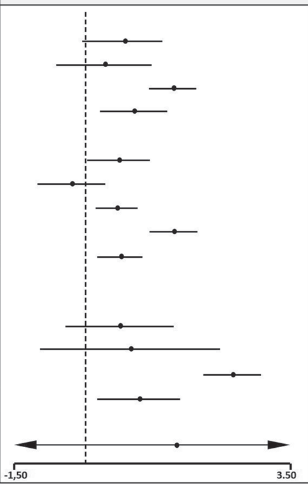


Fig. 5 Meta-analyses with subgroups of CCIs on people with MCI vs. control immediately post intervention. **a** ES: effect size; definition of SMD is Hedges' g, which is categorized in 0.15, 0.40 and 0.75 for small, medium, and large effect sizes [40, 41]. **b** PC: personal computer. **c** VR: virtual reality. **d** AR: augmented reality. **e** L: large effect size. **f** M: medium effect size. **g** T: tablet

executive functions, attention/concentration/processing speed, language and visuospatial/constructional abilities revealed no significant differences between the intervention and control group. In Li et al. [59], 2 out of 6 measurements on memory showed significant effects for participants using a PC-based CT (Addenbrooke's Cognitive Examination Revised (ACER), memory $p<0.05$; Auditory Verbal Learning Test, 5-min recall, $p<0.01$). Furthermore one out of 3 measurements in executive functions (ACER, fluency, $p<0.01$), one out of 5 on attention/concentration/processing speed (ACER, attention, $p<0.05$) and one out of 2 for visuospatial/constructional abilities (Rey-Osterreith Complex Figure, copy, $p<0.05$) were significant, while one measurement on language showed no significant effects. In the third study [56], one of three measurements for memory function showed significant improvements for participants with a CT on tablets as intervention (Word List Recall Test, $p=0.031$).

Two studies [55, 58] that had the same CCIs in the intervention and control groups, with the only difference being the adjustability of difficulty levels in the intervention group, were pooled for meta-analyses on memory, working memory and executive functioning immediately after the intervention, but showed no significant benefits (Figures 24–29 in Additional file 4).

Domain-specific cognition (Months after Intervention)

A follow-up was conducted in two studies, in one of which Li et al. [59] found no significant group differences 12 months after the intervention, in contrast to the post-intervention evaluation, while the second study [57] found continuing significant differences for the intervention group after 6 months in memory (Doors recognition subtest, Set A, $p<0.05$; BEM144, 12-word-list-recall test, total score, $p<0.05$) and working memory (Digit Span, forward, $p<0.05$).

Pooling the follow-up data of Hyer et al. [58] (3 months after the intervention) and Flak et al. [55] (4 months after the intervention), which had the same CCIs in the intervention and control group, only differing in the adjustability of difficulty levels for the intervention group, showed no significant effects (Figures 30–35 in Additional file 4).

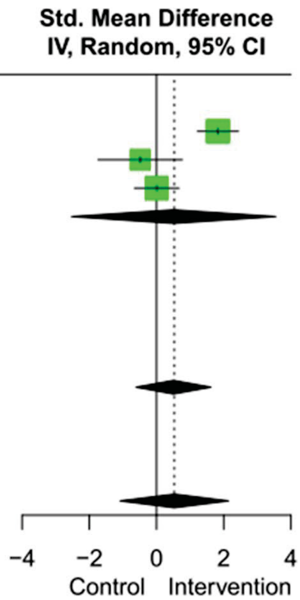
Effects of CCIs on cognition of people with dementia

Global Cognition (immediately after Intervention)

Four studies were pooled for a meta-analysis (Fig. 6) of CCIs vs. control immediately post intervention on global function in people with dementia, which demonstrated a non-significant effect (SMD 0.53, CI 95% [-1.08, 2.14]), with a heterogeneity of $I^2=86\%$. Excluding Cinar et al. [45], with a large SMD, let the heterogeneity drop to $I^2=0\%$, remaining in a non-significant effect (SMD 0.03, CI 95% [-0.91, 0.97]) (Figure 36 in Additional file 4).

One Study [69] could not be included in the meta-analysis, because of inappropriate data for pooling, but confirmed the non-significant effect, measured by the MMSE and the MoCA.

Study or Subgroup	Intervention Mean	Intervention SD	Intervention Total	Control Mean	Control SD	Control Total	Weight	Std. Mean Difference IV, Random, 95% CI
2.1.1 PC								
Cinar 2020 (1)	23.23	3.68	30	16.17	3.94	30	28.2%	1.83 [1.22; 2.44]
Galante 2007 (2)	23.00	3.90	7	24.90	2.80	4	21.3%	−0.49 [−1.74; 0.77]
Heiss 1994 (3)	19.33	6.82	18	19.29	5.89	17	27.7%	0.01 [−0.66; 0.67]
Subtotal (95% CI)			**55**			**51**	**77.2%**	**0.51 [−2.53; 3.55]**
Heterogeneity: Tau^2 = 1.3256; Chi^2 = 20.5, df = 2 (P < 0.001); I^2 = 90%								
Test for overall effect: t_2 = 0.72 (P = 0.544)								
2.1.2 Tablet								
Lee 2013 (4)	19.67	5.20	7	17.29	3.15	6	22.8%	0.50 [−0.61; 1.62]
Subtotal (95% CI)			**7**			**6**	**22.8%**	**0.50 [−0.61; 1.62]**
Heterogeneity: not applicable								
Test for overall effect: t_{Inf} = 0.89 (P = 0.375)								
Total (95% CI)			**62**			**57**	**100.0%**	**0.53 [−1.08; 2.14]**
Heterogeneity: Tau^2 = 0.8626; Chi^2 = 20.78, df = 3 (P < 0.001); I^2 = 86%								
Test for overall effect: t_3 = 1.04 (P = 0.373)								
Test for subgroup differences: Chi^2 = 0.00, df = 1 (P = 0.994)								



Footnote
(1) Montreal Cognitive Assessment (MoCA)
(2) Mini Mental State Examination (MMSE)
(3) MMSE; intervention group 1 (IG1) vs. control group
(4) MMSE

Fig. 6 Meta-analysis of CCIs for people with dementia vs. control immediately post intervention on global cognition

Global cognition (Months after Intervention)

Two studies using a PC [65] and tablet [47] for their intervention examined global cognition after a 3-month follow-up and were pooled for a meta-analysis, with a non-significant result (SMD -0.06, CI 95% [-4.40, 4.28], $I^2=0\%$) (Figures 37–38 in Additional file 4).

Domain-specific cognition (immediately after Intervention)

A meta-analysis with 4 studies (Fig. 7) demonstrated a non-significant effect, but a tendency of CCIs to increase memory functions in people with dementia (SMD 0.33, CI 95% [-0.10, 0.77], $I^2=0\%$) (for composite scores computation see Figures 39–41 in Additional file 4). Further meta-analyses (Fig. 8) on the outcomes working memory, attention/concentration/processing speed and executive functioning showed that participants, performing CCIs whether using a PC nor VR-technology had no beneficial effects compared to control groups (Figures 42–49 in Additional file 4).

Two studies could not be included in meta-analyses because of inappropriate reported [45, 69] data. Yu [69], confirmed the pooled results with non-significant group differences in working memory and executive functioning. In contrast, the other study of Cinar et al. [45] revealed significant improvements with the Cambridge Cognition CANTAB assessment for the intervention group in memory (DMS, percent correct, $p=0.001$; DMS, percent correct, all delays, $p=0.01$; PAL, total errors (adjusted), $p=0.001$; PAL, total errors, 6 shapes adjusted, $p=0.02$). The authors [45] also reported significant results on PRM and sub outcomes on DMS and SWM, but without clear descriptions of the specific outcome measures (e.g. latency). The RT of the CANTAB assessment showed a non-significant change between the groups.

Domain-specific cognition (Months after Intervention)

Meta-analyses with studies which conducted a follow-up after 3 months, showed no beneficial effects for memory, working memory, attention/concentration/processing speed, executive function and memory (Figures 50–59 in Additional file 4).

Discussion

This systematic review and meta-analyses investigated whether individually performed CCIs have an impact on global and domain-specific cognition in community-dwelling people with SCD, MCI and dementia. CCIs were especially beneficial for people with MCI, revealing significant effects in memory, working memory, attention/concentration/processing speed and executive functioning, but no significant improvements in global cognition and language. Most of the overall outcomes

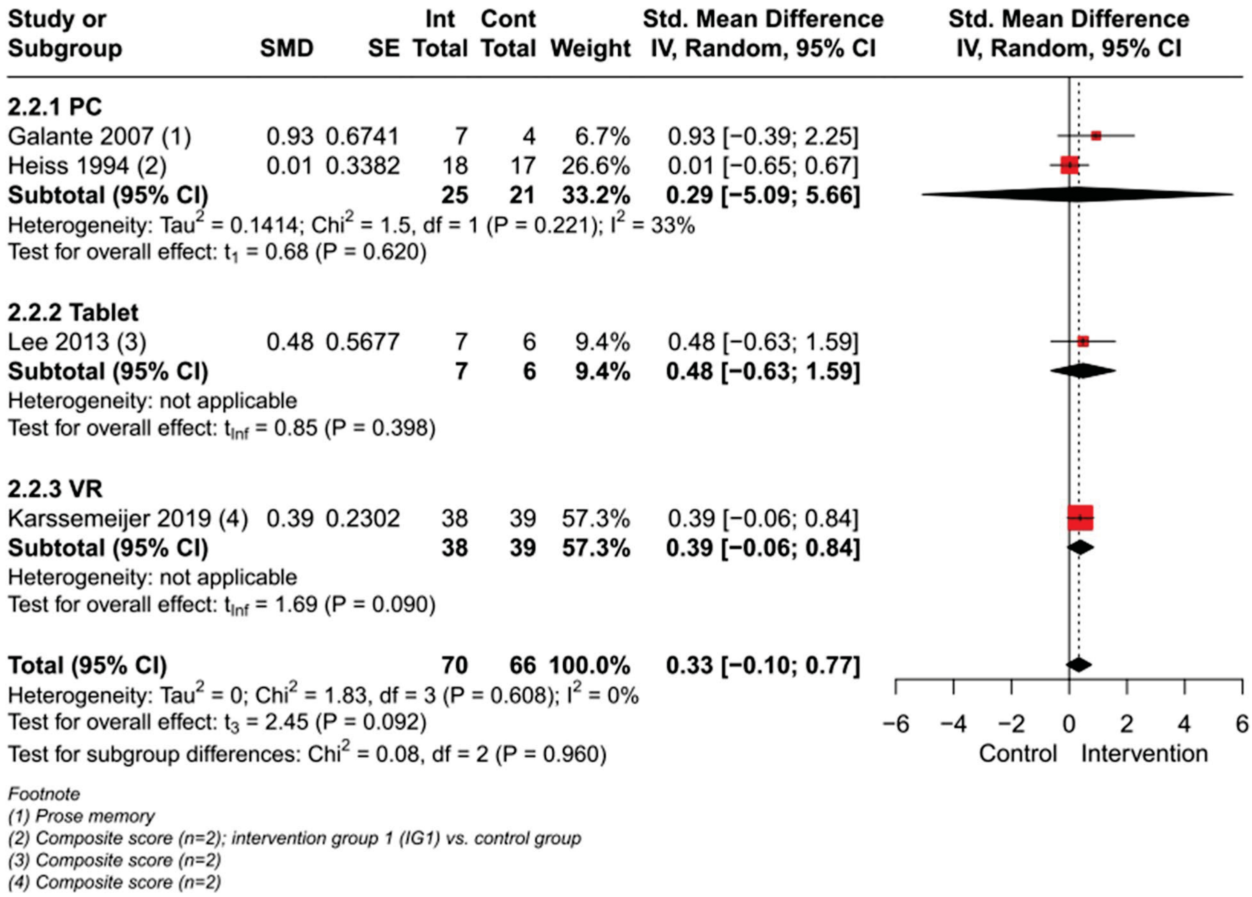


Fig. 7 Meta-analysis of CCIs for people with dementia vs. control immediately post intervention on memory

Outcome	Technology	Number of studies	N	Forrest plots	Effect SMD (CI 95%)	Effect p-value	I^2
Working memory							
	PC [a]	2 [57, 58]	46		-0.19 (-2.77, 2.38)	0.515	0%
	VR [b]	1 [60]	77		-0.15 (-0.60, 0.30)	0.511	-
	Total	3	123		-0.17 (-0.54, 0.21)	0.201	0%
Attention/concentration/ processing speed	PC	2 [57, 58]	46		0.09 (-2.76, 2.94)	0.752	0%
	VR	1 [60]	77		0.29 (-0.16, 0.74)	0.206	-
	Total	3	123		0.22 (-0.29, 0.72)	0.207	0%
Executive functioning							
	PC	2 [57, 58]	46		0.25 (-1.03, 1.52)	0.248	0%
	VR	1 [60]	77		0.08 (-0.37, 0.53)	0.726	-
	Total	3	123		0.14 (-0.16, 0.45)	0.186	0%

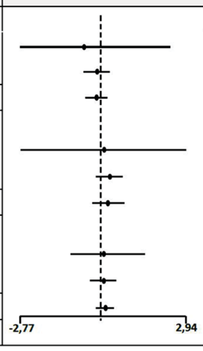


Fig. 8 Meta-analyses with subgroups of CCIs on people with dementia vs. control immediately post intervention. [a] PC: personal computer. [b] VR: virtual reality

showed a large effect size, but also a substantial or considerable heterogeneity, which is why the confidence in these results is limited. Pooled results of studies on people with dementia demonstrated no significant effects on cognition, but a tendency towards an increased memory function (SMD 0.33, CI 95% [-0.10, 0.77], $I^2 = 0\%$) was observed. While statistically not significant, with a current small effect size, this finding may be clinically significant, but more studies with larger samples are needed to investigate a possible statistical significance. Only one RCT [45] was identified investigating a web-based CT on a PC in people with SCD, which reported significant results on memory function for participants in the intervention group. Follow-up evaluations examining the long-term effect of such interventions were only conducted by a few studies [47, 55, 57–59, 65, 67], where pooled estimates showed no significant effects for people with MCI or dementia. Of the studies that could not have been pooled, only one [57] showed continuing significant improvements for MCI-patients in the intervention group at 6 months after intervention in memory and working memory functions.

No meta-analyses on the condition of SCD could be conducted in our systematic review, as only one study [45] met our eligible criteria. Two systematic reviews and meta-analysis [70, 71] on SCD demonstrated a growing research interest and indicated beneficial impacts of cognitive exercises on cognition of people with SCD. One [70] of those reviews included the RCT of Pereira-Morales et al. [72] investigating a web-based CT on cognition. Primary findings of this study [72] showed at least a significant improvement for the CCI on an memory outcome, as it was also measured in Cinar et al. [45], the study included in our review. However, diagnostic criteria of SCD for participants in Pereira-Morales et al. [72] were not clearly described and hence it was not considered for the inclusion in our review. Therefore, it is demonstrated that more high-quality research on CCIs' effectiveness, applying standard and emerging technologies with standardized SCD criteria, is needed. This is important for demonstrating whether CCIs at this early stage present a promising option for dementia prevention. Furthermore, the necessity for rising awareness about SCD in general must be also considered earlier, as the Behavioral Risk Factor Surveillance System survey, which asked people for self-perceived memory loss, found that in 11% of affected persons only 46% of these consulted health care professionals [2, 8, 73].

According to our findings, people with MCI benefit from CCIs the most. Zhang et al. [21] and Hill et al. [22] evaluated computer-based CT on people with MCI in their systematic reviews and corroborate our results, as most of their pooled study results showed significant improvements in different cognitive domains (e.g. memory, working memory) for participants in the intervention group. In contrast to our findings, meta-analyses on the global cognition revealed significant effects in both reviews [21, 22]. The reason for the differing findings could be that Zhang et al. [21] and Hill et al. [22] had defined other eligible criteria, as they had not considered the training format (individual or group trainings) or the setting (e.g. nursing homes) nor included emerging technologies like VR [21] and AR [21, 22]. Although we included emerging technologies in our review, PCs were the most common technology used in MCI-studies. Pooled VR-studies for people with MCI ($n=3$), however, already showed a significant effect on attention/concentration/processing speed. In this regard a significant effect on executive functioning was identified in the systematic review of Wu et al. [19], who evaluated VR-based cognitive interventions in people with MCI. In contrast to our review, Wu et al. [19] identified another auspicious finding, namely the effectiveness of such interventions in global functions demonstrated by a meta-analysis with 13 RCTs. Wu et al. [19] included studies utilizing VR along with traditional rehabilitative treatment, limiting the interpretation of pooled effects, which was not the case in our review.

The aforementioned systematic review of Hill et al. [22] did not conduct meta-analyses on people with MCI only, but also separately on people with dementia. In contrast to the non-effective findings in our review the authors [22] reported beneficial evidence with pooled studies on overall cognitive outcomes and visuospatial skills in people with dementia performing computer-based CT. A further meta-analysis from Garcia-Carsal et al. [17] demonstrated a significant effect of CCIs on global cognition of people with dementia and additionally revealed that CCIs seemed to be more beneficial compared to non-computer-based CT. However, Garcia-Carsal et al. [17] included not only RCTs but also heterogeneous study designs such as case control studies in their meta-analyses, which have a lower level of evidence compared to RCTs [74].

Only one study investigated a CCI with an emerging technology, namely non-immersive VR by people with dementia [67], although such technologies seem to be very promising in terms of their cognitive approaches to CR and CS. In the context of CR, technologies like AR, VR and MR could be used for carrying out individual (I)ADL-trainings (e.g. making tea) or even be integrated in everyday live to independently stay at home as long as possible [75]. However, an increased cognition did not lead concurrently to an improvement in (I)ADL, which the results of Hill et al. [22] and Garcia et al. [17] justified with significant effects regarding cognition but not for the outcome of (I)ADL. In this regard, especially increased executive functions are associated with an improvement in (I)ADL performance [76, 77], which raises the need for more research on CR and emerging technologies that focus on this cognitive domain.

Furthermore, CS, which is not represented in the present review, could be well applied, for example by practicing reminiscence therapy by integrating scenarios from individuals' biography [75]. Reminiscence therapy on persons with dementia using a tablet was already investigated by a recent RCT [78] (out of our search time frame), showing no significant results on cognition. With emerging technologies, new possibilities open up for people with dementia to immerse themselves in the past, stimulating their cognition with the help of a virtual environment [75]. However, in terms of such technologies and different cognitive approaches, RCTs are needed to verify their effectiveness. It was also observed that more studies investigating emerging technologies for MCI than on dementia were included in our review. This may be due to the greater resources required for conducting studies on persons with dementia (e.g. supervision, time for assessments), because of disease-related symptoms [79].

We identified two additional recent RCTs that were published after our literature search and therefore were not included in our analysis. Duff et al. [80] investigated CCIs in people with MCI. The authors [80] compared an intervention group utilizing selected exercises from a known computerized cognitive training program on a PC, which already showed beneficial effects on cognition in previous literature, with a control group using computerized games from the same program, without clear beneficial findings. The primary outcome, a composite score named auditory memory/attention significantly increased for participants in the active control group. Despite the similarity of the compared interventions, the composite score does not match our domain classification. Furthermore, global cognition did not increase significantly in the intervention group [80], corresponding with our findings. The second identified RCT [81] evaluated a CCI also on a PC compared to a control group which received only educational material during the pretest on people with dementia. Results on objective cognition revealed no significant impact corresponding with the meta-analysis in our review, whereas subjective cognition evaluated by participants' relatives showed significant effects for participants in the intervention group [81]. However, proxy-measurements on subjective cognition were not considered in our systematic review.

Overall, most interventions were conducted in a lab setting under optimal conditions (e.g. constant technical support), as it is important to investigate the effectiveness more realistically at the participants' home, giving them the opportunity to practice any time [23]. There is a particular need for research for persons with dementia, as only one [45] of six studies was conducted at the home of a participant. Since people with dementia are usually limited in (I)ADLs, the need for a transport to visit the training lab can be challenging and could cause additional burden on their caregivers [2].

For the application of CCIs at home, the acceptance and usability of the interventions are particularly necessary to enable an easy use and regular training performances [82, 83], as the training intensity appears to be important for effectiveness [13]. Usability research for CCIs, specifically on the older population, is still lacking [82, 83].

Furthermore, the implementation of emerging technologies in the home setting may be hindered by the current high cost of the needed products (e.g. head-mounted display for immersive virtual reality). However, research on the use of smartphones is already underway that may open the option of creating a virtual environment for computer-based cognitive interventions at home [19].

Strengths and limitations

A strength of this systematic review was the comprehensive literature search and the well-structured selection process to identify relevant studies and to minimize a publication bias. Despite the effort to avoid a publication bias, it cannot be excluded, as a screening of study registries had not taken place [31]. It might be possible that technology companies did not publish studies because of non-significant results.

The authors had defined clear eligible criteria for this systematic review to show effects for specific subgroups, however, it was recognized that some studies did not describe their eligibility criteria, such as the setting or diagnostic criteria of participants in a manner that was sufficient to fit our definitions and for further inclusion in this review. While the authors were contacted for further information, insufficient reporting may have resulted in missed inclusion of potential studies.

Furthermore, our review focused on a broad outcome containing global and domain-specific cognition, for three different target groups measured immediately after post-intervention and at follow-up, which resulted in more than 120 different outcome (sub)measurements. In some cases, measurements were reported with minor differences in naming or with insufficient detail of which instrument was used. Measurements of this kind were excluded in cases of serious doubts. Most studies used multiple measures for different kind of cognitive domains, which constituted a challenge in classifying those in one of our pre-defined cognitive domains and furthermore made a calculation of composite scores [44] necessary for most pooled studies. For that reason, different (un)established instruments were summarized for calculating such a composite score, which could not always result in an optimal assessment for a given cognitive domain.

Finally, for the conduction of our meta-analyses we applied the random-effects model, because of the variability in the participants, interventions and outcomes, as it cannot be assumed that the true effect sizes are all the same or rather fix [30, 39, 84]. Although, in practice, the random-effects model predominates [84], it is not entirely controversial, especially for smaller studies, as this model may have a poor precision with a small number of studies in a meta-analysis [39]. However, the Hartung-Knapp adjustment addresses the issue of small number of studies [30].

Conclusions

The findings of this systematic-review and meta-analyses demonstrated that individually performed CCIs had beneficial effects on domain-specific cognition in community-dwelling people with MCI, but no significant effects on people with dementia. However, for people with dementia, a tendency towards an increased memory function could be observed. In particular, for people with MCI, most meta-analyses revealed a substantial or considerable heterogeneity, which is why the confidence in these results is limited. In terms of SCD, only one study was identified that demonstrated significant results on memory functions for participants in the intervention group using a web-based CT on a PC. In general, most CCIs were conducted with PCs, followed by tablets, VR, AR, and MR.

When considering CCIs, the maxim "the earlier, the better" summarizes our results best, as the findings suggested that CCIs are already a valuable intervention for people with MCI to preserve/improve cognition, but more research on SCD is needed. CCIs therefore have the potential to complement standard (non-) pharmacological treatment as they open a low threshold offering in a stigmatized area. Apart from the underlying condition, the decision to provide such trainings should additionally be made with consideration for the personal values, preferences, and available resources of the people concerned. In this context, it would be particularly important to investigate CCIs not only in well-prepared laboratory settings, as was the case in most of the included studies, but more realistically in people's homes to provide easy access and the opportunity to conduct the training at any time, since a higher training intensity appears to increase the chance for effectiveness. However, a prerequisite for regular practice is the user-friendliness of CCIs, which must be evaluated and considered in the context of the needs people have, in respect to technologies and the home setting. Furthermore, future studies should focus more on emerging technologies (e.g. VR) where people could interact with its environment, as these technologies are predicted as important game changers in the field of dementia prevention and treatment.

Finally, the development of a set of essential cognitive outcomes and instruments for consistent use in RCTs is recommended, as well as to report such findings comprehensively and transparently, making the pooling of evidence easier and more precise for future decisions.

Abbreviations

ADL	Activities of daily living
ACER	Addenbrooke's Cognitive Examination Revised
AR	Augmented reality
CCIs	Computer-based cognitive interventions
CG	Control group
CR	Cognitive rehabilitation
CS	Cognitive stimulation
CT	Cognitive training
DMS	Delayed matching sample
IADL	Instrumental activities of daily living
IG	Intervention group
MCI	Mild cognitive impairment
MMSE	Mini Mental State Examination
MoCA	Montreal Cognitive Assessment
MR	Mixed reality
PAL	Paired associated learning
PRM	Pattern recognition memory
RCT	Randomized controlled trial
RT	Reaction time
SCD	Subjective cognitive decline
SWM	Spatial-working memory
SMD	Standardized mean difference
VR	Virtual reality

Supplementary Information

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Additional file 1. Search strategies of all databases.

Additional file 2. Characteristics of the included RCTs.

Additional file 3. Outcomes of the systematic review and the respective assigned instruments identified in the studies.

Additional file 4. Meta-analyses and composite scores.

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Authors' contributions

JZ was the major contributor to the manuscript. SS, MK and LP contributed equally as joint senior authors. All authors (JZ, DS, AH, SAH, SR, KP, MF, MMH, RRW, LP, MK; SS) made substantial contributions to the conception and design of the review and were providing expertise and advice. JZ, DS, AH, SS in particular made substantial contributions to acquisition of data, data extraction and risk of bias assessment. JZ, DS, MK, SAH, SS, AH, LP were responsible for the analysis and interpretation of data. All authors were involved in drafting the manuscript and revising it critically for important intellectual content and in approving the submitted version. Furthermore, all authors have agreed to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

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Availability of data and materials
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Declarations

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Competing interests
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Additional file 1

Table 1: Search strategies of all databases

Queries	Hits
Medline via Pubmed	
((dementia [MH] OR alzheimer disease [MH] OR dementia, vascular [MH] OR cognitive impairment OR MCI OR cognition disorders [MH] OR neurocognitive disorders [MH] OR cognitive dysfunction [MH])) AND (computerized cognitive training OR computer-based cognitive training OR computer-based memory training OR touchscreen technology OR tablet* OR serious game* OR brain training game* OR virtual reality [MH] OR augmented reality [MH] OR game console* OR Wii OR video gam* OR computer gam* OR web-based training OR internet-based training OR computer training OR telerehabilitation [MH]) Sort by: Best Match Filters: English; German	2.587
CINAHL via Ovid	
((MH “dementia+”) OR (MH "Alzheimer's Disease") OR (MH "Dementia, Vascular") OR cognitive impairment OR MCI OR (MH "Cognition Disorders") OR neurocognitive disorders OR cognitive dysfunction) AND (computerized cognitive training OR computer-based cognitive training OR computer-based memory training OR web-based training OR internet-based training OR computer training OR touchscreen technology OR tablet* OR serious game* OR brain training game* OR (MH "Virtual Reality") OR (MH "Augmented Reality") OR game console* OR Wii OR video gam* OR computer gam* OR (MH "Telerehabilitation")) Limiters - Language: English, German	1.047
Embase via Ovid	
((dementia or alzheimer disease or dementia, vascular or cognitive impairment or MCI or cognition disorders or neurocognitive disorders or cognitive dysfunction) and (computerized cognitive training or computer-based cognitive training or computer-based memory training or web-based training or internet-based training or computer training or touchscreen technology or tablet* or serious game* or brain training game* or virtual reality or augmented reality or game console* or Wii or video gam* or computer gam* or telerehabilitation)).af limit 2 to (english or german)	1.766
Cochrane RCT via Ovid	
((dementia or alzheimer disease or dementia, vascular or cognitive impairment or MCI or cognition disorders or neurocognitive disorders or cognitive dysfunction) and (computerized cognitive training or computer-based cognitive training or computer-based memory training or web-based training or internet-based training or computer training or touchscreen technology or tablet* or serious game* or brain training game* or virtual reality or augmented reality or game console* or Wii or video gam* or computer gam* or telerehabilitation)).af.	1.071
IEEE	
(("All Metadata":dementia OR alzheimer disease OR vascular dementia OR cognitive impairment OR MCI OR cognition disorder OR neurocognitive disorders) AND "All Metadata":"cognitive training" OR "computerized cognitive training" OR "computer-based cognitive training" OR "memory training" OR "serious game*" OR "brain training")	2.731

Web of Science	
TS=(dementia OR alzheimer disease OR dementia, vascular OR cognitive impairment OR MCI OR cognition disorders OR neurocognitive disorders OR cognitive dysfunction) AND TS=(computerized cognitive training OR computer-based cognitive training OR computer-based memory training OR web-based training OR internet-based training OR computer training OR touchscreen technology OR tablet* OR serious game* OR brain training game* OR virtual reality OR augmented reality OR game console* OR Wii OR video gam* OR computer gam* OR telerehabilitation) Refined by: LANGUAGES: (ENGLISH OR GERMAN) Timespan: All years. Databases: WOS, KJD, MEDLINE, RSCI, SCIELO. Search language=Auto	6.177
Scopus	
(TITLE-ABS-KEY (*"dementia"*) OR TITLE-ABS-KEY (*"alzheimer disease"*) OR TITLE-ABS-KEY (*"dementia, vascular"*) OR TITLE-ABS-KEY (*"cognitive impairment"*) OR TITLE-ABS-KEY (*"MCI"*) OR TITLE-ABS-KEY (*"cognition disorders"*) OR TITLE-ABS-KEY (*"neurocognitive disorders"*) OR TITLE-ABS-KEY (*"cognitive dysfunction"*)) AND (TITLE-ABS-KEY (*"computerized cognitive training"*) OR TITLE-ABS-KEY (*"computer-based cognitive training"*) OR TITLE-ABS-KEY (*"computer-based memory training"*) OR TITLE-ABS-KEY (*"web-based training"*) OR TITLE-ABS-KEY (*"internet-based training"*) OR TITLE-ABS-KEY (*"computer training"*) OR TITLE-ABS-KEY (*"touchscreen technology"*) OR TITLE-ABS-KEY (*"tablet*"*) OR TITLE-ABS-KEY (*"serious game*"*) OR TITLE-ABS-KEY (*"brain training game*"*) OR TITLE-ABS-KEY (*"virtual reality"*) OR TITLE-ABS-KEY (*"augmented reality"*) OR TITLE-ABS-KEY (*"game console*"*) OR TITLE-ABS-KEY (*"Wii"*) OR TITLE-ABS-KEY (*"video gam*"*) OR TITLE-ABS-KEY (*"computer gam*"*) OR TITLE-ABS-KEY (*"telerehabilitation"*)) AND (LIMIT-TO (LANGUAGE , *"English"*) OR LIMIT-TO (LANGUAGE , *"German"*))	2.189
PsycInfo via Ovid	
((dementia or alzheimer's disease or vascular dementia or cognitive impairment or MCI or cognition disorders or neurocognitive disorders or cognitive dysfunction) and (computerized cognitive training or computer-based cognitive training or computer-based memory training or web-based training or internet-based training or computer training or touchscreen technology or tablet* or serious game* or brain training game* or virtual reality or augmented reality or game console* or Wii or video gam* or computer gam* or telerehabilitation)).mp. [mp=title, abstract, heading word, table of contents, key concepts, original title, tests & measures, mesh]	700
Google Scholar (the first 100 hits)	
(dementia OR alzheimer's disease OR vascular dementia OR cognitive impairment OR MCI OR cognition disorder OR neurocognitive disorder) AND (computerized cognitive training OR computer-based cognitive training OR serious game OR memory training)	
Research Gate (the first 100 hits)	
dementia and computerized cognitive training or computer-based cognitive training	

Additional file 2

Table 1: Characteristics of the included RCTs

Authors; Country	Sample						Intervention							Follow-up (months)
	Type of cognitive decline	Sample size (IG [a]/CG [b])	Age $\overline{x}$	Female %	Global cognition $\overline{x}$	Years of education $\overline{x}$	TECH [c]	Description	Cognitive approach	Duration in weeks	Sessions/week, (minutes/session)	Total number of sessions	Setting	
Cinar et al. 2020; [45] Turkey	SCD [d]	60 (30/30)	67.4 [e]	61.7	23.8 MoCA [f]	12.4 [e]	PC [g]	IG: BEYNEX, web-based program included 3 different games and physical exercises (per video) *Addressed cognitive domains:* nr	CT [h]	12 (or at least 1200 min of training)	about 7 (15-20 minutes)	60-80	Home	-
								CG: No intervention						
Amjad et al. 2019; [50] Pakistan	MCI [i] not specified	38 (18/20)	nr [j]	nr	nr	nr	VR [k]	IG: VR-based Xbox 360 Kinect platform with commercially available games (''Body and Brain Exercises'' by Dr. Kawashima) *Addressed cognitive domains:* logic, physical, memory, reflexes, math	CT	6	5 (20-30 minutes)	30	Lab	-
								CG: Motion and stretching exercises of upper and lower limbs						
Barnes et al. 2009; [51] USA	MCI all types	47 (22/25)	74.0	40.0	86.5 RBANS [l]	17.0	PC	IG: Computer-based, cognitive training program developed by Post Science Corporation (San Francisco, CA) *Addressed cognitive domains:* processing speed, accuracy in the auditory cortex	CT	6	5 (100 minutes)	30	Home	-
								CG: Three types of computer-based activities (audio books, online newspapers, visuospatial-oriented computer game)						
Damirchi et al. 2018; [52] Iran	MCI not specified	44 (11/11/13/9)	68.4 [e]	100	23.4 MMSE [m]	3.2 [e]	PC	IG1: Program titled "Modified My Better Mind" with 4 different games *Addressed cognitive domains:* visual attention, visual working memory (visuospatial and verbal), processing speed, anectodal knowledge, verbal memory, reasoning, spatial executive processing, visual-spatial skills	CT	8	3 (30 minutes in weeks 1-6; 60 minutes in 7th and 8th week)	24	Lab	-
								IG2: Physical activity group						
								IG3: Program "Modified My Better Mind" combined with physical group activities						
								CG1: Waiting list group						
Dimitriadis et al. [53] 2016; Greece	MCI not specified	158 (53/50/55)	69.1 [e]	73.7	24.9 MMSE [e]	7.3 [e]	AR [n]	IG: Novel Serious game (Mnemonic Strategy training) with a hide-and-seek exercise and a dual task condition using the hands and arms *Addressed cognitive domains:* working and spatial memory, executive function (eg, volition, self-awareness, planning, inhabitation of dominant response and external distraction during response control and dual-task coordination)	CT	10	4-5 (90 minutes)	40-50	Home	-
								CG1: Watching YouTube documentaries						
								CG2: Waiting list group						

Finn et al. 2011; [54] Australia	MCI amnestic multiple domain	16 (8/8)	72.7 [e]	50.0	28.0 MMSE [e]	12.6 [e]	PC	IG: Training software by Lumosity Inc, which consisted of 30 training sessions each containing four or five cognitive exercises *Addressed cognitive domains:* nominally attention, processing speed, visual memory, cognitive control CG: Waiting list group	CT	average of 11.4[o]	4-5 (nr)	30	Home	-
Flak et al. 2019; [55] Norway	MCI all types	69 (35/34) [p]	66.0 [e]	33.3	nr	13.2 [e]	PC	IG: Cogmed [®3], adaptive (ie. available difficulty levels) computerized training program *Addressed cognitive domains:* visuospatial working memory, a combination of verbal and visual working memory CG: Cogmed [®3], non-adaptive (fixed low level of difficulty) computerized training program	CT	5	5 (30-40 minutes)	20-25	Home	4
Hagovska et al. 2017; [46] Slovakia	MCI not specified	60 (30/30)	68.0 [e]	51.7	25.3 MMSE [e]	Education level (%): Secondary 85.0 University 15.0	PC	IG: CogniPlus program that involved activities that are similar to everyday activities *Addressed cognitive domains:* attention, working memory, long-term memory, planning of everyday activities, visual-motor abilities CG: Group cognitive training program	CR [q]	10	2 (30 minutes)	20	Lab	-
Han et al. 2017; [56] South Korea	MCI all types	43 (43/42) [r]	74.0	46.5	25.1 MMSE	13.2	Tablet	IG: Ubiquitous Spaced Retrieval-based Memory Advancement and Rehabilitation Training (USMART) *Addressed cognitive domains:* memory CG: Usual treatment	CT	4	2 (30 minutes)	8	Lab	-
Herrera et al. 2012; [57] France	MCI amnestic multiple domain	22 (11/11)	76.6 [e]	50.0	27.3 MMSE [e]	Education level (%) [e]: Primary school 45.5 Secondary school 40.5 more than secondary school 14.0	PC	IG: Cognitive training includes memory and attentional tasks. *Addressed cognitive domains:* memory, attention (visual focused attention, visuospatial focused attention, divided attention) CG: Cognitive activities (eg. finding names of countries read a text and then answer questions)	CT	12	2 (60 minutes)	24	Lab	6
Hyer et al. 2016; [58] USA	MCI amnestic and non- amnestic	68 (34/34)	75.2 [e]	52.9	84.5 RBANS [e]	Education level (%): High school or more 68.0	PC	IG: Cogmed [QM©], adaptive (ie, available difficulty levels) computerized training program *Addressed cognitive domains:* working memory (temporary storage and manipulation of sequential visuospatial and/or verbal information) CG: Cogmed, non-adaptive (fixed low level of difficulty) computerized training program (ie. Sham).	CT	5-7	about 5 (40 minutes)	25	Lab or Home	3
Li et al. 2019; [59] China	MCI amnestic (due to AD [s])	141 (78/63)	70.4	nr	28.0 MMSE [e]	13.7 [e]	PC	IG: Training comprised 8 tasks *Addressed cognitive domains:* visual working memory, 30-second memory, episodic memory, seed of calculation, visual search, alertness, mental rotation, images re-arrangement task CG: No intervention	CT	24	3-4 (about 40 minutes)	72-69	Home	12
Lin et al. 2016; [60] USA	MCI amnestic multiple domain (due to AD)	21 (10/11)	72.0 [e]	47.6	25.0 MoCA [e]	Education level (%): High school or lower 28.6	PC	IG: Vision-based speed of processing (VSOP) training used the INSIGHT online program (Posit Science) which included five training tasks. *Addressed cognitive domains:* visual processing speed, attention CG: Mental leisure activities like online crossword, Sudoku, and solitaire games	CT	6	4 (60 minutes)	24	Home	-

Nousia et al. 2019; [48] Greece	MCI all types	46 (25/21)	71.6 [e]	76.1	21.8 MoCA [e]	8.7 [e]	PC	IG: RehaCom Cognitive Therapy Software *Addressed cognitive domains:* episodic and delayed memory, verbal memory, attention, processing speed, executive function.	CR	15	2 (60 minutes)	30	Lab	-
								CG: Usual treatment						
Park et al. 2019; [49] South Korea	MCI single and multiple domain	21 (10/11)	71.9 [e]	81.0	26.7 MMSE [e]	7.1 [e]	Mixed Reality	IG: MR-based cognitive training system (Mixed Reality System for Health), which combines augmented and virtual reality. *Addressed cognitive domains:* selective attention, visual and verbal working memory, executive function, (including sequencing, planning, and problem solving), calculation.	CR	6	3 (30 minutes)	18	Lab	-
								CG: Computer-assisted cognitive training system COMOG (Maxmedica), which provides 10 training activities *Addressed cognitive domains:* visual and auditory processing, selective attention, working memory, emotional attention						
Park et al. 2020; [61] South Korea	MCI amnestic	21 (10/11)	70.6 [e]	66.7	25.7 MMSE [e]	7.6 [e]	VR	IG: Culture-based VR-training program stimulating cognitive function with 6 games *Addressed cognitive domains:* attention, processing speed, executive function, memory	CT	12	2 (30 minutes)	24	Lab	-
								CG: Waiting list group						
Rosen et al. 2011; [62] USA	MCI amnestic	12 (6/6)	74.3 [e]	nr	28.6 MMSE [e]	17.5 [e]	PC	IG: Computer-based, cognitive training program developed by Post Science Corporation (San Francisco, CA), with 7 exercises *Addressed cognitive domain:* processing speed	CT	Average of 8 [t]	5 (100 minutes)	24	Home	-
								CG: Three types of computer-based activities (audio books, online newspapers, visuospatial-oriented computer game)						
Savulich et al. 2017; [63] United Kingdom	MCI amnestic (due to AD)	42 (21/21)	76.1 [e]	40.5	26.7 MMSE [e]	Age left education, $\bar{x}$ [e]: 15.95	Tablet PC	IG: Memory game "Game Show", with the intention to motivate *Addressed cognitive domain:* episodic memory	CT	4	nr (60 minutes)	8	Lab	-
								CG: No intervention						
Thapa et al. 2020; [64] South Korea	MCI not specified	68 (34/34) [u]	72.5 [e]	76.5	26.2 MMSE [e]	8.9 [e]	VR	IG: 1) Training consists of 4 games developed by SY Innotech Inc. *Addressed cognitive domain:* attention, memory, processing speed (Information on the right refers to Part 1 only) 2) Educational program on general health care	CT	8	3 (100 minutes)	24	Lab	-
								CG: Educational program on general health care						
Cinar et al. 2020; [45] Turkey	Dementia AD	60 (30/30)	72.6 [e]	50	20.0 MoCA [e]	9.7 [e]	PC	IG: BEYNEX, web-based program included 3 different games and physical exercises (per video) *Addressed cognitive domains:* nr	CT	12 (or at least 1200 min of training)	about 7 (15-20 minutes)	60-80	Home	-
								CG: No intervention						
Galante et al. 2007; [65] Italy	Dementia AD	12 (7/5) [v]	76.0	nr	23.0 MMSE [e]	6.3	PC	IG: Selected tasks from Software Training NeuroPsicologico (TNP) *Addressed cognitive domains:* memory, language, perception, attention, spatial cognition	CT	4	3 (60 minutes)	12	Lab	3; 9
								CG: Semi-structured interviews on current affairs and events relevant to participants' lives						

Heiss et al. 1994; [66] Germany	Dementia AD	70 (18/17/18/17)	66.3	45.7	20.8 MMSE [e]	nr	PC	IG1: Computer-based cognitive training program *Addressed cognitive domains:* memory, perceptual or motor tasks	CT	24	2 (60 minutes)	48	Lab	-
								IG2 [w]: Computer-based cognitive training program in combination with oral pyritinol 600 mg twice a day						
								IG3 [w]: Computer-based cognitive training program in combination with oral phosphatidylserine 200 mg twice a day						
								CG: Social support through conversations about participants' personal problems and how they managed daily life						
Karssemeijer et al. 2019; [67, 68] The Netherlands	Dementia all types	115 (38/38/39)	79.9	46.1	22.4 MMSE	Education level (%): Primary school education or lower 16.5 Secondary education or vocational training 58.3 Higher education 25.2	VR	IG1: Training consisted of a combined cognitive–aerobic bicycle training developed by Bike Labyrinth (www.bikelabyrinth.com), by which a stationary bike was connected to a video screen *Addressed cognitive domains:* response inhibition, task switching, processing speed	CT	12	3 (30-40 minutes)	36	Lab	3
								IG2: Single aerobic exercise group consisted of cycling on a stationary bike without a video screen						
								CG: Active control group performed relaxation and flexibility exercises						
Lee et al. 2013; [47] China	Dementia AD	19 (7/6/6)	77.7	68.4	16.6 MMSE [e]	Education level (%): 0 years 31.6 <2 years 15.8 3-6 years 26.3 Secondary21.0 University 0.05	Tablet	IG1: Computer-assisted errorless learning program (CELP) *Addressed cognitive domains:* sensory memory (visual and auditory), working memory, prospective memory, memory strategies for using mnemonics (eg, chunking, organization, and categorization), learning principles, name/face association, advanced memory training on application of strategies to train task in activities of daily living	CR	6	2 (12-30 minutes)	12	Lab	3
								IG2: Therapist-led training program (TELP) (not computer-based) The content and structure of both programs CELP and TELP were similar, except for the mode of delivery.						
								CG: Waiting-list control group, which received general cognitively challenging activities to perform, such as card sorting						
Yu et al. 2015; [69] China	Dementia not specified	32 (16/16)	83.0	69.0	16.6 MMSE	nr	Tablet	IG: Computer-assisted video game training, with 4 games *Addressed cognitive domains:* working memory, attention	CT	4-8	1-2 (30 minutes)	8	Lab	-
								CG: Conventional cognitive training activities in which the training elements were matched with those in the computer-assisted videogame training						

[a] IG: intervention group
[b] CG: control group
[c] TECH: Technology
[d] SCD: subjective cognitive decline
[e] marginal mean

[f] MoCA: Montreal Cognitive Assessment (score 0-30, the more the better)
[g] PC: personal computer
[h] CT: cognitive training
[i] MCI: mild cognitive impairment
[j] nr: not reported
[k] VR: virtual reality
[l] RBANS: Repeatable Battery for the Assessment of Neuropsychological Status (score 0-100, the more the better)
[m] MMSE: Mini Mental State Examination (score 0-30, the more the better)
[n] AR: augmented reality
[o] The authors anticipated 6–10 weeks. Participants completed at least 80% of the sessions.
[p] 68 (34/34) participants were included in the final analysis of the respectively study
[q] Cross-over randomized controlled trial
[r] CR: cognitive rehabilitation
[s] AD: Alzheimers' disease
[t] Participants had to use the program until either achievement of asymptotic performance levels over a several day period or completion of 80% of the training material in a given exercise
[u] 66 (33/33) participants were included in the final analysis of the respectively study
[v] 11 (7/4) participants were included in the final analysis of the respectively study
[w] These intervention groups were not considered for analysis, as medication used were non-commercial substances for the treatment of dementia, as well as non-registered substances of the Austrian Register of Pharmaceutical Specialties

Additional file 3

Table 1: Outcomes of the systematic review and the respective assigned instruments identified in the studies

Global cognition	Memory	Working memory
Ref.: 45-47, 50, 51, 53, 56, 59, 61, 63-66, 69	**Ref.: 45-49, 51, 53-59, 62, 63, 65-67**	**Ref.: 48, 51-53, 55, 57, 58, 60, 61, 65-67, 69**
Mini Mental State Examination (MMSE)	RBANS, list learning	WMS III, letter number sequenceing
Montreal Cognitive Assessment (MoCA)	RBANS, story memory	WMS III, spatial span forward
Repeatable Battery for Assessment of Cognitive Status (RBANS), total score	RBANS, list recall	WMS III, spatial span backward
Milan Overal Dementia Assessment (MODA)	RBANS, list recognition	WMS III, spatial span
Mattis Dementia Rating Scale	RBANS, story telling	Wechsler adult intelligence scale (WAIS) III, digit span
Addenbrooke's Cognitive Examination (ACE), total score	RBANS, story recognition	EXAMINER, working memory
Addenbrooke's Cognitive Examination (Revised) (ACER), total score	RBANS, immediat memory	RBANS, digit span
	California verbal learning test (CVLT) , totals learned	Digit Span, forward
	CVLT, delayed free recall	Digit Span, backward
	CVLT II, delayed recall	Corsi block tapping test
	CVLT II, short delayed (cued) recall	
	CVLT II, immediate recall	
	CVLT II, intrusions error	
	CVLT II, memory decay	
	CVLT II, Trial 1	
	CVLT II, Trial B	
	CVLT II, Trial 5	
	CVLT II, total hits recognition trial	
	CVLT II, perseverative errors	
	CVLT II, short delay free recall	
	CVLT II, long delay free recall	
	CVLT II, long delay cued recall	
	CANTAB-Paired associated learning (PAL), error (adj.)	
	CANTAB-Pattern recognition memory (PRM), % correct	
	CANTAB-Spatial working memory (SWM), errors	
	CANTAB-Delayed matching sample (DMS), percent correct	
	CANTAB-DMS, percent correct (all delays)	
	Rey-Osterreith Complex Figure, recall/36	
	Rey-Osterreith Complex Figure, long delay recall	
	Rey-Osterreith Complex Figure, short delay recall	
	Wechsler memory scale (WMS) III, logical memory, short/long delay recall	
	WMS III, faces, short/long delay recall	
	WMS III, span board	
	Doors recognition subtest (Set A)	
	Doors recognition subtest (Set B)	
	Delayed Matching Sample Task (DMS48)	
	BEM144 (12-word-list-recall test), total score	
	Word list memory test	
	Word list recall test	
	Word list recognition test	
	Word list learning test	
	ACE, memory	
	Auditory Verbal Learning Test (AVLT), immediate recall	
	AVLT, 5min recall	
	AVLT, 20 min recall	
	AVLT, recognition	
	Brief visuospatial memory test - Revised	
	Hong Kong List Learning Test (HKLLT)	
	Brief Assessment of Prospective Memory (BAPM), short form	
	Location Learning Test (revised), displacement score delayed recall	
	Location Learning Test (revised), displacement score trial 1-5	
	16-item free and cued reminding test	
	Recall, word recognition and delayed word memory test, recall	
	Recall, word recognition and delayed word memory test, delayed memory	
	Recall, word recognition and delayed word memory test, word recognition	
	Prose memory	
	Verbal selective reminding	
	Selective reminding test/task (recognition) "Recognition hits"	
	Selective reminding test/task (false positives) "Recognition false-positive"	

Additional file 3

Table 1: Outcomes of the systematic review and the respective assigned instruments identified in the studies

Attention/concentration/processing speed	Executive functions	Language	Visuospatial/constructional abilities
Ref.: 45, 46, 48-55, 59-61, 63-67	**Ref.: 45, 46, 48-51, 53-55, 58-61, 64-67, 69**	**Ref.: 46, 48, 49, 54, 60, 66**	**Ref.: 46, 49, 51, 55, 59**
TMT A	TMT B	RBANS, Picture Naming	RBANS, copy
ACE, attention/concentration	ACE, verbal fluency	Boston Naming Test	RBANS, line orientation
Alters-Konzentrationstest (AKT), time	EXAMINER, verbal fluency	ACE, language	Rey-Osterreith Complex Figure, copy
CANTAB-Rapid visual information processing (RVP)	EXAMINER, cognitive control	Token Test, DeRenzi	ACE, Visuospatial
CANTAB-Reaction time (RT)	CANTAB - SWM, strategy		Constructional Praxis Test
CANTAB-Choice reaction time (CRT), correct trials	CANTAB- Intra-/extra-dimensional set shifting (IED), errors (adj.)		
CANTAB-Choice reaction time (CRT), time latency	Shape Trail Test Version B		
Stroop Color-Word Test (SCWT), words, personal tempo, time (sec.)	Rule Shift Cards Test, errors		
SCWT, colors, perception factor (sec.)	Go/no go reaction time		
SCWT, color word interference test, naming (ie. word), score	Design Fluency Test (Delis Kaplan)		
SCWT, color word interference test, reading (ie. color), score	Delis Kaplan, Color Word Interference Test, inhibition (interference)		
Digit Cancellation Test	Delis Kaplan, Color Word Interference Test, inhibition switching		
Symbol Digit Substitution Test	Delis Kaplan, Verbal fluency test, category fluency		
Digit Symbol Coding Test	Delis Kaplan, Verbal fluency test, category switching		
Useful Field of View (UFOV)	Semantic verbal fluency		
Shape Trail Test Version A	Phonemic verbal fluency		
	Word fluency test (Korean names)		
	Word fluency test (animals)		
	Verbal fluency test, letter fluency		
	Verbal fluency test (supermarket)		
	Controlled Oral Word Association Test (COWAT)		
	Category Fluency Test (CFT)		

Additional file 4

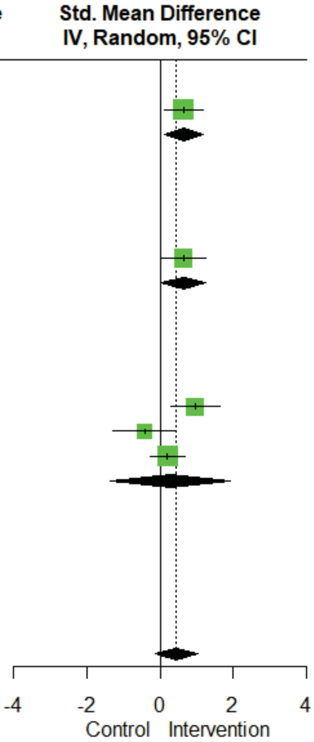
Meta-analyses and composite scores

Table of Contents

Abbreviations:

Cont: Control; Int: Intervention; IV: inverse variance; SD: standard deviation; SE: standard error; SMD; standardized mean difference; 95 % CI: 95 % confidence interval;

Study or Subgroup	Intervention Mean	SD	Total	Control Mean	SD	Total	Weight	Std. Mean Difference IV, Random, 95% CI
1.1.1 PC								
Hagovska 2017 (1)	85.63	8.22	30	80.52	7.30	30	23.8%	0.65 [0.13; 1.17]
Subtotal (95% CI)			**30**			**30**	**23.8%**	**0.65 [0.13; 1.17]**
Heterogeneity: not applicable								
Test for overall effect: t_{Inf} = 2.45 (P = 0.014)								
1.1.2 Tablet								
Savulich 2017 (2)	27.40	1.50	21	26.10	2.40	21	19.8%	0.64 [0.02; 1.26]
Subtotal (95% CI)			**21**			**21**	**19.8%**	**0.64 [0.02; 1.26]**
Heterogeneity: not applicable								
Test for overall effect: t_{Inf} = 2.01 (P = 0.044)								
1.1.3 VR								
Amjad 2019 (3)	26.25	1.47	18	23.72	3.27	20	18.0%	0.96 [0.28; 1.64]
Park 2020 (4)	25.80	2.74	10	26.82	1.94	11	13.0%	-0.42 [-1.28; 0.45]
Thapa 2020 (5)	26.90	2.00	33	26.40	2.70	33	25.4%	0.21 [-0.28; 0.69]
Subtotal (95% CI)			**61**			**64**	**56.4%**	**0.28 [-1.36; 1.92]**
Heterogeneity: Tau^2 = 0.2892; Chi^2 = 6.41, df = 2 (P = 0.041); I^2 = 69%								
Test for overall effect: t_2 = 0.74 (P = 0.535)								
1.1.4 AR								
Dimitriadis 2016 (6)	28.10	1.10	53	24.90	1.20	55	0.0%	2.76 [2.23; 3.29]
Total (95% CI)			**165**			**170**	**100.0%**	**0.45 [-0.13; 1.03]**
Heterogeneity: Tau^2 = 0.0810; Chi^2 = 7.88, df = 4 (P = 0.096); I^2 = 49%								
Test for overall effect: t_4 = 2.16 (P = 0.097)								
Test for subgroup differences: Chi^2 = 0.70, df = 2 (P = 0.706)								

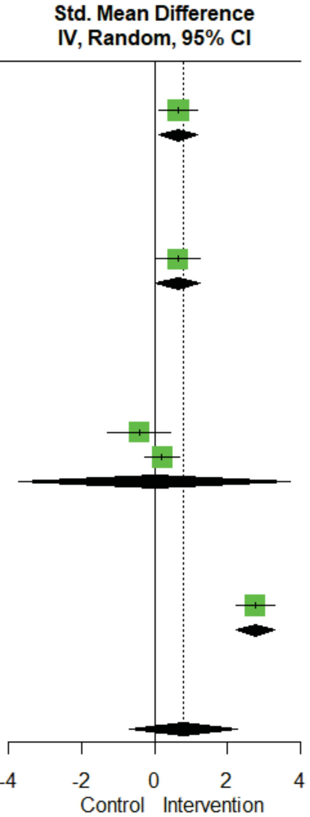


Footnote

(1) Addenbrooke's Cognitive Examination (ACE)
(2) Mini Mental State Examination (MMSE)
(3) MMSE
(4) MMSE
(5) MMSE
(6) MMSE; intervention group vs. control group 2 (CG2)

Figure 1: Sensitivity meta-analysis; Computer-based cognitive interventions without Dimitriadis 2016 (large SMD) (MCI) vs. control immediately post intervention; Outcome: **Global cognition**

Study or Subgroup	Intervention Mean	SD	Total	Control Mean	SD	Total	Weight	Std. Mean Difference IV, Random, 95% CI
1.1.1 PC								
Hagovska 2017 (1)	85.63	8.22	30	80.52	7.30	30	20.4%	0.65 [0.13; 1.17]
Subtotal (95% CI)			**30**			**30**	**20.4%**	**0.65 [0.13; 1.17]**
Heterogeneity: not applicable								
Test for overall effect: t_{Inf} = 2.45 (P = 0.014)								
1.1.2 Tablet								
Savulich 2017 (2)	27.40	1.50	21	26.10	2.40	21	20.0%	0.64 [0.02; 1.26]
Subtotal (95% CI)			**21**			**21**	**20.0%**	**0.64 [0.02; 1.26]**
Heterogeneity: not applicable								
Test for overall effect: t_{Inf} = 2.01 (P = 0.044)								
1.1.3 VR								
Amjad 2019 (3)	26.25	1.47	18	23.72	3.27	20	0.0%	0.96 [0.28; 1.64]
Park 2020 (4)	25.80	2.74	10	26.82	1.94	11	18.7%	-0.42 [-1.28; 0.45]
Thapa 2020 (5)	26.90	2.00	33	26.40	2.70	33	20.5%	0.21 [-0.28; 0.69]
Subtotal (95% CI)			**61**			**64**	**39.3%**	**0.00 [-3.71; 3.72]**
Heterogeneity: Tau^2 = 0.0663; Chi^2 = 1.52, df = 1 (P = 0.218); I^2 = 34%								
Test for overall effect: t_1 = 0.01 (P = 0.991)								
1.1.4 AR								
Dimitriadis 2016 (6)	28.10	1.10	53	24.90	1.20	55	20.4%	2.76 [2.23; 3.29]
Subtotal (95% CI)			**53**			**55**	**20.4%**	**2.76 [2.23; 3.29]**
Heterogeneity: not applicable								
Test for overall effect: t_{Inf} = 10.17 (P < 0.001)								
Total (95% CI)			**165**			**170**	**100.0%**	**0.79 [-0.70; 2.27]**
Heterogeneity: Tau^2 = 1.3242; Chi^2 = 65.21, df = 4 (P < 0.001); I^2 = 94%								
Test for overall effect: t_4 = 1.47 (P = 0.215)								
Test for subgroup differences: Chi^2 = 56.39, df = 3 (P < 0.001)								



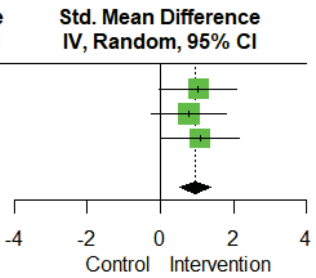
Footnote

(1) Addenbrooke's Cognitive Examination (ACE)
(2) Mini Mental State Examination (MMSE)
(3) MMSE
(4) MMSE
(5) MMSE
(6) MMSE; intervention group vs. control group 2 (CG2)

Figure 2: Sensitivity meta-analysis; Computer-based cognitive interventions without Amjad 2019 (non-immersive VR technology) (MCI) vs. control immediately post intervention; Outcome: **Global cognition**

Study	Intervention Mean	SD	Total	Control Mean	SD	Total	Weight	Std. Mean Difference IV, Random, 95% CI
Finn 2011 (1)	-34.13	17.28	8	-55.33	21.53	8	32.8%	1.03 [-0.03; 2.09]
Finn 2011 (2)	90.62	9.39	8	80.22	15.39	8	35.0%	0.77 [-0.26; 1.80]
Finn 2011 (3)	-28.63	30.28	8	-91.75	71.72	8	32.2%	1.08 [0.01; 2.15]
Total (95% CI)			**24**			**24**	**100.0%**	**0.96 [0.54; 1.37]**

Heterogeneity: $Tau^2 = 0$; $Chi^2 = 0.20$, df = 2 (P = 0.91); $I^2 = 0\%$
Test for overall effect: $t_2 = 9.84$ (P = 0.01)



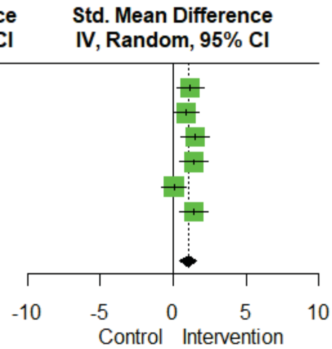
Footnote

(1) CANTAB-Spatial working memory (SWM), errors
(2) CANTAB-Pattern recognition memory (PRM), % correct
(3) CANTAB-Paired associated learning (PAL), error (adj.)

Figure 3: Composite score; Memory_Finn 2011 (see Figure 4 in Manuscript)

Study	Intervention Mean	SD	Total	Control Mean	SD	Total	Weight	Std. Mean Difference IV, Random, 95% CI
Herrera 2012 (1)	9.64	1.76	11	7.64	1.56	11	16.7%	1.16 [0.24; 2.07]
Herrera 2012 (2)	6.36	2.19	11	4.64	1.49	11	17.5%	0.88 [-0.00; 1.77]
Herrera 2012 (3)	96.91	1.92	11	90.82	5.17	11	15.5%	1.50 [0.53; 2.47]
Herrera 2012 (4)	7.28	0.86	11	6.05	0.83	11	15.9%	1.40 [0.45; 2.35]
Herrera 2012 (5)	10.45	4.51	11	10.23	2.89	11	18.7%	0.06 [-0.78; 0.89]
Herrera 2012 (6)	42.91	2.52	11	39.91	1.46	11	15.8%	1.40 [0.45; 2.35]
Total (95% CI)			**66**			**66**	**100.0%**	**1.03 [0.45; 1.62]**

Heterogeneity: $Tau^2 = 0.1170$; $Chi^2 = 7.46$, df = 5 (P = 0.19); $I^2 = 33\%$
Test for overall effect: $t_5 = 4.52$ (P < 0.01)



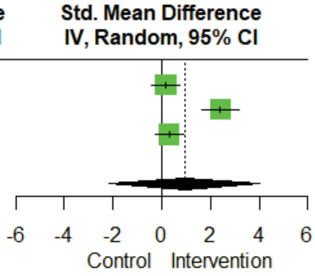
Footnote

(1) Doors recognition subtest (Set A)
(2) Doors recognition subtest (Set B)
(3) Delayed Matching Sample Task (DMS48)
(4) BEM144 (12-word-list-recall test), total score
(5) Rey-Osterreith Complex Figure, recall/36
(6) 16-item free and cued reminding test

Figure 4: Composite score; Memory_Herrera 2012 (see Figure 4 in Manuscript)

Study	Intervention Mean	Intervention SD	Intervention Total	Control Mean	Control SD	Control Total	Weight	Std. Mean Difference IV, Random, 95% CI
Nousia 2019 (1)	21.00	2.72	25	20.57	2.93	21	33.8%	0.15 [-0.43; 0.73]
Nousia 2019 (2)	3.04	1.21	25	0.67	0.58	21	32.4%	2.39 [1.62; 3.16]
Nousia 2019 (3)	19.68	0.48	25	19.48	0.81	21	33.8%	0.30 [-0.28; 0.89]
Total (95% CI)			**75**			**63**	**100.0%**	**0.93 [-2.16; 4.01]**

Heterogeneity: $Tau^2 = 1.4085$; $Chi^2 = 23.60$, df = 2 ($P < 0.01$); $I^2 = 92\%$
Test for overall effect: $t_2 = 1.29$ ($P = 0.33$)



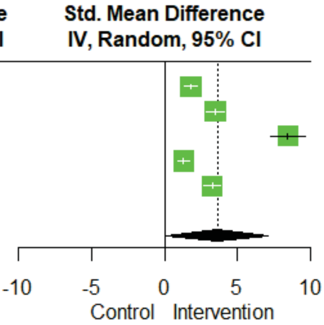
Footnote

(1) Recall, word recognition and delayed word memory test, recall
(2) Recall, word recognition and delayed word memory test, delayed memory
(3) Recall, word recognition and delayed word memory test, word recognition

Figure 5: Composite score; Memory_Nousia 2019 (see Figure 4 in Manuscript)

Study	Intervention Mean	Intervention SD	Intervention Total	Control Mean	Control SD	Control Total	Weight	Std. Mean Difference IV, Random, 95% CI
Dimitriadis 2016 (1)	10.80	1.50	53	7.80	1.80	55	20.2%	1.79 [1.35; 2.24]
Dimitriadis 2016 (2)	-1.10	1.00	53	-4.80	1.10	55	20.1%	3.49 [2.89; 4.10]
Dimitriadis 2016 (3)	-0.60	0.40	53	-3.60	0.30	55	19.4%	8.45 [7.24; 9.65]
Dimitriadis 2016 (4)	-1.10	1.00	53	-2.50	1.10	55	20.2%	1.32 [0.90; 1.74]
Dimitriadis 2016 (5)	10.50	1.80	53	6.10	0.60	55	20.1%	3.28 [2.70; 3.86]
Total (95% CI)			**265**			**275**	**100.0%**	**3.63 [0.15; 7.11]**

Heterogeneity: $Tau^2 = 7.5715$; $Chi^2 = 150.19$, df = 4 ($P < 0.01$); $I^2 = 97\%$
Test for overall effect: $t_4 = 2.89$ ($P = 0.04$)

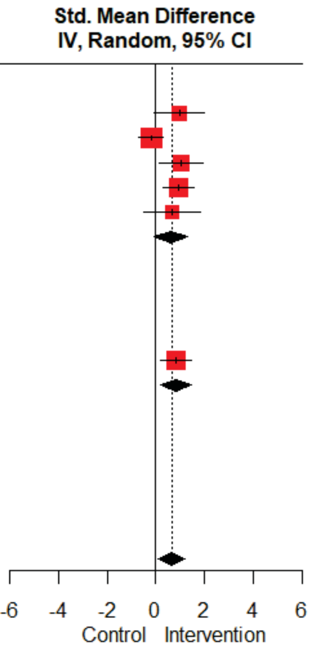


Footnote

(1) California Verbal Learning Test (CVLT) II, immediate recall
(2) CVLT II, perseverative errors
(3) CVLT II, intrusions error
(4) CVLT II, memory decay
(5) CVLT II, delayed recall

Figure 6: Composite score; Memory_Dimitriadis 2016 (see Figure 4 in Manuscript)

Study or Subgroup	SMD	SE	Int Total	Cont Total	Weight	Std. Mean Difference IV, Random, 95% CI
1.3.1 PC						
Finn 2011 (1)	0.96	0.5369	8	8	12.0%	0.96 [-0.09; 2.01]
Hagovska 2017 (2)	-0.19	0.2588	30	30	22.9%	-0.19 [-0.70; 0.32]
Herrera 2012 (3)	1.03	0.4596	11	11	14.4%	1.03 [0.13; 1.93]
Nousia 2019 (4)	0.93	0.3125	25	21	20.4%	0.93 [0.31; 1.54]
Rosen 2011 (5)	0.65	0.5996	6	6	10.4%	0.65 [-0.53; 1.83]
Subtotal (95% CI)			**80**	**76**	**80.1%**	**0.61 [-0.09; 1.30]**
Heterogeneity: $Tau^2 = 0.2260$; $Chi^2 = 11.04$, df = 4 (P = 0.026); $I^2 = 64\%$						
Test for overall effect: $t_4 = 2.42$ (P = 0.073)						
1.3.2 Tablet						
Savulich 2017 (6)	0.83	0.3229	21	21	19.9%	0.83 [0.20; 1.46]
Subtotal (95% CI)			**21**	**21**	**19.9%**	**0.83 [0.20; 1.46]**
Heterogeneity: not applicable						
Test for overall effect: $t_{Inf} = 2.57$ (P = 0.010)						
1.3.3 AR						
Dimitriadis 2016 (7)	3.63	0.3135	53	55	0.0%	3.63 [3.01; 4.24]
Total (95% CI)			**154**	**152**	**100.0%**	**0.64 [0.11; 1.18]**
Heterogeneity: $Tau^2 = 0.1760$; $Chi^2 = 12.07$, df = 5 (P = 0.034); $I^2 = 59\%$						
Test for overall effect: $t_5 = 3.08$ (P = 0.027)						
Test for subgroup differences: $Chi^2 = 0.30$, df = 1 (P = 0.585)						

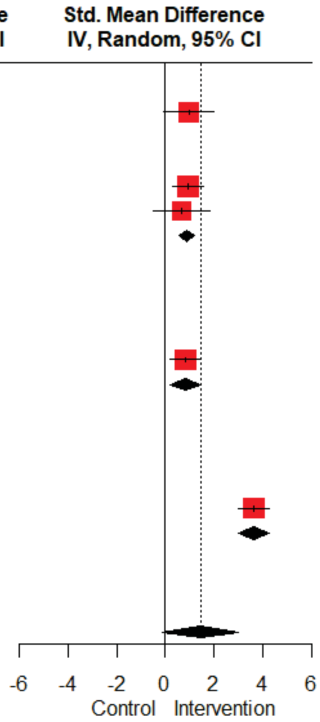


Footnote

(1) Composite score (n=3)
(2) Addenbrooke's Cognitive Examination (ACE), memory
(3) Composite score (n=6)
(4) Composite score (n=3)
(5) Repeatable Battery for Assessment of Cognitive Status (RBANS), immediate memory
(6) Brief Visuospatial Memory Test-Revised (BMVT-R)
(7) Composite score (n=5); intervention group vs. control group 2 (CG2)

Figure 7: Sensitivity meta-analysis; Computer-based cognitive interventions without Dimitriadis 2016 (large SMD) (MCI) vs. control immediately post intervention; Outcome: **Memory**

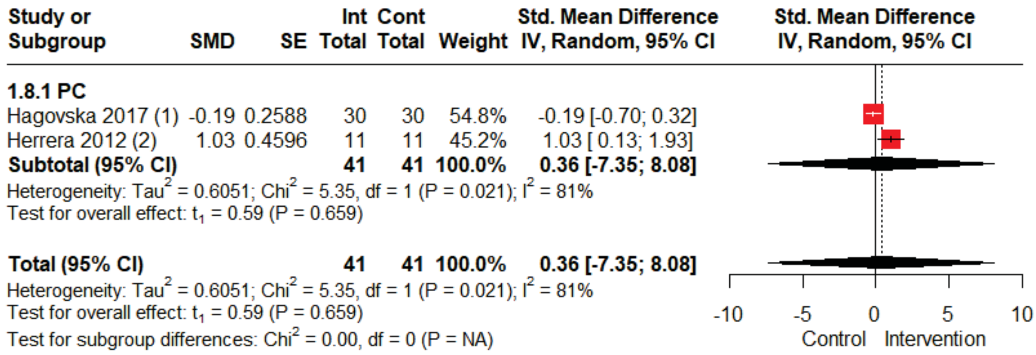
Study or Subgroup	SMD	SE	Int Total	Cont Total	Weight	Std. Mean Difference IV, Random, 95% CI
1.3.1 PC						
Finn 2011 (1)	0.96	0.5369	8	8	18.8%	0.96 [-0.09; 2.01]
Hagovska 2017 (2)	-0.19	0.2588	30	30	0.0%	-0.19 [-0.70; 0.32]
Herrera 2012 (3)	1.03	0.4596	11	11	0.0%	1.03 [0.13; 1.93]
Nousia 2019 (4)	0.93	0.3125	25	21	21.1%	0.93 [0.31; 1.54]
Rosen 2011 (5)	0.65	0.5996	6	6	18.1%	0.65 [-0.53; 1.83]
Subtotal (95% CI)			**80**	**76**	**58.0%**	**0.89 [0.56; 1.21]**
Heterogeneity: $Tau^2 = 0$; $Chi^2 = 0.19$, df = 2 (P = 0.909); $I^2 = 0\%$						
Test for overall effect: $t_2 = 11.68$ (P = 0.007)						
1.3.2 Tablet						
Savulich 2017 (6)	0.83	0.3229	21	21	21.0%	0.83 [0.20; 1.46]
Subtotal (95% CI)			**21**	**21**	**21.0%**	**0.83 [0.20; 1.46]**
Heterogeneity: not applicable						
Test for overall effect: $t_{Inf} = 2.57$ (P = 0.010)						
1.3.3 AR						
Dimitriadis 2016 (7)	3.63	0.3135	53	55	21.1%	3.63 [3.01; 4.24]
Subtotal (95% CI)			**53**	**55**	**21.1%**	**3.63 [3.01; 4.24]**
Heterogeneity: not applicable						
Test for overall effect: $t_{Inf} = 11.57$ (P < 0.001)						
Total (95% CI)			**154**	**152**	**100.0%**	**1.43 [-0.15; 3.01]**
Heterogeneity: $Tau^2 = 1.5000$; $Chi^2 = 56.05$, df = 4 (P < 0.001); $I^2 = 93\%$						
Test for overall effect: $t_4 = 2.51$ (P = 0.066)						
Test for subgroup differences: $Chi^2 = 72.62$, df = 2 (P < 0.001)						



Footnote

(1) Composite score (n=3)
(2) Addenbrooke's Cognitive Examination (ACE), memory
(3) Composite score (n=6)
(4) Composite score (n=3)
(5) Repeatable Battery for Assessment of Cognitive Status (RBANS), immediate memory
(6) Brief Visuospatial Memory Test-Revised (BMVT-R)
(7) Composite score (n=5); intervention group vs. control group 2 (CG2)

Figure 8: Sensitivity meta-analysis; Computer-based cognitive interventions without Hagovska 2017 and Herrera 2012 (non-computer-based cognitive training as control group intervention) (MCI) vs. control immediately post intervention; Outcome: **Memory**

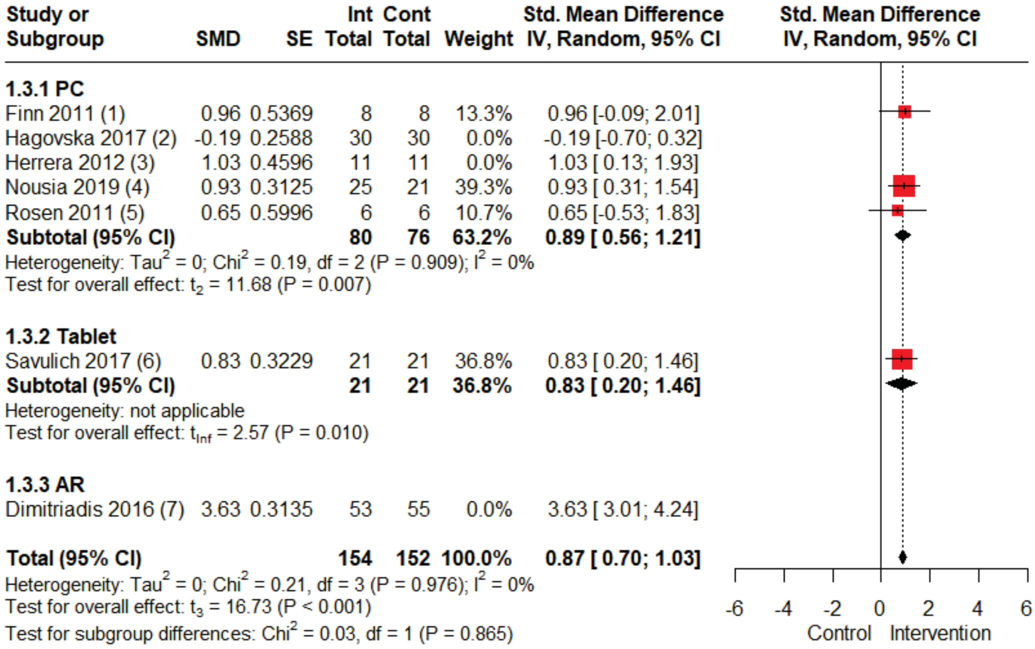


Footnote

(1) Addenbrooke's Cognitive Examination (ACE), memory

(2) Composite score (n= 6)

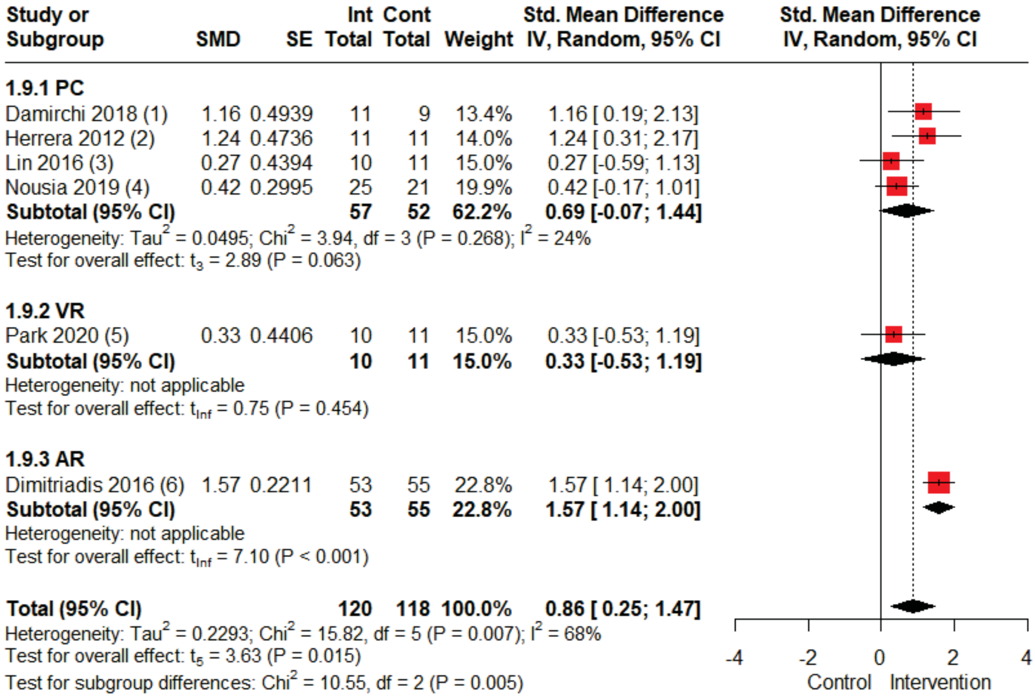
Figure 9: Meta-analysis; Computer-based cognitive interventions (MCI) vs. non-computer-based cognitive intervention as control immediately post intervention, Outcome: **Memory** (Composite score Herrera 2012 see Figure 4)



Footnote

(1) Composite score (n=3)
(2) Addenbrooke's Cognitive Examination (ACE), memory
(3) Composite score (n=6)
(4) Composite score (n=3)
(5) Repeatable Battery for Assessment of Cognitive Status (RBANS), immediate memory
(6) Brief Visuospatial Memory Test-Revised (BMVT-R)
(7) Composite score (n=5); intervention group vs. control group 2 (CG2)

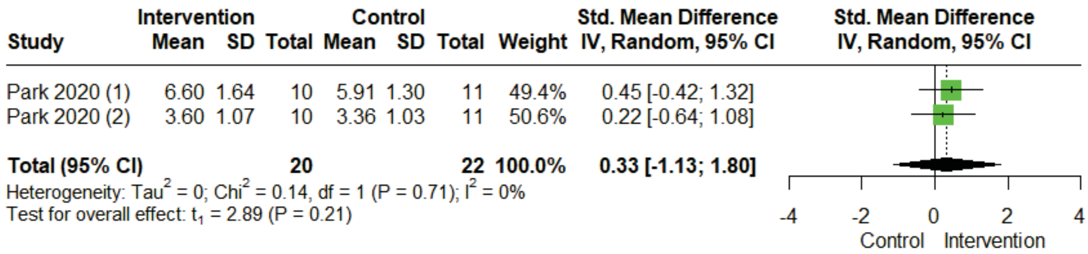
Figure 10: Sensitivity meta-analysis; Computer-based cognitive interventions without Hagovska 2017, Herrera 2012 (non-computer-based cognitive training as control group intervention) and Dimitriadis 2016 (large SMD) (MCI) vs. control immediately post intervention; Outcome: **Memory**



Footnote

(1) Digit span forward
(2) Digit span forward
(3) EXAMINER working memory (computerized test)
(4) Digit span forward
(5) Composite score (n=2)
(6) Composite score (n=2)

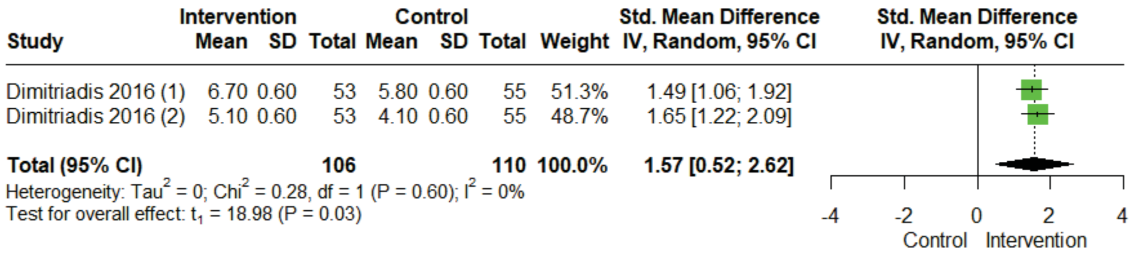
Figure 11: Meta-analysis; Computer-based cognitive interventions (MCI) vs. control immediately post intervention; Outcome: **Working memory** (see Figure 5 in Manuscript).



Footnote

(1) Digit span forward
(2) Digit span backward

Figure 12: Composite score; Working memory_Park 2020 (see Figure 11)

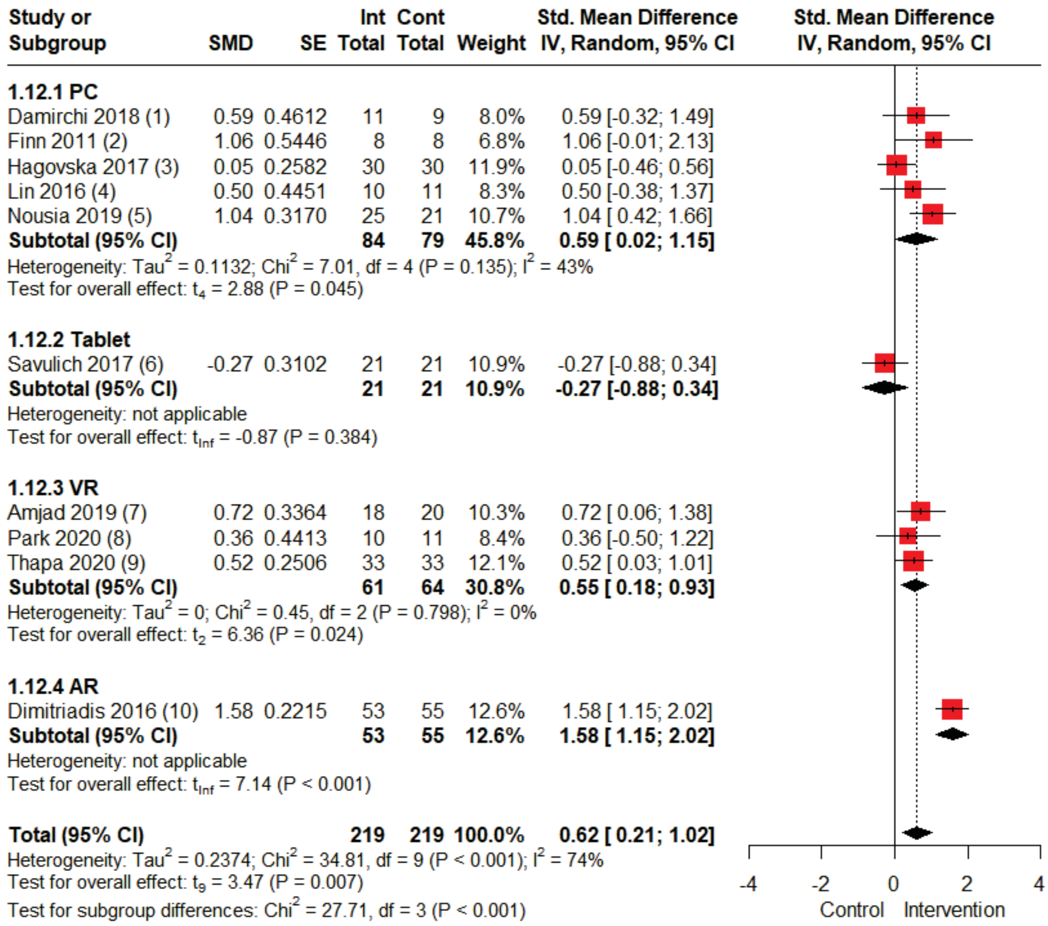


Footnote

(1) Digit span forward

(2) Digit span backward

Figure 13: Composite score; Working memory_Dimitriadis 2016 (see Figure 11)



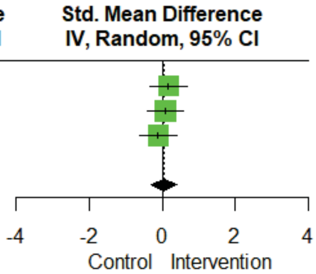
Footnote

(1) Digit symbol coding
(2) CANTAB-Rapid visual information processing (RVP)
(3) Composite score (n=3)
(4) Useful Field of View (UFOV) (computerized test)
(5) TMT A
(6) Composite score (n=2)
(7) TMT A
(8) Composite score (n=2)
(9) TMT A
(10) TMT A

Figure 14: Meta-analysis; Computer-based cognitive interventions (MCI) vs. control immediately post intervention, Outcome: **Attention/concentration/processing speed** (see Figure 5 in Manuscript)

Study	Intervention Mean	SD	Total	Control Mean	SD	Total	Weight	Std. Mean Difference IV, Random, 95% CI
Hagovska 2017 (1)	17.50	2.77	30	17.10	1.79	30	33.3%	0.17 [-0.34; 0.68]
Hagovska 2017 (2)	-63.75	23.09	30	-66.10	32.03	30	33.4%	0.08 [-0.42; 0.59]
Hagovska 2017 (3)	-67.84	20.36	30	-64.92	30.64	30	33.3%	-0.11 [-0.62; 0.40]
Total (95% CI)			**90**			**90**	**100.0%**	**0.05 [-0.31; 0.40]**

Heterogeneity: $Tau^2 = 0$; $Chi^2 = 0.62$, df = 2 (P = 0.73); $I^2 = 0\%$
Test for overall effect: $t_2 = 0.57$ (P = 0.63)



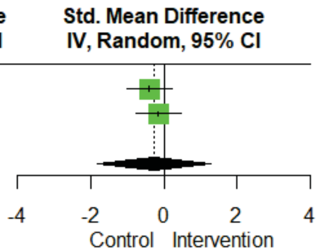
Footnote

(1) Addenbrooke's Cognitive Examination (ACE), attention/concentration
(2) Stroop Color-Word Test (SCWT), words, personal tempo, time (sec.))
(3) SCWT, colors, perception factor (sec.)

Figure 15: Composite score; Attention/concentration/processing speed_Hagovska 2017 (see Figure 14)

Study	Intervention Mean	SD	Total	Control Mean	SD	Total	Weight	Std. Mean Difference IV, Random, 95% CI
Savulich 2017 (1)	98.40	1.60	21	99.10	1.90	21	49.6%	-0.39 [-1.00; 0.22]
Savulich 2017 (2)	-541.00	187.60	21	-512.60	192.50	21	50.4%	-0.15 [-0.75; 0.46]
Total (95% CI)			**42**			**42**	**100.0%**	**-0.27 [-1.82; 1.28]**

Heterogeneity: $Tau^2 = 0$; $Chi^2 = 0.31$, df = 1 (P = 0.58); $I^2 = 0\%$
Test for overall effect: $t_1 = -2.19$ (P = 0.27)



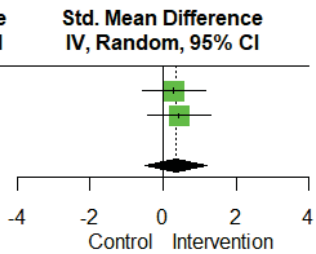
Footnote

(1) CANTAB-Choice reaction time (CRT), correct trials
(2) CANTAB-Choice reaction time (CRT), time latency

Figure 16: Composite score; Attention/concentration/processing speed_Savulich 2017 (see Figure 14)

Study	Intervention Mean	SD	Total	Control Mean	SD	Total	Weight	Std. Mean Difference IV, Random, 95% CI
Park 2020 (1)	-100.60	20.80	10	-105.82	12.34	11	50.4%	0.30 [-0.57; 1.16]
Park 2020 (2)	-58.10	35.71	10	-73.91	34.96	11	49.6%	0.43 [-0.44; 1.30]
Total (95% CI)			**20**			**22**	**100.0%**	**0.36 [-0.48; 1.21]**

Heterogeneity: $Tau^2 = 0$; $Chi^2 = 0.05$, df = 1 (P = 0.83); $I^2 = 0\%$
Test for overall effect: $t_1 = 5.46$ (P = 0.12)

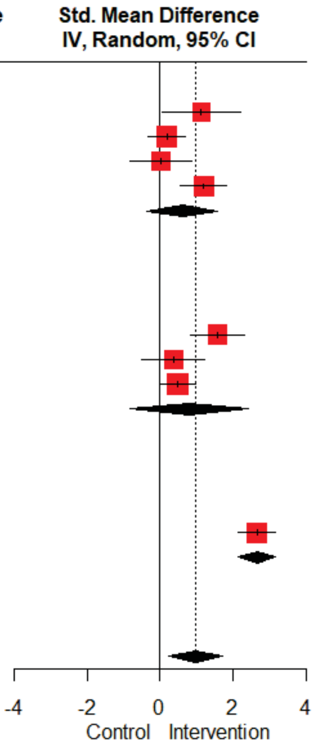


Footnote

(1) SCWT, color word interference test, naming (ie. word), score
(2) SCWT, color word interference test, reading (ie. color), score

Figure 17: Composite score; Attention/concentration/processing speed_Park 2020 (see Figure 14)

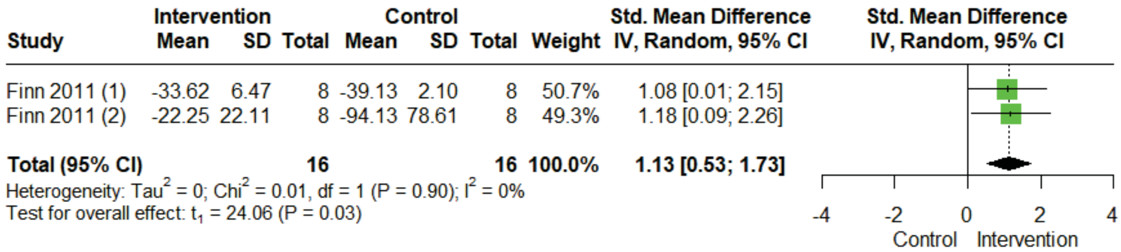
Study or Subgroup	SMD	SE	Int Total	Cont Total	Weight	Std. Mean Difference IV, Random, 95% CI
1.16.1 PC						
Finn 2011 (1)	1.13	0.5504	8	8	10.4%	1.13 [0.05; 2.21]
Hagovska 2017 (2)	0.19	0.2588	30	30	13.6%	0.19 [-0.32; 0.69]
Lin 2016 (3)	0.02	0.4369	10	11	11.7%	0.02 [-0.84; 0.88]
Nousia 2019 (4)	1.20	0.3236	25	21	13.0%	1.20 [0.57; 1.83]
Subtotal (95% CI)			**73**	**70**	**48.7%**	**0.60 [-0.37; 1.58]**
Heterogeneity: $Tau^2 = 0.2392$; $Chi^2 = 8.59$, df = 3 (P = 0.035); $I^2 = 65\%$						
Test for overall effect: $t_3 = 1.97$ (P = 0.144)						
1.16.2 VR						
Amjad 2019 (5)	1.57	0.3767	18	20	12.4%	1.57 [0.84; 2.31]
Park 2020 (6)	0.37	0.4415	10	11	11.7%	0.37 [-0.50; 1.24]
Thapa 2020 (7)	0.47	0.2498	33	33	13.7%	0.47 [-0.02; 0.96]
Subtotal (95% CI)			**61**	**64**	**37.8%**	**0.80 [-0.83; 2.43]**
Heterogeneity: $Tau^2 = 0.2983$; $Chi^2 = 6.75$, df = 2 (P = 0.034); $I^2 = 70\%$						
Test for overall effect: $t_2 = 2.10$ (P = 0.170)						
1.16.3 AR						
Dimitriadis 2016 (8)	2.65	0.2661	53	55	13.5%	2.65 [2.13; 3.17]
Subtotal (95% CI)			**53**	**55**	**13.5%**	**2.65 [2.13; 3.17]**
Heterogeneity: not applicable						
Test for overall effect: $t_{Inf} = 9.96$ (P < 0.001)						
Total (95% CI)			**187**	**189**	**100.0%**	**0.96 [0.21; 1.71]**
Heterogeneity: $Tau^2 = 0.7049$; $Chi^2 = 62.60$, df = 7 (P < 0.001); $I^2 = 89\%$						
Test for overall effect: $t_7 = 3.04$ (P = 0.019)						
Test for subgroup differences: $Chi^2 = 30.62$, df = 2 (P < 0.001)						



Footnote

(1) Composite score (n=2)
(2) Addenbrooke's Cognitive Examination (ACE), verbal fluency
(3) Composite score (n=2)
(4) Composite score (n=2)
(5) TMT B
(6) Composite score (n=4)
(7) TMT B
(8) TMT B

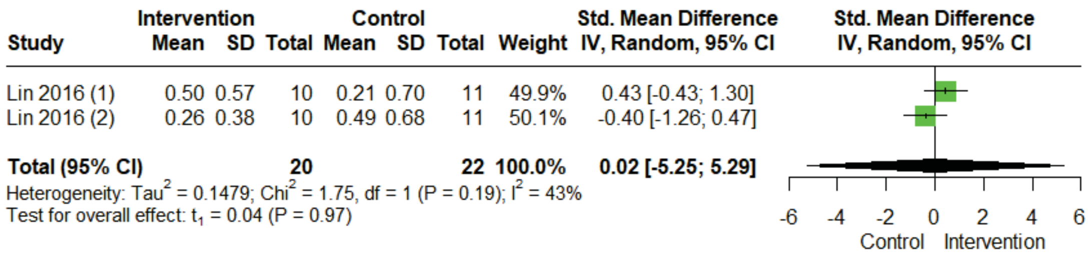
Figure 18: Meta-analysis; Computer-based cognitive interventions (MCI) vs. control immediately post intervention, Outcome: **Executive functioning** (see Figure 5 in Manuscript)



Footnote

(1) CANTAB-Spatial-working memory (SWM) strategy
(2) CANTAB- Intra-/extra-dimensional set shifting (IED), errors (adj.)

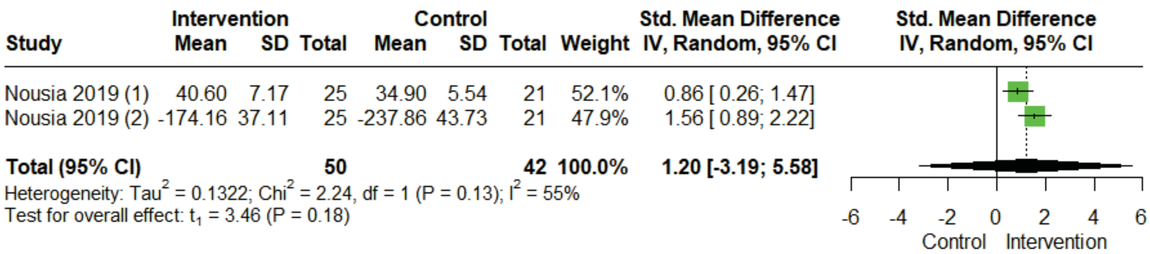
Figure 19: Composite score; Executive functioning_Finn 2011 (see Figure 18)



Footnote

(1) EXAMINER, verbal fluency
(2) EXAMINER, cognitive control (set shift and flanker task)

Figure 20: Composite score; Executive functioning_Lin 2016 (see Figure 18)



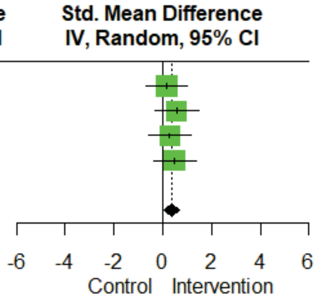
Footnote

(1) Semantic Fluency measure (SF)
(2) TMT B

Figure 21: Composite score; Executive functioning_Nousia 2019 (see Figure 18)

Study	Intervention Mean	Intervention SD	Intervention Total	Control Mean	Control SD	Control Total	Weight	Std. Mean Difference IV, Random, 95% CI
Park 2020 (1)	11.60	3.53	10	11.00	3.79	11	25.5%	0.16 [-0.70; 1.01]
Park 2020 (2)	8.00	3.27	10	6.00	3.35	11	24.4%	0.58 [-0.30; 1.46]
Park 2020 (3)	6.20	4.71	10	5.09	2.43	11	25.3%	0.29 [-0.57; 1.15]
Park 2020 (4)	7.70	4.81	10	5.82	2.48	11	24.8%	0.48 [-0.39; 1.35]
Total (95% CI)			**40**			**44**	**100.0%**	**0.37 [0.07; 0.67]**

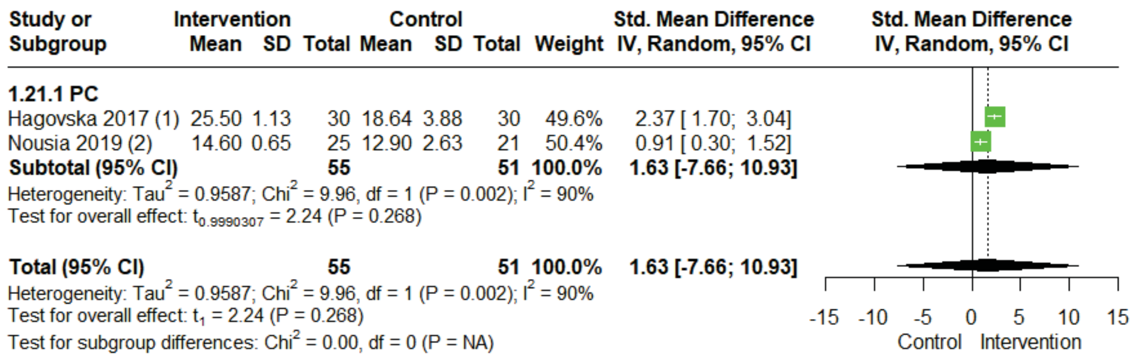
Heterogeneity: $Tau^2 = 0$; $Chi^2 = 0.55$, df = 3 (P = 0.91); $I^2 = 0\%$
Test for overall effect: $t_3 = 3.94$ (P = 0.03)



Footnote

(1) Word fluency test (animal)
(2) Word fluency test (Korean names 1)
(3) Word fluency test (Korean names 2)
(4) Word fluency test (Korean names 3)

Figure 22: Composite score; Executive functioning_Park 2020 (see Figure 18)

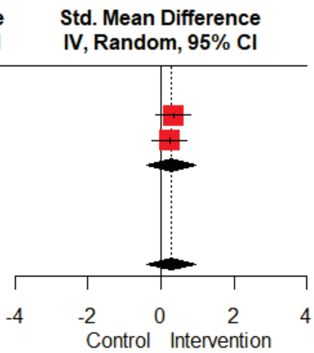


Footnote

(1) Addenbrooke's Cognitive Examination (ACE), language
(2) Boston Naming Test

Figure 23: Meta-analysis; Computer-based cognitive interventions (MCI) vs. control immediately post intervention, Outcome: **Language** (see Figure 5 in Manuscript)

Study or Subgroup	SMD	SE	Int Total	Cont Total	Weight	Std. Mean Difference IV, Random, 95% CI
4.1.1 PC						
Flak 2019 (1)	0.34	0.2444	34	34	49.8%	0.34 [-0.14; 0.82]
Hyer 2015 (2)	0.24	0.2434	34	34	50.2%	0.24 [-0.24; 0.71]
Subtotal (95% CI)			**68**	**68**	**100.0%**	**0.29 [-0.37; 0.95]**
Heterogeneity: $Tau^2 = 0$; $Chi^2 = 0.09$, df = 1 (P = 0.763); $I^2 = 0\%$						
Test for overall effect: $t_1 = 5.54$ (P = 0.114)						
Total (95% CI)			**68**	**68**	**100.0%**	**0.29 [-0.37; 0.95]**
Heterogeneity: $Tau^2 = 0$; $Chi^2 = 0.09$, df = 1 (P = 0.763); $I^2 = 0\%$						
Test for overall effect: $t_1 = 5.54$ (P = 0.114)						
Test for subgroup differences: $Chi^2 = 0.00$, df = 0 (P = NA)						

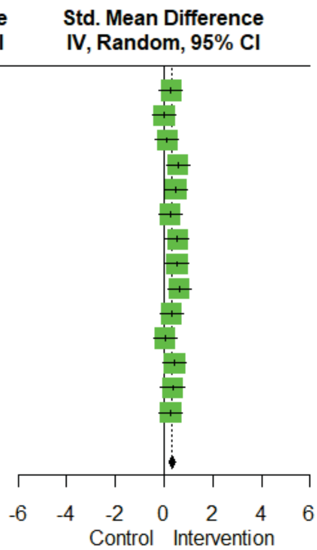


Footnote

(1) Composite score (n=14)
(2) Span Board (WMS III)

Figure 24: Meta-analysis; Computer-based cognitive interventions (MCI) vs. computer-based cognitive interventions as control immediately post intervention, Outcome: **Memory**

Study	Intervention Mean	Intervention SD	Intervention Total	Control Mean	Control SD	Control Total	Weight	Std. Mean Difference IV, Random, 95% CI
Flak 2019 (1)	15.53	8.54	34	13.19	8.01	34	7.2%	0.28 [-0.20; 0.76]
Flak 2019 (2)	34.44	7.98	34	34.47	5.84	34	7.3%	-0.00 [-0.48; 0.47]
Flak 2019 (3)	34.18	6.10	34	33.35	7.33	34	7.3%	0.12 [-0.35; 0.60]
Flak 2019 (4)	8.48	3.69	34	6.41	3.39	34	7.0%	0.58 [0.09; 1.06]
Flak 2019 (5)	37.57	12.83	34	32.00	10.18	34	7.1%	0.48 [-0.01; 0.96]
Flak 2019 (6)	13.06	5.05	34	11.73	5.38	34	7.2%	0.25 [-0.23; 0.73]
Flak 2019 (7)	7.00	3.92	34	4.97	3.61	34	7.0%	0.53 [0.05; 1.02]
Flak 2019 (8)	6.91	4.52	34	4.61	4.06	34	7.0%	0.53 [0.05; 1.01]
Flak 2019 (9)	7.56	4.60	34	4.81	4.02	34	6.9%	0.63 [0.14; 1.12]
Flak 2019 (10)	4.52	1.75	34	4.00	1.63	34	7.2%	0.30 [-0.17; 0.78]
Flak 2019 (11)	3.76	1.56	34	3.70	1.40	34	7.3%	0.04 [-0.44; 0.52]
Flak 2019 (12)	9.24	3.50	34	7.85	3.03	34	7.1%	0.42 [-0.06; 0.90]
Flak 2019 (13)	17.33	8.77	34	14.15	9.48	34	7.2%	0.34 [-0.13; 0.82]
Flak 2019 (14)	14.88	7.90	34	12.84	7.64	34	7.2%	0.26 [-0.22; 0.74]
Total (95% CI)			**476**			**476**	**100.0%**	**0.34 [0.22; 0.45]**
Heterogeneity: $Tau^2 = 0$; $Chi^2 = 8.55$, df = 13 (P = 0.81); $I^2 = 0\%$								
Test for overall effect: $t_{13} = 6.35$ (P < 0.01)								

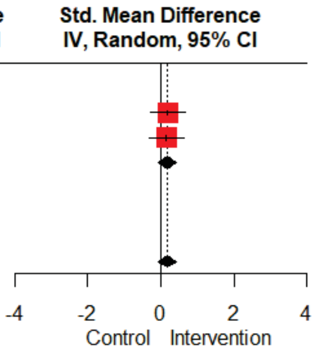


Footnote

(1) Rey-Osterreith Complex Figure, long delay recall
(2) Wechsler Memory Scale (WMS) III Faces, short delay recall
(3) Wechsler Memory Scale (WMS) III Faces, long delay recall
(4) California Verbal Learning Test (CVLT) II Short delay cued recall
(5) CVLT II, totals learned
(6) CVLT II, total hits recognition trial
(7) CVLT II, short delay free recall
(8) CVLT II, long delay free recall
(9) CVLT II, long delay cued recall
(10) CVLT II, Trial 1
(11) CVLT II, Trial B
(12) CVLT II, Trial 5
(13) WMS III, logical memory, long delay recall
(14) Rey-Osterreith Complex Figure, short delay recall

Figure 25: Composite score; Memory_Flak 2019 (see Figure 24)

Study or Subgroup	SMD	SE	Int Total	Cont Total	Weight	Std. Mean Difference IV, Random, 95% CI
4.3.1 PC						
Flak 2019 (1)	0.19	0.2431	34	34	50.0%	0.19 [-0.29; 0.67]
Hyer 2015 (2)	0.15	0.2429	34	34	50.0%	0.15 [-0.32; 0.63]
Subtotal (95% CI)			**68**	**68**	**100.0%**	**0.17 [-0.08; 0.42]**
Heterogeneity: $Tau^2 = 0$; $Chi^2 = 0.01$, df = 1 (P = 0.910); $I^2 = 0\%$						
Test for overall effect: $t_1 = 8.77$ (P = 0.072)						
Total (95% CI)			**68**	**68**	**100.0%**	**0.17 [-0.08; 0.42]**
Heterogeneity: $Tau^2 = 0$; $Chi^2 = 0.01$, df = 1 (P = 0.910); $I^2 = 0\%$						
Test for overall effect: $t_1 = 8.77$ (P = 0.072)						
Test for subgroup differences: $Chi^2 = 0.00$, df = 0 (P = NA)						

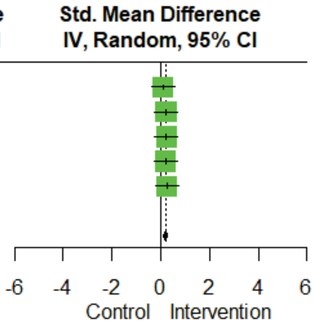


Footnote

(1) Composite score (n=5)
(2) Letter Number Sequencing (LNS)

Figure 26: Meta-analysis; Computer-based cognitive interventions (MCI) vs. computer-based cognitive interventions as control immediately post intervention, Outcome: **Working memory**

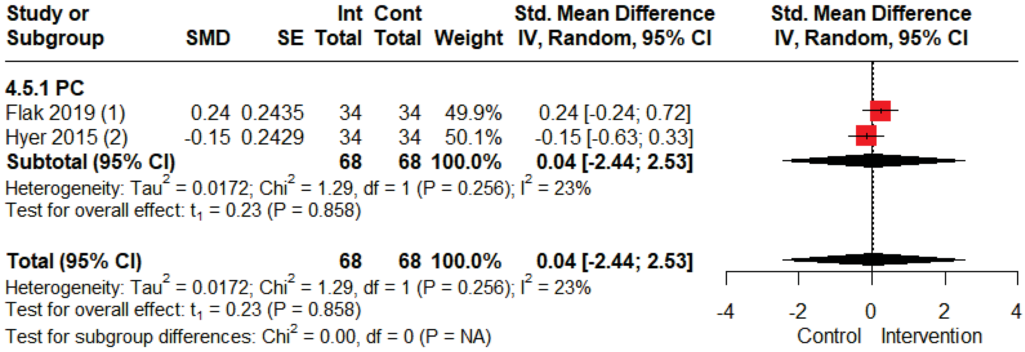
Study	Intervention Mean	Intervention SD	Intervention Total	Control Mean	Control SD	Control Total	Weight	Std. Mean Difference IV, Random, 95% CI
Flak 2019 (1)	5.50	1.05	34	5.41	1.04	34	20.1%	0.09 [-0.39; 0.56]
Flak 2019 (2)	4.24	1.25	34	4.00	0.98	34	20.0%	0.21 [-0.27; 0.69]
Flak 2019 (3)	8.38	2.69	34	7.74	2.71	34	20.0%	0.23 [-0.24; 0.71]
Flak 2019 (4)	6.82	2.24	34	6.44	1.77	34	20.0%	0.19 [-0.29; 0.66]
Flak 2019 (5)	6.85	2.21	34	6.35	1.85	34	20.0%	0.24 [-0.23; 0.72]
Total (95% CI)			**170**			**170**	**100.0%**	**0.19 [0.11; 0.27]**
Heterogeneity: $Tau^2 = 0$; $Chi^2 = 0.27$, df = 4 (P = 0.99); $I^2 = 0\%$								
Test for overall effect: $t_4 = 6.73$ (P < 0.01)								



Footnote

(1) Digit Span forward
(2) Digit Span backward
(3) WMS III, letter number sequenceing
(4) WMS III, spatial span backward
(5) WMS III, spatial span forward

Figure 27: Composite score; Working memory_Flak 2019 (see Figure 26)



Study or Subgroup	SMD	SE	Int Total	Cont Total	Weight	Std. Mean Difference IV, Random, 95% CI
4.5.1 PC						
Flak 2019 (1)	0.24	0.2435	34	34	49.9%	0.24 [-0.24; 0.72]
Hyer 2015 (2)	-0.15	0.2429	34	34	50.1%	-0.15 [-0.63; 0.33]
Subtotal (95% CI)			**68**	**68**	**100.0%**	**0.04 [-2.44; 2.53]**
Total (95% CI)			**68**	**68**	**100.0%**	**0.04 [-2.44; 2.53]**

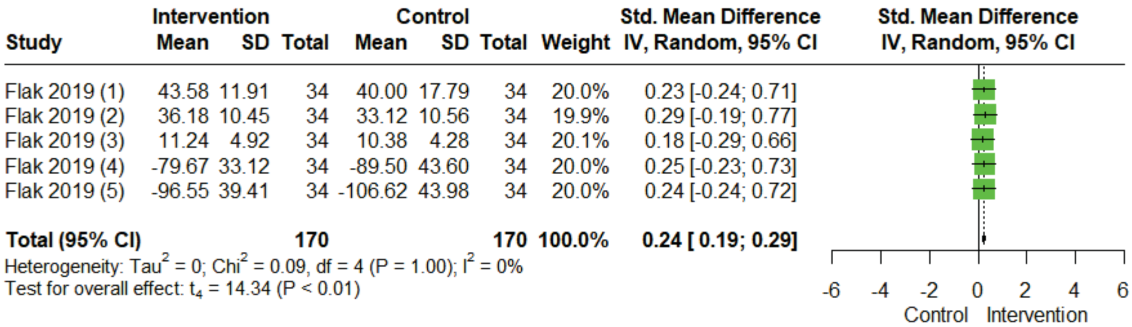
Subtotal: Heterogeneity: $Tau^2 = 0.0172$; $Chi^2 = 1.29$, df = 1 (P = 0.256); $I^2 = 23\%$
Test for overall effect: $t_1 = 0.23$ (P = 0.858)

Total: Heterogeneity: $Tau^2 = 0.0172$; $Chi^2 = 1.29$, df = 1 (P = 0.256); $I^2 = 23\%$
Test for overall effect: $t_1 = 0.23$ (P = 0.858)
Test for subgroup differences: $Chi^2 = 0.00$, df = 0 (P = NA)

Footnote

(1) Composite score (n=5)
(2) TMT B

Figure 28: Meta-analysis; Computer-based cognitive interventions (MCI) vs. computer-based cognitive interventions as control immediately post intervention, Outcome: **Executive functioning**



Study	Intervention Mean	SD	Total	Control Mean	SD	Total	Weight	Std. Mean Difference IV, Random, 95% CI
Flak 2019 (1)	43.58	11.91	34	40.00	17.79	34	20.0%	0.23 [-0.24; 0.71]
Flak 2019 (2)	36.18	10.45	34	33.12	10.56	34	19.9%	0.29 [-0.19; 0.77]
Flak 2019 (3)	11.24	4.92	34	10.38	4.28	34	20.1%	0.18 [-0.29; 0.66]
Flak 2019 (4)	-79.67	33.12	34	-89.50	43.60	34	20.0%	0.25 [-0.23; 0.73]
Flak 2019 (5)	-96.55	39.41	34	-106.62	43.98	34	20.0%	0.24 [-0.24; 0.72]
Total (95% CI)			**170**			**170**	**100.0%**	**0.24 [0.19; 0.29]**

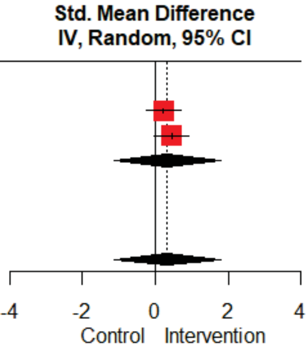
Heterogeneity: $Tau^2 = 0$; $Chi^2 = 0.09$, df = 4 (P = 1.00); $I^2 = 0\%$
Test for overall effect: $t_4 = 14.34$ (P < 0.01)

Footnote

(1) Verbal Fluency Test Letter fluency
(2) Verbal Fluency Test Category fluency
(3) Verbal Fluency Test Category Switching
(4) Delis Kaplan, Color Word Interference Test, inhibition (interference)
(5) Delis Kaplan, Color Word Interference Test, inhibition switching

Figure 29: Composite score; Executive functioning_Flak 2019 (see Figure 28)

Study or Subgroup	SMD	SE	Int Total	Cont Total	Weight	Std. Mean Difference IV, Random, 95% CI
5.1.1 PC						
Flak 2019 (1)	0.22	0.2433	34	34	50.5%	0.22 [-0.26; 0.70]
Hyer 2015 (2)	0.45	0.2458	34	34	49.5%	0.45 [-0.03; 0.93]
Subtotal (95% CI)			**68**	**68**	**100.0%**	**0.33 [-1.13; 1.80]**
Heterogeneity: $Tau^2 = 0$; $Chi^2 = 0.44$, df = 1 (P = 0.506); $I^2 = 0\%$						
Test for overall effect: $t_1 = 2.90$ (P = 0.211)						
Total (95% CI)			**68**	**68**	**100.0%**	**0.33 [-1.13; 1.80]**
Heterogeneity: $Tau^2 = 0$; $Chi^2 = 0.44$, df = 1 (P = 0.506); $I^2 = 0\%$						
Test for overall effect: $t_1 = 2.90$ (P = 0.211)						
Test for subgroup differences: $Chi^2 = 0.00$, df = 0 (P = NA)						

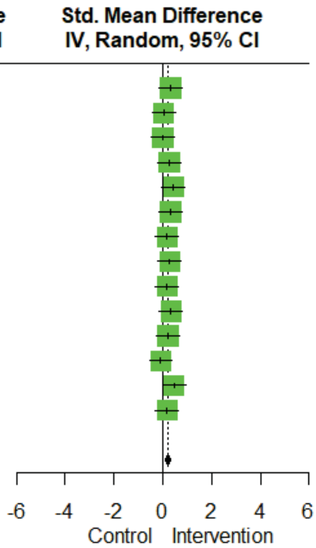


Footnote

(1) Composite score (n=14)
(2) Wechsler Memory Scale (WMS) III, span board

Figure 30: Meta-analysis; Computer-based cognitive interventions (MCI) vs. computer-based cognitive interventions follow-up, Outcome: **Memory**

Study	Intervention Mean	Intervention SD	Intervention Total	Control Mean	Control SD	Control Total	Weight	Std. Mean Difference IV, Random, 95% CI
Flak 2019 (1)	7.14	4.00	34	5.81	4.36	34	7.1%	0.31 [-0.16; 0.79]
Flak 2019 (2)	4.75	1.62	34	4.68	2.13	34	7.2%	0.04 [-0.44; 0.51]
Flak 2019 (3)	3.97	1.56	34	3.97	1.47	34	7.2%	0.00 [-0.48; 0.48]
Flak 2019 (4)	9.09	3.49	34	8.26	2.84	34	7.1%	0.26 [-0.22; 0.74]
Flak 2019 (5)	19.29	10.86	34	14.50	10.98	34	7.0%	0.43 [-0.05; 0.91]
Flak 2019 (6)	17.12	8.45	34	14.15	9.69	34	7.1%	0.32 [-0.16; 0.80]
Flak 2019 (7)	16.00	8.91	34	14.29	9.55	34	7.2%	0.18 [-0.29; 0.66]
Flak 2019 (8)	35.05	7.10	34	32.82	8.36	34	7.1%	0.28 [-0.19; 0.76]
Flak 2019 (9)	35.88	6.64	34	34.44	8.82	34	7.2%	0.18 [-0.29; 0.66]
Flak 2019 (10)	8.19	3.31	34	7.03	3.56	34	7.1%	0.33 [-0.15; 0.81]
Flak 2019 (11)	36.84	14.08	34	34.13	12.37	34	7.2%	0.20 [-0.27; 0.68]
Flak 2019 (12)	12.69	4.21	34	13.03	4.10	34	7.2%	-0.08 [-0.56; 0.39]
Flak 2019 (13)	6.91	3.88	34	5.10	3.86	34	7.0%	0.46 [-0.02; 0.94]
Flak 2019 (14)	6.34	4.72	34	5.52	4.38	34	7.2%	0.18 [-0.30; 0.65]
Total (95% CI)			**476**			**476**	**100.0%**	**0.22 [0.13; 0.31]**
Heterogeneity: $Tau^2 = 0$; $Chi^2 = 5.38$, df = 13 (P = 0.97); $I^2 = 0\%$								
Test for overall effect: $t_{13} = 5.28$ (P < 0.01)								

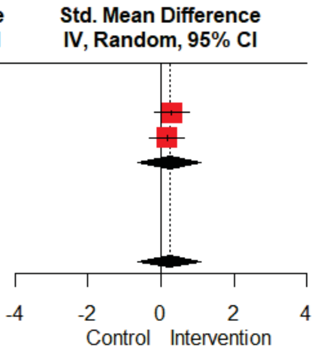


Footnote

(1) California Verbal Learning Test (CVLT) II, long delay cued recall
(2) CVLT II, Trial 1
(3) CVLT II, Trial B
(4) CVLT II, Trial 5
(5) Wechsler Memory Scale (WMS) III, logical memory, long delay recall
(6) Rey-Osterreith Complex Figure, short delay recall
(7) Rey-Osterreith Complex Figure, long delay recall
(8) WMS III, faces, long delay recall
(9) WMS III, faces, short delay recall
(10) CVLT II, short delay cued recall
(11) CVLT II, totals learned
(12) CVLT II, total hits recognition trial
(13) CVLT II, short delay free recall
(14) CVLT II, long delay free recall

Figure 31: Composite score; Memory_Flak 2019 (see Figure 30)

Study or Subgroup	SMD	SE	Int Total	Cont Total	Weight	Std. Mean Difference IV, Random, 95% CI
5.3.1 PC						
Flak 2019 (1)	0.30	0.2440	34	34	49.8%	0.30 [-0.18; 0.78]
Hyer 2015 (2)	0.16	0.2430	34	34	50.2%	0.16 [-0.31; 0.64]
Subtotal (95% CI)			**68**	**68**	**100.0%**	**0.23 [-0.63; 1.10]**
Heterogeneity: $Tau^2 = 0$; $Chi^2 = 0.16$, df = 1 (P = 0.693); $I^2 = 0\%$						
Test for overall effect: $t_1 = 3.41$ (P = 0.182)						
Total (95% CI)			**68**	**68**	**100.0%**	**0.23 [-0.63; 1.10]**
Heterogeneity: $Tau^2 = 0$; $Chi^2 = 0.16$, df = 1 (P = 0.693); $I^2 = 0\%$						
Test for overall effect: $t_1 = 3.41$ (P = 0.182)						
Test for subgroup differences: $Chi^2 = 0.00$, df = 0 (P = NA)						



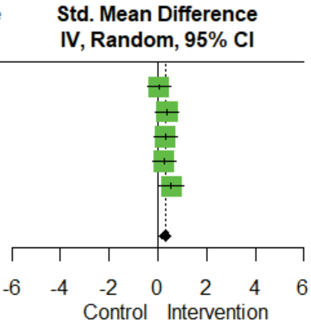
Footnote

(1) Composite score (n=5)

(2) Letter Number Sequencing (LNS)

Figure 32: Meta-analysis; Computer-based cognitive interventions (MCI) vs. computer-based cognitive interventions follow-up, Outcome: **Working memory**

Study	Intervention Mean	Intervention SD	Intervention Total	Control Mean	Control SD	Control Total	Weight	Std. Mean Difference IV, Random, 95% CI
Flak 2019 (1)	5.35	1.07	34	5.32	1.09	34	20.3%	0.03 [-0.45; 0.50]
Flak 2019 (2)	4.24	1.23	34	3.79	1.20	34	20.0%	0.37 [-0.11; 0.85]
Flak 2019 (3)	8.18	2.88	34	7.26	3.32	34	20.1%	0.29 [-0.19; 0.77]
Flak 2019 (4)	6.29	1.81	34	5.82	1.89	34	20.1%	0.25 [-0.23; 0.73]
Flak 2019 (5)	7.38	1.90	34	6.38	1.68	34	19.5%	0.55 [0.07; 1.04]
Total (95% CI)			**170**			**170**	**100.0%**	**0.30 [0.06; 0.53]**
Heterogeneity: $Tau^2 = 0$; $Chi^2 = 2.41$, df = 4 (P = 0.66); $I^2 = 0\%$								
Test for overall effect: $t_4 = 3.49$ (P = 0.03)								



Footnote

(1) Digit Span forward

(2) Digit Span backward

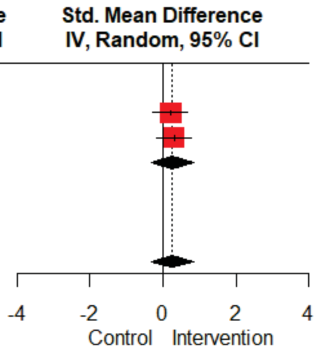
(3) Wechsler Memory Scale (WMS) III, Letter-number sequencing

(4) WMS III, Spatial Span Backward

(5) Spatial span forward

Figure 33: Composite score; Working memory_Flak 2019 (see Figure 32)

Study or Subgroup	SMD	SE	Int Total	Cont Total	Weight	Std. Mean Difference IV, Random, 95% CI
Flak 2019 (1)	0.21	0.2432	34	34	50.2%	0.21 [-0.27; 0.69]
Hyer 2015 (2)	0.30	0.2440	34	34	49.8%	0.30 [-0.18; 0.78]
Subtotal (95% CI)			**68**	**68**	**100.0%**	**0.26 [-0.33; 0.84]**
Heterogeneity: $Tau^2 = 0$; $Chi^2 = 0.07$, df = 1 (P = 0.789); $I^2 = 0\%$						
Test for overall effect: $t_1 = 5.56$ (P = 0.113)						
Total (95% CI)			**68**	**68**	**100.0%**	**0.26 [-0.33; 0.84]**
Heterogeneity: $Tau^2 = 0$; $Chi^2 = 0.07$, df = 1 (P = 0.789); $I^2 = 0\%$						
Test for overall effect: $t_1 = 5.56$ (P = 0.113)						
Test for subgroup differences: $Chi^2 = 0.00$, df = 0 (P = NA)						

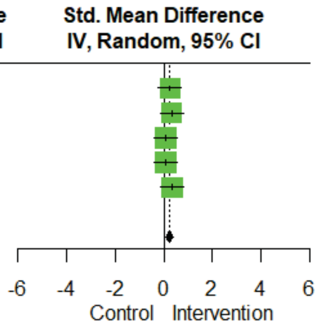


Footnote

(1) Composite score (n=5)
(2) TMT B

Figure 34: Meta-analysis; Computer-based cognitive interventions (MCI) vs. computer-based cognitive interventions follow-up, Outcome: **Executive functioning**

Study	Intervention Mean	SD	Total	Control Mean	SD	Total	Weight	Std. Mean Difference IV, Random, 95% CI
Flak 2019 (1)	42.61	11.39	34	39.06	16.59	34	20.0%	0.25 [-0.23; 0.72]
Flak 2019 (2)	36.21	12.04	34	32.50	10.55	34	19.9%	0.32 [-0.15; 0.80]
Flak 2019 (3)	11.13	4.30	34	10.74	4.64	34	20.1%	0.09 [-0.39; 0.56]
Flak 2019 (4)	-80.09	31.38	34	-82.85	40.47	34	20.1%	0.08 [-0.40; 0.55]
Flak 2019 (5)	-93.48	38.22	34	-107.74	43.41	34	19.8%	0.34 [-0.13; 0.82]
Total (95% CI)			**170**			**170**	**100.0%**	**0.21 [0.06; 0.37]**
Heterogeneity: $Tau^2 = 0$; $Chi^2 = 1.11$, df = 4 (P = 0.89); $I^2 = 0\%$								
Test for overall effect: $t_4 = 3.74$ (P = 0.02)								

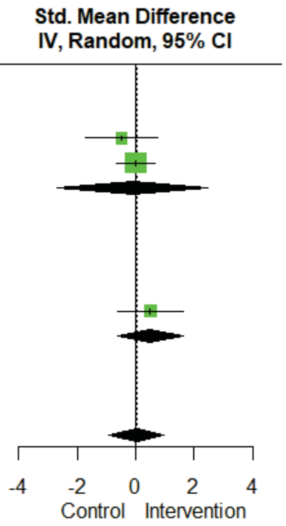


Footnote

(1) Verbal fluency test, letter fluency
(2) Delis Kaplan, Verbal fluency test, category fluency
(3) Delis Kaplan, Verbal fluency test, category switching
(4) Delis Kaplan, Color Word Interference Test, inhibition (interference)
(5) Delis Kaplan, Color Word Interference Test, inhibition switching

Figure 35: Composite score; Executive functioning_Flak 2019 (see Figure 34)

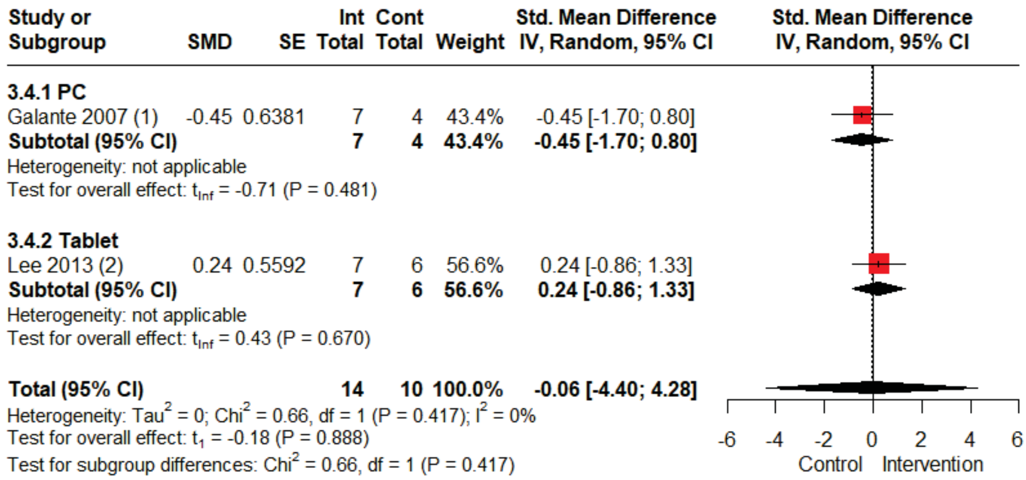
Study or Subgroup	Intervention Mean	Intervention SD	Intervention Total	Control Mean	Control SD	Control Total	Weight	Std. Mean Difference IV, Random, 95% CI
2.1.1 PC								
Cinar 2020 (1)	23.23	3.68	30	16.17	3.94	30	0.0%	1.83 [1.22; 2.44]
Galante 2007 (2)	23.00	3.90	7	24.90	2.80	4	17.1%	-0.49 [-1.74; 0.77]
Heiss 1994 (3)	19.33	6.82	18	19.29	5.89	17	61.2%	0.01 [-0.66; 0.67]
Subtotal (95% CI)			**55**			**51**	**78.3%**	**-0.10 [-2.69; 2.48]**
Heterogeneity: $Tau^2 = 0$; $Chi^2 = 0.46$, df = 1 (P = 0.496); $I^2 = 0\%$								
Test for overall effect: $t_1 = -0.50$ (P = 0.706)								
2.1.2 Tablet								
Lee 2013 (4)	19.67	5.20	7	17.29	3.15	6	21.7%	0.50 [-0.61; 1.62]
Subtotal (95% CI)			**7**			**6**	**21.7%**	**0.50 [-0.61; 1.62]**
Heterogeneity: not applicable								
Test for overall effect: $t_{Inf} = 0.89$ (P = 0.375)								
Total (95% CI)			**62**			**57**	**100.0%**	**0.03 [-0.91; 0.97]**
Heterogeneity: $Tau^2 = 0$; $Chi^2 = 1.35$, df = 2 (P = 0.509); $I^2 = 0\%$								
Test for overall effect: $t_2 = 0.14$ (P = 0.904)								
Test for subgroup differences: $Chi^2 = 1.01$, df = 1 (P = 0.316)								



Footnote

(1) Montreal Cognitive Assessment (MoCA)
(2) Mini Mental State Examination (MMSE)
(3) MMSE; intervention group 1 (IG1) vs. control group
(4) MMSE

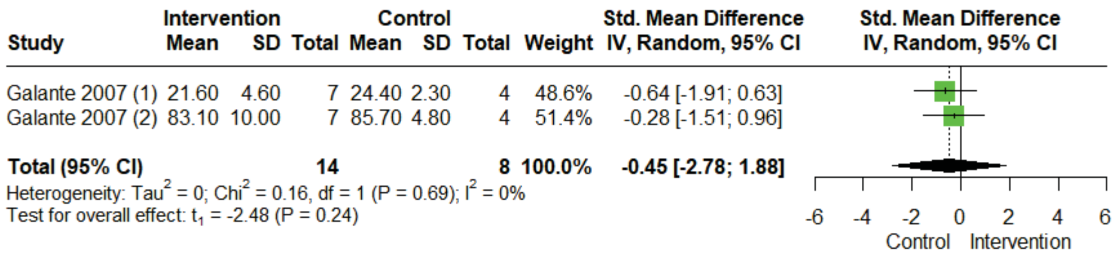
Figure 36: Sensitivity meta-analysis; Computer-based cognitive interventions without Cinar 2020 (large SMD) (DEMENTIA) vs. control immediately post intervention, Outcome: **Global cognition**



Footnote

(1) Composite score (n=2)
(2) Mini Mental State Examination (MMSE)

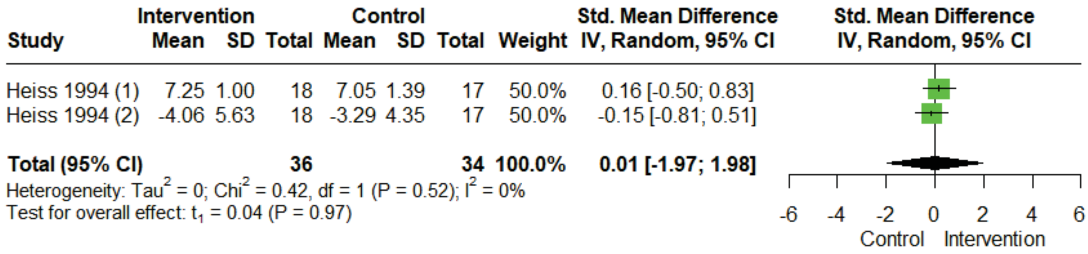
Figure 37: Meta-analysis; Computer-based cognitive interventions (DEMENTIA) vs. control follow-up (3 months), Outcome: **Global cognition**



Footnote

(1) Mini Mental State Examination (MMSE)
(2) Milan Overall Dementia Assessment (MODA)

Figure 38: Composite score; Global cognition_Galante 2007 (see Figure 37)

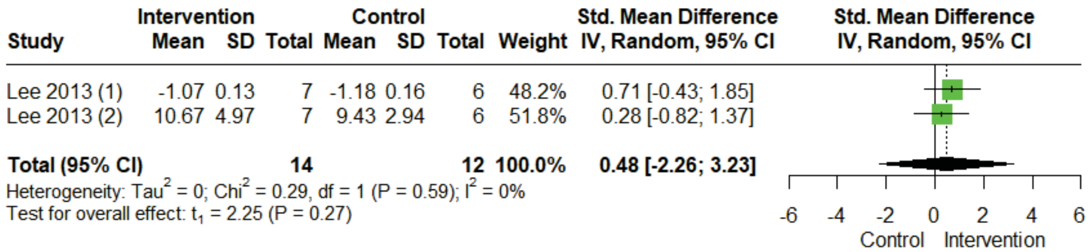


Footnote

(1) Selective reminding test/task - Recognition (hits)

(2) Selective reminding test/task - Recognition (false-positive)

Figure 39: Composite score; Memory_Heiss 1994 (see Figure 7 in Manuscript)

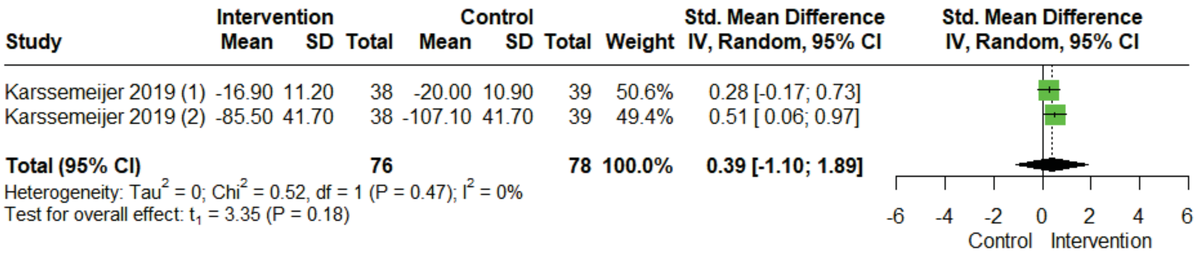


Footnote

(1) Brief Assessment of Prospective Memory-Short Form (BAPM)

(2) Hong Kong List Learning Test (HKLLT)

Figure 40: Composite score; Memory_Lee 2013 (see Figure 7 in Manuscript)



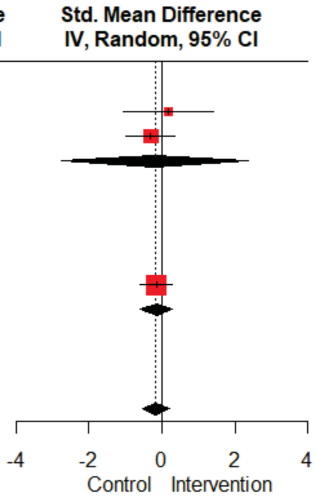
Footnote

(1) Location learning test (revised) – displacement score delayed recall

(2) Location learning test (revised) – displacement score trial 1-5

Figure 41: Composite score; Memory_Karssemeijer 2019 (see Figure 7 in Manuscript)

Study or Subgroup	SMD	SE	Int Total	Cont Total	Weight	Std. Mean Difference IV, Random, 95% CI
2.6.1 PC						
Galante 2007 (1)	0.18	0.6286	7	4	8.3%	0.18 [-1.05; 1.41]
Heiss 1994 (2)	-0.30	0.3404	18	17	28.4%	-0.30 [-0.97; 0.36]
Subtotal (95% CI)			**25**	**21**	**36.8%**	**-0.19 [-2.77; 2.38]**
Heterogeneity: $Tau^2 = 0$; $Chi^2 = 0.46$, df = 1 (P = 0.499); $I^2 = 0\%$						
Test for overall effect: $t_1 = -0.95$ (P = 0.515)						
2.6.2 VR						
Karssemeijer 2019 (3)	-0.15	0.2283	38	39	63.2%	-0.15 [-0.60; 0.30]
Subtotal (95% CI)			**38**	**39**	**63.2%**	**-0.15 [-0.60; 0.30]**
Heterogeneity: not applicable						
Test for overall effect: $t_{Inf} = -0.66$ (P = 0.511)						
Total (95% CI)			**63**	**60**	**100.0%**	**-0.17 [-0.54; 0.21]**
Heterogeneity: $Tau^2 = 0$; $Chi^2 = 0.47$, df = 2 (P = 0.790); $I^2 = 0\%$						
Test for overall effect: $t_2 = -1.88$ (P = 0.201)						
Test for subgroup differences: $Chi^2 = 0.02$, df = 1 (P = 0.888)						

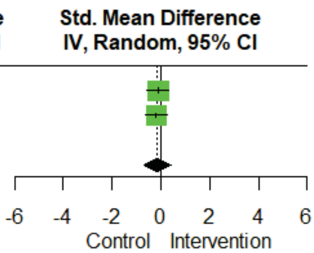


Footnote

(1) Corsi's block tapping test
(2) Corsi's block tapping test
(3) Composite score (n=2)

Figure 42: Meta-analysis; Computer-based cognitive interventions (DEMENTIA) vs. control immediately post intervention, Outcome: **Working memory** (see Figure 8 in Manuscript)

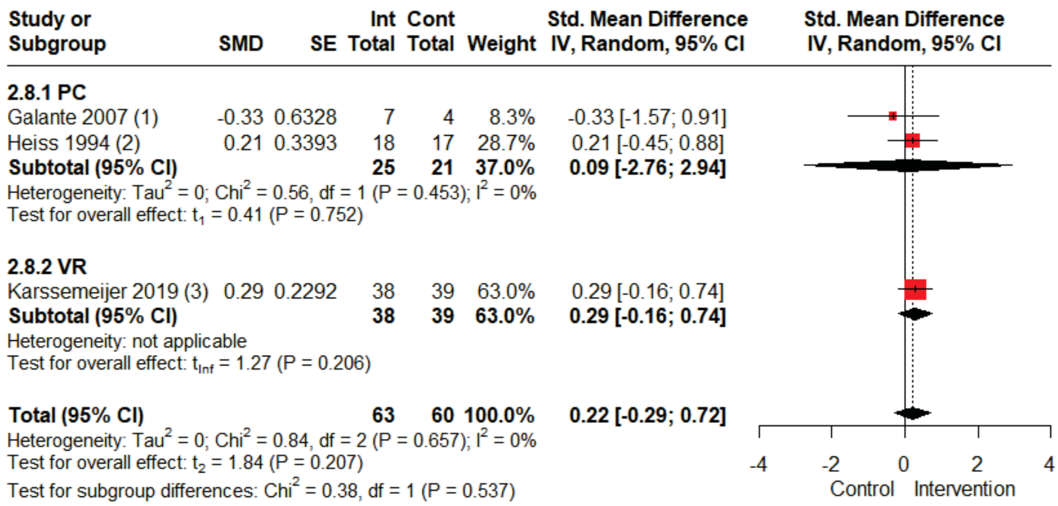
Study	Intervention Mean	Intervention SD	Intervention Total	Control Mean	Control SD	Control Total	Weight	Std. Mean Difference IV, Random, 95% CI
Karssemeijer 2019 (1)	8.30	3.60	38	8.70	3.60	39	50.1%	-0.11 [-0.56; 0.34]
Karssemeijer 2019 (2)	10.10	2.90	38	10.80	4.00	39	49.9%	-0.20 [-0.65; 0.25]
Total (95% CI)			**76**			**78**	**100.0%**	**-0.15 [-0.71; 0.40]**
Heterogeneity: $Tau^2 = 0$; $Chi^2 = 0.07$, df = 1 (P = 0.79); $I^2 = 0\%$								
Test for overall effect: $t_1 = -3.50$ (P = 0.18)								



Footnote

(1) Spatial Span
(2) Digit span (WAIS-III)

Figure 43: Composite score; Working memory_Karssemeijer 2019 (see Figure 42)



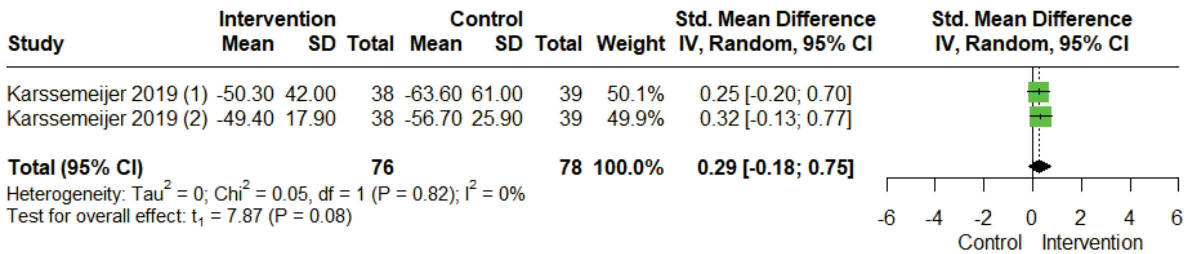
Footnote

(1) Digit cancellation test

(2) Alters-Konzentrationstest (AKT) (t)

(3) Composite score (n=2)

Figure 44: Meta-analysis; Computer-based cognitive interventions (DEMENTIA) vs. control immediately post intervention, Outcome: **Attention/concentration/processing speed** (see Figure 8 in Manuscript)



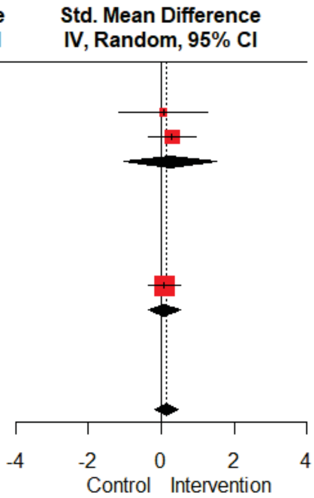
Footnote

(1) TMT A

(2) Stroop Color-Word Test (SCWT) – word reading (sec)

Figure 45: Composite score; Attention/concentration/processing speed_Karssemeijer 2019 (see Figure 44)

Study or Subgroup	SMD	SE	Int Total	Cont Total	Weight	Std. Mean Difference IV, Random, 95% CI
2.10.1 PC						
Galante 2007 (1)	0.06	0.6270	7	4	8.4%	0.06 [-1.17; 1.29]
Heiss 1994 (2)	0.30	0.3403	18	17	28.4%	0.30 [-0.37; 0.97]
Subtotal (95% CI)			**25**	**21**	**36.8%**	**0.25 [-1.03; 1.52]**
Heterogeneity: $Tau^2 = 0$; $Chi^2 = 0.11$, df = 1 (P = 0.737); $I^2 = 0\%$						
Test for overall effect: $t_1 = 2.44$ (P = 0.248)						
2.10.2 VR						
Karssemeijer 2019 (3)	0.08	0.2280	38	39	63.2%	0.08 [-0.37; 0.53]
Subtotal (95% CI)			**38**	**39**	**63.2%**	**0.08 [-0.37; 0.53]**
Heterogeneity: not applicable						
Test for overall effect: $t_{Inf} = 0.35$ (P = 0.726)						
Total (95% CI)			**63**	**60**	**100.0%**	**0.14 [-0.16; 0.45]**
Heterogeneity: $Tau^2 = 0$; $Chi^2 = 0.31$, df = 2 (P = 0.858); $I^2 = 0\%$						
Test for overall effect: $t_2 = 1.98$ (P = 0.186)						
Test for subgroup differences: $Chi^2 = 0.44$, df = 1 (P = 0.507)						

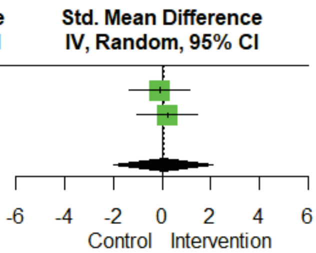


Footnote

(1) Composite score (n=2)
(2) Composite score (n=2)
(3) Composite score (n=3)

Figure 46: Meta-analysis; Computer-based cognitive interventions (DEMENTIA) vs. control immediately post intervention, Outcome: **Executive functioning** (see Figure 8 in Manuscript)

Study	Intervention Mean	Intervention SD	Intervention Total	Control Mean	Control SD	Control Total	Weight	Std. Mean Difference IV, Random, 95% CI
Galante 2007 (1)	11.90	4.70	7	12.40	5.10	4	50.2%	-0.09 [-1.32; 1.13]
Galante 2007 (2)	33.10	9.20	7	30.80	9.70	4	49.8%	0.22 [-1.01; 1.46]
Total (95% CI)			**14**			**8**	**100.0%**	**0.06 [-1.96; 2.09]**
Heterogeneity: $Tau^2 = 0$; $Chi^2 = 0.13$, df = 1 (P = 0.72); $I^2 = 0\%$								
Test for overall effect: $t_1 = 0.40$ (P = 0.76)								



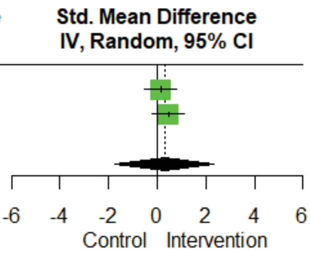
Footnote

(1) Semantic verbal fluency
(2) Phonemic verbal fluency

Figure 47: Composite score; Executive functioning_Galante 2007 (see Figure 46)

Study	Intervention Mean	SD	Total	Control Mean	SD	Total	Weight	Std. Mean Difference IV, Random, 95% CI
Heiss 1994 (1)	-0.67	0.12	18	-0.69	0.16	17	50.7%	0.14 [-0.52; 0.80]
Heiss 1994 (2)	12.43	5.84	18	9.81	5.21	17	49.3%	0.46 [-0.21; 1.13]
Total (95% CI)			**36**			**34**	**100.0%**	**0.30 [-1.75; 2.35]**

Heterogeneity: $Tau^2 = 0$; $Chi^2 = 0.45$, df = 1 (P = 0.50); $I^2 = 0\%$
Test for overall effect: $t_1 = 1.85$ (P = 0.32)



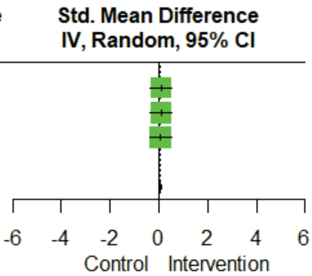
Footnote

(1) Go/no go reaction time
(2) Verbal fluency (Supermarket)

Figure 48: Composite score; Executive functioning_Heiss 1994 (see Figure 46)

Study	Intervention Mean	SD	Total	Control Mean	SD	Total	Weight	Std. Mean Difference IV, Random, 95% CI
Karssemeijer 2019 (1)	-8.30	6.40	38	-8.80	6.20	39	33.3%	0.08 [-0.37; 0.53]
Karssemeijer 2019 (2)	-160.70	106.20	38	-170.10	106.80	39	33.3%	0.09 [-0.36; 0.53]
Karssemeijer 2019 (3)	20.90	10.60	38	20.20	12.00	39	33.3%	0.06 [-0.39; 0.51]
Total (95% CI)			**114**			**117**	**100.0%**	**0.08 [0.04; 0.11]**

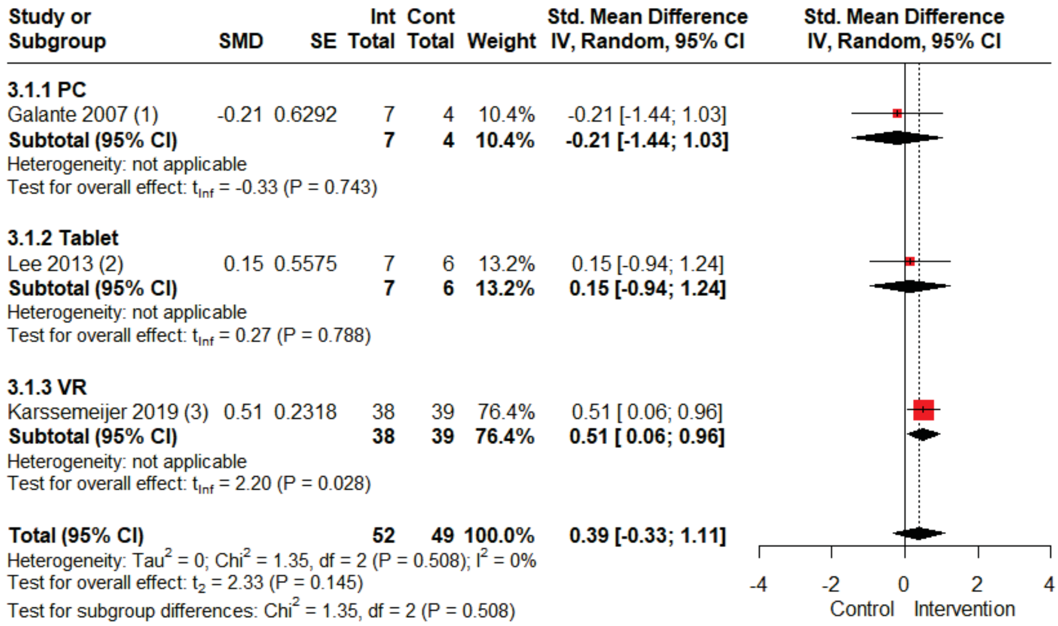
Heterogeneity: $Tau^2 = 0$; $Chi^2 = 0.01$, df = 2 (P = 1.00); $I^2 = 0\%$
Test for overall effect: $t_2 = 9.83$ (P = 0.01)



Footnote

(1) Rule Shift Cards Test, errors
(2) TMT B
(3) Verbal fluency test, letter fluency

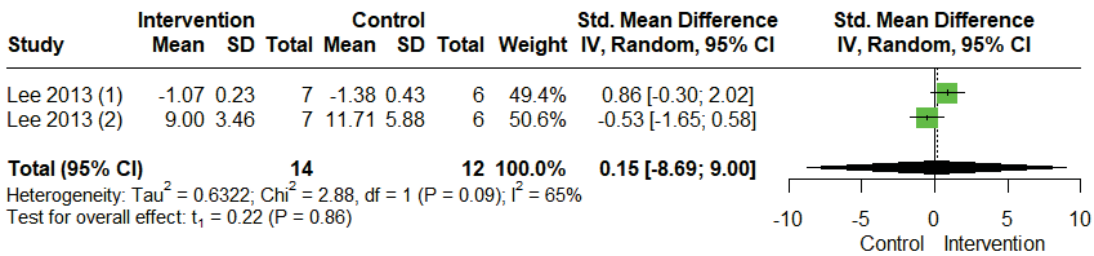
Figure 49: Composite score; Executive functioning_Karssemeijer 2019 (see Figure 46)



Footnote

(1) Prose memory
(2) Composite score (n=2)
(3) Composite score (n=2)

Figure 50: Meta-analysis; Computer-based cognitive interventions (DEMENTIA) vs. control follow-up (3 months), Outcome: **Memory**



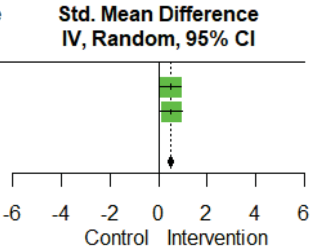
Footnote

(1) Brief Assessment of Prospective Memory-Short Form (BAPM)
(2) Hong Kong List Learning Test (HKLLT)

Figure 51: Composite score; Memory_Lee 2013 (see Figure 50)

Study	Intervention Mean	SD	Total	Control Mean	SD	Total	Weight	Std. Mean Difference IV, Random, 95% CI
Karssemeijer 2019 (1)	-18.50	8.10	38	-23.30	10.80	39	50.1%	0.50 [0.04; 0.95]
Karssemeijer 2019 (2)	-96.10	34.10	38	-118.80	51.20	39	49.9%	0.52 [0.06; 0.97]
Total (95% CI)			**76**			**78**	**100.0%**	**0.51 [0.39; 0.62]**

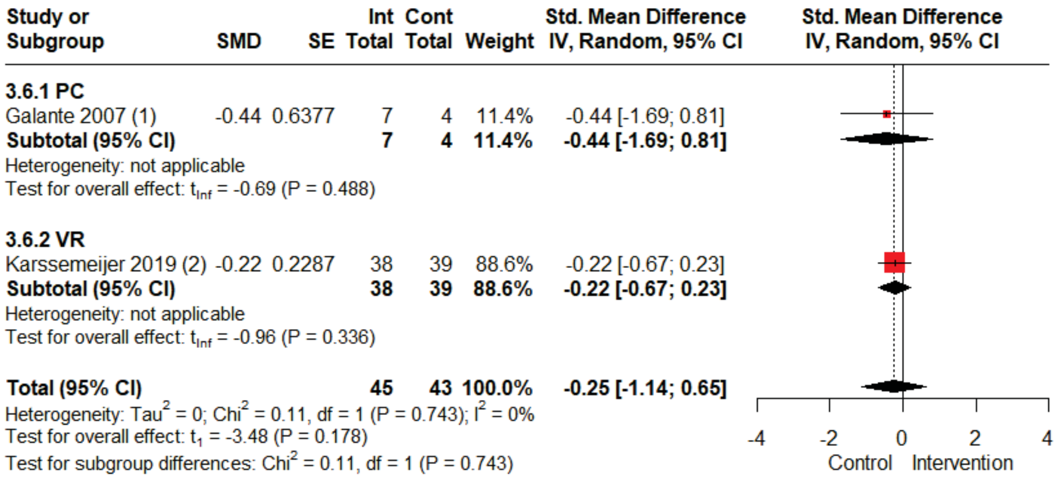
Heterogeneity: $Tau^2 = 0$; $Chi^2 = 0.00$, df = 1 (P = 0.96); $I^2 = 0\%$
Test for overall effect: $t_1 = 54.89$ (P = 0.01)



Footnote

(1) Location learning test (revised) – displacement score delayed recall
(2) Location learning test (revised) – displacement score trial 1-5

Figure 52: Composite score; Memory_Karssemeijer 2019 (see Figure 50)

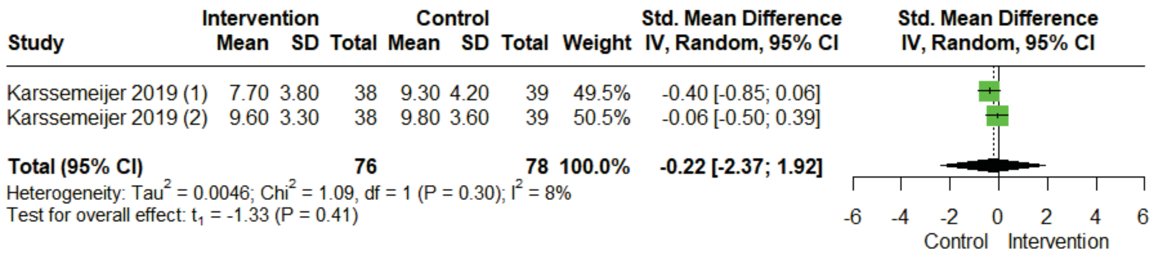


Footnote

(1) Corsi tapping test

(2) Composite score (n=2)

Figure 53: Meta-analysis; Computer-based cognitive interventions (DEMENTIA) vs. control follow-up (3 months), Outcome: **Working memory**

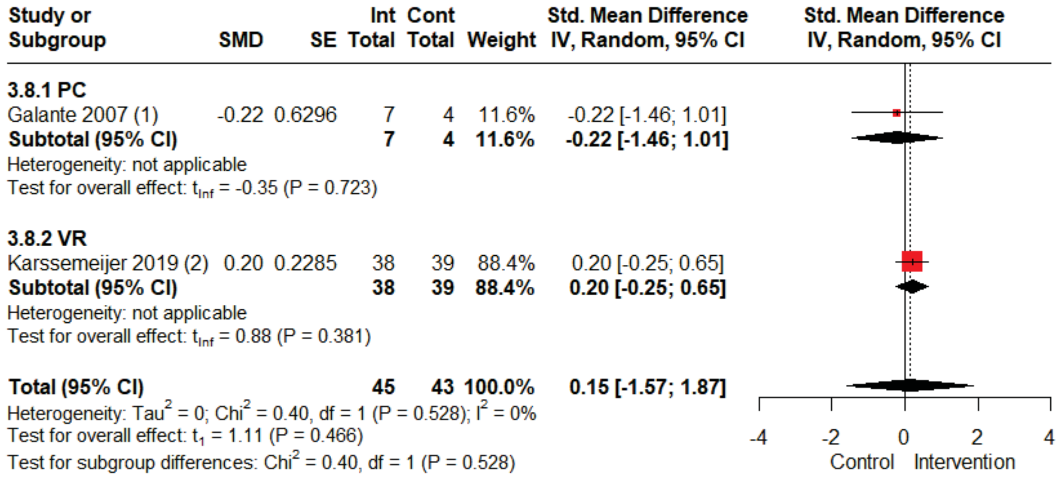


Footnote

(1) Spatial Span

(2) Digit span (WAIS-III)

Figure 54: Composite score; Working memory_Karssemeijer 2019 (see Figure 53)

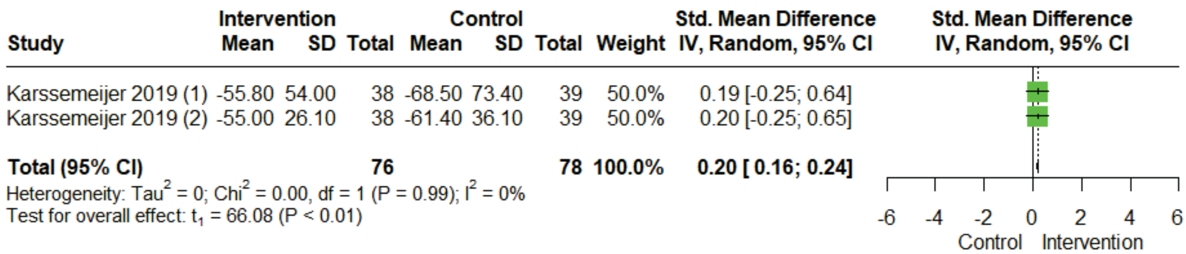


Footnote

(1) Digit cancellation test

(2) Composite score (n=2)

Figure 55: Meta-analysis; Computer-based cognitive interventions (DEMENTIA) vs. control follow-up (3 months), Outcome: **Attention/concentration/processing speed**

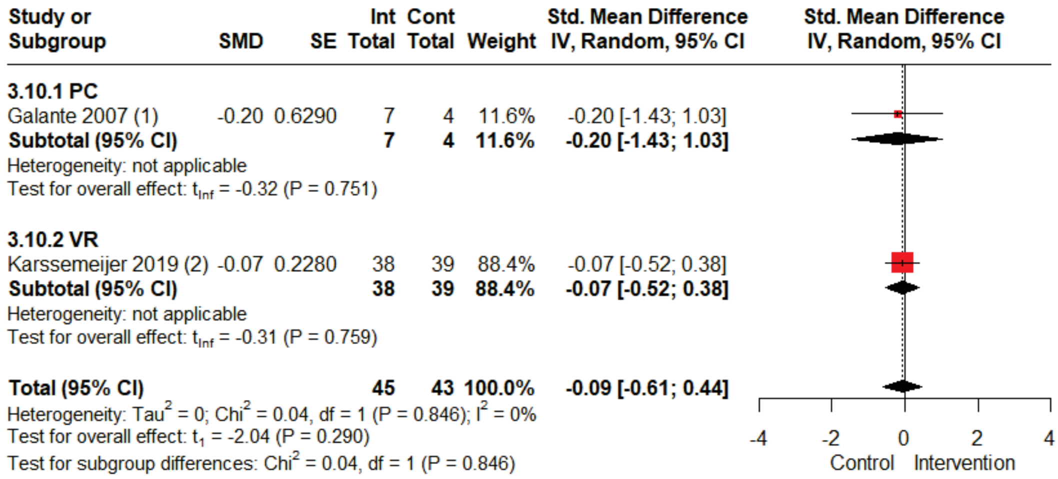


Footnote

(1) TMT A

(2) Stroop Color-Word Test (SCWT) – word reading (sec)

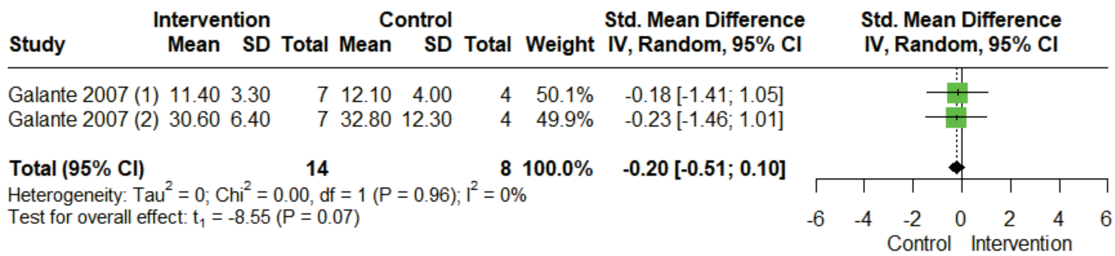
Figure 56: Composite score; Attention/concentration/processing speed_Karssemeijer 2019 (see Figure 55)



Footnote

(1) Composite score (n= 2)
(2) Composite score (n= 2)

Figure 57: Meta-analysis; Computer-based cognitive interventions (DEMENTIA) vs. control follow-up (3 months), Outcome: **Executive functioning**



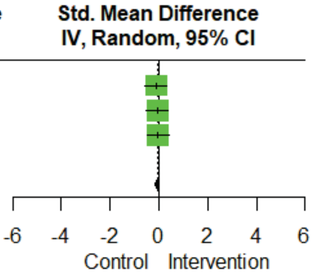
Footnote

(1) Semantic verbal fluency
(2) Phonemic verbal fluency

Figure 58: Composite score; Executive functioning_Galante 2007 (see Figure 57)

Study	Intervention Mean	Intervention SD	Intervention Total	Control Mean	Control SD	Control Total	Weight	Std. Mean Difference IV, Random, 95% CI
Karssemeijer 2019 (1)	-178.10	105.40	38	-166.10	105.10	39	33.3%	-0.11 [-0.56; 0.33]
Karssemeijer 2019 (2)	20.90	11.20	38	21.70	15.10	39	33.3%	-0.06 [-0.51; 0.39]
Karssemeijer 2019 (3)	-9.20	5.50	38	-8.90	6.70	39	33.4%	-0.05 [-0.50; 0.40]
Total (95% CI)			**114**			**117**	**100.0%**	**-0.07 [-0.16; 0.01]**

Heterogeneity: $Tau^2 = 0$; $Chi^2 = 0.05$, df = 2 (P = 0.98); $I^2 = 0\%$
Test for overall effect: $t_2 = -3.70$ (P = 0.07)



Footnote
(1) TMT B
(2) Verbal fluency test, letter fluency
(3) Rule Shift Cards Test, errors

Figure 59: Composite score; Executive functioning_Karssemeijer 2019 (see Figure 57)

Psychosocial effects of a humanoid robot on informal caregivers of people with dementia: A randomised controlled trial with nested interviews

Julia Zuschnegg, Alfred Häussl, Gerald Lodron, Thomas Orgel, Silvia Russegger, Michael Schneeberger, Maria Fellner, Magdalena Holter, Dimitrios Prodromou, Anna Schultz, Regina Roller-Wirnsberger, Lucas Paletta, Marisa Koini, Sandra Schüssler

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Psychosocial effects of a humanoid robot on informal caregivers of people with dementia: A randomised controlled trial with nested interviews

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ABSTRACT

Background: Dementia rates are rising globally, impacting healthcare systems and society. The care of people with dementia is largely provided by informal caregivers (e.g., family, friends), which can present significant challenges and increase caregivers' burden. New technologies, such as humanoid socially assistive robots, show promise in reducing this burden, as such robots were considered to be supportive devices for both informal caregivers and people with dementia.
Objective: To explore the psychosocial effects of the humanoid social assistive robot Coach Pepper (equipped with functions like tablet-based multimodal training for people with dementia) compared to exclusively tablet-based multimodal training for people with dementia on informal caregivers. Additionally, informal caregivers' attitudes and experiences with Coach Pepper were examined.
Design: A randomised controlled parallel two-arm trial with a nested qualitative study was conducted.
Setting: The study took place in the home setting (i.e. private households).
Participants: Thirty-two informal caregivers of people with dementia participated in the study.
Methods: Informal caregivers (and their loved one with dementia) were randomly assigned to Coach Pepper (n = 16) or a solely tablet-based multimodal training (n = 16) for a three-week period. Data for caregivers were collected at baseline and after the intervention by standardised questionnaires for caregiver burden (primary outcome), quality of life, depressive symptoms and affect. Additionally, acceptance was measured in both groups and semi-structured interviews were conducted in the Coach Pepper group post-interventionally.
Results: No significant differences in mean changes between groups were identified in the outcomes, except that two domains of acceptance (usefulness and accessibility) were rated significantly higher for the control group. Qualitative findings showed mostly positive attitudes towards Coach Pepper in dementia care and neutral feelings on caregiver burden. Caregivers reported usefulness of Coach Pepper on being assistive in six components of human needs: 'learning ability', 'recreational activities', 'contact with others', 'mobility/body posture', 'communication' and 'avoiding danger'. However, they recommended further improvement in all fourteen components of human needs.

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Conclusions: Coach Pepper had no significant psychosocial effects on informal caregivers of people with dementia. Qualitative findings demonstrated the participants' positive attitudes but highlighted a need for improvements regarding Coach Pepper's usability.

Registration: NCT03818217 (date of registration: 09.01.2019; date of first recruitment: 04.02.2019).

What is already known

- Dementia rates are increasing, and the care is predominantly provided by informal caregivers, often leading to significant caregiver burden.
- Qualitative and mixed-method literature already underscores informal caregivers' expectations and needs for potential support options involving humanoid socially assistive robots in home dementia care.
- To the best of our knowledge, there is currently no evidence that has investigated the effectiveness of a humanoid social assistive robot in home dementia care on informal caregiver burden and further psychosocial effects.

What this paper adds

- It demonstrates that humanoid social assistive robots had no statistically significant negative or positive psychosocial effects on informal caregivers of people with dementia living at home.
- It shows that most informal caregivers had positive perceptions of humanoid social assistive robots in dementia care.
- It presents the status quo of the usefulness of humanoid social assistive robots in dementia care in the home setting regarding components of physical and psychosocial human needs, as well as the (specific) needs for further research.

1. Background

The increasing global prevalence of dementia impacts clinical, public health and social care systems, as most people with dementia are living at home supported by informal caregivers (Alzheimer's Association, 2023; Boccardi, 2017; WHO, 2012). Informal caregivers (hereafter called ‘caregivers’) of people with dementia include family members, friends or other significant individuals who provide unpaid regular care and/or supervision (WHO, 2012). They are key in providing dementia care and the sustainability of systems, but face major challenges that consequently lead to caregiver burden (Alzheimer's Association, 2023). New technologies, such as socially assistive robots, seem to be a promising option to support caregivers in dementia care, creating an opportunity to reduce caregiver burden (Koutentakis et al., 2020; Sohn et al., 2023; Zuschnegg et al., 2021).

1.1. Caregiver burden in dementia

Dementia care presents a major challenge, as the decrease in cognitive abilities and change in peoples' behaviour reflect higher levels of care dependency regarding physical and psychosocial human needs (e.g., hygiene, social contact) compared with those without dementia (Alzheimer's Association, 2023; Schüssler and Lohrmann, 2015). Dementia caregivers often experience a transgression of bounds of what is usual in relationships in the family and among friends (Schulz and Martire, 2004). A significant expenditure of time, energy and money over time, as well as the necessity of unpleasant and uncomfortable tasks, which may be psychologically stressful and physically exhausting, characterise the task profile of dementia caregivers (Schulz and Martire, 2004). This impact of caregiving is conceptualised as ‘caregiver burden’ and can be defined as the level of multifaceted strain perceived by caregivers from caring for a loved one over time (Liu et al., 2020).

The concept of caregiver burden is often distinguished into objective and subjective burden, where objective caregiver burden describes the informal care situation (e.g., amount of time spent on caregiving) and the subjective burden indicates how caregivers perceive their caregiving role in terms of emotional and physical health, social life, and financial status (Cao and Yang, 2020; Zarit et al., 1986). Subjective burden is therefore often used as outcome in studies with caregivers, because it provides important information about how they are coping with their caregiving situation, which is not necessarily related to their objective burden (Hoefman, 2013). In particular, dementia caregivers show a higher risk of subjective burden, compared with non-dementia caregivers, leading to negative consequences for their mental and physical health (e.g., depression, hypertension, decreased quality of life) (Alzheimer's Association, 2023; Karg et al., 2018; WHO, 2017). Furthermore, subjective caregiver burden can subsequently impact the people with dementia's quality of life as well as their care provision, culminating in institutionalisation and leaving their preferred familiar environment (Boccardi, 2017; Liu et al., 2020). To tackle this challenge the aim is to find solutions, one of which could be socially assistive robots (Koutentakis et al., 2020; Sohn et al., 2023; Zuschnegg et al., 2021).

1.2. Socially assistive robots and their potential impact in dementia care

Socially assistive robots are a hybrid of assistive robots (aiding human users) and socially interactive robots (communicating with human users through social and non-physical interactions) for the purpose of providing assistance to human users through social interaction (Feil-Seifer and Mataric, 2005). Their designs can vary from mechanoids with a machine-like appearance; humanoids with an unrealistic human-like appearance; androids with a realistic human-like appearance; to robot animals, which look like animals (Pino et al., 2015; Walters et al., 2009).

Research interest in socially assistive robots (hereafter called ‘robots’) has increased since 2015, but the availability is still limited (Sohn et al., 2023; Van Aerschot and Parviainen, 2020). According to a review by Bedaf et al. (2015), six out of 107 commercially available robots were identified focusing on older people, whereas Buhtz et al. (2018) found only three (an animal robot, a box-like robot with a display and a telepresence robot) out of 13 for older people living at home. The best-known, commercially available robot is the animal robot ‘Paro’, resembling a baby harp seal, which has already been well investigated, especially in institutionalised people with (mainly moderate to severe) dementia (Yu et al., 2022). Its effectiveness, however, is inconclusive, as a recent systematic review (Yu et al., 2022) found no evidence that Paro improves the lives of people with dementia (e.g., cognition, agitation, depression), in contrast to previous findings by Leng et al. (2019), whose meta-analyses showed significant improvements on agitation and depression.

Humanoid robots are still mostly in the (early) development phase, with a predominantly mechanoid design, whereas the first industrially produced humanoid robot called ‘Pepper’ was launched in 2014 (Buhtz et al., 2018; Pandey and Gelin, 2018). In contrast to animal robots, the design of humanoid robots indicate a completely different kind of support for people with dementia and their caregivers, as the interaction with animal and humanoid robots happens on different levels (emotional vs. verbal communication level), and the robots' appearance influences its assistive capabilities (Campa, 2016).

A recent systematic review (Yu et al., 2022) identified two randomised controlled trials that investigated the use of a humanoid robot for people with dementia. One trial (Valentí-Soler et al., 2015) showed significant results in reducing apathy and cognition in the intervention group, while the other (Chen et al., 2020) showed no significant effects. Caregivers were not considered in both studies and in contrast to our project, the studies were conducted in long-term care facilities using different kind of robots (i.e. Valentí-Soler et al. (2015): NAO, 58 cm tall; Chen et al. (2020): Kabochan, 28 cm tall; see Fig. 1 for 'Coach Pepper'). Furthermore, a recent scoping review (Sohn et al., 2023) demonstrated that no studies investigating the effectiveness of robots in dementia caregivers are currently available. However, the literature (Pino et al., 2015; Wang et al., 2017; Zuschnegg et al., 2021) provides evidence that dementia caregivers already have expectations and needs in respect of humanoid robots regarding support for several physical and psychosocial human needs, where results demonstrate that such robots were considered to be supportive devices for themselves and people with dementia with the potential to reduce caregiver burden. Considering the fact that informal caregivers constitute an essential part of dementia care and can therefore experience subjective burden, there is an urgent need to investigate the impact of such promising humanoid robots on informal caregivers of people with dementia living at home.

1.3. Aims

The primary aim of this study was to examine the effect of the humanoid social assistive robot 'Coach Pepper' (equipped with functions like tablet-based multimodal training for people with dementia) on caregivers' subjective burden in dementia care compared with exclusively tablet-based multimodal training for people with dementia.

The secondary aims were to investigate the effects of Coach Pepper on caregivers' quality of life, depressive symptoms, affect and acceptance versus the tablet-based multimodal training.

Furthermore, interviews with caregivers were conducted to gain a deeper understanding of their attitudes and experiences regarding the usability of Coach Pepper at home.

2. Methods

2.1. Design

We conducted a randomised controlled parallel two-arm trial (RCT) with a nested qualitative descriptive study involving semi-structured interviews. The design was chosen to investigate the use of Coach Pepper in a quantitative way and gain a deeper insight into caregivers' attitudes and experiences. As a part of the larger AMIGO project, where both caregivers and their people with dementia participated, this study concentrates solely on the outcomes related to the caregivers.

The study protocol was registered on ClinicalTrials.gov (NCT03818217; date of registration: 09.01.2019; date of first recruitment: 04.02.2019) and published by Schüssler et al. (2020). The CONSORT-Statement and Checklist (Schulz et al., 2010) for quantitative and the COREQ-Checklist (Tong et al., 2007) for qualitative research guided the reporting process.

2.2. Sample and participants

The study was performed in private households in the Austrian province Styria. Pairs, i.e., persons with mild or moderate dementia (≥10 points, DEGAM (2008)), with a stable medical therapy along with their caregivers, were recruited through convenience sampling via a non-profit organisation providing dementia services (see Schüssler et al. (2020)).

All types of dementia were included except for individuals with frontotemporal dementia, due to the known potential for negative symptoms in social behaviours (e.g., impulsivity, aggression), which pose a risk to themselves or the robot (National Institute on Aging, 2024; Schüssler et al., 2020).

The recruitment was primarily focused on people with dementia and secondly on their caregivers. Flyers were placed at service points of the non-profit organisation, at social events, in medical practices and on social media platforms. Participants were contacted in person or by telephone and were offered a home visit to inform them about the study. If there was interest, the non-profit organisation checked, among others, the diagnosis and stage of dementia during this or a separate visit using the medical records. However, the current cognitive status of all people with dementia was assessed by a clinical health psychologist using the Mini-Mental State Examination (Folstein et al., 1975) within four weeks before the start of the intervention. If no diagnosis had been established, individuals were encouraged to consult a physician, or utilise the clinical health psychologist of the non-profit organisation for a clinical psychology dementia diagnostic.

Only participants who were willing to be randomly assigned to the intervention or control group as well as to participate in both parts (i.e., quantitative and qualitative) of the study were considered. Caregivers had to be ≥18 years old and speak and understand German. Further inclusion criteria were:

- Caregivers had to be significant persons (e.g., relatives, friends) of the participating person with dementia who perform supervision.
- In the case of moderate dementia, caregivers had to live in the same household as the person with dementia.
- If the person with dementia needed care, the nursing care provision could have been provided professionally and/or informally (e.g., by relatives).
- In case the person with dementia had received paid 24-h care (regardless of whether they have mild or moderate dementia), a caregiver still had to be recruited as a participant, had to live in the same house or household and had to be in daily contact with the person with dementia.

2.3. Sample size determination

The justification of the sample size was based on the assessment of people with dementia's primary aim in the AMIGO trial (see also Schüssler et al. (2020)). It revealed a calculation of 40 people with dementia (20 for each group), which, due to the recruitment of pairs, resulted in a sample size of 40 caregivers for the present study.

2.4. Randomisation and blinding

Participants were allocated in a 1:1 ratio either to receive Coach Pepper or a tablet, using a randomisation software (https://www.randomizer.at/) by authorised researchers only. Clinical healthcare psychologists who obtained quantitative data before and after the intervention were blinded about group assignments.

2.5. Intervention

In total, the study lasted 10 months from May 2019 to March 2020 (as per the study protocol), excluding the month December, in which the study was paused for the winter holidays.

The intervention group received 'Coach Pepper', a humanoid robot based on 'Pepper' developed by Softbank Robotics (2024). Pepper was the first commercially available humanoid socially assistive robot (launched in 2014) and has already been studied in observational studies within the context of institutional dementia care (Yu et al., 2022). In these studies, Pepper was enhanced with Softbank Robotics' applications for teleoperated mobility and communication (Martín Rico et al., 2020; Nakamura et al., 2021) and was also used for the teleoperated control of games played by people with dementia (Martín Rico et al., 2020).

In our study, Pepper was adapted into 'Coach Pepper' through the integration of the newly developed AMIGO system (Fig. 1). This adaptation also includes an external tablet-based multimodal training app

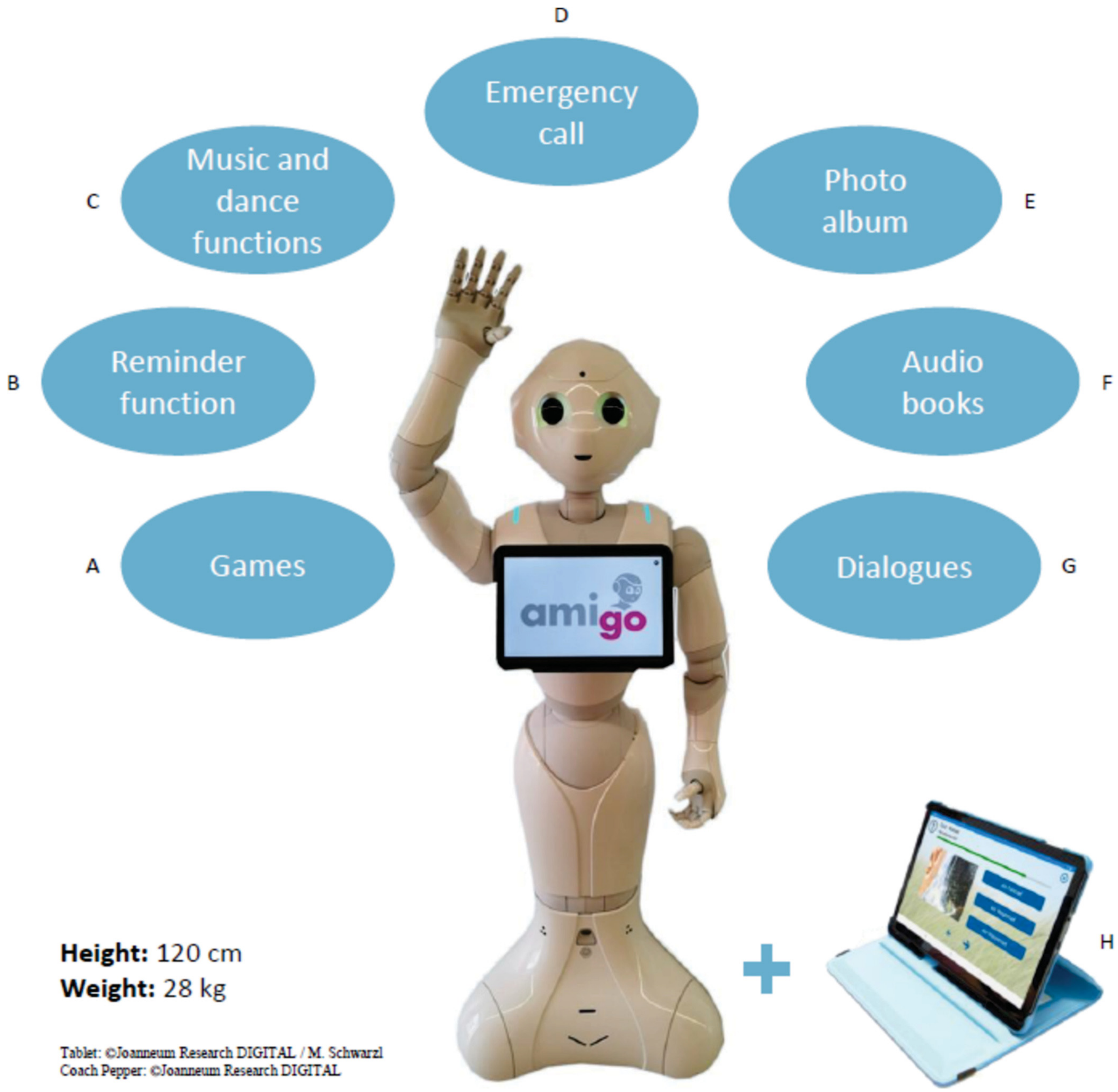

Fig. 1. Functions of Coach Pepper. The humanoid robot Pepper from Softbank Robotics with its augmentation representing the AMIGO system and the tablet-based multimodal training by the research team.
A existing function provided by Softbank Robotics.
B new function added by the research team that was attributed with individualised content for each person with dementia and caregiver in the study.
C existing functions by Softbank Robotics expanded by the research team to include content for people with dementia and their caregivers.
D new function added by the research team for the communication with trusted support in case of emergency.
E new function added by the research team, which was also individualised (i.e. pictures and narration text) for each person with dementia and caregiver in the study.
F new function added by the research team to include content for people with dementia and their caregivers.
G existing function by Softbank Robotics, expanded by DP and his team and further adapted by the research team to include specific dialogues and movements (e.g., gestures) that are appropriate for people with dementia - especially for the tablet-based training (H) - and their caregivers; additionally dialogues were individualised for each person with dementia and caregiver in the study (excluding the tablet-based training).
H new function added by the research team, tablet-based multimodal training contains physical and cognitive exercises with two levels of difficulty; the results of the interaction with each exercise were communicated to the robot via a wireless interface in real-time; the robot in turn provided a motivating feedback to the person with dementia in terms of an applauding or encouraging statement in the language of the users; this content was developed with input from people with dementia, caregivers, nurses, and dementia trainers, it was programmed to provide a randomised response from a predetermined list.

featuring cognitive and physical exercises for people with dementia. The AMIGO system emerged from research and developments within the AMIGO project, where the robot platform Pepper from Softbank Robotics was firstly augmented by DP and his team with basic software functionalities for content management enabling behaviour programming, graphical and touch-sensitive user interfaces (Paletta et al., 2019). In a further step, these program prototypes were specifically adapted for dementia care in the home setting. This adaptation involved qualitative findings and knowledge from people with dementia, caregivers, as well as nurses and dementia trainers (Zuschnegg et al., 2021).

Fig. 1 provides an overview on the functional capabilities of the AMIGO system including the functions that were based on Softbank Robotics and DP and his team, as well as the expansions and additions applied by the further research team.

To provide support tailored to the needs of people with dementia and their caregivers, the robots' functions (i.e., reminder functions, dialogues, and a photo album) were individualised. For this purpose, both were interviewed in person during a home visit, with most of the input for the reminder function, dialogues, and photos (including narration text for Coach Pepper) was provided by the caregiver.

In total, two robots were employed, with each household receiving a robot for a three-week period. The robot actively encouraged people with dementia to engage with the tablet-based multimodal training app and guided them through it (e.g. with gestures, speech). Throughout the intervention period, a dementia trainer visited the person with dementia once a week for one hour to conduct a collaborative supervised multimodal training session with Coach Pepper. In these sessions, the dementia trainers also ensured that the cognitive and physical exercises were appropriately performed and further helped both the person with dementia and the caregiver if any questions concerning the training or the robot (and its functions) arose.

Generally, caregivers and people with dementia could use Coach Pepper independently and were motivated by the robot to use its functionalities by themselves. After three weeks, the robots were picked up and customised for the next pair within one week. Subsequently, the robots were transported to the new participants and placed at a fixed location (e.g. living room).

The control group received only the tablet-based multimodal training app, without the robot. Otherwise, the procedure was the same as in the intervention group. For a more detailed description of the interventions, please see Schüssler et al. (2020).

Before the study commenced, the non-profit organisation staff received training from experienced research team members on their specific responsibilities regarding data collection and the utilisation of Coach Pepper. Caregivers and people with dementia were trained in the use of Coach Pepper or tablet by the staff upon delivery. Furthermore, the organisation offered a hotline for participants.

2.6. Data collection

2.6.1. Quantitative measurements

Caregivers underwent measurements conducted by a clinical health psychologist one week prior to and after the intervention. The Technology Usage Inventory (TUI) (Kothgassner et al., 2012) was solely obtained post-intervention, allowing participants to gain experience with the interventions beforehand.

2.6.1.1. Measurement for primary outcome. The Zarit Burden Interview (ZBI) (Braun et al., 2010; Zarit et al., 1980) was used to capture the subjective care burden of the caregivers. The instrument includes 22 items (five-point Likert scale) with a sum score ranging between 0 and 88 points. Higher scores indicate greater caregiver burden. The German ZBI was found to demonstrate very high internal consistency ($\alpha = 0.91$) (Braun et al., 2010).

2.6.1.2. Measurements for secondary outcomes. The short version of the World Health Organisation Quality of Life Questionnaire (WHOQoL-BREF) (Conrad et al., 2016) was used to measure quality of life in caregivers. It contains 26 items, four domains (physical and psychological quality of life, social relationship, environment) and a facet for global quality of life. For every item, 1–5 points can be obtained and higher domain scores indicate a higher quality of life. Domain scores from 0 to 100 are calculated to compare the individual domains. The four domains of the German version showed satisfactory to very good internal consistency ($\alpha = 0.74$–0.91). In addition, a total score of all items was calculated.

Furthermore, depressive symptoms were assessed by the Center for Epidemiological Studies Depression Scale (CESD-scale) (Hautzinger et al., 2012; Radloff, 1977). The scale includes 20 items (four-point Likert scale) with a total of 0–60 points. Higher scores indicate a higher level of depressive symptoms. Internal consistency of the German CESD-scale for informal caregivers revealed a Cronbach's alpha of 0.87 (Hautzinger et al., 2012).

Moreover, the Positive and Negative Affect Schedule (PANAS) (Breyer and Bluemke, 2016) was used to measure affect. The instrument is based upon an evaluation of 20 adjectives, ten positive and ten negative. The mean values of the adjectives are calculated for each dimension. Higher scores indicate higher positive or rather negative affect. The reliability of the German PANAS was assessed with a Cronbach's alpha of 0.86 for both dimensions.

Further, the TUI (Kothgassner et al., 2012) assessed participants' acceptance of new technologies and consists of eight domains including 30 items (four items: curiosity, anxiety, interest, immersion, usefulness, scepticism; three items: user-friendliness, accessibility) using a seven-point Likert scale. For domains with four items 4–28 points and for three items 3–21 points can be obtained. Additionally, the instrument includes a 10-cm visual analog scale, measuring the intention to use (3 items, endpoints for agreement and disagreement). Evaluation entails measuring the distance from the right endpoint (disagreement) to the marked point across the line. The summed distances, ranging from 0 to 300, represent the overall score. For all domains, higher scores indicate a higher level of expression in the respective construct. The internal consistencies of the eight domains can be rated as good ($\alpha = 0.70$–0.89). For this study, the immersion domain was excluded because it is only intended in the context of relevant technologies (e.g. virtual reality).

2.6.2. Interviews

To explore caregivers' attitudes and experiences with Coach Pepper, individual semi-structured interviews were conducted on the day of pickup with all caregivers in the intervention group. Interviews were held face-to-face in participants' homes by JZ, a nursing scientist and experienced interviewer. All interviews lasted 45 to 100 min (median 55 min) and were audio-recorded. Data saturation was reached.

Drawing from literature and the research team's expertise, a semi-structured interview guide (Supplementary material Table 1) was developed for caregivers' attitudes and experiences. The guide was shaped by items from the ‘Care Dependency Scale (CDS)’, based on Virginia Henderson's nursing theory. The CDS assesses the care dependency of people with dementia and individuals with intellectual disabilities across 15 physical and psychosocial human needs (Dijkstra et al., 1996; Lohrmann et al., 2003). ‘Care dependency’ denotes the requirement for (professional) support due to decreased self-care abilities (e.g., hygiene, communication) (Dijkstra, 2017; Schüssler and Lohrmann, 2015). Given the comprehensive coverage of crucial physical and psychosocial human needs, we deemed the CDS items appropriate for thoroughly exploring caregivers' experiences with Coach Pepper in dementia care (Dijkstra et al., 1996; Lohrmann et al., 2003; Schüssler and Lohrmann, 2015).

During the interviews, JZ noted the caregivers' main statements and summarised them at the end, asking caregivers for clarification (Kidd and Parshall, 2000). One pilot-test interview was conducted (JZ) before the study with a caregiver who had tested Coach Pepper during a one-week prototype test to adjust the order of questions and improve comprehensibility.

2.7. Data analysis

2.7.1. Quantitative outcome measure

A intention-to-treat analysis based on the ICH E9 Guideline (Phillips and Haudiquet, 2003) was performed. To be included in the modified intention-to-treat analysis, participants (i.e., in pairs) had to be randomly assigned to the intervention or control group, have had the baseline evaluation on their primary outcome, people with dementia should have had received at least one of three planned weekly supervised multimodal trainings with the assigned intervention, and participants should have had an evaluation on the primary efficacy.

Descriptive statistics are presented as absolute and relative frequencies for categorical data and as medians and minimum and maximum for continuous data. The primary aim of this study, to investigate the effect of two different interventions on caregiver burden, was analysed by a median regression. To account for baseline values, the difference between baseline and follow-up was used to estimate an effect of the intervention. The secondary outcome measures were analysed the same way. To assess differences between the two intervention groups regarding their acceptance of new technologies, a Wilcoxon rank-sum test was used. The significance level was set to $p < 0.05$. Statistical analyses were conducted using SAS 9.4 (SAS Institute Inc., Cary, NC,

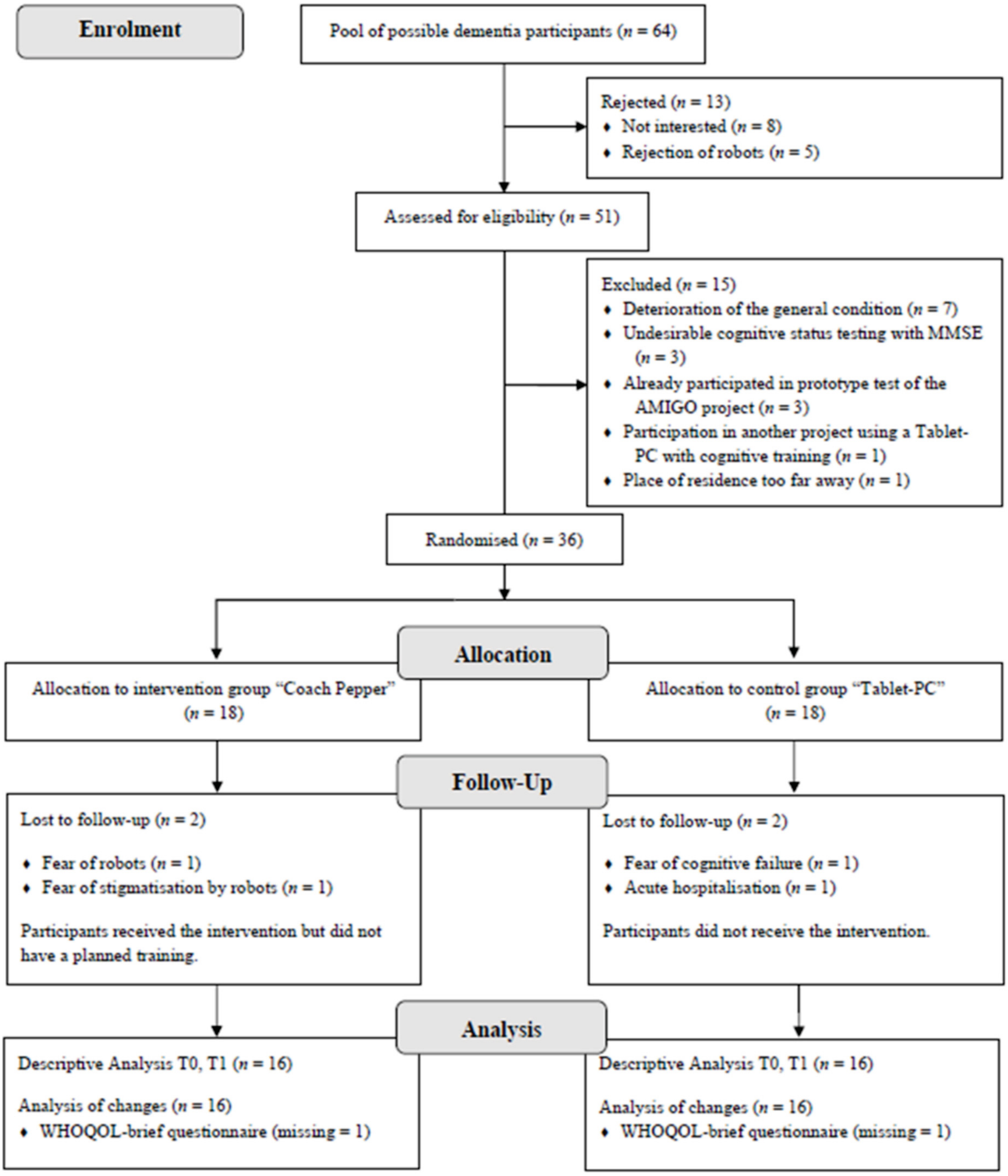

Fig. 2. Flow diagram of dementia participants through the study (Figure based on CONSORT-Statement).

Table 1
Baseline sociodemographic and clinical characteristics of caregivers and people with dementia.

Characteristics	All (n = 32)	Coach Pepper (n = 16)	Tablet-PC (n = 16)
Caregivers			
Age in years	59.2 (12.5)	60.4 (12.0)	57.9 (13.4)
Female	22 (68.8)	12 (75.0)	10 (62.5)
Highest education			
Primary school[a]	1 (3.1)	0.0	1 (6.3)
Secondary school[a]	1 (3.1)	0.0	1 (6.3)
Polytechnic school[b]	2 (6.3)	2 (12.5)	0.0
Apprenticeship[b]	10 (31.3)	4 (25.0)	6 (37.5)
School for intermediate vocational education[b]	6 (18.8)	3 (18.8)	3 (18.8)
Academic secondary school upper cycle[b]	2 (6.3)	1 (6.3)	1 (6.3)
Apprenticeship with master certification[c]	4 (12.4)	2 (12.5)	2 (12.5)
College for higher vocational education[c]	4 (12.4)	2 (12.5)	2 (12.5)
Continuing education course at a university[c]	1 (3.1)	1 (6.3)	0.0
University[c]	1 (3.1)	1 (6.3)	0.0
Occupation			
In employment	17 (53.1)	7 (43.8)	10 (62.5)
Unemployed	2 (6.3)	1 (6.3)	1 (6.3)
In retirement	13 (40.6)	8 (61.5)	5 (28.5)
Level of employment (n = 17)			
Full-time	11 (64.7)	4 (57.1)	7 (70.0)
Part-time	6 (18.8)	3 (42.9)	3 (30.0)
Marital status			
Unmarried	6 (18.8)	2 (12.5)	4 (25.0)
Married	24 (75.0)	13 (81.3)	11 (68.8)
Divorced	1 (3.1)	1 (6.3)	0.0
Widowed	1 (3.1)	0.0	1 (6.3)
Relationship between caregiver and person with dementia			
Wife	5 (15.6)	4 (25.0)	1 (6.3)
Husband	3 (9.4)	1 (6.3)	2 (12.5)
Daughter	11 (34.4)	6 (37.5)	5 (31.3)
Son	6 (18.8)	2 (12.5)	4 (25.0)
Daughter in law	4 (12.5)	1 (6.3)	3 (18.8)
Grandchildren	2 (6.3)	1 (6.3)	1 (6.3)
Acquaintance (e.g., friend)	1 (3.1)	1 (6.3)	0.0
Housing situation (living with the person with dementia in the same household)	27 (84.4)	13 (81.3)	14 (87.5)
Main diseases[d]			
Musculoskeletal system and connective tissue	5 (15.6)	4 (25.0)	1 (6.3)
Nervous system (without sleep disorder, spinal cord injury/paraplegia)	4 (12.5)	1 (6.3)	3 (18.8)
Eye and adnexa	3 (9.3)	1 (6.3)	2 (12.5)
Sleep disorder	2 (6.3)	1 (6.3)	1 (6.3)
Ear and mastoid process	2 (6.3)	0.0	2 (12.5)
Others	8 (25.0)	2 (12.5)	6 (37.5)
People with dementia			
Age in years	82.8 (8.6)	81.9 (8.6)	83.6 (8.8)
Female	24 (75.0)	11 (68.8)	13 (81.3)
Type of dementia			
Alzheimer's disease	22 (68.8)	11 (68.8)	11 (68.8)
Vascular dementia	3 (9.4)	2 (12.5)	1 (6.3)
Mixed dementia	6 (18.8)	2 (12.5)	4 (25.0)
Parkinson's disease dementia	1 (3.1)	1 (6.3)	0.0
Stage of dementia[e]			
Mild	20 (62.5)	10 (62.5)	10 (62.5)
Moderate	12 (37.5)	6 (37.5)	6 (37.5)
First diagnosis of dementia in years	3.1 (2.3)	3.2 (2.6)	3.1 (2.0)
Diagnosis by profession			
Neurologist	20 (62.5)	11 (68.8)	9 (56.3)
Psychiatrist	3 (9.4)	2 (12.5)	1 (6.3)
Other specialist physician	2 (6.3)	0.0	2 (12.5)
Clinical health psychologist	7 (21.9)	3 (18.8)	4 (25.0)
Mini Mental State Examination	20.3 (5.5)	19.9 (5.7)	20.7 (5.4)

Note: Values are displayed either as mean (SD) or n (%).
[a] Low education according to the International Standard Classification of Education (ISCED) (The Austrian Education System, 2024; UNESCO, 2012).
[b] Medium education (The Austrian Education System, 2024; UNESCO, 2012).
[c] High education (The Austrian Education System, 2024; UNESCO, 2012).
[d] Diagnosis of diseases according to ICD-10 classification (multiple answers possible).
[e] Classification of dementia stages according to the guideline of DEGAM (2008).

USA).

2.7.2. Interviews

Transcribed interviews (n = 16) were analysed using qualitative content analysis described by Schreier (2012) according to the following five steps: 1) development of a concept-driven coding frame based on the interview guide, consisting of main categories and subcategories regarding attitudes (i.e., feelings about Coach Pepper, impact on subjective caregiver burden) and experiences (i.e., perceived usefulness and future needs regarding human needs) (see Supplementary material

Table 2
Characteristics of care and support for people with dementia provided by caregivers.

Characteristics	All (n = 32)	Coach Pepper (n = 16)	Tablet-PC(n = 16)
Duration of care provided			
>1 month ≤ 1 year	7 (21.9)	4 (25.0)	3 (18.8)
2–4 years	12 (37.5)	6 (37.5)	6 (37.5)
5–6 years	7 (21.9)	2 (12.5)	5 (31.3)
>7 years	6 (18.8)	4 (25.0)	2 (12.5)
Number of days per week care provided			
<7	7 (21.9)	3 (18.8)	4 (25.0)
7	25 (78.1)	13 (81.3)	12 (75.0)
Person with dementia can be without supervision			
Yes, several hours or even longer	18 (56.3)	6 (37.5)	12 (75.0)
Yes, but no longer than 1 h	2 (6.3)	2 (12.5)	0.0
No, continuous supervision necessary	12 (37.5)	8 (50.0)	4 (25.0)
Additional informal care support (e.g., family, friends, acquaintances)	19 (59.4)	10 (62.5)	9 (56.3)
Use of formal services for people with dementia[a]			
No use	11 (34.4)	4 (25.0)	7 (43.8)
Formal 24-hour home care	7 (21.9)	3 (18.8)	4 (25.0)
(Disease-specific) recreational offerings	7 (21.9)	6 (37.5)	1 (6.3)
Hourly professional care and support services	6 (18.8)	2 (15.5)	4 (25.0)
Other services	5 (15.6)	4 (25.0)	1 (6.3)
Use of formal services for caregivers[a]			
No use	20 (62.5)	5 (31.3)	15 (93.8)
Advisory services (e.g., in person, in writing)	9 (28.1)	9 (56.2)	0.0
Psychotherapy/Psychological support	3 (9.4)	2 (12.5)	1 (6.3)
Other services	6 (18.8)	6 (37.5)	0.0
Financial burden due to care			
For (self-)employed (n = 17)[b]	7 (43.8)	2 (28.6)	5 (55.6)[b]
For retirees (n = 13)	4 (30.8)	3 (37.5)	1 (20.0)
For unemployed (n = 2)	1 (50.0)	0.0	1 (100.0)
Impact of caregiving on the employment of caregivers (n = 17)			
None	8 (47.1)	2 (28.6)	6 (60.0)
Reduction of employment level	6 (35.3)	3 (42.9)	3 (30.0)
Increase of employment level	1 (5.9)	0.0	1 (10.0)
Other impacts	2 (11.8)	2 (28.6)	0.0

Note: Values are displayed as n (%).
[a] Multiple answers possible.
[b] One missing data.

Table 2), 2) development of a data-driven coding frame based on the transcripts, with five transcripts categorised independently by two researchers, compared and discussed, and subsequently finished by JZ, 3) trial and main coding using thematic segmentation with five transcripts checked by a second researcher and subsequently finished by JZ, 4) summary and interpretation of categories by JZ, 5) discussion of findings within the research team.

We used the strategy of continuous text with exemplary quotes to describe our qualitative findings, structuring the presentation according to the concept-driven main and subcategories (Schreier, 2012).

MAXQDA (2020) was used to manage the data.

2.8. Ethical considerations

Ethical approval was obtained from the Ethics Committee of the Medical University of Graz, Austria (Approval Number: 30-401ex17/18, 20 June 2018). Caregivers received verbal and written information about the study and gave their oral and written informed consent to participate.

3. Results

3.1. Participants' characteristics

In total, out of 64 possible pairs, 36 were randomised, of which four pairs dropped out and were not analysed due to personal reasons concerning people with dementia (Fig. 2). Therefore, two people with dementia in the control group did not receive the tablet, while two in the intervention group had Coach Pepper for at least two days, but without supervised training sessions. Finally, 32 caregivers were analysed, having a mean age of 59.2 years, being predominantly female (68.8 %) (Table 1). More than half of the caregivers (53.1 %) were daughters/sons of the person with dementia. Most of them cared for a person with a type of Alzheimer's (68.8 %) in a mild stage (62.5 %). With between over one month and one year care duration, 21.9 % of the participants were relatively new to the role of a caregiver, while most (40.6 %) had already provided care and support for five years or more (Table 2). Furthermore, most caregivers (78.1 %) provided care with a frequency of seven days a week.

3.2. Quantitative results

Results of the RCT showed no statistically significant difference in mean changes between the Coach Pepper and the tablet-based multimodal training group with regard to caregiver burden, quality of life, depressive symptoms and affect (Table 3). The usefulness and accessibility of the tablet-based multimodal training was rated significantly higher compared with participants using Coach Pepper.

3.3. Qualitative findings

3.3.1. Attitudes

The following findings illustrate the feelings and opinions regarding Coach Pepper in dementia care, encompassing its impact on subjective caregiver burden.

3.3.1.1. Feelings about Coach Pepper. Most caregivers experienced Coach Pepper as positive and enjoyable. This was expressed through enthusiasm, curiosity and interest in new technologies. Furthermore, some caregivers mentioned that Coach Pepper had grown close to the person with dementia and themselves, and was seen as a housemate or

Table 3
Results of primary and secondary outcomes between groups.

Outcomes	Coach Pepper (n = 16)	Tablet-PC (n = 16)	*P* value
Caregiver burden			
Baseline	36.0 (25.0, 52.0)	31.0 (17.0, 69.0)	
3 weeks	37.5 (21.0, 51.0)	28.0 (14.0, 63.0)	
Baseline − 3 weeks	0.0 (−22.0, 13.0)	−3.0 (−14.0, 7.0)	.255
Quality of life total score[a]			
Baseline	74.9 (47.6, 100.0)	76.1 (32.8, 91.9)	
3 weeks	74.2 (42.8, 89.1)	74.4 (37.6, 90.5)	
Baseline − 3 weeks	−4.5 (−20.6, 10.7)	−1.1 (−21.0, 11.0)	>.999
Global quality of life[a]			
Baseline	62.5 (25.0, 100.0)	75.0 (25.0, 100.0)	
3 weeks	62.5 (12.5, 87.5)	75.0 (37.5, 87.5)	
Baseline − 3 weeks	0.0 (−25.0, 12.5)	0.0 (−12.5, 25.0)	>.999
Physical quality of life[a]			
Baseline	82.1 (28.6, 100.0)	85.7 (46.4, 100.0)	
3 weeks	71.4 (28.6, 92.9)	78.6 (42.9, 96.4)	
Baseline − 3 weeks	−3.6 (−32.1, 14.3)	−3.6 (−21.4, 7.1)	>.999
Psychological quality of life[a]			
Baseline	75.0 (58.3, 100.0)	75.0 (29.2, 87.5)	
3 weeks	70.8 (37.5, 95.8)	70.8 (37.5, 83.3)	
Baseline − 3 weeks	−8.3 (−25.0, 16.7)	−4.2 (−16.7, 8.3)	.486
Social relationships[a]			
Baseline	66.7 (25.0, 100.0)	75.0 (16.7, 100.0)	
3 weeks	75.0 (33.3, 100.0)	75.0 (16.7, 100.0)	
Baseline − 3 weeks	0.0 (−16.7, 25.0)	0.0 (−41.7, 58.3)	>.999
Environment[a]			
Baseline	78.1 (56.3, 100.0)	68.8 (46.9, 93.8)	
3 weeks	75.0 (53.1, 93.8)	71.9 (46.9, 93.8)	
Baseline − 3 weeks	−3.1 (−18.8, 12.5)	0.0 (−18.8, 9.4)	.500
Depressive symptoms			
Baseline	14.0 (5.0, 24.0)	11.0 (6.0, 41.0)	
3 weeks	12.0 (4.0, 25.0)	12.0 (3.0, 34.0)	
Baseline − 3 weeks	0.0 (−16.0, 14.0)	0.0 (−8.0, 14.0)	.961
Positive affect			
Baseline	3.0 (2.4, 4.1)	3.4 (2.2, 4.4)	
3 weeks	3.1 (2.5, 4.6)	3.2 (2.2, 3.9)	
Baseline − 3 weeks	0.1 (−1.0, 1.4)	−0.1 (−0.9, 0.4)	.375
Negative affect			
Baseline	1.8 (1.0, 3.0)	1.8 (1.2, 3.5)	
3 weeks	1.5 (1.0, 2.7)	1.8 (1.1, 3.0)	
Baseline − 3 weeks	−0.1 (−2.0, 1.0)	−0.1 (−0.6, 1.0)	>.999
Curiosity			
3 weeks	19.5 (10.0, 28.0)	23.0 (4.0, 28.0)	.302
Anxiety			
3 weeks	10.0 (4.0, 23.0)	12.0 (4.0, 24.0)	.663
Interest			
3 weeks	18.5 (8.0, 28.0)	22.0 (4.0, 28.0)	.113
User-friendliness			
3 weeks	14.0 (9.0, 21.0)	18.0 (3.0, 21.0)	.099
Usefulness			
3 weeks	18.0 (7.0, 28.0)	27.0 (4.0, 28.0)	.042*
Scepticism			
3 weeks	11.0 (4.0, 20.0)	11.0 (4.0, 18.0)	.858
Accessibility			
3 weeks	10.0 (3.0, 16.0)	15.0 (3.0, 21.0)	.034*
Intention to use[b]			
3 weeks	192.5 (31.0, 295.0)	92.5 (5.0, 296.0)[b]	.271

Note: Values are displayed as med (min, max).
[a] 15 participants in Coach Pepper Group and 15 participants in Tablet-PC group were analysed, because of missing data.
[b] Two missing data points.
* p-value < 0.05.

even as a family member. "*Yes, it [Coach Pepper] has actually become a bit of a family member these past three weeks.* (C7)"

For some caregivers the intervention was just a pleasant experience and neither positively nor negatively affected. They reported that some people with dementia needed time to get used to Coach Pepper's presence for engaging with him. In this regard, some reported that the person with dementia was initially fearful of or disinterested in Coach Pepper, which subsided during the intervention. One caregiver expressed negative feelings about the use of robots in dementia care. "*I worked in nursing myself for 38 years (...) and my feeling is that it's better when people work with people.* (C9)"

3.3.1.2. Impact on subjective caregiver burden. Some caregivers reported relief from Coach Pepper. People with dementia were engaged by Coach Pepper's communication function, as well as by its entertainment and training program, so that caregivers had some time for themselves, for household activities, errands or for other family members. This led to emotional and psychological relief and to an improved relationship with the person with dementia. In this regard, caregivers highlighted that Coach Pepper was patient and persevering, which, unlike a human being, could be available 24 h a day. “*You can't endure for 24 hours, you can't! No human being can do that, 24 hours, constantly. (…) From that point of view, that would be a great help!* (C6)”

Most caregivers felt Coach Pepper was neither a burden nor a relief in dementia care. Some people with dementia needed regular support in using the robot for further self-occupation, giving caregivers (only) a little free time from care. “*Yes and no. It was a relief in the sense that Coach Pepper had programs which she could work with on her own. But you have go and check again and again.* (C9)”

Some caregivers stated an additional burden due to co-caring with Coach Pepper, in order for the person with dementia to exercise with the robot at all. One participant expressed relief that finally everyday life could return after the intervention. “*Well, I actually said that I'm glad when he [Coach Pepper] is gone, so that normal everyday life can return.* (C12)”

3.3.2. Experiences of perceived usefulness and future needs

The following findings outline caregivers' perceived usefulness of Coach Pepper and future needs concerning the robot. Caregivers expressed both aspects in six components of physical and psychosocial human needs, while in the further categories, only future needs are mentioned.

3.3.2.1. Learning ability. The individualised reminder function already provided support in that Coach Pepper addressed people with dementia by their name and reminded them to drink regularly, take their medication and motivated/animated them to engage in (joint) recreational activities (e.g. dancing). Most caregivers said that the cognitive exercises of the multimodal training were well received and thought that the people with dementia also enjoyed doing them. Some caregivers emphasised that the praising/motivating statements of Coach Pepper (e.g., ‘You can do it!’) during training were especially important. “*He [Coach Pepper] always praised her when she finished a task. And that, I think, also gave her a lot (C6)*.”

To enhance the trainings' usability one caregiver suggested enabling voice commands for operation, while another proposed including tutorial videos before each exercise considering memory challenges. With regard to the reminder function, caregivers imagined that Coach Pepper should support people with dementia in the following human needs: eating/drinking (e.g., eating (healthily) and drinking regularly at appropriate times of day, making a shopping list), daily activities (e.g., keeping appointments, taking medications), hygiene (e.g., brushing teeth, showering), learning ability (e.g., asking questions about personal/temporal orientation), continence (e.g., leaving a clean toilet), avoiding danger (e.g. turning off appliances/water, using fall prevention aids), contact with others (e.g., maintaining social contacts calling/meeting friends/family), mobility/body posture (e.g., doing regular exercise, having an upright posture), getting (un)dressed (e.g., undressing before going to bed), (body) temperature (e.g., not turning the heating up too high), and day/night pattern (e.g., going to bed). One caregiver felt that it would be important to check or confirm the implementation of (certain) reminders (e.g., taking medication). Some caregivers wanted the function to be easy to customise. “*You could individualise it [reminder function] for the task and timing of the person being cared for. If it were simple to make adjustments without an immense expenditure of time, it would be very, very substantial.* (C3)”

3.3.2.2. Recreational activities. Coach Pepper was generally found to be very entertaining. Caregivers said that they and the person with dementia liked its dances, jokes and riddles. Most caregivers indicated that the person with dementia really liked Coach Pepper's music function that they also sang along to. Caregivers stated that they seemed happy, cheered up and even relaxed when singing. Furthermore, caregivers mentioned that the customised photo album function was positively received and frequently used by people with dementia. Some looked at the pictures alone, together with their family, or liked to show the pictures to visitors (e.g., friends). “*The pictures that were stored, she looked at them, and then she also showed the pictures to guests.* (C9).”

In this regard, the photo album function should be expanded to include personal videos of family/friends, as suggested by most caregivers. Additionally, caregivers expressed the desire for a broader selection of music and audiobooks to cater to the individual needs of people with dementia, indicating the importance of connecting Coach Pepper to the internet. One caregiver suggested displaying song lyrics on Coach Pepper's tablet to facilitate singing along, while another proposed recording audiobooks with familiar voices. Furthermore, a few caregivers mentioned the idea of Coach Pepper accompanying people with dementia in everyday life, as well as going for walks together. “*How great it would be if Pepper could take people who are able to walk by the hand and take them for a walk in the garden or around the yard.* (C3)”

3.3.2.3. Contact with others. Some caregivers observed that Coach Pepper already was a “contact person” for the person with dementia. In this regard, caregivers believed that Coach Pepper was non-judgemental towards the person with dementia and also patiently repeated frequently asked questions. Some said that the person with dementia had become friends with Coach Pepper and engaged with the robot more and more on their own. Coach Pepper made the caregivers, but especially some people with dementia, feel that someone was there, at home. “*Well, especially that he [Coach Pepper] gave a sense that you're just not alone. Even if he was not switched on, I just always had the feeling when I was downstairs that she is not alone. And she also felt that way, I think.* (C4)”

To promote social contacts, Coach Pepper should enable (video) calls via a voice function to make contact with family/friends. Since older people leave the house less often, one caregiver suggested that the robot would also be suitable for group activities (e.g. gymnastics with neighbours). Another caregiver said that Coach Pepper should increase social contact in the form of touching (e.g., hugging) and should also offer this on his own initiative. Furthermore, Coach Pepper should also be able to respond to emotions and show feelings to support social contact. “*I think my mother also imagined that she could talk to him [Coach Pepper] the way the two of us are talking now. And that's just not the case. (…) That she can somehow make her emotions known, ‘I am not feeling well’, and get a response.* (C12)”

3.3.2.4. Mobility/body posture. Most caregivers found the physical exercises from the multimodal training program to be a good start for the subsequent cognitive exercises. By making the physical exercises part of the multimodal training, regular movement was promoted in everyday life. “*That's very important, because you're lazy. And then you're asked to do it and then you do it.* (C16)”

However, some caregivers felt that the number and types of exercises in the multimodal training program needed to be expanded to provide more variety. Likewise, it would be good if Coach Pepper demonstrated or participated in the exercises himself and actively provided feedback to the person with dementia on how to perform them. “‘*Lift the left arm, lift the right arm’, if such things were programmed, then it would be ideal. The device should also recognise whether the person is doing it correctly, via the camera, whether she lifts the right arm or any arm, and give feedback.* (C3)”

3.3.2.5. Communication. With regard to Coach Pepper's voice function, some caregivers said it worked well to communicate with Pepper when using the predefined phrases/dialogues. Furthermore, Coach Pepper's eye contact and visualisation of the interlocutor, as well as the confirming nod from the robot, positively supported communication. “*As I said, the visualisation is a very, very important issue because that's what makes her [Coach Pepper] speak to me. It's about eye contact, it's about nodding, she responds very, very quickly when you nod at her. And as a result, you also accept her well.* (C3)”

Especially in this category, there were numerous requests for improvement. Some caregivers reported that the person with dementia wanted to talk to the robot more than the speech function allowed. They expressed the need for a more fluent, dynamic, and intelligent speech function in future. In this regard, Coach Pepper should know the person's biography, be connected to the internet to provide more conversation material (e.g., about politics, TV program). In addition, the whole operation of the robot and its (future) functions should work via voice commands. "*Because if you could say, for example, 'turn on Radio Styria!', then it would be a great help.* (C1)"

3.3.2.6. Avoiding danger. According to one participant, Coach Pepper was able to provide the person with dementia a sense of security just by being there. The robot's integrated emergency function was tested by some caregivers and was found to be good. However, the function was not put to serious use during the intervention. "*We tested that, yes! It worked! It was just a German number who called me, but that's completely irrelevant. The voice notification also worked great.* (C1)"

However, many caregivers wanted a more intelligent emergency function. Coach Pepper should be able to recognise dangers (e.g., fire/smoke), accidents (e.g., falls) or even dangerous situations (e.g., sleepwalking, fall hazards). Coach Pepper should also be able to hear cries for help or even specific sounds (e.g., from a fall), (move there) and decide if there was an emergency or whether to alert anyone. "*If he [Coach Pepper] could recognise danger or notice that someone has fallen, and then perhaps activate the emergency, that would not be bad.* (C16)"

3.3.2.7. Caregivers' future needs on further categories. Regarding 'sense of rules/values', some caregivers suggested that Coach Pepper should recognise when people with dementia need rest and give them privacy. In this regard, the robot should follow instructions/commands like 'Leave me alone' and refrain from interacting after a certain period. In terms of '(body)temperature', caregivers expressed a desire for Coach Pepper to measure body/room temperature and provide weather updates. Coach Pepper should also assist people with dementia with reminders (e.g., take a blanket). Additionally, caregivers suggested that Coach Pepper should be capable of regulating room temperature autonomously. Concerning 'hygiene', some caregivers imagined Coach Pepper demonstrating actions to people with dementia (e.g., brushing teeth). Furthermore, the robot should help to wash the back, hand the hairbrush, wash/blow-dry the hair. However, for direct support from Coach Pepper some caregivers said that people with dementia should be in such a healthy condition to still stay in the bathroom independently. Coach Pepper should also assist with '(un)dressing' by helping choose clothes (e.g., appropriate for occasion, matching colours) and bringing clothes, if necessary. "*She always asks, 'What should I wear? What suits me?' I just always have to look. I mean, when we are staying at home, I let her decide on her own, but when we go out, then I'm looking for something suitable! And that's where he [Coach Pepper] might be able to help.* (C6)"

For 'day/night pattern', it would be helpful if the robot could wake the person with dementia after a certain time. In addition, it should be integrated into a smart home so it can raise/lower blinds and turn lights on/off. For 'eating/drinking', two caregivers said that Coach Pepper should do service activities, such as bringing a glass of water. With regard to support with 'daily activities', one caregiver said that Coach Pepper should dispense medication, vacuum, fetch laundry from the washing machine, sort by colour and tidy the closet. In terms of 'continence', one participant would find it useful for Coach Pepper to detect if an incontinence product needs changing. "*Of course, you never know when the patient needs their diaper changed. If Pepper scans when it gets wet and calls you via an app.* (C3)"

4. Discussion

This RCT with a nested qualitative study investigated the psychosocial effects on informal caregivers of people with dementia receiving Coach Pepper (intervention) or exclusively tablet-based multimodal training (control) for three weeks at home, and additionally explored the subsequent attitudes and experiences of caregivers in the intervention group with semi-structured interviews. Quantitative results showed no statistically significant differences in mean group changes between groups regarding caregiver burden (primary outcome), quality of life, depressive symptoms and affect. The usefulness and accessibility (evaluated post-interventionally) of the tablet-based multimodal training was rated significantly higher compared with participants using Coach Pepper. Qualitative findings showed that most caregivers liked Coach Pepper, but in terms of caregiver burden also reported that the robot was neither a relief nor a burden. Furthermore, caregivers perceived Coach Pepper as being useful in dementia care in the following components of human needs: 'learning ability', 'recreational activities', 'contact with others', 'mobility/body posture', 'communication', 'avoiding danger'. In these six components, as well as 'sense of rules/values', '(body)temperature', 'hygiene', '(un)dressing', 'day/night pattern', 'eating/drinking', 'daily activities' and 'continence', all caregivers expressed future needs and improvements regarding the support provided by Coach Pepper.

According to the results of the reviews of Yu et al. (2022) and Sohn et al. (2023), this study appears to be the first to evaluate the effectiveness of a humanoid robot on informal caregivers of people with dementia in a home setting. Apart from our larger project 'AMIGO', which investigated not only caregivers as described in this study, but also people with dementia (Schüssler et al., 2020), Khosla et al. (2021) conducted a study utilising also both quantitative (survey questionnaires) and qualitative (observations) methods to assess a robot intervention for people with dementia in a home setting. The study involved the humanoid robot 'Betty' (39 cm tall, weighs 6.5 kg) in the households of five participants for three months. Interaction and engagement with the robot were measured, but although a relative had to be in the household for people with dementia's participation in the study, relatives were not examined further (Khosla et al., 2021). While there is already qualitative (Wang et al., 2017; Zuschnegg et al., 2021) and mixed-method research (Pino et al., 2015) of caregivers' expectations and needs of potential support options in dementia care regarding humanoid robots, with the intention of reducing their caregiver burden, evidence about the effectiveness was missing.

However, in our study, we found no evidence that a humanoid robot reduces caregiver burden. When using the cut-off values from Hébert et al. (2000), caregivers in the intervention group would have experienced 'severe burden' at both points in time (see Table 3). Caregivers in the control group also had a 'severe burden' at the start but shifted slightly to the 'high burden' category after the intervention. In this regard, the qualitative findings could explain the lack of change in the outcome within the intervention group, as most caregivers indicated that Coach Pepper was neither a relief nor a burden in dementia care. Furthermore, for some, supervising and using Coach Pepper even felt like an additional burden. This aligns with findings from a qualitative study by Arthanat et al. (2020), in which caregivers expressed concerns about the complexity and potential flaws of using robots in dementia care after a demonstration. Addressing this issue might involve providing thorough training on the specific technology to both caregivers and people with dementia, along with offering regular support, as was done in our study. However, it also requires a technology that is tailored to users' needs, user-friendly and easy to operate to be useful. In this context, it is interesting to note that the tablet-based multimodal training was rated as significantly more useful and accessible than Coach Pepper. A reason for these results could be the expectation placed on each technology (Kothgassner et al., 2012). The expectation that the tablet would be useful for cognitive and physical training, as well as easily accessible, was probably more likely met by caregivers in the control group than the presumably higher expectations of usefulness in dementia care, and accessibility associated with the robot in the intervention group. While caregivers already perceived support in dementia care from Coach Pepper in six components of human needs, improvements and further needs regarding support and application were predominantly expressed in all 14 components, reflecting the quantitative results of the significantly lower usefulness of Coach Pepper compared with the tablet training. Therefore, it is possible that some caregivers had higher expectations on Coach Pepper, which is shown within the future needs they expressed (e.g., communication function), yet Coach Pepper did not possess. A gap between caregivers' expectations and Coach Peppers' actual functions may have influenced the study results (Manzi et al., 2021).

Findings regarding the caregivers' future needs indicate that Coach Pepper's speech function (e.g., reminders, conversations), customisation (e.g., music) and mobilisation (e.g., going for a walk, service activity) is of particular importance in dementia care, as well as its recognition of things/situations/contexts and its appropriate reaction (e.g., emergency), which matches qualitative (Wang et al., 2017; Zuschnegg et al., 2021) and the mixed methods literature (Pino et al., 2015). In contrast to this study, the participants in the aforementioned studies did not receive a three-week intervention in the home environment, but only a demonstration of a robot (e.g., via video or laboratory setting) before the interviews. Nevertheless, there are similarities in the functions required of robots to support dementia care. The perception and assessment of implementation by caregivers who actually used a robot for a certain period of time can be more precise and, therefore, the inclusion of this target group in the research and development of robots in dementia care is vital (Sohn et al., 2023).

Considering the future needs expressed by the caregivers, Coach Pepper needs advances in artificial intelligence performance, for example, to be able to recognise (complex) care situations and react accordingly, for an extended speech function, or to empathically respond to emotions. A scoping review (Abdi et al., 2020) of ten emerging technologies for care and support in older people reported that there are already ongoing projects to develop and apply artificial intelligence to robots, which in the future may lead to more autonomous robots with enhanced non(verbal) interaction (through artificial emotional intelligence) that can adapt to the environment and needs of older people. Another significant future technology on the top-ten list of Abdi et al. (2020) was voice-based interfaces (e.g., chatbots). There are already commercially available voice-controlled devices such as Google Assistant and Amazon Alexa, which were already seen as promising assistants for the elderly at home (e.g., medication reminders). In particular, regarding Coach Pepper's speech function, caregivers expressed a significant need for improvement. The combination of Coach Pepper and an improved speech function could significantly increase its usefulness in dementia care, as the human brain is more likely to react emotionally to human-like appearances as communication partners (e.g. Coach Pepper) than to artificial objects (e.g., chatbots) (Campa, 2016).

Robots like Coach Pepper could also be used in the future for intelligent homes, which are largely enabled by the ‘Internet of Things’. ‘Internet of Things’ is a system that transfers and processes data from a group of internet-connected physical devices, allowing home devices, such as lights, heat, blinds, or mobile robots, to connect and exchange information adapted to the routines and needs of the user (Abdi et al., 2020). Embedded in this context, caregivers wanted Coach Pepper to actively support them or people with dementia in the household, for example by regulating room temperature, raising/lowering the blinds and turning the lights on/off. As a further consequence, robots could also enable monitoring the health status of people with dementia twenty-four-seven by supporting them in everyday living, as expressed by caregivers in the interviews, and thus detect changes in condition and intervene early enough by forwarding data to caregivers or healthcare facilities (Abdi et al., 2020). This could lead to a possible reduction of caregiver burden in the future, as Sohn et al. (2023) found in their review, that smart home devices and telemedicine already increased informal caregivers' quality of life by monitoring people with dementia. However, despite the great potential of possibilities and the great research trend, particular consideration must be given to ethical concerns regarding data protection and privacy for such technologies in the future (Sohn et al., 2023).

For this study, the intervention Coach Pepper was developed and adapted for dementia care by involving also caregivers of people with dementia (Zuschnegg et al., 2021). Furthermore, caregivers were involved in the present study by personalising specific functions such as dialogues, reminders, and the photo album, allowing Coach Pepper to be customised to meet their individual needs for dementia care support. However, while Coach Pepper was designed to assist in dementia care, it did not include direct support functions aimed at enhancing caregivers' well-being or health.

In previous qualitative research within the AMIGO project (Zuschnegg et al., 2021), others (Arthanat et al., 2020; Wang et al., 2017) and in this study, almost all wishes and needs expressed by caregivers focused on a robot like Coach Pepper providing support in care and everyday life, thus freeing up time for other activities. However, a device like Coach Pepper, likely shared in a household, could serve not only the person with dementia as the ‘client’ but also include functions directly adapted for the caregivers themselves.

A recent scoping review (Ma et al., 2024) on technology for dementia care found that studies on direct caregiver support were underrepresented. Most studies focused on technologies aiding the caregiving process (e.g., AR-based dementia training) rather than supporting caregivers' own well-being. Interestingly, the review of Ma et al. (2024) and the study of Bhargava and Baths (2022) showed that numerous innovations and research trends in lifestyle and health focused exclusively on people with dementia, using for example unobtrusive monitoring (e.g., for sleep, stress) through wearables, but these were not intended for caregivers. To significantly enhance the (psychological) well-being and health of caregivers, technologies like Coach Pepper may need functions such as lifestyle and health monitoring, where Coach Pepper could intervene by suggesting breaks, facilitating mindfulness training, or recommending a doctor's visit. In this context, Coach Pepper may require further adaptation based on more specific caregiver input. Future research should prioritise integrating such interventions into new dementia care technologies.

4.1. Limitations

One limitation of this study is the small sample size, as the authors did not reach the number of 40 caregivers to be included. It may be that the true effect for caregivers on the primary outcome of caregiver burden was therefore not detected. However, for the control group, a statistically significant difference was found on two domains of the secondary outcome of acceptance measured post-interventionally. For the qualitative part, data saturation was reached.

Second, it should be noted that the inclusion criteria for caregivers did not account for the duration of care they had been providing to the person with dementia, which ranged from up to one month to more than seven years. This may have influenced the study's results, as caregiver burden tends to increase with the care duration (van den Kieboom et al., 2020). However, there was consistency in some caregiver burden risk factors (van den Kieboom et al., 2020; Wang et al., 2022) in our sample, as the distribution of the duration (around three years) and stages of dementia (mild and moderate) across the groups was even. Nevertheless, future research should consider caregiving aspects such as care duration when selecting their sample.

In this context, the third limitation is the short intervention period of this study. A longer testing period, associated with increased caregiving duration and the resulting rise in caregiver burden, may have yielded different results (van den Kieboom et al., 2020). Furthermore, caregivers had to get used to Coach Pepper within the three weeks, support the person with dementia in its use, and organise/keep project appointments (e.g., supervised training, interviews) for themselves and for the person with dementia. Longer intervention periods could increase habituation and familiarity with Coach Pepper and its functions, which could lead to a decrease in caregiver burden over time.

Fourth, the results of this study are limited to the home-based population and are therefore difficult to transfer to other relevant settings. However, this was our intended setting for this robotic study, since due to the shortage of nurses and the consequences for healthcare provision, care at home will face severe challenges in the future and will need support (Buchan and Howard, 2023).

Nonetheless, the mixed-method approach represents a valuable strength, as the combination of the RCT and nested interviews provides a broader insight into this complex topic, gives a better understanding of the research problem and a wider range of answers (Mayer and Mitterer, 2014).

5. Conclusions

To the best of our knowledge, this RCT with nested interviews was the first to investigate psychosocial effects of the humanoid socially assistive robot Coach Pepper on informal caregivers of people with dementia living at home. After the three-week intervention period, interviews were conducted to explore caregivers' attitudes and experiences regarding the robot.

Results of the RCT revealed no statistically significant differences on caregiver burden (primary outcome), quality of life, depressive symptoms and affect. Regarding accessibility and usefulness, the tablet-based multimodal training was rated significantly higher by caregivers compared with Coach Pepper. Findings of the interviews showed that most caregivers in the intervention group liked Coach Pepper, and regarding caregiver burden, reported that the robot had neither decreased nor increased their caregiver burden. Caregivers perceived usefulness in six of fourteen components of human needs, these being 'learning ability', 'recreational activities', 'contact with others', 'mobility/body posture', 'communication' and 'avoiding danger'. However, they also stated the need for future support options and improvements of Coach Pepper in all components of human needs.

The findings of the interviews seem to support the quantitative results. The usefulness of Coach Pepper was rated significantly lower than the tablet intervention, which confirms the predominant need for improvement expressed in the interviews. Overall, it can be concluded from our data that caregivers in particular wish for a more intelligent speech function, improvements in mobilisation, customisation, as well as advances in (emotional) artificial intelligence and, to some extent, in an intelligent home via Internet of Things. In this context, it is vital that future robots are designed in such a way that people with dementia can operate them (mainly) on their own, thus being more independent and relieving caregivers.

In addition, research should also focus on integrating functions for caregivers themselves (e.g., lifestyle and health monitoring) into new dementia care technologies, as the well-being of both caregivers and those they care for is crucial. In this regard, studies with a mixed-method approach are highly recommended to evaluate the stepwise development of technologies like robots in a quantitative way, but also to gain qualitative feedback on its status quo, as well as further needs of caregivers and people with dementia.

Furthermore, as realised in our study, it is recommended to include a broad range of scientific disciplines in future studies to cover this comprehensive topic. Nursing science in robotic research will be pivotal in optimising the impact of humanoid robots within nursing practice and patient well-being.

Based on the current technical status of Coach Pepper, its use at home (complementary to conventional care) can already be recommended, albeit with continuous support by a caregiver and technical support available by telephone/in person.

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CRediT authorship contribution statement

Julia Zuschnegg: Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Alfred Häussl:** Writing – review & editing, Investigation, Formal analysis. **Gerald Lodron:** Writing – review & editing, Software, Investigation. **Thomas Orgel:** Writing – review & editing, Software, Investigation. **Silvia Russegger:** Writing – review & editing, Software, Project administration, Funding acquisition, Conceptualization. **Michael Schneeberger:** Writing – review & editing, Software, Investigation. **Maria Fellner:** Writing – review & editing, Software, Project administration, Methodology, Funding acquisition, Conceptualization. **Magdalena Holter:** Writing – review & editing, Visualization, Methodology, Formal analysis, Data curation. **Dimitrios Prodromou:** Writing – review & editing, Software, Investigation, Conceptualization. **Anna Schultz:** Writing – review & editing, Visualization. **Regina Roller-Wirnsberger:** Writing – review & editing, Visualization. **Lucas Paletta:** Writing – review & editing, Validation, Supervision, Software, Project administration, Methodology, Funding acquisition, Conceptualization. **Marisa Koini:** Writing – review & editing, Visualization. **Sandra Schüssler:** Writing – review & editing, Visualization, Validation, Supervision, Project administration, Methodology, Formal analysis, Data curation, Conceptualization.

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Data availability

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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Supplementary Material. Table 1. Interview guide for informal caregivers

QUESTIONS
Please tell me how you experienced the presence of Coach Pepper in your home?
What feelings did Coach Pepper evoke in you?
I will now show you pictures of different human needs one after another. I would like you to tell me in which cases Coach Pepper was able to support you or your family member with dementia in the last 3 weeks and where you would like additional support from Coach Pepper in the future.
Recreational activities • How was Coach Pepper able to support you or your family member with dementia in pursuing hobbies and recreational activities? • What support (or reminder) would you like to receive from Coach Pepper in terms of hobbies and leisure for yourself or your family member with dementia in the future?
Communication • How was Coach Pepper able to support you or your family member in terms of communication (or conversations)? • How did you like the conversations with Coach Pepper? • What kind of support would you or your family member with dementia like to receive in terms of communication (or conversations) from Coach Pepper in the future?
Contact with others • How was Coach Pepper able to support you or your family member with dementia regarding friendships and relationships? • What support (or reminder) would you like to receive from Coach Pepper regarding friendships and relationship for yourself or your family member with dementia in the future?
Learning ability • How was Coach Pepper able to support you or your family member with dementia in terms of learning and memory? • What has been your or your loved one’s experience with the multimodal training? (memory exercises) • What support (or reminder) would you like to receive from Coach Pepper regarding the learning and memory for yourself or your family member with dementia in the future?
Mobility/Body posture • How was Coach Pepper able to support you or your family member with dementia in terms of mobility and body posture?

- What has been your or your loved one's experience with the multimodal training? (physical exercises)
- What support (or reminder) would you like to receive from Coach Pepper regarding mobility and body posture for yourself or your family member with dementia in the future?

Daily activities

- How was Coach Pepper able to support you or your family member with dementia in terms of daily activities?
- How did you or your loved ones like the reminder function of Coach Pepper?
- What support (or reminder) would you like to receive from Coach Pepper regarding daily activities for yourself or your family member with dementia in the future?

Avoiding danger

- How was Coach Pepper able to support you or your family member with dementia in terms of avoiding danger and providing security?
- What experience have you or your family member had with the emergency function (or SOS function) of Coach Pepper?
- What support (or reminder) would you like to receive from Coach Pepper in terms of avoiding danger and providing security for yourself or your family member with dementia in the future?

Sense of rules/Values

- How was Coach Pepper able to support you or your family member with dementia in terms of observing rules and values (e.g., privacy, rules, instructions)?
- What support (or reminder) would you like to receive from Coach Pepper in terms of observing rules and values (e.g., privacy, rules, instructions) for yourself or your family member with dementia in the future?

Eating/Drinking

- How was Coach Pepper able to support you or your family member with dementia regarding eating and drinking?
- What support (or reminder) would you like to receive from Coach Pepper regarding eating and drinking for yourself or your family member with dementia in the future?

Day/Night pattern

- How was Coach Pepper able to support you or your family member with dementia regarding day and night patterns?
- What support (or reminder) would you like to receive from Coach Pepper regarding day and night patterns for yourself or your family member with dementia in the future?

Getting (un)dressed

- How was Coach Pepper able to support you or your family member with dementia regarding dressing and undressing?
- What support (or reminder) would you like to receive from Coach Pepper regarding dressing and undressing for yourself or your family member with dementia in the future?

Hygiene

- How was Coach Pepper able to support you or your family member with dementia regarding hygiene?
- What support (or reminder) would you like to receive from Coach Pepper regarding hygiene for yourself or your family member with dementia in the future?

(Body) temperature

- How was Coach Pepper able to support you or your family member with dementia regarding body temperature and thermal sensation?
- What support (or reminder) would you like to receive from Coach Pepper regarding body temperature and thermal sensation for yourself or your family member with dementia in the future?

Continence

- How was Coach Pepper able to support you or your family member with dementia regarding continence?
- What support (or reminder) would you like to receive from Coach Pepper regarding continence for yourself or your family member with dementia in the future?

Did you find Coach Pepper's presence to be a relief or a burden in caring for your loved one?
Please give reasons for your answer.

A short overview about 2–3 minutes by the interviewer.
Did I summarise the conversation properly? Did I forget anything?

Would anyone like to add something that has not been discussed in our conversation yet?

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Supplementary Material. Table 2. Concept-driven coding frame. Demonstration and definitions of the concept-driven main categories and subcategories.

MAIN CATEGORIES	SUBCATEGORIES (LEVEL 1)	SUBCATEGORIES (LEVEL 2)	SUBCATEGORIES (LEVEL 3)	SUBCATEGORIES (LEVEL 4)
ATTITUDES Feelings or opinions regarding the application of Coach Pepper in dementia care (Cambridge Dictionary, 2018; Heerink et al., 2010).	FEELINGS ABOUT COACH PEPPER (e.g., enjoyable, anxiety) (Heerink et al., 2010)	*The idea of subdividing into the following subcategories is based on the literature (Wu et al., 2016).* POSITIVE NEITHER POSITIVE NOR NEGATIVE NEGATIVE	-	-
	IMPACT ON SUBJECTIVE CAREGIVER BURDEN How caregivers perceived Coach Pepper's impact on their subjective caregiver burden in context of their home care situation (Cao & Yang, 2020; Zarit et al., 1986).	POSITIVE NEITHER POSITIVE NOR NEGATIVE NEGATIVE		
EXPERIENCES Experiences are defined as a process of acquiring knowledge or skills from doing, seeing, feeling or being influenced, regarding Coach Pepper (Cambridge University Press, 2018)	PERCEIVED USEFULNESS The perceived ability of the system (i.e. Coach Pepper) to be of assistance in dementia care regarding different (physical and psychosocial) human needs (Dijkstra, 2017; Heerink et al., 2010; Kothgassner et al., 2012; Lohrmann et al., 2003).	*Perceived usefulness of Coach Pepper regarding the following human needs:* LEARNING ABILITY The perceived usefulness of assistive applications from Coach Pepper to provide support in acquiring knowledge/skills and/or retaining knowledge/skills learned in the past (Heerink et	REMINDER FUNCTION	LEARNING ABILITY EATING/DRINKING MOBILITY/BODY POSTURE DAILY ACTIVITIES GETTING (UN)DRESSED (BODY)TEMPERATURE

	al., 2010; Kothgassner et al., 2012; Lohrmann et al., 2003; Schüssler & Lohrmann, 2015).		HYGIENE AVOIDING DANGER COMMUNICATION CONTACT WITH OTHERS SENSE OF RULES/VALUES DAY/NIGHT PATTERN CONTINENCE RECREATIONAL ACTIVITIES
		COGNITIVE EXERCISES (MULTIMODAL TRAINING)	-
	Any type of assistive application by Coach Pepper without reminder or instructions that was perceived as direct support.		
	EATING/DRINKING The perceived usefulness of assistive applications from Coach Pepper to provide support in eating and drinking/preparing food/beverages (Heerink et al., 2010; Kothgassner et al., 2012; Lohrmann et al., 2003; Schüssler & Lohrmann, 2015).	-	
	MOBILITY/BODY POSTURE *(These two items of the CDS have been combined in the study.)*	PHYSICAL EXERCISES (MULTIMODAL TRAINING)	-

The perceived usefulness of assistive applications from Coach Pepper to provide support in movement and the adoption of appropriate activity-dependent positions (Heerink et al., 2010; Kothgassner et al., 2012; Lohrmann et al., 2003; Schüssler & Lohrmann, 2015).		
DAILY ACTIVITIES The perceived usefulness of assistive applications from Coach Pepper to provide support in managing/structuring/performing daily activities (e.g., household, shopping, money, appointments) (Heerink et al., 2010; Kothgassner et al., 2012; Lohrmann et al., 2003; Schüssler & Lohrmann, 2015).	-	-
GETTING (UN)DRESSED The perceived usefulness of assistive applications from Coach Pepper to provide support in getting (un)dressed (Heerink et al., 2010; Kothgassner et al., 2012; Lohrmann et al., 2003; Schüssler & Lohrmann, 2015).	-	-
(BODY)TEMPERATURE The perceived usefulness of assistive applications from Coach Pepper to provide	-	-

	support in maintaining an appropriate body temperature despite external influences (Heerink et al., 2010; Kothgassner et al., 2012; Lohrmann et al., 2003; Schüssler & Lohrmann, 2015).		
	HYGIENE The perceived usefulness of assistive applications from Coach Pepper to provide support in maintaining personal hygiene and grooming (Heerink et al., 2010; Kothgassner et al., 2012; Lohrmann et al., 2003; Schüssler & Lohrmann, 2015).	-	-
	AVOIDING DANGER The perceived usefulness of assistive applications from Coach Pepper to provide support in recognizing danger and ensuring safety (Heerink et al., 2010; Kothgassner et al., 2012; Lohrmann et al., 2003; Schüssler & Lohrmann, 2015).	-	-
	COMMUNICATION The perceived usefulness of assistive applications from Coach Pepper to provide support in communication with others (verbally and non-verbally) (Heerink et al., 2010; Kothgassner et al., 2012;	-	-

Lohrmann et al., 2003; Schüssler & Lohrmann, 2015).		
CONTACT WITH OTHERS The perceived usefulness of assistive applications from Coach Pepper to provide support in making, maintaining, and ending social contacts (Heerink et al., 2010; Kothgassner et al., 2012; Lohrmann et al., 2003; Schüssler & Lohrmann, 2015).	-	-
SENSE OF RULES/VALUES The perceived usefulness of assistive applications from Coach Pepper to provide support in observing rules and values and asserting the protection of privacy (Heerink et al., 2010; Kothgassner et al., 2012; Lohrmann et al., 2003; Schüssler & Lohrmann, 2015).	-	-
DAY/NIGHT PATTERN The perceived usefulness of assistive applications from Coach Pepper to provide support in maintaining an appropriate day/night cycle (Heerink et al., 2010; Kothgassner et al., 2012; Lohrmann et al., 2003; Schüssler & Lohrmann, 2015).	-	-

	CONTINENCE The perceived usefulness of assistive applications from Coach Pepper to provide support in controlling the discharge of urine/bowel movements and taking appropriate measures in response (Heerink et al., 2010; Kothgassner et al., 2012; Lohrmann et al., 2003; Schüssler & Lohrmann, 2015).	-	-
	RECREATIONAL ACTIVITIES The perceived usefulness of assistive applications from Coach Pepper to provide support in terms of sensible use of free time/participating in leisure activities (Heerink et al., 2010; Kothgassner et al., 2012; Lohrmann et al., 2003; Schüssler & Lohrmann, 2015).	-	-

FUTURE NEEDS An assessment of the technical tasks and functions that a technology (i.e. Coach Pepper) must be capable of performing or the needs that it should be able to meet (i.e. in dementia care regarding different components of human physical and psychosocial needs). Determining whether they are realistic, necessary, and affordable is not crucial at this point (Dijkstra, 2017; Lohrmann et al., 2003; National Center for Education Statistics, 2019)	*Future needs of Coach Pepper regarding the following human needs:* LEARNING ABILITY	REMINDER FUNCTION	LEARNING ABILITY EATING/DRINKING MOBILITY/BODY POSTURE DAILY ACTIVITIES GETTING (UN)DRESSED (BODY) TEMPERATURE HYGIENE AVOIDING DANGER COMMUNICATION CONTACT WITH OTHERS SENSE OF RULES/VALUES DAY/NIGHT PATTERN CONTINENCE RECREATIONAL ACTIVITIES
		COGNITIVE EXERCISES (MULTIMODAL TRAINING)	-
	Any type of assistive application by Coach Pepper without reminder or instructions where direct support is needed.		
	EATING/DRINKING	-	-
	MOBILITY/BODY POSTURE	-	-

		DAILY ACTIVITIES	-	-
		GETTING (UN)DRESSED	-	-
		(BODY) TEMPERATURE	-	-
		HYGIENE	-	-
		AVOIDING DANGER	-	-
		COMMUNICATION	-	-
		CONTACT WITH OTHERS	-	-
		SENSE OF RULES/VALUES	-	-
		DAY/NIGHT PATTERN	-	-
		CONTINENCE	-	-
		RECREATIONAL ACTIVITIES	-	-

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