New technology can go above and beyond the impact of traditional cognitive training for episodic memory decline in older adults: a literature review

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Abstract - **The demand for intervention in older adults' episodic memory decline is extremely high as this deterioration has numerous negative consequences on their quality of life. To address this issue, researchers have developed various forms of cognitive training. Each type has its own advantages, but some common limitations faced by traditional cognitive training are ecological validity and transfer effects. Fortunately, several studies using technological interventions such as computerized cognitive training programs, video games, and virtual reality have addressed these issues while still finding improvements in episodic memory and other secondary outcome measures. Although older adults' mobility problems, financial insecurity, or other age-related challenges to accessing healthcare services may create a potent hindrance when implementing technological interventions, research has shown that they are still feasible and applicable for the elderly. Therefore, this paper postulates that technological cognitive training interventions can transcend traditional ones in many aspects concerning episodic memory decline in older adults.**

I. INTRODUCTION

The ability to consciously recollect what happened on one's eighteenth birthday, when one met his best friend, where one's graduation took place, or how one felt when being promoted depends solely on episodic memory function. According to Tulving (1972), episodic memory receives and stores information about episodes or events that occur in an individual's life, as well as the temporal-spatial relations among these events. In other words, it relates to one's personal life and helps us recall things we have done and experienced.

In addition to episodic memory, semantic memory is also a subtype of long-term memory. Semantic memory governs whether or not one can recall his family members' birthdays, recognize his best friend's hair color, know the shape of his graduation cap, or create grammatically well-structured sentences in his CV. It is a "mental thesaurus" that provides "the memory necessary for the use of language" (Tulving, 1972). It entails the long-term storage of systemized factual knowledge acquired during one's lifetime.

Although these two memory subtypes appear to function distinctly, they are actually interdependent (Menon et al., 2002). Prior studies demonstrated that when stimuli are meaningfully processed through semantic memory, episodic memory retrieval is enhanced, which augments both recollection and familiarity (Greve, van Rossum, & Donaldson, 2007). Biologically, the left lateral temporal lobe regions involved in semantic memory also appear to play an important role in accurate episodic memory retrieval (Menon et al., 2002). Such an interconnected relationship has led researchers to propose the concept of autobiographical memory, the multifaceted higher-order recollection of specific personal events that comprises both episodic and semantic memory elements (Tulving, 2002).

The existing literature predominantly agrees that episodic memory exhibits the most significant degree of age-related decline across the lifespan and is the first memory system to decline in both normal and pathological aging (Tromp et al., 2015), whereas semantic memory remains stable and well-preserved and even improves in older age (Lovden et al., 2004). To be more specific, episodic memory deficits have been linked to deficient encoding processes (Chalfonte & Johnson, 1996) and inadequate consolidation of storage of unfamiliar information (Weintraub, Wicklund, & Salmon, 2012). These impairments as functions of normal aging are also found to be more pronounced when evaluated utilizing tasks that depend on free recall rather than recognition (Craik & McDowd, 1987). Therefore, episodic memory is usually assessed through immediate and delayed recall (e.g., Belleville et al., 2006; Herrera et al., 2012; McAvinue et al., 2013; Miller et al., 2013; Yesavage & Rose, 1983) or face-name association (e.g., Belleville et al., 2006; Hampstead et al., 2008). There is no consensus regarding the age at which memory degradation initially begins. Cross-sectional analyses indicated gradual age-related decrements, possibly beginning at 31 years of age (Cansino, 2009). Nevertheless, most available longitudinal studies that apply appropriate control for practice effects revealed little decrements before age 60-65 (Rönnlund et al., 2005; Schaie, 2005). Since there is limited evidence for a much earlier onset of episodic memory decline, significant episodic memory decline is more likely to begin after 60 years of age.

Understanding the functional architecture and underlying biological mechanisms of episodic memory decline in healthy aging is important since episodic memory decline is connected to many neurochemical, structural, and functional brain changes rather than a single cortical region or circuit (Cabeza, Nyberg, & Park, 2005; Nyberg et al., 2012; Rugg, Otten, & Henson, 2002). Research has shown that successful recollection of episodic information is associated with the activation of the lateral parietal cortex and the dorsolateral and anterior prefrontal cortex. As Rugg et al. (2002) demonstrated, the representation of retrieved information is related to parietal regions, and the alignment of behavior with the demands of the retrieval task is supported by prefrontal areas. As a result, such impairments in these brain regions may severely affect episodic memory. In addition, age-related deficits in hippocampal volume and activation seem to account for episodic memory deterioration (Persson et al., 2011), with the atrophy and the malfunction of excitability in neurons of the hippocampal circuit probably induced by amyloid β-protein pathologies (Mormino et al., 2008). Age-related deficiencies in episodic memory are also associated with age-related dopamine losses (Bäckman et al., 2006, 2010) and genetic influence (Wilson et al., 2011).

Vascular and neuropsychiatric risk factors also seem to be associated with episodic memory decline. A retrospective longitudinal study showed that interventions managing current smoking and depressive symptoms in older adults might preserve episodic memory (Ahn et al., 2021). Furthermore, researchers contended that controlling blood pressure might be a critical preventative measure to minimize abnormal cognitive aging before the onset of clinical dementia (Gifford et al., 2013).

Memorability—the observation that some stimuli are more likely to be remembered than others regardless of the testing situation and individuals (Bainbridge et al., 2013)—may improve recollection and familiarity of episodic memory (Broers & Busch, 2020). Understanding the brain mechanisms and networks that underpin this feature may thus help assess episodic memory deterioration (Grande et al., 2021).

Episodic memory deterioration also plays a vital role in memory diseases and their progression, especially in Mild Cognitive Impairment (MCI) and Alzheimer's disease (AD). MCI is defined clinically as a state of mild impairment that is intermediate between normal, healthy brain aging and dementia (Smith & Bondi, 2013). Individuals with MCI have subjective cognitive deficits, objective memory impairments, or other cognitive deficits without impairments in daily activities (Petersen et al., 1999). AD is a chronic neurodegenerative brain disease and the leading cause of dementia in the elderly. It is also to blame for most cases of late-life cognitive dysfunction (Alzheimer's Association, 2019; Wilson et al., 2012). Significant impairment of episodic autobiographical memory performance is associated with MCI (Berna et al., 2012), and MCI individuals at a higher risk of progressing to AD dementia often exhibit a prominent impairment in episodic memory (Albert et al., 2013). Episodic memory is also the first subtype of memory to decline in AD (Hodges, 2000), and its impairment in AD is associated with the dysfunction of an integrated network of the medial temporal lobe, mammillary bodies, dorso-mesial thalamus and posterior cingulate (Nestor, Fryer, & Hodges, 2006).

Since episodic memory decline results in not only impairments and malfunctions in healthy aging but also pathologies such as MCI and AD, it undoubtedly has a detrimental impact on our daily lives. It not only reduces productivity and efficiency but also causes many inconveniences to our most essential activities. Initially, older adults may struggle with remembering names, locations, or other common items. However, as episodic memory decline worsens, they can undergo many dangerous situations, such as forgetting to turn off the stove, locking the door when leaving the house, or keeping an eye on young children. In fact, many existing studies have examined the relationship between episodic memory decline and activities of daily functioning (ADL). As evidenced by MCI and AD patients' worse performances on the Direct Assessment of Functional Status (DAFS), a performance-based measure commonly used to assess ADL areas, functional impairment is a defining feature of both AD and MCI, and these patients also exhibit more significant deficits in ADLs than do their cognitively normal counterparts (Bangen et al., 2010; Brown et al., 2011; Jefferson et al., 2008; Martyr & Clare, 2012; Reppermund et al., 2010). Such functional damage in older adults means that they have to rely substantially on the care and support of younger people. Combined with the loneliness and accident-proneness associated with increasing age, older adults can excessively worry that they will become useless, thus exacerbating their stress levels and leading to long-term psychological disorders (Skoog, 2011). Some studies have shown that other symptoms—such as anxiety, depression, avoidance, confusion, and personality changes—may also arise as side effects of the dysfunctional retrieval of episodic memory (Zlomuzica et al., 2014). Dependency upon others to execute ADL is also a major factor influencing Health-Related Quality of Life (HRQoL) in patients with dementia (Andersen et al., 2004).

Emotions, lifestyle, and activities of daily living may all be mildly or drastically impacted by episodic memory decline, especially in those with AD or MCI. Researchers have studied the interventions of episodic memory decline to call for heightened awareness about the importance of episodic memory and the need to enhance older adults' memory, prevent associated functional impairments, and safeguard their well-being. There are two major types of interventions: pharmacological and non-pharmacological interventions. The former encompasses interventions such as vitamin E, donepezil, rivastigmine, rofecoxib, galantamine, and beta-adrenergic antagonists such as propranolol. Glannon (2006) stated that beta-adrenergic antagonists could prevent or erase non-conscious pathological emotional memories in the amygdala. By modifying storage and retrieval mechanisms in the hippocampus and prefrontal cortex, novel psychopharmacological agents can also improve long-term semantic and short-term working memory (Glannon, 2006). However, most studies have shown that pharmacological interventions have little to no benefits in patients with MCI and AD, do not postpone the progression of MCI to AD, and may lead to cholinergic adverse events and higher mortality rates than the placebo group (Feldman et al., 2007; Glannon, 2006; Petersen et al., 2005; Thal et al., 2005; Winblad et al., 2008). Non-pharmacological interventions consist of resistance and acute exercise, non-invasive brain stimulation, and cognitive intervention (Cotelli et al., 2012; Lustig et al., 2009; Weinberg et al., 2014). Still, thus far, the most traditional and popular intervention method in episodic memory decline is cognitive intervention, particularly cognitive training. Nevertheless, the lack of ecological validity and transference to real-world improvement in traditional interventions may also necessitate exploring other technological alternatives that address these limitations (Chaytor & Schmitter-Edgecombe, 2003; Farias et al., 2003; Schultheis, Himelstein, & Rizzo, 2002). As Chaytor & Schmitter-Edgecombe (2003) highlight in their discussion of ecological validity, traditional cognitive training tasks fail to reflect the complexity and diversity of memory situations that older adults encounter daily, resulting in a lack of transfer effects to untrained tasks and underlying reference cognitive abilities. Therefore, considering how technology can go above and beyond the impact of traditional cognitive training interventions for episodic memory decline in older adults (≥ 60 years), I will delve deeper into this issue in my paper.

This literature review begins by considering the mental-exercise hypothesis and a brief history of cognitive intervention in general and cognitive training in specific. Since the research question contains two crucial parts—technology and traditional interventions—I will next identify, synthesize, and evaluate scientific findings surrounding the interventions for episodic memory decline in older adults, first on traditional and then on technological interventions. I will also mention contradictory results on this topic and put forward some explanations or indicate that those aspects need future research. Then, I will analyze the effectiveness of both types of interventions before and after the decline, as well as their feasibility and applicability. Finally, after making several comparisons between traditional and technological interventions, I will argue how the latter can tackle the shortcomings of the former. I will also discuss the implications for future research and then conclude my review.

II. MENTAL-EXERCISE HYPOTHESIS

Researchers in the field of cognitive aging have endeavored to understand the nature and validity of the mental-exercise hypothesis for several decades (e.g., Hertzog, 2009; Hultsch et al., 1999; Salthouse, 2006, 2007; Schooler, 2007). The mental-exercise hypothesis refers to the relationship between mental exercise and mental aging. This viewpoint suggests that keeping a person mentally active will help maintain one's level of cognitive functioning, make age-related cognitive decline less pronounced, and may even delay the onset of dementia. In other words, individuals' actions can impact their cognitive development in adulthood and partially determine their cognitive status in old age (Hultsch et al., 1999). This hypothesis is also called "Use it or lose it." Two crucial perspectives are involved in this hypothesis: the differential-preservation hypothesis and the preserved-differentiation hypothesis (Salthouse et al., 2006). According to Salthouse and other researchers, the differential-preservation hypothesis postulates that the degree to which performance is preserved with growing age varies according to the level of mental activity. Individuals with greater amounts of mental stimulation are thought to have less negative (or more positive) correlations between age and performance levels on cognitive tasks. Mental activity is also viewed as a factor that protects against age-related decline in mental ability. In contrast, the preserved-differentiation hypothesis claims that high levels of cognitive functioning throughout life are found in more mentally active people. Performance differences are preserved throughout adulthood, and an individual's present level of mental activity is, at least in part, considered a manifestation of his or her earlier mental ability.

However, the current controversy surrounding the mental-exercise hypothesis still stands. Salthouse's review (2006) is the most well-known article that took the opposite stance. He argued that there was insufficient scientific evidence supporting that differential engagement in mentally stimulating activities affects the pace of mental aging. To be more specific, first, in samples with relatively high levels of ability (and likely high levels of mental activity), moderate to significant age variations in many measures of cognitive functioning have been documented. Therefore, lack of mental exercise is presumably not the primary factor contributing to those age-related declines. The same activities may also become more challenging and potentially more stimulating as an individual's cognitive abilities deteriorate, while the mental-exercise hypothesis argues that the decline is attributable to a low level of mentally challenging activities. Thus, according to the hypothesis, no decline might be predicted, which is paradoxical. The influence of mental exercise may also differ across different periods of adulthood. Still, in analyses of cognitive function linked to this hypothesis, none of the interactions between mentally stimulating activities and age were significant. Access to environmental enrichment associated with interventions is also likely to increase opportunities for socialization and physical activity for the elderly (Cooper & Zubek, 1958; Stoddard & Wellman, 1940; van Praag, Kempermann, & Gage, 2000), which could intervene in the cycle of worrying about their self-perceived loneliness and uselessness and accumulating psychological disorders. Indeed, multiple studies have demonstrated that enriched environments could improve cognitive function and enhance learning and memory mechanisms (Arai & Feig, 2011; Frick & Fernandez, 2003; van Praag et al., 2000). Therefore, it is difficult to determine the role of mental stimulation on any effects that might be found.

Contrary to Salthouse, supporters of the mental-exercise hypothesis assert that to prevent cognitive decline, individuals should arrange their lives in such a manner that they are constantly placed in new situations and confronted with novel problems (Sorenson, 1938). Furthermore, since physical exercise and physical fitness are positively correlated, it is intuitively plausible to reason about the same relationship between mental exercise and mental fitness (Green & Crouse, 1995). Longitudinal studies have also indicated that older adults without dementia who engage in more intellectually challenging daily activities exhibit less decline over time on different cognitive performance tests (Gatz, 2005). Salthouse's argument is disputed by Schooler, who contended that the available evidence clearly pointed to the probability that for older individuals, mental exercise had a positive effect both on the level of cognitive functioning and on the probable rate of decline. Schooler also concluded that in terms of cognitive function, at some level and to some degree, "using" it often delayed the eventuality of "losing" it (Schooler, 2007). However, Salthouse replied to Schooler, maintaining that the phrases "possible" and "perhaps preferable" frequently used by Schooler in his argument did not imply that the evidence was "definitive" and "conclusive" (Salthouse, 2007). Despite the inconclusive empirical evidence, Salthouse (2006) still admitted that the mental-exercise hypothesis was a compelling analogy to the effects of physical exercise on functioning and a solid commitment to the assumption that humans could exert control over their destiny through lifestyle choices. He also mentioned that there might be some absolute threshold for functioning. He encouraged people to engage in mentally stimulating activities since there is still no conclusive evidence stating these activities have beneficial effects in delaying age-related cognitive decline, but there is also little evidence showing that they involve adverse effects. Moreover, these activities are often enjoyable and may contribute to a better quality of life, and engagement in cognitively challenging activities may serve as existence proof, too.

Since Salthouse, Schooler, and other researchers proposed the arguments about the mental-exercise hypothesis decades ago, it is necessary to address recent arguments and evidence within the last ten years. The relationship between mental exercise and cognitive reserve is worth mentioning. Cognitive reserve suggests that the brain actively attempts to cope with brain damage by using pre-existing cognitive processing approaches or by enlisting compensatory approaches (Stern, 2002). The Reserve, Resilience and Protective Factors PIA Empirical Definitions and Conceptual Frameworks Workgroup (2020) defines cognitive reserve as "adaptability (i.e., efficiency, capacity, flexibility) of cognitive processes that helps to explain differential susceptibility of cognitive abilities or day-to-day function to brain aging, pathology or insult." Therefore, cognitive reserve refers to individual differences in how people process tasks, allowing some to cope better than others with brain pathology (Stern, 2003). It is difficult to conclude whether cognitive activity is a reflective or formative indicator of cognitive reserve; however, according to Jones and colleagues (2011), mental exercise may be formative and expected to boost cognitive reserve. Furthermore, previous cognitive reserve studies suggested that higher educational and occupational levels were associated with lower risk of dementia, compensated for early pathological changes of dementia, and protected against further cognitive decline for about seven years (Amieva et al., 2014; Meng & D'Arcy, 2012). Lower risk does not imply no risk—episodic memory continues to decline in older adults during normal aging (Tromp et al., 2015). Besides, since intensive cognitive engagement can mitigate the education-related gap in performance, it is suggested that everyone should exercise mentally to some extent (Guerra-Carrillo, Katovich, & Bunge, 2017). Various studies on cognitive interventions also substantiate the mental-exercise hypothesis, with the majority demonstrating that mental exercise could indeed improve many cognitive domains and produce beneficial transfer effects to everyday tasks (e.g., Belleville et al., 2011; Chandler et al., 2016; Cotelli et al., 2012; Li et al., 2011; Uchida & Kawashima, 2008). Hence, this hypothesis may play a critical role in aiding our understanding of cognitive interventions and their relevance to intervening in episodic memory decline.

III. COGNITION-ORIENTED TREATMENTS AND COGNITIVE TRAINING

Evidence suggests that cognitive plasticity—the latent cognitive ability to acquire cognitive skills given specific contextual situations, especially under optimal ones—exists in later life (Greenwood & Parasuraman, 2010; Nyberg et al., 2021), (Mercado, 2008; Singer, Lindenberger, & Baltes, 2003). A basic assumption underlying cognitive intervention is that engaging in cognitively stimulating activities may improve or at least preserve function in the corresponding cognitive domain, as stated by the mental-exercise hypothesis and backed by several studies. These ideas indicate the possibility of improving cognitive performance in old age, and such interventions are cognition-oriented treatments.

"Cognition-oriented treatments" (COTs)—also known as "cognition-focused interventions" or "cognitive interventions" (Clare et al., 2002; Clare et al., 2004)—is an umbrella term for a variety of non-pharmacological interventions that apply several techniques to engage thinking and cognition with various degrees of breadth and specificity. The aims of COTs include enhancing or sustaining cognitive processes or addressing the impact of cognitive impairment on associated functional ability in daily life (Bahar-Fuchs, Clare, & Woods, 2013; Clare et al., 2004). Based on prior research, cognitive interventions are divided into three approaches: cognitive training, cognitive stimulation therapy, and cognitive rehabilitation (Clare & Woods, 2003). Faucounau et al. (2010) and Bahar-Fuchs et al. (2018) listed the fundamental differences among these three types in their paper. Cognitive training focuses on restoring specific cognitive processes and abilities. Cognitive stimulation improves general cognition in self-reported quality of life, well-being, and social functioning through group activities. Cognitive rehabilitation concentrates on collaborative goal-setting and optimal daily functioning levels by addressing identified specific practical difficulties related to daily life.

Cognitive training (CT)

Cognitive training is the most commonly reported form of COTs. My paper will be primarily concerned with this type of COTs. Cognitive training (CT) is often known as "brain training," "retraining," or "remediation" in the literature. CT usually consists of the repeated guided practice of organized and standardized tasks designed to train relatively well-defined cognitive processes and abilities such as memory, attention, problem-solving, speed of information processing, or language. The mechanism of CT is mainly restorative and linked to neuroplasticity. Its goal is to address cognitive functions, mitigate the impact of impairments, and improve performances in the aforementioned cognitive domains (Bahar-Fuchs et al., 2018; Bahar-Fuchs et al., 2013; Clare & Woods, 2003).

Some authors recommend categorizing CT into two subtypes: cognitive exercise and strategy training (Gates et al., 2011). Training in cognitive exercises necessitates the repeated practice of targeted cognitive abilities in a repetitions-sessions format similar to "reps-sets" regimes in physical resistance training: users typically perform several iterations of a cognitive task in one session, then move on to new tasks in the next session, and eventually return to further train the original task at a more challenging level in future sessions (i.e., staircase design) (Gates et al., 2011). Several software applications that implement computer cognitive exercises have been developed recently (Herrera et al., 2012; Schmiedek, Lövdén, & Lindenberger, 2010). Memory strategies, on the other hand, entail the instruction and practice of techniques to minimize memory impairments and improve performance and include learning and practicing strategies such as the method of loci, mnemonics, and visual imagery (Verhaeghen, Marcoen, & Goossens, 1992; Yesavage & Rose, 1983). Similar to cognitive exercises, there is now a method of loci training program developed in an innovative phone application (Sandberg et al., 2021). Therefore, both traditional and technological interventions are used in both subtypes of CT.

CT may be performed in various settings and formats. It can be offered in individual sessions (Barnes et al., 2009; Günther et al., 2003), group sessions (Belleville et al., 2006, 2011), or by family members with therapist support (Neely, Vikström, & Josephsson, 2009; Quayhagen et al., 2000). Initially delivered primarily in paper-and-pencil formats (Ball et al., 2002; Carretti et al., 2013), computerized cognitive training (CCT) programs have significantly replaced more traditional methods over the last two decades (Anguera et al., 2013; Basak et al., 2008; Brehmer, Westerberg, & Bäckman, 2012; Edwards et al., 2002; McAvinue et al., 2013). Furthermore, the difficulty level can be graded to account for individual differences in ability. The degree of specificity of the chosen tasks varies, with some interventions concentrating on particular abilities and strategies and others taking a more multimodal and holistic approach. The frequency and duration of training sessions also vary greatly.

A typical CT experiment is the ACTIVE trial of Ball et al. (2002). With 2802 older adults, it is the largest study of cognitive interventions for improving older adults' performance on particular cognitive and perceptual abilities. Researchers randomly assigned participants in this study to 1 of 4 groups: 10-session group training for memory (verbal episodic memory), reasoning (ability to solve problems that follow a serial pattern), or speed of processing (visual search and identification); or a no-contact control group. For the 3 treatment groups, researchers gave a 60% random sample 4-session booster training 11 months later. This study reported reliable cognitive improvements compared with baseline in 87% of speed-, 74% of reasoning-, and 26% of memory-trained participants immediately after the intervention period, which lasted for 2 years. Booster training also enhanced training gains in speed and reasoning interventions, which were maintained at a 2-year follow-up. Ball and colleagues detected no training impact on daily functioning at 2 years.

A fundamental underlying premise of CT is that any effects of practice on cognitive ability or process will transfer beyond the immediate training context. In other words, better performance on one task should lead to better performance on others that rely on the same cognitive process or ability. However, certain evidence does not support this assumption. Martin et al. (2011) conducted a systematic review to examine the effect of cognitive training interventions on various domains of cognitive function in healthy older people and people with MCI. This review included 36 randomized controlled trials published between 1970 and 2017. The findings indicated that CT resulted in performance gains, but none of the benefits could be attributed specifically to CT because the improvements reported did not surpass the improvement under active control conditions. There was also no indication of transfer effects to untrained tasks and underlying reference cognitive abilities, but the gains were relatively insignificant, task-specific, and inconclusive (Ackerman, Kanfer, & Calderwood, 2010; Ball et al, 2002; Boot et al., 2013; Carrion et al., 2018; Owen et al., 2010; Simons et al., 2016). Furthermore, researchers indicated that most CT studies did not employ latent variables—the shared variance of several measures (Kline, 1998)—for transfer evaluation. They also did not test for the convergent and discriminant validity of construct validity—the capacity of a test to appropriately reflect the qualities and characteristics of an intended construct (Cronbach & Meehl, 1995). These constraints prevent definitive conclusions concerning training efficacy and the benefits of brain training for everyday activities (Noack, Lövdén, & Schmiedek, 2014; Simons et al., 2016). A previous study also discovered that training improved cognitive performance in the domain trained in older adults with normal cognition but did not prevent or postpone cognitive decline or dementia (Butler et al., 2017). Hence, there is still debate about the use of CT.

Nonetheless, a large number of studies agree that CT may help enhance or maintain cognitive performance and hence delay or prevent future declines in elderly adults based on their findings (e.g., Ball et al., 2002; Belleville et al., 2006; Li et al., 2011; Verhaeghen et al., 1992; Yesavage & Rose, 1983). A study confirmed that CT improved cognitive functions in well-functioning older adults and that the improvements remained for up to 5 years after the intervention began (Willis et al., 2006). Biologically, CT is linked to changes in neural activation patterns in critical brain regions in healthy older adults (Belleville et al., 2014). Such increased brain activation may result from synaptic development and repair mechanisms prompted by repeated practice on standardized tests. However, the improvements are not confined to healthy older adults only. People with MCI are potentially an ideal target demographic for COTs since they are found to exhibit learning capacity and maintain cognitive plasticity (Schreiber & Schneider, 2007). Indeed, CT has been classified as having Level C evidence in newly released clinical practice guidelines for MCI, implying that practitioners may propose this type of cognitive intervention (Petersen et al., 2018). The issue is more problematic for patients with AD and dementia. At present, most systematic reviews of CT for people with early-stage AD or vascular dementia have yielded negative results (e.g., Bahar-Fuchs et al., 2013; Clare & Woods, 2003; Hill et al., 2017). However, according to some studies and systematic reviews, CT may enhance some cognitive and function measures in AD (Bahar-Fuchs et al., 2018; Sitzer, Twamley, & Jeste, 2006). Therefore, the application of CT in dementia remains somewhat contentious, and researchers advocated for more well-designed trials to help provide more conclusive evidence about this problem (Clare & Woods, 2003). Moreover, researchers suggested that sustained engagement in cognitively stimulating activities could impact neural structure and develop neural scaffolding (Park & Bischof, 2013; Recanzone, 2000), or multi-domain CT enhanced memory proficiency, while single-domain CT augmented visuospatial/constructional and attention abilities (Cheng et al., 2012). Currently, some issues remain unresolved regarding whether or not CT can result in improved cognitive and functional outcomes and whether or why some cognitive domains are more likely to respond to training than others. Furthermore, some researchers question whether training should target single or multiple cognitive domains and whether it should improve impaired functions or build on preserved ones (Bahar-Fuchs et al., 2018). Still, CT may help improve memory functioning in individuals with memory disorders, ranging from healthy older adults to those with dementia, thereby partially helping support continued independence and maximize the quality of life for otherwise healthy older people.

IV. TRADITIONAL INTERVENTIONS

Traditional interventions of episodic memory decline in cognitive training are interventions that do not use any means of technology in the training process or that are delivered in paper-and-pencil formats. Effectiveness of interventions can be considered in terms of improvements on test scores in episodic memory, maintenance of such improvements over time, transfer of training effects to other kinds of cognitive tasks, and generalization of effects to everyday functioning.

Participants in traditional intervention groups are usually taught mnemonic strategies for remembering word lists and sequences of items, text material, locations, faces and names, or main ideas and details of stories. They receive instruction in a strategy or mnemonic rule, exercises, individual or/and group feedback on performance, and a practice test. For example, participants are instructed to arrange word lists into meaningful categories and construct visual images and mental associations to recall specific details (Kliegl, Smith, & Baltes, 1990; Rebok & Balcerak, 1989). Another mnemonic strategy is teaching participants to visually identify a facial feature, link a phonological cue to that feature, and recall the associated name (Hampstead et al., 2008). Additionally, participants can learn texts presented with a musical association (e.g., songs, jingles) (Palisson et al., 2015). Method of loci is also a well-known mnemonics approach (Bower, 1970). Participants have to generate and memorize a set of familiar locations in their home environments. They are then instructed to make unique associations between a face, digit, or word to remember and a place in their mental map, thus facilitating encoding and recall of details. Furthermore, researchers often employ the PQRST (Preview, Question, Read, State, Test) method to teach participants the hierarchical arrangement of mnemonics (Moffat, 1992). This technique guides individuals through an ordered series of steps favoring thorough analysis and organization of texts to be learned, which improves later retention. Whatever types of mnemonic strategy are used, the exercises frequently involve laboratory-like memory tasks in which participants are presented with to-be-remembered materials (e.g., recalling a list of adjectives or sentences encountered in a laboratory setting) and memory tasks in which to-be-remembered materials are related to everyday life—e.g., recalling the details of a location or people from a birthday party (Rebok & Balcerak, 1989).

Many studies have employed mnemonic strategies in CT to address whether they benefit episodic memory in older adults. Long ago, a study explored the effects of concentration training-mnemonic training sequence (CT-MT) on episodic memory in elderly subjects (Yesavage & Rose, 1983). In this study, mnemonic training involved an associative imagery strategy designed to enhance the organization and retrieval of information. Researchers discovered significant improvements in immediate and delayed serial recall using this sequence. Transfer effects were also found on a paired-associates learning task. The ACTIVE study examining the long-term outcomes of CT in older adults also found that expression or word mnemonic training improved episodic memory compared with baseline with two-year durability (Ball et al., 2002). The magnitude of such training effects was equivalent to the deterioration expected in the elderly without dementia across 7- to 14-year intervals. The improvements found in this study were consistent with a prior finding in a mnemonic training meta-analysis of 33 studies conducted with older adults. Verhaeghen et al. (1992) found more significant pre-to-posttest increases in training groups than in control groups, suggesting that mnemonic training in the elderly enhances performance more reliably than either mere retesting or placebo treatment. Bråthen et al. (2022) investigated the effects of the mnemonic technique method of loci on episodic memory decline in older adults, indicating that memory training could lead to sustained benefits in episodic memory performance for at least 3 years and the relative increases of hippocampal volume could be maintained for some months following discontinuation of training.

Besides investigating normal older adults, many CT reviews and studies have investigated the effectiveness of episodic memory strategies in MCI patients. A study employing visual imagery, method of loci, and hierarchical organization of texts showed that the intervention effect on delayed list recall and face-name association was significant when compared to the MCI and normal elderly people controls (Belleville et al., 2006). Hampstead et al. (2008) instructed eight patients with MCI during three-hour long sessions to use episodic memory strategies with 45 face-name pairs. For trained face-name pairs, participants significantly improved recognition accuracy and reaction times. Moreover, during the follow-up, the benefits of training were extended to untrained associations, and the gains persisted for one month. A meta-analysis of 11 CT studies also discovered that patients with MCI received minor gains in episodic memory and benefited from the CT in the follow-up data (Li et al., 2011). The findings of the studies above are supported by biological evidence from Belleville et al. (2011), who also suggested that episodic memory strategies may be utilized as an intervention for people with MCI. Belleville and her colleagues studied 15 MCI patients and 15 healthy elders. They detected significant neural activity changes in both MCI and healthy participants after training, as well as increased brain activation that correlated with improved performance in long-term episodic memory abilities. The activations included a vast network of frontal, temporal, and parietal regions. Researchers also tested the hypothesis that the benefit observed in episodic memory is specific to music (Palisson et al., 2015). Main findings showed that sung texts were better remembered than spoken texts, both immediately and after a retention delay, for both groups; the musical benefit was robust, being observed in most AD patients; and the nonmusical association might also facilitate verbal learning but to a lesser extent. The results indicated that training older adults with music mnemonics positively affected episodic memory in AD, and this advantage appeared to be music-specific.

In addition to enhancing episodic memory, previous research found improvements in other measures after training. A significant pre-post-effect was found on measures of subjective memory and well-being of participants (Belleville et al., 2006). Patients with MCI improved considerably in overall self-ratings after training with moderate benefits in anxiety, functional ability, and mild benefits in memory problems, quality of life (QoL), activities of daily living (ADL), and depression (Li et al., 2011).

However, the findings of the abovementioned studies do not concur with the results of Unverzagt et al. (2000). They discovered that the elderly with poor baseline memory performance improved more than controls in reasoning and speed-of-processing but not in episodic memory measures. Furthermore, the studies above have several limitations that are worth mentioning. First, some studies did not randomize group assignment or did not use a control group (Belleville et al., 2006, 2011; Hampstead et al., 2008; Li et al., 2011). Consequently, researchers could not entirely rule out the possibility that the effects were caused by placebo or other confounding factors. Second, the improvements found in most of the studies did not clarify the transfer effects of the intervention or lacked transfer effects to real-world outcomes—they were rather domain-specific (Ball et al., 2002; Belleville et al., 2006; Li et al., 2011; Verhaeghen et al., 1992). Even if researchers discovered transfer effects to non-trained memory tasks, those effects were observed in younger adults, not older adults (Bråthen et al., 2022). This is a crucial issue for the practical significance of an intervention that future studies and technological innovations may improve. Third, most of the studies presented only dealt with normal older adults and MCI patients—only one (or few) explored the intervention in people with AD (Palisson et al., 2015). Hence, future research should investigate ways or formats of CT that produce and maintain training benefits in individuals with AD.

V. TECHNOLOGICAL INTERVENTIONS

To increase the ecological validity, construct validity, and generalization of memory assessments and interventions, researchers have investigated several potential interventions incorporating technological elements for episodic memory decline in older adults. Computerized cognitive training, video games, and virtual reality are typical examples of such technology interventions.

Computerized cognitive training (CCT)

Computerized cognitive training (CCT) is an intervention in which individuals can access cognitive exercises from computers or mobile devices using commercially available or purpose-built CT packages (e.g., Buschkuehl et al., 2008; Gonzalez-Palau et al., 2014; Günther et al., 2003; Herrera et al., 2012; McAvinue et al., 2013). CCT can target many domains, but the most popular types used to intervene in episodic memory are memory CCT and multidomain CCT.

Memory CCT is an intervention that focuses primarily on improving memory through memory tasks. By using *Cognition I*, Günther et al. (2003) trained 19 older adults with MCI in one 45-minute session per week for 14 weeks and found significant improvements in long-term memory. Training older adults with visual WM CCT programs can also effectively improve episodic memory through near transfer effects. Buschkuehl et al. (2008) trained 39 older adults (mean age = 80 years) twice a week over 3 months. They discovered that CCT resulted in substantial gains in the performance in the visual WM tasks but, to a lesser degree, in a visual episodic memory task (visual free recall). Nonetheless, the above findings contradict those of McAvinue et al. (2013), who found that older trainees showed a significant, not mild, transfer effect in episodic memory on immediate and delayed word recall tasks.

The utility of multidomain CCT is also examined. This type of CCT simultaneously targets numerous cognitive domains. Herrera et al. (2012) performed a 12-week memory-attention-based training study with 22 aMCI participants who received twenty-four 1-hour sessions. Although only recognition was trained, both episodic recognition and recall processes improved significantly across participants, demonstrating that training gains were transferred between different mechanisms of episodic memory. Moreover, the authors found that improved recognition or recall remained for at least 6 months following training. Finn & McDonald (2011) also found improvements in episodic memory for older people with MCI using computerized exercises that target a variety of cognitive functions, including attention, processing speed, visual memory, and executive functions. Klusmann et al. (2010) trained healthy older women for 6 months with diverse and multifaceted themes, including creative matters and coordinating memory tasks. They found that naturalistic episodic memory function increased while episodic memory in the classical experimental condition was maintained for the CCT group. Although Miller et al. (2013) found no significant group differences in immediate memory, they found significant improvements in delayed memory after training the testing group with *Brain Fitness, a* structured, computerized brain-training program that trains individuals in six cognitive domains. These positive findings demonstrate that multidomain CCT holds promise as an intervention for episodic memory decline in older adults.

CCT may also prove effective when combined with other training components or programs. A program that comprises both the cognitive training component (CTC) and physical training component (PTC) may benefit older adults. Gonzalez-Palau et al. (2014) trained healthy and MCI subjects three times per week for 12 weeks using the *Long Lasting Memories* program and discovered significant improvements in episodic memory following training. For CTC, researchers used *Gradior Software*, a multidomain CCT program that includes attention, perception, episodic memory, and working memory tasks. For PTC, researchers employed *FitForAll*, a novel, low-cost physical training platform. Another study combined computerized process-based cognitive training (pb-CT) with reminiscence therapy (RT). Computerized pb-CT involves repetitive cognitive exercises without explicit strategies, while RT consists of recalling personal past events supported by memory triggers. Barban et al. (2016) found that this intervention improved episodic verbal memory outcomes in patients with mild Alzheimer's disease (mAD), MCI, and healthy elderly subjects. At the follow-up, both MCI and healthy elderly participants maintained these benefits. Therefore, the combination of CCT with other training components or programs may be a promising solution for older adults.

Video games

Video games share some features with CCT: both target various domains, necessitating coordination of several cognitive and perceptual abilities (Kueider et al., 2012). Although many people would group video games with CCT, they are actually different. In contrast to CCT, video games are less focused on specific cognitive abilities but instead have higher motivations (i.e., a mission or goal to achieve), which can contribute to affective well-being (Green & Bavelier, 2012; Johannes, Vuorre, & Przybylski, 2021). Furthermore, researchers have found that cognitive engagement and exercise can strengthen scaffolding, a normal process that occurs across the lifetime that uses and develops neural circuits to safeguard cognitive function in the aging brain (Park & Reuter-Lorenz, 2009). Because video games primarily aim to provide satisfaction, enjoyment, and sustained player engagement (Anguera & Gazzaley, 2015; Klimmt et al., 2009), they may trigger a secondary route to cognitive enhancement.

There are several approaches for categorizing video games, but in psychology, they are often classified as non-action and action video games (e.g., Ballesteros, 2014; Green & Bavelier, 2007; McDermott, 2014; Toril et al., 2016). Action video games require players to simultaneously juggle various activities in a relatively short time and in unpredictable settings, necessitating different aspects of visual processing and attentional control (Green & Bavelier, 2003, 2006). Although some researchers have employed action video games to train older adults, the qualities above lead to lower intervention compliance and a less pleasurable experience for older adults when compared to non-action video games (Boot et al., 2013). Since non-action video games are more appropriate for the elderly, researchers have extensively studied their impact on several cognitive domains, especially episodic memory.

Ballesteros et al. (2014) conducted a non-action video game training study using 10 video games from *Lumosity*, a web-based CT platform (Sternberg et al., 2013). The games involved were *Speed match*, *Memory matrix*, *Rotation matrix*, *Face memory*, *Memory match*, *Money comb*, *Lost in migration*, *Space junk*, *Raindrops*, and *Chalkboard*. In both immediate and delayed visual episodic memory measures (Family Pictures I and II), the trained group outperformed the control group. Toril et al. (2016) also conducted a longitudinal intervention study with older adults using a series of video games selected from *Lumosity*: *Speed match*, *Memory matrix*, *Rotation matrix*, *Face memory*, *Money comb*, and *Lost in migration*. Trainees outperformed controls on immediate and delayed visual episodic memory tasks, comparable to the findings of the study conducted by Ballesteros et al. (2014). Transfer effects on these tasks were maintained after a 3-month no-contact follow-up period. Savulich et al. (2017) also evaluated the effects of "gamified" CT on performance improvement, near transfer, and maintenance of enjoyment and motivation. This study examined patients with aMCI, the state of MCI in which memory loss predominates and is linked to an increased risk of progression to AD (Griffith et al., 2006). Over 4 weeks, the testing group participated in eight 1-hour sessions of supervised CT using *Game Show* on iPad, a novel learning and memory game designed to improve episodic memory. The researchers discovered significant improvements in episodic memory and near transfer to visuospatial abilities.

Virtual reality (VR)

Virtual reality (VR) immerses users in a dynamic 3D virtual world, allowing them to interact with that stimulus through cognitive and sensorimotor tasks (Loomis, Blascovich & Beall, 1999). One significant advantage of VR is that it provides real-time immersive, interactive, multi-sensory graphics that immerse users in the model world and allow direct manipulation rather than external observation of the environment (Gigante, 1993). Including examples of daily cognitive demands enables VR to sample the integrity of cognitive functions and their related transfer effects.

Based on the characteristics of virtual reality, Man, Chung, & Lee (2012) adopted a within-group design to assess the effectiveness of VR-based memory training for older adults with questionable dementia, a memory condition that lies between the "normal" and "dementia" categories (Devanand et al., 1997). The researchers randomly assigned participants to a VR-based or a therapist-led memory training group. Both groups demonstrated positive training effects in episodic memory, with the VR group showing more remarkable improvements in memory strategies usage and immediate and delayed recall of episodic memory. Surprisingly, the VR group had a higher percentage of older adults with lower levels of education but showed greater improvements than the non-VR group (higher percentage of better education), thus possibly widening the application of VR to different populations.

Furthermore, VR technology enables active navigation, in which the user actively explores the environment by manipulating items (Sauzéon et al., 2011). Jebara et al. (2014) studied the impact of training several forms of virtual navigation on episodic memory in older adults. With a common task to navigate a virtual city, participants were randomly assigned to one of four experimental conditions: (1) the passive condition, where subjects were immersed as passengers in a car with no active navigation or decision making; (2) the itinerary control, where subjects were immersed as passengers and chose the itinerary but did not drive the car; (3) the low navigation control, where subjects moved the car on rails, but the itinerary was fixed; and (4) the high navigation control, where subjects drove the car using the usual drive mode, but the itinerary was fixed. Participants were then instructed to memorize as many events as they could in the virtual world along with their factual (what), spatial (where), and temporal (when) details. They discovered improved episodic memory in older adults in low navigation and itinerary control conditions. Plancher et al. (2012) also found that active exploration with VR improved recall of central and allocentric spatial information, as well as binding for healthy older adults, patients with aMCI, and patients with AD. These results are consistent with previous findings that moderate, non-demanding active navigation control as well as decision making can significantly enhance episodic memory (Bakdash, Linkenauger & Profitt, 2008; Brooks et al., 1999; Gaunet et al., 2001; Sauzéon et al., 2011), thus promoting the use of VR as a viable intervention for episodic memory.

The above studies investigating computerized cognitive training, video games, and virtual reality suggest that training older adults with these technological interventions can be an effective means of enhancing episodic memory function. However, aside from limitations shared with those of traditional interventions—such as small sample size, lack of control group(s), demographic issues, or inability to separate confounding factors—the results from the above studies conflict with other findings. For example, Schmiedek et al. (2010) did not detect strong latent levels of episodic memory in older adults after training participants with PC-based practice tests of perceptual speed, working memory, and episodic memory. Legault et al. (2011) similarly used computers to deliver cognitive training to participants but found no statistically significant differences in 4-month changes in composite episodic memory scores. Nevertheless, systematic reviews and meta-analyses support technological interventions' effectiveness in improving episodic memory after training (Ge et al, 2018; Lampit, Hallock, & Valenzuela, 2014). There are still conflicting results regarding far-transfer effects of episodic memory, though. Some research discovered those effects (Herrera et al., 2012; Klusmann et al., 2010; Savulich et al., 2017; Schmiedek et al., 2010; Toril et al., 2016), while others did not mention them (Brehmer et al., 2012; Gonzalez-Palau et al., 2014; Günther et al., 2003). For maintenance effects, the same discrepancies occur. Maintenance effects were reported in some studies at follow-up (Barban et al., 2016; Klusmann et al., 2010; Toril et al., 2016), whereas others were not (Man et al., 2012; McAvinue et al., 2013). This may be explained by a low training frequency, a brief training duration, or a short follow-up period. In addition, although there have been relatively few studies investigating the effects of technological interventions on AD populations, the improvements found by using pb-CT combined with RT (Barban et al., 2016) and VR (Plancher et al., 2012) hold promise for future research. Moreover, CCT had no discernible impacts on self-rating measures of mood, subjectively experienced aging, everyday memory functioning, and attention slips (Finn & McDonald, 2011; Günther et al., 2003; McAvinue et al., 2013). Still, it is important to stress that researchers found considerably higher satisfaction ratings in trained participants (McAvinue et al., 2013), a trend toward improvement in affection and assertiveness (Ballesteros et al., 2014), and high levels of enjoyment and motivation maintained throughout all hours of gameplay (Savulich et al., 2017). Plancher et al. (2012) also found stronger correlations between the patients' daily memory complaints and their performances on the virtual test than on the traditional memory test. Such positive secondary outcome measures indicate that technological interventions not only enhance episodic memory but also improve some aspects of well-being.

VI. ANALYSIS AND DISCUSSION

To assess how well technological interventions go above and beyond the impact of traditional ones, it is necessary to investigate their effectiveness before and after episodic memory impairment as well as their feasibility and applicability in older adults. It is also crucial to determine how cognitive training sessions with technological interventions are designed to achieve their best.

How may technological interventions prevent younger adults from developing episodic memory decline?

Although most researchers agree that episodic memory decline typically begins around 60 years old (Rönnlund et al., 2005; Schaie, 2005), some argue that gradual age-related declines can occur as early as 31 years of age (Cansino, 2009). While there is no consensus about this issue, there is no harm in preventing later episodic memory deterioration when people are young. Cognitive training can help prevent this decline. Bråthen et al. (2022) employed traditional cognitive training for 53 younger adults and observed relative increases in hippocampal volume even after 10 weeks of no training, which is a good indication of improved episodic memory, according to Pohlack et al. (2014). Training gains on memory performance can prevail for at least 3 years, and the young also showed an immediate near-transfer effect on a word-association task. Besides traditional cognitive training, computerized cognitive training programs may also work with younger adults, as evidenced by the long-term positive transfer effects on the latent factor of working memory, episodic memory, reasoning, and fluid intelligence (Schmiedek et al., 2010). Therefore, such cognitive training in young adulthood would equip younger adults with cognitive processing approaches to cope better with brain damage (Stern, 2003) and lower the risk of dementia (Amieva et al., 2014; Meng & D'Arcy, 2012), according to the mental-exercise and cognitive reserve hypothesis.

How may technological interventions help reduce the impact of episodic memory decline once the decline has been detected?

The usefulness of an intervention depends on both the occurrence of transfer effects and the durability of the training effects. Researchers have shown that most traditional cognitive training programs yielded improvements in episodic memory performance (e.g., Ball et al., 2002; Belleville et al., 2006, 2011; Bråthen et al., 2022; Hampstead et al., 2008; Li et al., 2011; Palisson et al., 2015; Yesavage & Rose, 1983; Verhaeghen et al., 1992). However, the main problem with traditional interventions is the absence of transfer effects (Ball et al., 2002; Belleville et al., 2006; Bråthen et al., 2022; Li et al., 2011; Verhaeghen et al., 1992). Similar to traditional interventions, enhanced episodic memory performance for older adults is also found in most studies of CCT, video games, and VR. These technological interventions, on the other hand, may help address the limitations of traditional ones. Through the coordination of several cognitive and perceptual abilities, the strengthening of scaffolding through cognitive engagement and exercise, and the enablement of direct manipulation and active navigation, technological interventions found transfer effects to real-life episodic memory, other cognitive domains, and everyday functioning (e.g., Herrera et al., 2012; Klusmann et al., 2010; Savulich et al., 2017; Schmiedek et al., 2010; Toril et al., 2016). Maintenance effects were similar for both types of interventions, with the durability ranging from one month to 3 years (Ball et al., 2002; Bråthen et al., 2022; Hampstead et al., 2008; Li et al., 2011). These findings imply that CCT, video games, and VR are viable interventions to reduce the impact of episodic memory decline via improved transfer effects and durability.

How feasible and applicable are technological interventions?

Assessment of age effects of episodic memory and early diagnosis of pathological aging is critical for both preventing and mitigating the impact of decline because they can help slow the progression to a more severe memory profile and identify the most effective and appropriate interventions for each aging population. Transfer effects are also essential since they reflect how well the interventions work in everyday life, rather than only in experimental settings. Most episodic memory training studies employ classic neuropsychological tests, which usually involve pen-and-paper, verbal or computer-based tasks to assess both verbal and visual episodic memory. For verbal episodic memory, participants will often be asked to remember a list of words or recall a story after memorization (immediate recall) and after a delay (delayed recall) on tests such as the Hopkins Verbal Learning Test or Rey Auditory Verbal Learning Test (e.g., Ball et al., 2002; Barban et al., 2016). For visual episodic memory, participants will often be asked to recall face-name associations or report the differences between two almost identical pictures (e.g., Belleville et al., 2006; Buschkuehl et al., 2008; Hampstead et al., 2008). However, these classic neuropsychological tests only have a limited ecological validity when predicting subjective memory complaints and everyday cognitive functioning (Chaytor & Schmitter-Edgecombe, 2003; Farias et al., 2003). Their construct-driven approaches—the evaluation of abstract constructs from a robust theoretical paradigm without any reference to real-life performance or behavior—could explain this (Parsons et al., 2015). As a result, function-led approaches—the direct observation of behavior to define a more ecologically valid neuropsychological testing—have gradually replaced the traditional ones (Parsons et al., 2015). One example of this approach is the Rivermead Behavioral Memory Test (Wilson, Cockburn, & Baddeley, 1985), which comprises a series of daily-life tasks to evaluate episodic memory. However, both the construct-driven and functional-led approaches, as well as the methods and designs used for traditional cognitive training, do not involve noisy environments or multi-dimensional materials. They instead adhere to experimental and clinical contexts, in which participants complete their tasks in quiet conditions, receive clear task instructions, encode unidimensional material most of the time, and focus their attention on the text (Lecavalier et al., 2020). This shortcoming renders traditional interventions unsuitable in terms of ecological validity.

While traditional cognitive training platforms are effective in certain aspects, they have significant limitations in terms of wide-scale distribution, as these platforms often require participants to meet as a group in a designated setting for paper-and-pencil training sessions taught by a qualified professional (e.g., Ball et al., 2002; Belleville et al., 2006, 2011). Limiting training to small-group didactic sessions with a professional trainer may limit the number of the elderly who can access the training (Rebok, Carlson, & Langbaum., 2007). Because episodic memory deterioration occurs in practically all adults as they age, there is a greater need for population-level alternatives to traditional group-based memory training. The growing demand for intervention options requires development of cost-effective, self-administered, and flexible training platforms that are widely accessible to the general population. Therefore, it is necessary to find alternative interventions that could capture the ecological validity, construct validity, complexity, and feasibility aspects. These issues could be improved by using CCT, video games, and VR.

CCT can target various domains such as memory, attention, speed of processing, or executive functions, both individually and simultaneously. This would result in a higher ecological validity and may help find transfer effects that were shortcomings in traditional interventions. Furthermore, whereas earlier versions of CT tended to be delivered in an inflexible "one size fits all" approach, CCT could tailor the program to the patient's neuropsychological pattern, pace, and needs to reach home-bound or institutionalized older adults based on individual cognitive profile and adaptive difficulty level (Bahar-Fuchs et al., 2018; Faucounau et al. 2010; Kueider et al. 2012; Peretz 2011). In individual sessions of memory CCT in an elderly residential home, Günther et al. (2003) interspersed simple tasks with guaranteed success with more adaptive complex tasks to avoid boredom and high frustration levels and allowed subjects to choose exercises based on their preferences to maintain a high level of motivation. Herrera et al. (2012) also modified parameters such as the time of image presentation, the number of pictures or words to recall, the choice of the target, or the presence of a distractor to increase or decrease the difficulty of each task. As patients progressed between sessions, these parameters were adjusted so that the tasks would continue to challenge their abilities without causing them distress when they failed. Furthermore, CCT allows the user to make an immediate objective comparison with previously collected data, assisting in the establishment of a systematic training plan by providing instant value-free feedback on performances or activities sessions (e.g., Barban et al., 2016; Gonzalez-Palau et al., 2014; Günther et al., 2003; Herrera et al., 2012). Additionally, because CCT involves less face-to-face training than traditional interventions, administrative expenses could be significantly lowered, rendering it a more cost-effective alternative with the potential for wider distribution among older adults (Kueider et al. 2012).

Video games are promising as a training intervention strategy because they incorporate many features of successful cognitive training paradigms such as task variability, feedback, adaptivity, and motivation (Green & Bavelier, 2008). One of the most popular web-based CT platforms is *Lumosity*, which comprises cognitive training exercises, assessments, and an integrated training system aimed at improving users' cognitive abilities (Sternberg et al., 2013). Like multidomain CCT, *Lumosity* targets various cognitive domains such as speed of processing in *Speed match*; memory in *Memory matrix*, *Rotation matrix*, *Face memory*, *Memory match*, *Money comb*; attention in *Lost in migration*, *Space junk*; problem-solving in *Raindrops*, and *Chalkboard*. Lumosity also provides users with feedback about their brain "fitness," updating their fitness status when performance on practiced tasks improves and offers small incremental increases in task difficulty depending on their scores through several levels. The same applies to *Game Show* (Savulich et al., 2017), a game developed to strengthen episodic memory. Its objective is to collect as many gold coins as possible. In each round, the player is challenged to connect different geometric patterns with different spatial locations. Each correct answer earns the player more coins until completion or after 6 attempts. Through aesthetically appealing displays, engaging music, and different levels with varying difficulty, video games such as *Lumosity* or *Game Show* induce higher motivations and provide satisfaction, enjoyment, and sustained player engagement for older adults.

VR also has several advantages that may improve existing neuropsychological assessment protocols and overcome many of the limitations of traditional methods. Lecavalier et al. (2020) found that the construct validity of virtual reality could be appropriate for assessing episodic memory for older adults because it is sensitive to age-related differences, and there is a positive correlation between performance in the VR task and performance on a traditional memory task. Ouellet et al. (2018) found that the performance on the *Virtual Shop* was slightly significantly correlated with the performance on the questionnaire, the traditional episodic memory, and executive tasks. Parsons & Rizzo (2008) demonstrated that the Virtual Reality Cognitive Performance Assessment Test measures a capacity commensurate with traditional memory measures, providing a unique opportunity to research memory function in an ecologically valid context. These findings align with prior ones reported in other virtual reality training studies or reviews concerned with older adults (Farias et al., 2003; Plancher et al., 2012; Schultheis et al., 2002). They discovered that the dynamic, interactive 3D stimuli within an immersive environment allow VR tests and interventions to reflect both objective and subjective cognitive deficits by testing rarely explored specific factual, temporal, or spatial episodic memory deficits both simultaneously and multimodally without deliberate memorization. VR could also integrate virtual human representations (avatars) to address episodic memory during social interaction (Rizzo et al., 2004). These benefits over traditional cognitive training programs allow VR to create a more ecologically valid assessment, capture a more comprehensive performance, and provide a more naturalistic or intuitive performance record for review and analysis. Accordingly, VR could characterize episodic memory profiles—including healthy older adults, patients with aMCI or MCI, and patients with early to moderate AD—and potentially resolve the transference issue of the cognitive benefits to everyday life.

Besides addressing the issues of ecological validity and transference effects, according to Rizzo et al. (2004), VR also has the ability to:

- provide instant performance feedback in a variety of formats and sensory modalities;
- pause assessment, treatment, and training for discussion and/or integration of other methods;
- provide safe testing and training environments that minimize the risks due to errors;
- increase motivation by incorporating gaming components into VR;
- allow professionals easy access through low-cost libraries of virtual environments; and
- allow clients to do self-guided independent testing and training when deemed appropriate.

What possible problems arise for older adults when using technological interventions?

The most common problems associated with technological interventions for episodic memory deterioration are technological illiteracy and dissatisfaction among older adults. Lee, Chen, & Hewitt (2011) discovered positive correlations between age and intrapersonal, interpersonal, and functional constraints, suggesting that seniors experience increasing difficulty working with computer-based technologies when growing old. However, this finding contradicts those of other researchers. Seals et al. (2008) concluded that seniors are not technology adverse but rather prefer technology that supports activities that they are already familiar with and technology that has great usability and is not frustrating. Schmiedek et al. (2010) found high rates of successful study completion, good perceived changes in everyday cognitive functioning, and positive experience ratings among older adults, indicating that they could complete extensive practice. Kueider et al. (2012) examined results from individual studies in their systematic review and also indicated that older adults do not need to be technologically savvy to benefit from training. Researchers also discovered significantly higher levels of contentment, affection, assertiveness, enjoyment, and motivation among trained older adults (Ballesteros et al., 2014; McAvinue et al., 2013; Savulich et al., 2017). Therefore, even if older adults might not have had much exposure to technology, CCT, video games, and virtual reality do not appear to impact their ability to feel comfortable in virtual environments, to experience similar feelings and reactions as in real-life situations, and to enjoy performing cognitive tasks in that sort of setting.

Another problem with technological interventions is possible cybersickness that occurs while immersed in a virtual environment—such as pallor, dizziness, nausea, headaches, oculomotor dysfunction, and general disorientation (Kennedy et al., 1993). Arns & Cerney (2005) found that older adults suffer more severe cybersickness than younger ones. However, in various studies, participants were trained with different games of VR such as *Virtual Shop*, or different types of VR such as image-based rendering virtual environment approach, head-mounted-display and demonstrated little to no experience of cybersickness (Appel et al., 2020; Benoit et al., 2015; Lecavalier et al., 2020). Other researchers also consider the relationship between cybersickness and presence—the subjective experience of being in one place or environment while physically being in another (Witmer & Singer, 1998). Lecavalier et al. (2020) saw positive presence ratings and minor cybersickness symptoms following immersion. Weech, Kenny, & Barnett-Cowan (2019) conducted a systematic review of 20 papers and identified a negative correlation between presence and cybersickness: participants experienced greater presence but less cybersickness. This finding is substantiated by Dilanchian, Andringa, & Boot (2021), who discovered the same relationship among older adults. The sense of presence, which suppresses cybersickness and directs attention away from intrusive elements such as sensory conflict, could explain these surprising findings (Cooper et al., 2018). Furthermore, as is common in many commercial VR programs, participants were stationary for all VR experiences and navigated using the "teleport" function or manipulated items such as joysticks and controllers, which allowed for immediate movement from one location to another (Dilanchian et al., 2021). This may account for low rates of cybersickness. Concerning the underlying reason for older adults' lower rates of cybersickness compared to those of younger adults, one hypothesis to consider is that the less aggressive and more tentative interaction of older adults with the VR environments, making fewer and slower head and body movements, resulting in less cybersickness.

How should practitioners design sessions of cognitive training with technological interventions for older adults?

Although technological interventions demonstrate numerous benefits over traditional ones, evaluating how the sessions with these interventions should be structured to suit older adults while avoiding counterproductive effects is still advisable. When conducted with older adults, short training interventions with a small number of training sessions provided better outcomes and adherence levels than protracted regimes with a large number of training sessions (Toril et al., 2014, 2016). They may prevent exhaustion and demotivation after many training sessions and possibly avoid cybersickness symptoms (Lecavalier et al., 2020). Lampit et al. (2014) similarly concluded that group-based sessions were more effective than unsupervised at-home training regimes, and training more than three times a week was ineffective. Additionally, Turunen et al. (2019) stated that the level of adherence may be higher for single-domain CCTs. Previous use of computers, better memory, marital/cohabitation status, and favorable study expectations were also independently associated with a higher likelihood of starting the CCT. Several studies suggest the presence of the experimenter may have an influence on participant training interest (Borella et al., 2010; Man et al., 2012). In addition to feedback provided by technological devices, the presence of human-human interaction may also raise interest in the training activities, aid in monitoring performance progress, reduce anxiety, and foster higher confidence. The experimenter may also provide personalized assistance in the form of giving study participants more detailed feedback than a device is capable of providing, or fundamentally altering their self-held beliefs about efficacy and controlling their memory. This would help participants feel more satisfied with their memory performance following training and contribute to the overall outcomes (Man et al., 2012). In fact, multiple studies with the experimenter present throughout the training session demonstrated substantial gains in episodic memory as well as transfer and maintenance effects (e.g., Ballesteros et al., 2014; Gonzalez-Palau et al., 2014; Jebara et al., 2014; Man et al., 2012; Toril et al., 2016).

Future directions

Since the maintenance effects found when using conventional and technological interventions of cognitive training for episodic memory were similar, future research should investigate the reason for this similarity and explore how technological interventions can improve these effects. Furthermore, in most reviewed studies, the experimenters would only administer the training process; they did not interview participants about how they felt about their memory before, immediately after, and at follow-up. Therefore, it would be interesting for future studies to implement these interviews and ascertain their impact on participants' episodic memory and other secondary outcome measures. Additionally, although various studies have found effects of technological interventions on measures such as well-being, satisfaction, and affection, there are still relatively few studies exploring those effects on quality of life, highlighting the need for more studies to address this issue. The same applies to multi-modal interventions. Future research should also examine the combination of CCT, video games, and VR, as well as the combination of technological interventions with traditional ones as well as other pharmaceutical, exercise, cognitive rehabilitation, or cognitive stimulation interventions. Researchers should also look into the effectiveness of individual versus group sessions when using technological interventions for episodic memory deterioration.

VII. CONCLUSIONS

Episodic memory decline has attracted decades of research to find suitable interventions for older adults. Not limited to only traditional cognitive training, researchers have expanded the literature by testing the effects of various technological interventions such as computerized cognitive training, video games, and virtual reality on older adults' episodic memory. The recent findings on technological interventions, including their applicability and feasibility, impact on episodic memory improvements, high ratings on secondary outcome measures, as well as transfer and maintenance effects, may help render technology suitable to both prevent and reduce the impact of episodic memory decline. Therefore, technological interventions can exceed the impact of traditional ones in various ways, proposing more alternatives for healthy older adults, patients with MCI, and possibly patients with AD to choose from when addressing the problematic issue of aging.

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