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Digital Compensatory Cognitive Training for Older Adults with Memory Complaints

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ABSTRACT

Many older people experience everyday memory complaints which can be a precursor condition to mild cognitive impairment and dementia. Research has consistently shown that compensatory cognitive training (CCT) benefits cognition in older adults. Providing CCT in a computerized format makes it more accessible and reduces its costs. We studied a newly developed digital CCT for older adults with everyday memory complaints that is multi-factorial and based on empirically supported techniques to improve memory. 55 older adults with self-reported everyday memory complaints participated in a study with outcomes assessed at baseline and post-intervention. We found that participants in the experimental condition improved significantly on the main objective outcome measure assessing associative memory compared to participants in a waitlist control condition. Specifically, after correcting for learning effects, 28% of participants in the experimental condition showed a reliable improvement. No effects were found on other objective outcome measures, most notably those assessing transfer to novel tasks. Participants in the experimental condition scored higher on measures of memory satisfaction, use of internal memory strategies, and quality of life. These findings contribute to existing knowledge on CCT by providing partial evidence for the efficacy of a digital CCT for older adults with everyday memory complaints. We recommend the use of digital CCT for older adults who experience memory complaints in their everyday life, but who do not qualify for medical treatment. Particular attention needs to be given to enhancing transfer of the learned strategies to everyday life.

Introduction

Many older people experience everyday memory complaints as they get older. Common everyday memory complaints include forgetting names (Bolla, Lindgren, Bonaccorsy, & Bleecker, 1991; Leirer, Morrow, Sheikh, & Pariante, 1990; Lovelace & Twohig, 1990), forgetting to do an intended activity in the future such as appointments or taking medication (Bolla et al., 1991; Burkard...
et al., 2014; Leirer et al., 1990; Lovelace & Twohig, 1990; Smith, Della Sala, Logie, & Maylor, 2000), and misplacing objects (Bolla et al., 1991; Leirer et al., 1990). These everyday memory complaints can be caused by various factors, including stress, fatigue, and normal age-related cognitive decline, most importantly episodic memory decline, which is caused by a number of structural and functional changes in the aging brain (Bishop et al., 2010). In addition to biological changes, concerns about cognitive decline play a role in everyday memory performance. Research has shown that normal age-related changes in memory performance can lead to decreased levels of confidence and increased worrying, which in turn exacerbate everyday memory complaints (Bolla et al., 1991; Valentijn et al., 2005; West, Bagwell, & Dark-Freudeman, 2008). Thus, both biological and psychological factors contribute to everyday memory complaints in older adults.

Everyday memory complaints can be a precursor condition to mild cognitive impairment (MCI) and dementia. Research has shown that everyday memory complaints and subjective cognitive decline (SCD) can lead to MCI and dementia and may in fact represent the first symptomatic manifestation of dementia (Jessen et al., 2014; Van Harten et al., 2018). Given the rapid increase in the proportion of older individuals in our population and the tremendous societal impact of cognitive decline and dementia, the scientific interest in non-medical interventions has increased in recent years. These interventions seem to be particularly beneficial for older adults who experience everyday memory complaints that may worsen over time, but who still have relatively preserved cognitive function and typically live independently (Jessen et al., 2014). For older adults who experience everyday memory complaints, the goal of non-medical interventions should be on improving overall well-being, delaying progression of cognitive impairment, and prolonging independence. There is evidence that non-pharmacological interventions such as cognitive and physical exercise programs can improve well-being and cognitive functioning in healthy older adults (Candela, Zucchetti, Magistro, & Rabaglitti, 2015; Fritsch et al., 2014; Hsieh et al., 2018; Hu et al., 2021; Shtompel, Ruggiano, Thomlinson, & Fant, 2020; Smart et al., 2017; Tommerdahl, Biggan, McKee, Nesbitt, & Ray, 2021).

Research has consistently shown that compensatory cognitive training (CCT) in particular has beneficial effects in healthy older adults and people with MCI (e.g. Belleville et al., 2006; Brom & Kliegel, 2014; Cavallini et al., 2014; Chandler et al., 2019; Fairchild & Scogin, 2010; Frankenmolen et al., 2018; Gross et al., 2013; Hampstead et al., 2012; Hastings & West, 2009; Horning, Young, Myhre, Osato, & Schantz Wilkins, 2016; Hu et al., 2021; Kinsella et al., 2016; Troyer, 2001; Valenzuela et al., 2003; Vandermorris, Au, Gardner, & Troyer, 2020; Woolverton, Scogin, Shackelford, Black, & Duke, 2001). CCT involves teaching cognitive strategies over the course of several sessions aiming at an incorporation of these strategies into daily
routines, thereby improving individuals’ everyday functioning. CCT addresses different cognitive functions and utilizes preserved abilities to compensate for age-related cognitive impairment. One of the underlying reasons for the effectiveness of CCT is that it utilizes cognitive functions that are typically well preserved in patients with mild cognitive impairments such as visual processes and semantic memory (Ally et al., 2009; Bäckman, 1996; Belleville et al., 2006). Moreover, CCT has been found to lead to increased activation in brain networks involved in memory and improvements in structural and functional brain network organizations (Chapman et al., 2015; Hampstead et al., 2012; Dresler et al., 2017; Valenzuela et al., 2003) suggesting that CCT can positively affect age-related structural and functional brain changes.

As has been pointed out by various researchers, metacognition, motivational aspects, and the ability to transfer knowledge learned during the CCT to real life situations play an important role in the efficacy of a CCT (Belleville et al., 2006; Bottiroli, Cavallini, Dunlosky, Vecchi, & Hertzog, 2013; Carretti, Borella, Zavagnin, & De Beni, 2010; Chandler et al., 2019; McDaniel & Bugg, 2012; Pike et al., 2018; Valentijn et al., 2005; Vandermorris et al., 2020; West et al., 2008). To address these aspects, it is therefore essential to include psychoeducation and transfer training. Psychoeducation focuses on increasing an individual’s knowledge of their own cognitive functioning (i.e. metacognition) as well as general knowledge on cognitive functions and how they are influenced by different factors such as aging, lifestyle and mood (Fairchild & Scogin, 2010; Troyer, 2001; Valentijn et al., 2005; West et al., 2008). Transfer training fosters use of the learned cognitive strategies in everyday life and includes training to recognize situations in which the learned strategy can be used (McDaniel & Bugg, 2012; West et al., 2008). The majority of studies exploring the efficacy of CCT in healthy older adults have used multifactorial approaches combining strategy training and psychoeducation, whereas transfer training is rarely explicitly included. Studies have found that CCT improves different aspects of episodic memory including prospective memory (Brom & Kliegel, 2014; Kinsella et al., 2016; Troyer, 2001; Woolverton et al., 2001), list learning (Belleville et al., 2006; Bottiroli et al., 2013; Gross et al., 2013; Valenzuela et al., 2003; West et al., 2008), face-name associations (Belleville et al., 2006; Bottiroli et al., 2013; Fairchild & Scogin, 2010; Hastings & West, 2009; Pike et al., 2018; West et al., 2008; Woolverton et al., 2001), and text learning (Bottiroli et al., 2013). Moreover, improvements in self-reported memory ability and satisfaction with memory, memory strategy knowledge, and increase in memory strategy use in everyday life have been found (Belleville et al., 2006; Fairchild & Scogin, 2010; Frankenmolen et al., 2018; Hastings & West, 2009; Kinsella et al., 2016; Troyer, 2001; Vandermorris et al., 2020; West et al., 2008).
The vast majority of studies on the efficacy of CCT has focused on analog delivery of CCT which is typically provided by cognitive therapists in one-on-one or group sessions. More recently, studies have looked into digitizing CCT as it is less time-consuming and less costly (e.g. Flinkel & Yesavage, 1989; Herrera, Chambon, Michel, Paban, & Alescio-Lautier, 2012; Irazoki et al., 2020; Mitrovic, Mathews, Ohlsson, Holland, & McKinlay, 2016; Pang & Kim, 2021; Reijnders, Geusgens, Ponds, & van Boxtel, 2017; Rose et al., 2015; Wesselman et al., 2019). Digital CCT enables personalized training, monitoring of performance, and could facilitate the integration of specific training modules into the daily life routines of individual users to facilitate transfer. Although research in the area of digital CCT is still scarce, studies show that digital CCT can be effective. More specifically, studies have found that digital CCT improves prospective memory (Rose et al., 2015), word and list recall (Boller, Ouellet, & Belleville, 2021; Flinkel & Yesavage, 1989; Herrera et al., 2012; Pang & Kim, 2021), and specific types of timed instrumental activities of daily living (Rose et al., 2015). Digital CCT was found to increase cognitive strategy use (Rose et al., 2015), feelings of control over one’s own memory functioning (Reijnders et al., 2017), and memory contentment (Pang & Kim, 2021). In addition, training-related changes in neurophysiological markers of memory performance have been found following digital CCT (Rose et al., 2015).

In order for digital CCT to be considered a valid intervention, it is essential to demonstrate that it is effective. Therefore, we explored the efficacy of a newly developed digital CCT in older individuals with self-reported everyday memory complaints with outcomes assessed at baseline and post-intervention. Older adults who experience memory complaints in their everyday life were selected as a target group for the present study because subjective memory complaints can be a precursor condition for MCI or dementia. In the present study, half of the participants received a CCT app for three weeks, while the other half of the participants were on a waiting list. The CCT included strategy training and emphasized psychoeducation and transfer to daily life. In contrast to previous studies, the CCT was focused on combining elements that are known to be required for an intervention to be effective as well as on providing the training digitally in order to reduce the need for a therapist to guide the training. Moreover, the training was designed to be user-friendly and to increase engagement. We expected that participants who received the CCT would show greater improvements on objective outcome measures that assess memory performance. Specifically, we expected effects to be strongest for objective outcome measures with highest resemblance to the training. In addition, we expected that participants who received the CCT would improve on subjective outcome measures that assess self-reported strategy use, memory ability, and satisfaction with memory. In addition, we explored whether participants who had received the CCT also experienced improvements in domains beyond memory, i.e. self-efficacy and quality of life.
Method

Participants

60 community-dwelling older adults\(^1\) were recruited through a recruitment agency who contacted potential participants based on specified inclusion and exclusion criteria. Older adults who were interested in participating in the study were then contacted by a research assistant. The following inclusion criteria were used: 55 years or older, everyday memory complaints, access to a tablet (iOS or Android), normal or corrected-to-normal vision, fluent in Dutch, and being able to visit our lab independently. Exclusion criteria were a diagnosis of MCI, dementia, or (a history of) other neurological conditions (such as traumatic brain injury, stroke or epilepsy), the use of medication or drugs that directly affect cognitive functioning, and current participation in other intervention programs that are designed to improve cognition. Participants were not screened for MCI or dementia with standardized tests. However, after completion of the study, we checked participants’ performance on the eCOG, an instrument that can be used to screen for risk of MCI (Marshall et al., 2014; Tomaszewski Farias et al., 2008; Van Harten et al., 2018). As described in Van Harten et al. (2018), we categorized participants into having occasional subjective cognitive decline (SCD; any item scored ≥2, but none ≥3) or having consistent SCD (any score of ≥3) based on their scores on the eCOG during the pre-assessment. Consistent SCD was found to be indicative of an increased risk of MCI (Van Harten et al., 2018).

All participants gave written informed consent according to the standards of the Declaration of Helsinki. The study protocol, data analysis plan, risk assessment, information letter, and informed consent were reviewed and approved by an ethical review board prior to the start of the study, but the study was not pre-registered. All subjects received €120 for their participation in the study.

Procedure

This randomized controlled trial (RCT) utilized a between-subjects repeated measures design. All participants visited our lab for a pre- and a post-assessment, each lasting around 2.5 hours. During the assessments, there were multiple breaks for participants. For each participant, pre- and post-assessments took place on the same day of the week and at the same time of the day. The post-assessment was always scheduled 21 days after the pre-assessment.

Participants were randomly assigned to either the experimental or the control condition. Randomization was stratified on age (50–60 years, 60–65 years, 65–70 years, 70–75 years, >75 years), gender (female/male), and education level (low, medium, high). Study procedures and participant flow
are detailed in the study flow chart in Figure 1. The experimental group (N = 29) received the CCT intervention for three weeks. Participants were instructed to train at least 15 to 30 minutes a day, for five days each week. Control subjects (N = 26) were on a waiting list for three weeks. After the post-assessment, the CCT was made available to participants in the control condition.

The pre- and post-assessment were conducted by a trained research assistant who was blind to subjects’ condition. After the pre-assessment, for each participant, the research assistant installed the CCT app on the participant’s own tablet. Participants were instructed to open the app at home. Upon first use of the app, they received a notification about which condition they had been assigned to and were instructed not to mention their condition to the research assistant during the post-assessment.

**Intervention**

The intervention is a digital CCT app called MemoryUp which has been developed by the authors of this paper and which runs on both iOS and Android tablets. It consists of three different training modules that focus on improving memory for (1) plans, i.e. future events, activities and appointments, such as taking medication or attending a doctor’s appointment, (2)
faces, i.e. first or last names linked to a person’s face, and (3) lists containing information in a fixed or random order, such as grocery or to-do lists, and key points from a newspaper article or speech. The memory strategies were called Plan Mnemonic, Face-Name Mnemonic, and Memory Palace, and were presented in the same order to all participants.

As can be seen in Table 1, each training module contained (a) an explanation of the memory strategy, (b) exercises to practice the memory strategy, (c) psychoeducation, and (d) tips for transfer to daily life. For each memory strategy, information was provided in a question-based manner to promote active processing of information and to enhance engagement. Each training module consisted of 10 to 13 levels with approximately 35 questions and exercises per level. Completion of one level took approximately 15 minutes. The levels gradually increased in difficulty and each subsequent level was made accessible after completion of the previous level. Participants were allowed to repeat each level and each training module as often as they liked. As a consequence, training intensity varied across participants.

**Explanation of the memory strategy**

The explanation of the memory strategy centered on association, visualization, and depth of information processing. For each strategy, participants were taught to make an association between two or more pieces of information (e.g. dog and sweater) by creating a mental image that contained the two concepts (e.g. a dog wearing a sweater). Participants were instructed to employ an in-depth level of processing to their mental images, including adding different sensual modalities (e.g. “What does the mental image sound like?”), emotions (e.g. “How does the mental image make you feel?”), and motion (e.g. “Is something dripping or falling in the mental image?”). It was stressed that most people find it easier to remember funny or bizarre mental images or images that have a strong personal meaning.

**Exercises**

Exercises were embedded throughout the strategy explanation, psychoeducation, and tips for transfer. The exercises were specifically designed to practice the different steps of the respective strategies. Exercises consisted of word-word, word-image, and image-image pairs whereby one of the items of the pair was the cue that was later presented to retrieve the other item. In addition, for the Memory Palace, exercises consisted of lists of unrelated words that had to be remembered and later recalled in the correct order. For all exercises, responses always relied on recognition memory, i.e. the participant had to choose the correct answer from four answer options. Difficulty of the exercises increased over the different levels by increasing the abstractness of the words, by increasing the number of items on the list, and by increasing the total number of
Table 1. Overview of CCT modules with (c) and (d) being similar across strategies except for minor strategy-specific information.

<table>
<thead>
<tr>
<th>Plan Mnemonic (10 levels)</th>
<th>Face-Name Mnemonic (10 levels)</th>
<th>Memory Palace (13 levels)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>(a) Explanation of strategy</strong></td>
<td>Step 1: Create a cue</td>
<td>Step 1: Select a distinctive feature</td>
</tr>
<tr>
<td></td>
<td>Step 2: Make a mental image</td>
<td>Step 2: Change the name to something concrete</td>
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<tr>
<td></td>
<td>Step 3: Look at the details of the mental image</td>
<td>Step 3: Make an association between the name and the distinctive feature</td>
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<td></td>
<td>Step 4: Make a mental image of the association</td>
<td>Step 4: Link each to-be-remembered item to one of the key locations and make a mental image of the item interacting with the key location</td>
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<td></td>
<td>Step 5: Look at the details of the mental image</td>
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<tr>
<td><strong>(b) Exercises to practice strategy</strong></td>
<td>Word – word pairs</td>
<td>Transferring names into concrete words</td>
</tr>
<tr>
<td></td>
<td>Word – image pairs</td>
<td>Face – name pairs</td>
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<tr>
<td><strong>(c) Psychoeducation</strong></td>
<td>Explanation of:</td>
<td></td>
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<tr>
<td></td>
<td>• How memory works (e.g. &quot;Memories are stored in an associative network and one part of a memory can be retrieved when another part of this network is activated.&quot;)</td>
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<td></td>
<td>• Normal forgetfulness and normal age-related cognitive decline (e.g. &quot;It is normal to occasionally forget an appointment.&quot;)</td>
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<td></td>
<td>• The influences of stress and anxiety on memory (e.g. &quot;Too much time pressure and stress can make it more difficult to retrieve information from your memory.&quot;)</td>
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<td></td>
<td>• The relation between attention and memory (e.g. &quot;It is easier to remember something if it is important to you and if you paid enough attention to it.&quot;)</td>
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<td></td>
<td>• The importance of a healthy lifestyle (e.g. &quot;A healthy lifestyle is important for your memory. A healthy lifestyle means that you are active, sleep enough, and have a healthy diet.&quot;)</td>
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<td></td>
<td>• Confidence and self-efficacy (e.g. &quot;We can influence how well our memory works to some extent, for example by learning a memory strategy.&quot;)</td>
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<tr>
<td><strong>(d) Tips for transfer</strong></td>
<td>Reminders and tips about how to use the strategy outside of the app (e.g. &quot;It is important that you also try to use the Plan Mnemonic in your everyday life, for example the next time you want to remember an appointment.&quot;)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Examples of ecologically valid everyday life situations in which the strategy could be used (e.g. remembering a doctor’s appointment, remembering doctor’s name, making lasagna)</td>
<td></td>
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<tr>
<td></td>
<td>Homework assignments (e.g. &quot;When you go to the supermarket, try to use the Memory Palace to remember your grocery list.&quot;)</td>
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</tbody>
</table>
exercises per level. In addition, for all exercises, lure words were presented among the different answer options to increase the difficulty of the exercises. Lure words were stimuli that had been presented as part of the exercises earlier in the same level, e.g. as one of the items in a previous stimulus pair.

**Psychoeducation**
The psychoeducation was similar in content for all three training modules. The psychoeducation component aimed at increasing metacognition and self-efficacy, and included information about neural, cognitive, and psychosocial aspects of aging. In addition, it contained information about the influence of different factors on memory performance, including stress, anxiety, attention, lifestyle, and confidence.

**Tips for transfer**
Different methods were used to motivate participants to apply the strategies in their everyday life. This was done by providing ecologically valid examples of everyday life situations in which the strategy could be used, inviting subjects to think about other situations in which the same strategy could be used, and by explicitly instructing participants to apply the strategy to specific tasks in their everyday life (i.e. homework assignments).

**Instruments**
A number of objective tests and subjective questionnaires were administered. The sequence in which questionnaires and tests were administered was the same during pre- and post-assessments. To prevent objective memory performance from affecting subjective experience of memory ability, questionnaires were always administered prior to the tests.

The following four subjective questionnaires were administered during both the pre- and post-assessment: Multifactorial Memory Questionnaire (MMQ), General Self-Efficacy Scale (GSES), Everyday Cognition (eCOG), and Short Form survey (SF12). To get more insight into actual strategy use, we asked participants to indicate how they had remembered the information in two of the objective outcome measures (word pairs and face-name pairs) during the assessments as well as how they remembered eight different daily life tasks, i.e. grocery lists, future appointments, placements of objects, routes, information from a film or book, routine activities (like taking medication), non-routine activities (like returning a book), and names. Participants were asked to indicate this during both the pre- and the post-assessment by briefly writing down how they had remembered the
information. We scored how many participants in both conditions had used a strategy to perform these tasks that was similar or equal to the strategies taught in the CCT.

**Multifactorial Memory Questionnaire (MMQ)**
The validated Dutch translation (Van der Werf & Vos, 2011) of the MMQ (Troyer & Rich, 2002) was used to assess metamemory skills in everyday life. Participants used a 5-point Likert scale ranging from 'strongly agree' to 'strongly disagree' to answer 18 questions on affect regarding memory (MMQ-Satisfaction), 20 questions on everyday memory functioning (MMQ-Ability), and 19 questions on current strategy use (MMQ-Strategy). Scores ranged from 0 to 72, 0 to 80, and 0 to 76, respectively. Sum-scores were derived for each scale separately. Higher scores reflect higher satisfaction, better subjective memory function, and more memory strategy use, respectively. Since the MMQ-Strategy includes both internal and external strategies, similar to other researchers (Frankenmolen et al., 2018; Troyer, 2001), we created a subscale for the MMQ-Strategy that contained only those items that measure strategy use of strategies that resemble the strategies in our training. These included items 3, 4, 11, 14, 17, and 19. We created a total score for this subscale by summing all scores on these six items. The validity and reliability of this subscale were not tested.

**General Self-Efficacy Scale (GSES)**
Memory complaints are known to be mediated by the feeling of control over one’s own cognitive functioning, also referred to as self-efficacy. We assessed self-efficacy with the validated Dutch version (Teeuw, Schwarzer, & Jerusalem, 1994) of the GSES (Schwarzer & Jerusalem, 1995). This short questionnaire addresses coping and adaptation abilities in daily activities as well as isolated stressful events. Subjects had to indicate on a 4-point scale to what extent 10 statements were ‘not at all true’ to ‘exactly true’ for them. The total score ranges from 10 to 40 and is calculated by summing all items. Higher scores reflect more self-efficacy.

**Everyday Cognition (eCOG)**
The eCOG (Tomaszewski Farias et al., 2008) assesses age-related cognitive decline in older people across multiple cognitive domains relevant to everyday life functioning. Since this questionnaire is not available in Dutch, two researchers independently translated the original English version to Dutch. The two translations were reviewed and merged into a single Dutch version by a third researcher.
Participants were instructed to rate their current ability to perform a variety of everyday tasks as compared to their ability to perform the same task ten years ago. Change over time was rated with a 4-point Likert scale ranging from ‘no change or performing better than 10 years ago’ to ‘performing the task much worse than 10 years ago.’ Total scores were divided by the number of questions answered. Scores were then reversed so that higher scores indicate better or unchanged ability and lower scores indicate worse ability. All 39 items were used to create one multi-domain score by adding the scores and dividing the total score by six. Total scores range between 1 and 4.

**Short form survey (SF12)**

We administered the SF12-version 2 (Ware, Kosinski, & Keller, 1996) to assess health-related quality of life (QoL). Scoring was done according to the original guidelines. First, reverse items were rescored so that higher values always reflect a higher QoL. Then, indicator variables (0 or 1) were created for each item response category except the one representing best health. Finally, these indicator variables were weighted with regression coefficients from the US general population and summed to compute raw physical and mental scale scores. Composite scores (t-scores) were computed by adding the regression intercept to the raw physical and mental scale scores. Scores range between 0 and 100.

Six objective tests were administered during pre- and post-assessments to assess the efficacy of the three memory strategies (see Table 2). These tests were specifically selected to assess effects of the different memory strategies. The Word Pairs Recognition, Word Pairs Recall, and Memory for Intentions Screening Test (MIST) were administered to measure efficacy of the Plan Mnemonic. The Face Name was administered to measure efficacy of the Face-Name Mnemonic. The Rey Auditory Verbal Learning Test (RAVLT) and the Stories subtest from the Rivermead Behavioral Memory Test (RBMT) were

<table>
<thead>
<tr>
<th>Strategy</th>
<th>Objective outcome measure</th>
<th>Description of outcome measure</th>
</tr>
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<tbody>
<tr>
<td>Plan Mnemonic</td>
<td>Word Pairs Recognition</td>
<td>Presentation: 20 word-word pairs on computer screen Recall: presentation of one word and selection of other word from list of four words</td>
</tr>
<tr>
<td></td>
<td>Word Pairs Recall</td>
<td>Presentation: 20 word-word pairs on computer screen Recall: presentation of one word and free recall of other word</td>
</tr>
<tr>
<td></td>
<td>MIST</td>
<td>Presentation: 8 prospective memory tasks to perform while engaged in word puzzle Recall: free recall and performance of tasks</td>
</tr>
<tr>
<td>Face-Name Mnemonic</td>
<td>Face Name</td>
<td>Presentation: 16 picture-first and last name pairs on computer screen Recall: presentation of picture and free recall of first and last name</td>
</tr>
<tr>
<td>Memory Palace</td>
<td>RAVLT</td>
<td>Presentation: 15 words read to participant Recall: free recall</td>
</tr>
<tr>
<td></td>
<td>Stories from RBMT</td>
<td>Presentation: 2 short stories read to participant Recall: free recall</td>
</tr>
</tbody>
</table>
administered to measure efficacy of the Memory Palace. Three of the six objective tasks were presented on a computer (i.e. Word Pairs Recognition, Word Pairs Recall, and Face Name) and three were administered on paper or verbally by the research assistant (i.e. RAVLT, MIST, Stories subtest from the RBMT). For each of the six objective tests, two versions containing different but highly comparable stimuli were counterbalanced across sessions and conditions to minimize practice effects.

**Word pairs recognition**

During the learning phase, 20 word-word pairs were presented in a period of five minutes. One word was presented on the left side of the screen (referred to as the cue) and one word was presented on the right side of the screen (referred to as the response). Stimulus pairs were presented one-by-one on a computer screen. Presentation was self-paced and subjects could go back and forth between stimuli. Ten of the 20 word pairs were concrete words only, five pairs consisted of concrete cues and abstract responses, and five pairs consisted of abstract cues and concrete responses. Concrete words had a concreteness rating of ≥ 3.5 and abstract words had a concreteness rating of ≤ 3 (Brysbaert, Stevens, De Deyne, Voorspoels, & Storms, 2014). All words had a high frequency and word prevalence (Brysbaert et al., 2014). A distraction phase of approximately three minutes followed after the learning phase in order to prevent mere rehearsal of the studied material. This was done by instructing participants to perform an unrelated “spot the differences” task.

To test recognition, cues were presented one-by-one and subjects were instructed to select the matching response from a set of four alternatives. Participants were instructed to say the correct answer aloud to prevent using a keyboard from interfering with memory processes. Scores can range between 0 and 20.

**Word pairs recall**

The Word Pairs Recall task was identical to the Word Pairs Recognition task, with the exception of word pair content (i.e. comparable but different stimuli) and response mode (free recall rather than recognition). Again, participants were instructed to say the correct answer aloud and scores can range between 0 and 20.

**Face name**

Participants were asked to study 16 face-name pairs that consisted of a photograph of a face presented on the left side of the computer screen with both a first and a last name presented on the right side of the computer screen in a period of ten minutes. Faces and names were obtained from databases for faces (http://experiments.wustl.edu/) and common Dutch names (http://www.meertens.knaw.nl/nvb/topnamen//land/Nederland). Stimulus pairs were presented one-by-one on a computer screen.
Presentation was self-paced and subjects could go back and forth between stimuli. Again, a distraction phase lasting approximately three minutes during which participants had to perform an unrelated task followed after the learning phase in order to prevent mere rehearsal of the studied material.

During recall, only the photograph of the face was presented. Participants were instructed to say the corresponding first and last name aloud. A correct recall of either the first or the last name was credited with 1 point, a correct recall of both the first and the last name was credited with 2 points. Scores can range between 0 and 32.

**Memory for Intentions Screening Test (MIST)**
The MIST (Raskin, 2009) is an ecologically valid test that measures prospective memory. Since it is currently only available in English, two researchers independently translated the original English version to Dutch. The two translations were reviewed and merged into a single Dutch version by a third researcher.

The MIST requires delayed execution of intended actions. Participants were presented with eight different prospective memory tasks while being engaged in an ongoing, paper-and-pencil word puzzle for a period of 30 minutes. Participants were instructed to give priority to the prospective memory task over the puzzles if needed. Intended actions varied in terms of delay interval (between two and 15 minutes), cue (time- or event-based), and response modality (verbal or physical). A correct recall of a specific action at the right time (± one minute) was credited with 2 points. Performing the correct intended action at the incorrect time or the incorrect action at the right time was credited with 1 point. Scores can range between 0 and 16.

**Rey Auditory Verbal Learning Test (RAVLT)**
The RAVLT (Rey, 1964) is the most frequently used verbal memory test. We used the validated Dutch translation of the RAVLT (Saan & Deelman, 1986). The RAVLT consists of 15 unrelated words that are read aloud. After presentation of the final word, the subject is requested to immediately recall as many words as possible. The immediate recall is followed by four more trials. This is followed by a delayed recall trial after a 15-minute break. We only used the delayed recall scores in our analyses. Scores can range between 0 and 15.

**Stories subtest from Rivermead Behavioral Memory Test (RBMT)**
The Stories subtest from the RBMT (Wilson, Cockburn, & Baddeley, 1991) is an ecologically valid instrument to assess everyday memory functioning. We used the validated Dutch translation of the Stories subtest (Van Balen & Groot Zwaartink, 1993), in which the experimenter reads two different stories aloud. Immediately after each story, participants had to recall the content they just
heard using the same words as much as possible. Every correct recall, or a good
description or synonym of the content, was credited with 1 point. Recalls that
were partly correct were credited with \( \frac{1}{2} \) point. The total score was calculated
by summing the points on both stories. Scores can range between 0 and 42.

**Data analysis**

Statistical analyses were conducted using IBM SPSS 23.0. To evaluate group
differences across assessments, 5x2x2 GLM repeated measures analyses were
performed with task (Word Pairs Recall, MIST, Face Name, RAVLT, and
Stories), session (pre-assessment, post-assessment) as within-subjects factor,
and condition as between-subjects factor (experimental, control). For the
objective measures, raw scores from each task were first recalculated as
percentage correct scores to allow for direct comparison across different
tasks. A significant interaction of task x session x condition was followed up
using GLM repeated measures for each task separately. This approach suffi-
ciently handles potential group differences in baseline measures (Bland &
Altman, 2011; Dinh & Yang, 2011; Harvey, 2018).

For subjective measures, GLM repeated measures were conducted for each
measure separately as comparing outcome measures directly by first recalcu-
lating raw scores into mutually comparable normalized scores is not evident
when using diverse questionnaires and scales. To maintain statistical power,
significance levels were not adjusted using Bonferroni correction (Field, 2009).
Boxplots and Shapiro-Wilk statistics indicated that the assumption of normal-
ity was supported for all difference scores (post-assessment minus pre-
assessment). Effect sizes \( (d) \) were calculated for all pairwise comparisons that
revealed significant differences between the two conditions. A \( d \) of .2 corre-
sponds to a small effect size, .5 corresponds to a medium effect size, and .8 to
a large effect size (Cohen, 1988).

To determine a reliable improvement on the objective outcome measures
for which we found a statistically significant difference between the experi-
mental and control condition, we calculated reliable change scores (Duff, 2012;
The method proposed by Iverson (2001) was used to correct for effects that are
related to prior exposure to the testing materials (that were presented during
the pre-assessment).

**Results**

60 community-dwelling older adults were included in the study. Five partici-
pants were excluded: three participants missed their pre-assessment due to
personal life circumstances and two participants were not considered fluent in
Dutch. The remaining 55 participants (49% females) were aged 56 to 83 years (mean age = 68 years, SD = 7 years). Demographic information is presented in Table 3.

To provide more insight into the cognitive status of the sample, we checked the pre-assessment eCOG scores for each participant. Using the method described in Van Harten et al. (2018), we found that 34 participants had occasional SCD (16 in the control condition, 18 in the experimental condition) and eight participants had consistent SCD (three in the control condition, five in the experimental condition) which is a risk factor for MCI.

Table 4 shows mean values (and standard deviations) for all outcome measures, separately for each condition and assessment session. As can be seen in Table 4, the mean percentage correct scores on the Word Pairs Recognition exceeded 90% in both groups and assessment sessions. Further exploration revealed that 40% of the participants achieved the maximum possible score on this task. Given this ceiling effect, we decided to exclude the Word Pairs Recognition from further analyses. For all other outcome measures, ceiling remained well below 15% (e.g. McHorney & Tarlov, 1995; Terwee et al., 2007).

Figure 2 (objective data) and Figure 3 (subjective data) visualize difference scores that were calculated by subtracting pre-assessment scores from post-assessment scores. Figure 2 shows the difference scores for the five objective outcome measure for the experimental and control condition. As can be seen, the experimental condition has larger mean difference scores on three of the five objective outcome measures (Word Pairs Recall, RAVLT, Stories), while the control condition has larger mean difference scores on two of the five objective outcome measures (Face Name, MIST). A GLM repeated measures analysis on percentage correct response scores indeed demonstrated a significant overall effect of condition x task x session ($F(4,50) = 2.64$, $p = .045$). Further GLM repeated measures analyses for each task separately demonstrated that the effect of group x session was only significant for the Word Pairs Recall ($F(1,53) = 7.36$, $p = .009$, $d = .74$). Although both groups improved from pre- to post-assessment on the Word Pairs Recall, the improvement was larger in the experimental than the control condition. Iverson’s reliable change index with correction for practice effects indicated

<table>
<thead>
<tr>
<th>Table 3. Demographic characteristics. Mean values (standard deviations) are displayed for each group separately.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Experimental condition (N = 29)</td>
</tr>
<tr>
<td>Age</td>
</tr>
<tr>
<td>Education level&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Gender: % female</td>
</tr>
</tbody>
</table>

<sup>a</sup>UNESCO (2006[1997]), p. 0 = pre-primary education; 1 = primary education or first stage of basic education; 2 = lower secondary or second stage of basic education; 3 = (upper) secondary education; 4 = post-secondary non-tertiary education; 5 = first stage of tertiary education; 6 = second stage of tertiary education.
that 28% of participants in the experimental condition showed reliable improvement ($z > 1.64$). Table 5 shows how many participants in the experimental condition fall within pre-defined percentile categories.

After exploring app usage data, we found that ten participants in the experimental condition had not practiced the Memory Palace sufficiently, i.e. they had only completed one or two of the thirteen levels of the Memory Palace. We therefore removed these ten participants and repeated the GLM repeated measures analysis. Again, a significant overall effect of condition x task x session was found ($F(4,40) = 2.99, p = .03$). A GLM repeated measures analysis for each task separately demonstrated that the effect of condition x session was significant for the Word Pairs Recall ($F(1,43) = 9.32, p = .004, d = .90$), but not for the other tasks.

Figure 3 suggests that the experimental condition has larger difference scores on five of the eight subjective measures (MMQ-Satisfaction, MMQ-Strategy, MMQ-Strategy subscale, GSES, SF12-mental), whereas the control condition has higher difference scores on two of the eight subjective measures (MMQ-Ability, SF12-physical). Mean difference scores on the eCOG were

### Table 4. Mean values (standard deviations) for objective and subjective outcome measures, separately displayed for each group and assessment session.

<table>
<thead>
<tr>
<th></th>
<th>Experimental condition Mean (SD)</th>
<th>Control condition Mean (SD)</th>
<th>Intervention x session</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre</td>
<td>Post</td>
<td>Diff</td>
</tr>
<tr>
<td>Word Pairs Recognition</td>
<td>90.5 (11.6)</td>
<td>93.4 (10.4)</td>
<td>2.9 (12.4)</td>
</tr>
<tr>
<td>Word Pairs Recall</td>
<td>32.8 (24.1)</td>
<td>57.1 (27.7)</td>
<td>24.3 (23.5)</td>
</tr>
<tr>
<td>Face Name</td>
<td>45.4 (23.0)</td>
<td>47.4 (24.5)</td>
<td>2.1 (19.2)</td>
</tr>
<tr>
<td>MIST</td>
<td>81.2 (14.3)</td>
<td>78.2 (14.6)</td>
<td>−2.8 (13.7)</td>
</tr>
<tr>
<td>RAVLT</td>
<td>49.7 (19.8)</td>
<td>55.9 (19.7)</td>
<td>6.2 (20.7)</td>
</tr>
<tr>
<td>Stories</td>
<td>29.3 (9.1)</td>
<td>35.4 (11.3)</td>
<td>6.2 (10.3)</td>
</tr>
<tr>
<td>MMQ-Satisfaction</td>
<td>46.3 (11.1)</td>
<td>52.8 (9.7)</td>
<td>6.5 (7.7)</td>
</tr>
<tr>
<td>MMQ-Ability</td>
<td>55.5 (10.5)</td>
<td>57.1 (9.0)</td>
<td>1.6 (8)</td>
</tr>
<tr>
<td>MMQ-Strategy</td>
<td>24.7 (10.9)</td>
<td>26.7 (9.90)</td>
<td>1.9 (7.3)</td>
</tr>
<tr>
<td>MMQ-Strategy subscale</td>
<td>4.7 (3)</td>
<td>6.4 (3.8)</td>
<td>1.7 (3.2)</td>
</tr>
<tr>
<td>GSES</td>
<td>32.1 (4.1)</td>
<td>33.4 (3.7)</td>
<td>1.3 (2.5)</td>
</tr>
<tr>
<td>eCOG⁴</td>
<td>3.4 (3)</td>
<td>3.5 (3.8)</td>
<td>.11 (3.2)</td>
</tr>
<tr>
<td>SF12-physical</td>
<td>48.2 (10.5)</td>
<td>47 (10.4)</td>
<td>−1.1 (7.4)</td>
</tr>
<tr>
<td>SF12-mental</td>
<td>49.9 (11.2)</td>
<td>54 (7.6)</td>
<td>4.1 (8.6)</td>
</tr>
</tbody>
</table>

⁴eCOG scores were reversed so that higher scores indicate better or unchanged ability

bsignificant at p < .05
noticeably low in both groups. GLM repeated measures analyses on raw scores for each scale separately demonstrated that the effect of condition x session was significant for MMQ-Satisfaction ($F(1, 53) = 7.04, p = .011, d = .72$), the MMQ-Strategy subscale ($F(1, 53) = 4.01, p = .05, d = .55$), and the SF12-mental ($F(1, 53) = 9.26, p = .004, d = .83$). Compared to controls, participants in the

Figure 2. Difference scores (post – pre) for five objective outcome measures. Standard error bars are shown.

Figure 3. Difference scores (post-pre) for eight subjective outcome measures. Standard error bars are shown.
experimental condition reported to be more satisfied and less concerned with their own memory, use more internal strategies that resemble those that were trained in our CCT and experienced better mental health.

To provide more insight into strategy use, we asked participants to indicate how they had remembered the information in two of the objective outcome measures (word-word pairs and face-name pairs) during the assessments as well as how they had remembered eight different daily life tasks. We found that before the training, use of strategies similar or equal to the strategies taught in the training was comparable across conditions: prior to the training, about half of participants in both conditions used a strategy similar to the Plan Mnemonic to remember word pairs and slightly over 30% used a strategy similar to the Face-Name Mnemonic to remember names (see Figure 4). In neither condition did participants use strategies similar to the strategies taught in the CCT to remember daily life tasks, with an exception for remembering names: during the pre-assessment, three participants in the control condition and two participants in the experimental condition described using a strategy

<table>
<thead>
<tr>
<th>Percentile</th>
<th>Number of participants</th>
</tr>
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<tbody>
<tr>
<td>0–5</td>
<td>1</td>
</tr>
<tr>
<td>5–25</td>
<td>2</td>
</tr>
<tr>
<td>25–50</td>
<td>2</td>
</tr>
<tr>
<td>50–75</td>
<td>8</td>
</tr>
<tr>
<td>75–95</td>
<td>8</td>
</tr>
<tr>
<td>95–100</td>
<td>8</td>
</tr>
<tr>
<td>Total</td>
<td>29</td>
</tr>
</tbody>
</table>

Table 5. Number of participants in the experimental condition who fall within pre-defined percentile categories based on calculation of Iverson’s reliable change index.

![Figure 4](chart.png)

Figure 4. Percentage of participants who used a strategy similar or equal to the strategies taught in the CCT during pre-assessment.
similar to the Face Name Mnemonic to remember names in their daily life. As can be seen in Figure 5, during the post-assessment, more participants in the experimental condition than in the control condition used strategies similar or equal to the strategies trained in the CCT when remembering word pairs (90% vs 50%) and names (79% vs 27%) during the post-assessment as well as when remembering daily life tasks after the training (7–38% vs 4%).

**Discussion**

The study provides partial evidence for the efficacy of a digital CCT in older adults with everyday memory complaints. The CCT aimed at improving memory for future plans (Plan Mnemonic), names (Face-Name Mnemonic), and lists of information (Memory Palace). The training included psychoeducation to increase metacognition and self-efficacy, and transfer training to enhance use of the learned memory strategies in daily life. Six objective outcome measures assessed the efficacy of each memory strategy: the Word Pairs Recognition, Word Pairs Recall, and MIST measured the effects of the Plan Mnemonic, the Face Name assessed the effects of the Face-Name Mnemonic, and the RAVLT and Stories measured the effects of the Memory Palace. In addition, we measured the efficacy of the CCT on self-reported strategy use, memory ability, satisfaction with memory, QoL, and self-efficacy.

Compared to control subjects, trained participants improved significantly on the Word Pairs Recall. A large effect size (d = .74) was found. We found that after correcting for effects that were due to prior exposure to the testing material, 28% of participants in the experimental condition showed a reliable improvement on the Word Pairs Recall. We did not find significant
effects on other objective measures, which raises two questions: first, why did we find an effect on the Word Pairs Recall, but not on the other two measures for the Plan Mnemonic? Second, why did the other two memory strategies, i.e. the Face-Name Mnemonic and the Memory Palace, not lead to measurable improvements?

Regarding the first question, two other objective measures assessed the effect of the Plan Mnemonic. As described, the Word Pairs Recognition was removed from analyses due to a ceiling effect. The MIST, which was included because of its high ecological validity, required transfer of the learned strategy to a novel task. Since we found an effect on the Word Pairs Recall, it seems that the Plan Mnemonic was successful in improving memory for a task similar to the training but was insufficient in leading to transfer to a novel task like the MIST. Regarding the second question, the finding that the Face-Name Mnemonic and the Memory Palace did not lead to measurable memory improvements is not in line with other studies showing improvements in face-name associations (Belleville et al., 2006; Fairchild & Scogin, 2010; Woolverton et al., 2001) and list learning (Belleville et al., 2006; Frankenmolen et al., 2018; Valenzuela et al., 2003). We believe that there are two possible explanations for this. First, the three strategies vary in difficulty with the Plan Mnemonic being easier to learn. All strategies build on visual imagery and associative memory. The Face-Name Mnemonic and Memory Palace however have additional steps compared to the Plan Mnemonic which makes them more complex. It is therefore possible that the training was sufficient in teaching the Plan Mnemonic, but not in teaching the other two strategies. Second, we believe that the effect on the Word Pairs Recall is partially due to training intensity. Because the sequence of the different strategies was set for all participants, the Plan Mnemonic was the most practiced strategy. This higher training intensity may have led to a measurable effect of the Plan Mnemonic.

Besides improvements on objective outcome measures, we also expected that the CCT would lead to increased strategy use, improvements on self-reported memory ability as well as improvements in satisfaction with memory and QoL. We did not find an effect on the MMQ-Strategy, most likely because it includes both external and internal strategies. We did however find an effect on the MMQ-Strategy subscale \((d = .55)\) that we created to better reflect use of strategies similar to the ones taught in the CCT. This finding is in line with other studies (e.g. Frankenmolen et al., 2018; Troyer, 2001; Vandermorris et al., 2020) and shows that the training was effective in making individuals use the strategies they had learned during the training. Previous research found that strategy use is an important predictor for episodic memory improvements in the long-term in older adults (Gross et al., 2013). In addition to increased strategy use, we also found that participants who received the CCT had higher memory contentment and
increased QoL with large effect sizes (MMQ-Satisfaction: $d = .72$, SF-12 mental: $d = .83$). This is in line with other studies that have found positive effects of CCT on subjective measures of memory contentment and mental wellbeing (Fairchild & Scogin, 2010; Kinsella et al., 2016; Pang & Kim, 2021; Troyer, 2001; Vandermorris et al., 2020). Improvements in memory contentment and mental wellbeing are likely linked to psychoeducation and are important because they can help decrease worrying which is known to exacerbate everyday memory complaints.

We did not find improvements on memory ability as measured with the MMQ. Findings on the effect of cognitive interventions on self-reported memory ability are inconsistent with some studies finding improvements in memory ability (Fairchild & Scogin, 2010; Vandermorris et al., 2020, 2020), while others find no or small effects (Boller et al., 2021; Kinsella et al., 2016; Woolverton et al., 2001). We believe that not finding an effect on the MMQ-Ability reflects a lack of sufficient transfer of the learned strategies to tasks outside of the training since the MMQ-Ability measures the ability to remember daily life activities. This is in line with the failure to find effects of the CCT on objective measures that assess transfer, like the MIST and Stories.

The CCT did not improve self-efficacy as measured with the GSES. Memory complaints are known to be mediated by the feeling of control over one’s own cognitive functioning and this was particularly targeted by the psychoeducation module. It seems that restructuring of control beliefs was not sufficiently achieved in the training. Since self-efficacy may at least partially determine the use of a memory strategy during a memory task, this may also explain why we did not find effects on some of the objective outcome measures. Interestingly, Hastings and West (2009) found that a memory training only increased self-efficacy when it was provided in a group setting and not when it was provided in a self-help manual. Similarly, a qualitative study on older adults’ experiences of change following a group memory intervention found that attitudes toward memory strategy use were influenced via social learning (Matthews, Wells, Pike, & Kinsella, 2020). It seems that positive effects present in group settings such as social interaction and peer sharing, experiencing success with the use of memory strategies as well as normalizing the experience of memory complaints play an important role in the efficacy of CCT. Based on these insights, we believe that it would be beneficial to incorporate aspects of social learning into a digital CCT.

Taken together, we found partial evidence for the CCT. Specifically, we found that the CCT improved performance on a word recall test similar to the tasks trained in the CCT, but did not improve performance on other, novel tasks. In addition, we found that participants reported increased use of strategies that resemble those that were trained, more satisfaction with their memory, and better mental health. Even though trained participants felt better after the CCT, they did not experience better memory performance or more
control over their own cognitive functioning. A possible explanation for these findings is that trained individuals tried to use strategies outside the training context, but that this did not lead to significant improvements on the memory tests that were administered during the post-assessment. This is supported by self-reported use of the learned strategies to remember word-word pairs and names during the post-assessment as well as to remember eight different daily life tasks after the training. We found that individuals who had received the CCT used strategies similar to those trained in the CCT to remember word-word pairs (90% vs 50%) and names (79% vs 27%) during the post-assessment more than individuals who had not received the CCT. Additionally, they were more likely to use strategies similar to those in the CCT to remember daily life tasks such as grocery lists or future appointments (7%-38% vs 0%-4%). Based on these insights, we conclude that participants successfully used a learned strategy (i.e. the Plan Mnemonic) during a memory test that closely resembled the task that was most intensely trained during the CCT (i.e. Word Pairs Recall), but were not able to use it successfully during a task that was novel (i.e. MIST). In addition, even though 79% of trained individuals used a strategy similar to the Face-Name Mnemonic to remember names during the post-assessment, this did not translate to an actual improvement in performance on the Face Name. Similarly, even though trained participants used a strategy to remember daily life tasks such as remembering a grocery list (28%) and the content of a film or book (21%), this did not translate to an actual improvement on any of the objective outcome measures specifically included to assess the effect of the Memory Palace (i.e. RAVLT, Stories).

This suggests that even though we found evidence for the efficacy of the CCT, the training did not lead to successful transfer. Difficulties with transfer might include improper or suboptimal use of learned strategies outside the training context, not being able to recognize situations in which the learned strategies are applicable, or increased effort involved in using a strategy to remember a daily life task. Digital CCT enables use of other technological features that may facilitate transfer of learned strategies to daily life, e.g. GPS could be used to provide reminders when someone is in a situation in which she could benefit from using a memory strategy.

**Limitations**

Several limitations of the present study merit discussion. First, since the absence of a diagnosis of MCI, dementia or other neurological conditions was based on self-report, the possibility of some of the participants having more serious cognitive decline cannot be excluded. In fact, the scores on the eCOG suggests that our sample consists of a heterogenous group with some participants having occasional SCD (N = 34) and some having consistent SCD (N = 8) which implies an increased risk of developing MCI. For future
research, we therefore recommend using standardized classification criteria or validated tests for SCD and other conditions that may affect cognitive functioning and to include severity of SCD in the design of the study.

Second, since the study did not include a follow-up assessment, it is not possible to draw any conclusions about whether effects were maintained after several months. In addition to including a follow-up assessment, we recommend including an active control condition in future research to better separate the degree to which use of the digital cognitive training influences memory performance. Although a limitation, we chose a waitlist control condition as it most closely resembles treatment-as-usual for people with everyday memory complaints.

A further limitation is that the sample consisted of individuals who were self-selected to the study and may therefore have been highly motivated to improve their memory. Due to practical constraints, we could only include individuals who had access to a tablet and were therefore familiar with tablets. In the general population of older people, a digital CCT would likely require pre-training for use of a tablet. Additionally, being digitally literate could indicate better general cognitive functioning which may have resulted in smaller differences between the pre-treatment and post-treatment outcomes. As indicated by Pike et al. (2018), several barriers, including designing for people with low technical skills and physical and cognitive limitations, need to be considered when developing and implementing digital cognitive interventions for older adults.

Another limitation is that the training was limited to a three-week period. This training duration was based on other studies (e.g. Hampstead et al., 2012; Troyer, 2001) and practical limitations. Since training programs are often between six and eight weeks (e.g. Fairchild & Scogin, 2010; Frankenmolen et al., 2018; Kinsella et al., 2016), it is possible that a longer training duration would have led to more significant improvements. While some studies have found larger effects with longer training durations (Woolverton et al., 2001), no advantage of more training has been found in a meta-analysis (Verhaeghen, Marcoen, & Goossens, 1992) and a systematic review (Reijnders, van Heugten, & van Boxtel, 2013). In addition to training duration, the fact that training intensity varied across participants is a limitation that may account for null findings on certain outcome measures. Nevertheless, we believe that this reflects real-world use of a CCT.

**Recommendations**

Based on the outcomes of the present study, we recommend to better integrate digital CCT into people’s everyday life to ensure transfer of the learned cognitive strategies to everyday life. Training older adults to recognize situations in which the learned strategy can be used seems to be crucial for successful transfer. Better transfer to everyday life could also be achieved by
providing additional support from healthcare professionals or caregivers and by increasing training intensity. Adding technological features such as GPS may prove valuable in further enhancing transfer. Besides transfer, we recommend incorporating aspects of social learning into a digital CCT as it may enhance the efficacy of the training.

We recommend clinical practitioners to implement CCT for older adults with everyday memory complaints. Digital CCT may be used as a stand-alone solution or in combination with other face-to-face training programs, e.g. broader treatment programs that also focus on lifestyle and incorporate physical exercise (Candela et al., 2015; Chandler et al., 2019; Hsieh et al., 2018). Group sessions that support the training may prove to enhance the efficacy of the training. In addition, it may be valuable for clinical practitioners to monitor and potentially support the integration of the learned strategies into older adults’ everyday life.

From a health policy perspective, we believe that a digital CCT can increase accessibility to an effective intervention for older adults with memory complaints who may otherwise not receive any support. Given the fact that subjective memory complaints can be a precursor condition to MCI or dementia as well as the fact that previous research has shown that CCT is more effective in older adults with SCD than older adults with MCI (Hu et al., 2021), CCT seems to be of particular value for older adults who experience subjective memory complaints but are still well enough to benefit from cognitive training. We recommend that CCT be provided to older adults who experience memory complaints but do not have a clinical diagnosis of MCI or dementia in order to enhance their cognitive functioning in everyday life as well as their overall well-being and independence.

Conclusion

The present study provides partial evidence for the efficacy of a digital CCT in older adults with everyday memory complaints. While the CCT was effective in improving performance on a test similar to the tasks trained, it was not effective in improving performance on novel tasks and it did not sufficiently facilitate the integration of the learned strategies into participants’ daily life routines. Even though participants reported increased use of strategies that resemble those that were trained, more satisfaction with their memory, and better mental health after the CCT, they did not experience better memory performance or more control over their own cognitive functioning. Given that we did not find an effect on self-efficacy and only found limited evidence for transfer, we recommend increased training intensity as well as incorporating aspects of social learning and other technological features that may facilitate transfer into a digital CCT.
Endnote

1. Sample size was determined with G*power based on expected small effect sizes (.2), with high test-retest effects (.7), a desired power of .8, and alpha of .005 (=0.5/10 since this study involved multiple testing with six objective and four subjective outcome measures). Power calculations indicated that 54 subjects were needed in total. 60 participants were recruited to compensate for early withdrawal, potential noncompliance or technical problems with the digital CCT.

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Disclosure statement

No potential conflict of interest was reported by the author(s).

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