Remediating Reduced Autobiographical Memory in Healthy Older Adults with the Computerized Memory Specificity Training (c-MeST): A Preliminary Investigation

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Abstract

Background: The ability to retrieve specific autobiographical memories decreases with cognitive aging. This decline is clinically relevant due to its association with impairments in problem solving, daily functioning and also depression. A therapist-delivered, group training protocol, Memory Specificity Training (MeST), has been shown to enhance the retrieval of specific memories whilst ameliorating the impairments and negative outcomes associated with reduced specificity. The therapist-delivered nature of this intervention means it is relatively expensive to deliver and difficult for people with mobility impairments, such as older adults.

Objective: The objective of this study was to test a novel, online computerised version of MeST (c-MeST).

Methods: Twenty-one participants (13 females; Mage = 67.05, SD = 6.55) who experienced a deficit in retrieving specific autobiographical memory were trained with c-MeST. Memory specificity was assessed pre- and post- intervention, as well as secondary processes such as depressive symptoms, rumination and problem solving skills.

Results: Memory specificity increased significantly after participants completed c-MeST (r = .57). Session-to-session scores indicated that AMS improved most from the online baseline assessment to the first online session. No significant change in symptoms or secondary processes such as problem solving skills was found.

Conclusions: An online automated individual version of MeST is a feasible, low-cost intervention for reduced memory specificity in healthy older adults, future studies can now clarify the preventative impact of c-MeST in other at-risk samples with longer follow-ups.

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Background: The ability to retrieve specific autobiographical memories decreases with cognitive aging. This decline is clinically relevant due to its association with impairments in problem solving, daily functioning and also depression. A therapist-delivered, group training protocol, Memory Specificity Training (MeST), has been shown to enhance the retrieval of specific memories whilst ameliorating the impairments and negative outcomes associated with reduced specificity. The therapist-delivered nature of this intervention means it is relatively expensive to deliver and difficult for people with mobility impairments, such as older people.

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Conclusions: An online automated individual version of MeST is a feasible, low-cost intervention for reduced memory specificity in healthy older adults, future studies can now clarify the preventative impact of c-MeST in other at-risk samples with longer follow-ups.

Keywords: memory specificity training; autobiographical memory; cognitive aging; online; depression;

Introduction

The world's rapidly aging population [1] poses several challenges for societies regarding whether they can develop scalable interventions for maintaining quality of life and independence amongst an increasingly older population. The current study translates a group-based intervention into an online self-help program targeting one important cognitive factor associated with cognitive aging: a decrease in the ability to retrieve specific, personal memories [2]. This factor, referred to as *reduced Autobiographical Memory Specificity (rAMS)* or *Overgeneral Autobiographical Memory* [3] is associated with depression [2], impaired problem solving [4] and difficulty maintaining independence [5]. The link between these processes can be explained by the constructive episodic simulation hypothesis, which states that similar episodic processes are central to retrieval of past memories and construction and simulation of hypothetical events [6]. As such, people who are more specific are better able to simulate possible events, they are also better able to formulate solutions to problems that might emerge in their future and plan for how to implement these solutions.

rAMS was first studied within depression (see [3] for a review) and trauma [7], and is now considered a trait marker for depression [8]. The first attempt to remediate rAMS [9] involved a four-session group training program called Memory Specificity Training (MeST). This intervention improved memory specificity and associated cognitive processes (problem solving, rumination and hopelessness) in depressed female inpatients. Subsequent investigations showed similar effects of MeST on rAMS in other patient groups [10–12]. In a cluster-randomized controlled platform pilot trial amongst people with depression, Werner-Seidler and colleagues [13] found that MeST was associated with improvements in memory specificity compared to a group receiving psychoeducation and supportive counselling.

The core component of MeST resembles the Autobiographical Memory Test (AMT) [14] used to assess rAMS. In the AMT participants are presented with cue words and instructed to retrieve specific memories which these cue words remind them of. In MeST, participants receive similar instructions with the exception that they also receive feedback on the specificity of their responses and instructions for how they might be more specific and more detailed. Exercises are completed during the sessions and as homework assignments. In addition to exercises with cue words, in a second kind of specificity exercise participants are instructed each evening to write down one or two memories of that day (with no cue words given). After retrieving a specific memory, participants are encouraged to retrieve details of this specific moment.

rAMS is also an age-related phenomenon in *healthy* older adults [2] and aging is shown to contribute more to rAMS than depressive symptoms in people older than 50 years [15]. As the ability to retrieve specific memories is considered to be a protective factor for mental health [16], Leahy, Ridout, Mushtaq, and Holland [17] examined if improving memory specificity was possible amongst healthy older adults over 70 years of age. In their study, they compared three groups: MeST, a group receiving *Life Review* which also emphasized the recall of *specific* life events but placed them within the broader context of a person's life narrative, and a control group which was asked to complete a workbook of cognitively stimulating activities not directly related to autobiographical memory (i.e., crossword and Sudoku puzzles). Each intervention took four weeks, with a post-training assessment in the fifth week and a follow-up three months later. They reported significant improvements in autobiographical memory specificity in the MeST and Life Review groups at post-training, relative to the control group. However, this effect was not found at three months follow-up. There was no effect of either intervention on depression symptoms, functional independence or executive functioning, but improvements in memory specificity were significantly related to improvements in social problem solving in both intervention groups.

Remediating rAMS has been found to be beneficial for older adults [17,18].

However, as societies age dramatically, making in-person training accessible to this growing and diverse population who may not have contact with health care providers or who may have mobility or independence problems, would be challenging. Translating MeST into a computerized individualized platform could offer promise as a solution to these challenges [19]. A recently designed computerized scoring algorithm for scoring specificity of written autobiographical memories [20] offers new possibilities given that memory specificity training might now be delivered in the absence of a therapist and at home. This scoring algorithm, which has demonstrated good agreement with human-expert scorings [20], was incorporated into an online platform for memory specificity training such that memories are coded and feedback can be given [21]. In a proof of concept study with participants with rAMS (operationalized as scoring less than 50% at AMT), this online computerized version of MeST (c-MeST) improved rAMS after two weeks of training (consisting of seven sessions of each 5 to 8 trials) and the effect was maintained at two-week follow-up, compared to a no-training control group.

The current study examined an online, individually-delivered, computerized version of MeST (c-MeST) that exclusively consists of specificity trials. In this version of c-MeST sessions were standardized as each session contained the same amount of neutral, negative and positive valence cue words, and between sessions cue words were equivalent in valence/pleasantness, activity/arousal, power/dominance [22] and concreteness [23]. As a result, session-by-session specificity scores were obtained and the progress of each participant could be observed. This standardization of sessions is in contrast to the study by Takano and colleagues [21], which followed the standard in-group version of MeST that increased the difficulty in exercises as the session progressed (e.g., retrieving two memories in response to a single emotional cue). In addition, depressive symptoms, rumination and problem solving skills were assessed online pre- and post- intervention.

We tested whether c-MeST remediates rAMS amongst older adults in terms of change from pre- to post- intervention and the trajectory of change from session-to-session. The extent to which c-MeST was associated with change in secondary outcomes and in particular a decrease in depressive symptoms and ruminative brooding, and an increase in problem solving skills, was also tested. The feasibility of c-MeST for older adults was also tested in terms of whether, and to what extent, participants completed the intervention and their reports of their experiences of c-MeST.

Methods

Participants

Participants were recruited between October 2017 and April 2018 via (a) a network of university-related organizations for elder alumni; (b) the website of a public advisory body for older adults; and, (c) an online forum of a commercial website targetting older adults. The study was described as the evaluation of an online training for a memory problem associated with cognitive aging and which is known to be a general vulnerability factor for associated processes such as impaired social problem solving and depression. The only inclusion criterion mentioned in the description of the study was a minimum age of 50 years. After the completion of the survey, participants were entered into a lottery to win a shopping coupon (€20). Participants showing rAMS were contacted and invited to participate in the pre-intervention measurement, until 20 participants completed c-MeST. The study received institutional ethical approval of the first author's institution.

Measures

Autobiographical Memory Test

Autobiographical Memory Specificity was measured pre- and post- training using an online version of the Autobiographical Memory Test [14]. Participants were instructed to retrieve a specific memory for each of ten cue words (five positive, five negative; presented as Multimedia Appendix 1). The instructions included that the memory needed to be specific – that is, the event recalled must have happened once and lasted shorter than a day but did not have to be an important event. One example of a correct answer and two examples of incorrect answers were provided. Due to the online assessment, in contrast with earlier studies in which an in-person verbal version of the AMT was used (i.e. [9]) no practice trials and no feedback during the test could be given and no time limit was used. The AMT was scored by the online classifier and manually by the fourth author. When scores contradicted each other (18.81% of the entries), the first author checked the answers and made the final decision. Two sets of cues were used, and although both sets were matched for imageability, familiarity and emotional extremity [8], they were administered in counterbalanced order across the two test moments to avoid an effect of the cue words. For this study, rAMS was operationalized as a score lower than 70%, which we considered as a deficit in memory specificity to be remediated via training. Published studies have some variability in the inclusion criterion, from no inclusion [9–11,17] to scoring lower than 50% [21] or lower than 70% [13].

Depressive symptomatology

The Patient Health Questionnaire 9 [24] was used to measure depressive symptomatology. The PHQ-9 is a nine-item self-report measure of depressive symptoms, scoring the nine DSM-5 Major Depressive Episode criteria based on the frequency with which they have been experienced in the past two weeks, from 0 (*not at all*) to 3 (*nearly every day*). Scores can vary from 0 to 27. PHQ-9 showed good internal consistency with a Cronbach's alpha of .76 at the pre-intervention measurement.

Rumination

The Ruminative Response Scale – Brooding subscale (RRS-Brooding) [25,26] is a self-report questionnaire consisting of five items measuring brooding from the 22-item Ruminative Response Scale [27]. The items on the brooding factor are considered to measure the maladaptive coping of passively comparing one's situation with some unachieved standard. E.g., participants are asked to report how frequently they tend to think "Why do I always react this way?" or "Why do I have problems other people do not have?" on a 1 (*almost never*) to 4 (*always*) scale. Scores vary from 5 to 20. Cronbach's alpha at pre-intervention was good (.81).

Problem Solving

The problem-solving skills of participants were measured with an online Dutch version of the Stress Anxiety Depression version of the Means-Ends Problem Solving Procedure (SAD-MEPS) [28]. Original MEPS [29] consists of a series of short stories or interpersonal problem situations faced by a hypothetical protagonist. Each story starts with the protagonist facing a specific problem, which is immediately followed by a successful ending. Participants are asked to provide the middle part of each story by typing in strategies or means for solving the particular problem. We used an adapted format [28], consisting of two versions of each three scenarios: one depression-related, one stress-related, and one anxiety-related story. Two sets of stories were used and were administered in counterbalanced order to avoid an effect of the difficulty of the stories. Answers were scored manually by one of the authors on two dimensions. First, in line with the original manual [29], stories were scored for number of relevant means (i.e. discrete sequenced steps that enable the protagonist to get closer to the stated goal). The more relevant means a participant mentions, the better. Second, in line with Marx, Williams, and Claridge [30] stories were also scored for their effectiveness from 1 (*totally ineffective*) to 7 (*very effective*). Total scores result from a mean of the scores on the three stories.

The intervention (c-MeST)

Online MeST consisted of nine sessions of eleven specificity trials, which is similar in dose as the original in-person MeST (99 specificity trials versus 104 specificity exercises; [9]). Original in-person MeST [9] consisted of one session each week for four weeks, with homework assignments for every day in between session. For the current study, participants are instructed to train one session every other day, resulting in 17 days of training. The eleven trials of each session, nine with cue words of different valences, can be categorized in four types: three positive, three negative, three neutral, and two *memories of the day* (one about a memory of yesterday and one about today, without cue words). In this version of c-MeST sessions are standardized as each session contained the same amount of each type of trial, and between sessions cue words were equivalent in valence/pleasantness, activity/arousal, power/dominance [22] and concreteness [23]. Cue words are listed in in the Multimedia Appendix 1. The nine sets of cue words were presented in a fixed order, but the order of the cue words was randomized within each session.

Participants complete each session on an online platform which contained instructions and tips about autobiographical specificity, similar to the instructions of the AMT but more examples are provided. In each of the eleven specificity trials, participants were asked to retrieve a specific memory. The website used the computerized scoring algorithm for the Autobiographical Memory Test [20] to score entries and to automatically give feedback if the entry was specific or not. The scoring algorithm showed good performances against expert-rated scores in discriminating specific versus non-specific memories (> .90 as Area under the Curve in Receiver Operating Characteristic analysis; [31]). If the entry was scored as not specific, participants received feedback stating that their answer was not specific enough, were reminded that they needed to provide a specific memory that occurred on as specific day and only occurred once, and were encouraged to re-enter the memory or another memory with greater specificity. If, despite the feedback, participants could not generate a specific memory within three attempts, the next cue word was presented automatically. If participants succeeded in providing a specific memory, positive feedback was provided and participants were invited to provide more spatio-temporal and contextual details on the next page (i.e., "Where did it happen? When did it happen? How long did it take? Who else was there? What can u see, hear, smell or taste? What kind of day was it?"). Participants were instructed to only fill out these details if they did not already provide them in their initial memory entry. Participants could skip a cue word if they wished to do so. There was no time limit per question.

Measures of training experiences

After each session participants were asked three closed and two open questions regarding (a) to what extent they found that the offered words helpful/easy to help them retrieve a specific memory (0 = *not easy at all, words are very difficult to retrieve memories for,* 10 = *very easy, words are very easy to retrieve memories for*); (b) to what extent they experienced the feedback provided by the software as correct (0 = *not at all, a lot of mistakes,* 10 = *very correct, no mistakes*); (c) to what extent they experienced the session okay in length (1 = *way too short,* to 5 = *way too long*); (d) how they experienced the training and (e) if they had any other remarks.

Procedure

In a first online assessment participants received an informed consent including a question asking whether they wanted to provide contact details to be invited for a follow-up study, in case their results made them eligible. After completing an online AMT, participants who showed rAMS (operationalized as a score of less than 70% on the AMT) were contacted by telephone and invited to participate in this study. Participants were explained that they were selected on their score of the online AMT. Participants were asked (a) if they recognized rAMS in their daily functioning and (b) if they were interested in participating in a study exploring the possibility of remediating this phenomenon. Because of concerns of feasibility and drop-out, participants were offered two options: (1) if they wished to receive instructions for c-MeST face-to-face they were welcome to visit the first author for an in-person conversation (n = 9); if not, (2) instructions were given by telephone and/or e-mail (n = 12). All instructions were provided by the first author, a clinical psychologist, who could potentially refer to appropriate care in case participants were worried about cognitive problems. No significant difference was found between both groups in terms of change in memory specificity between pre- and post-intervention measurements, assessed with a Mann Whitney U Test (U = 47.00, p = .61). In either case participants received an e-mail with a link to a pre-intervention measurement of secondary measures (SAD-MEPS, RRS Brooding and PHQ-9), a second informed consent, and a link to c-MeST. Participants were instructed to complete one session every other day, which would result in a training period of 17 days. Each online session contained questions on feasibility. After participants completed c-MeST another e-mail was sent with an invitation to an online post-intervention measurement of memory specificity (AMT) and secondary measures (SAD-MEPS, RRS Brooding and PHQ-9). When all data were gathered, participants were provided feedback about their scores and were invited to provide extra feedback on feasibility.

Analysis of data

C-MeST sessions were scored as the number of trials for which the patient's first answer was classified as a specific autobiographical memory, in accordance with the logic of the AMT, resulting in a maximum of 11 points per session. Memory specificity and secondary outcomes (depressive symptoms, rumination, problem solving skills) were tested for deviation from the normal distribution using Kolmogorov-Smirnoff test. Results suggested that at both time points (pre- and post-intervention) there were significant deviations from normality (AMT post-intervention, p = .02; RRS Brooding pre-intervention, p = .04; MEPS Means post-intervention, p = .02). For memory specificity per type of trial, the assumption of normality was not satisfied either (all *p*s < .001). Therefore, non-parametric analyses were used for all analyses.

To analyse the impact of c-MeST on memory specificity and secondary measures, a Wilcoxon signed-rank test was used. Relations between variables and change in variables were assessed with a Kendall's tau correlation. To compare scores on different types of trials, a Kruskal-Wallis Test was used with post-hoc Mann-Whitney U Tests.

Results

Sample characteristics

In total, 177 participants aged 50 years and over (121 female, M_{age} = 68.97, SD = 6.60) filled out an online version of the AMT. This screening assessment identified 63 participants with rAMS, operationalized as a score of less than 70% on the AMT (M = 37.46%, SD = 18.58). Among them, 40 people were contacted to participate in the current study. However, 16 people declined to participate, one person was excluded because Dutch was not their native language. The rest of 23 participants started c-MeST. During or after the training, two participants dropped out (one person was sick and one person stopped throughout the training without a post-intervention measurement). Finally, 21 participants (13 female) completed the post-intervention measurements. A flow diagram of the selection and inclusion process is illustrated in Figure 1.

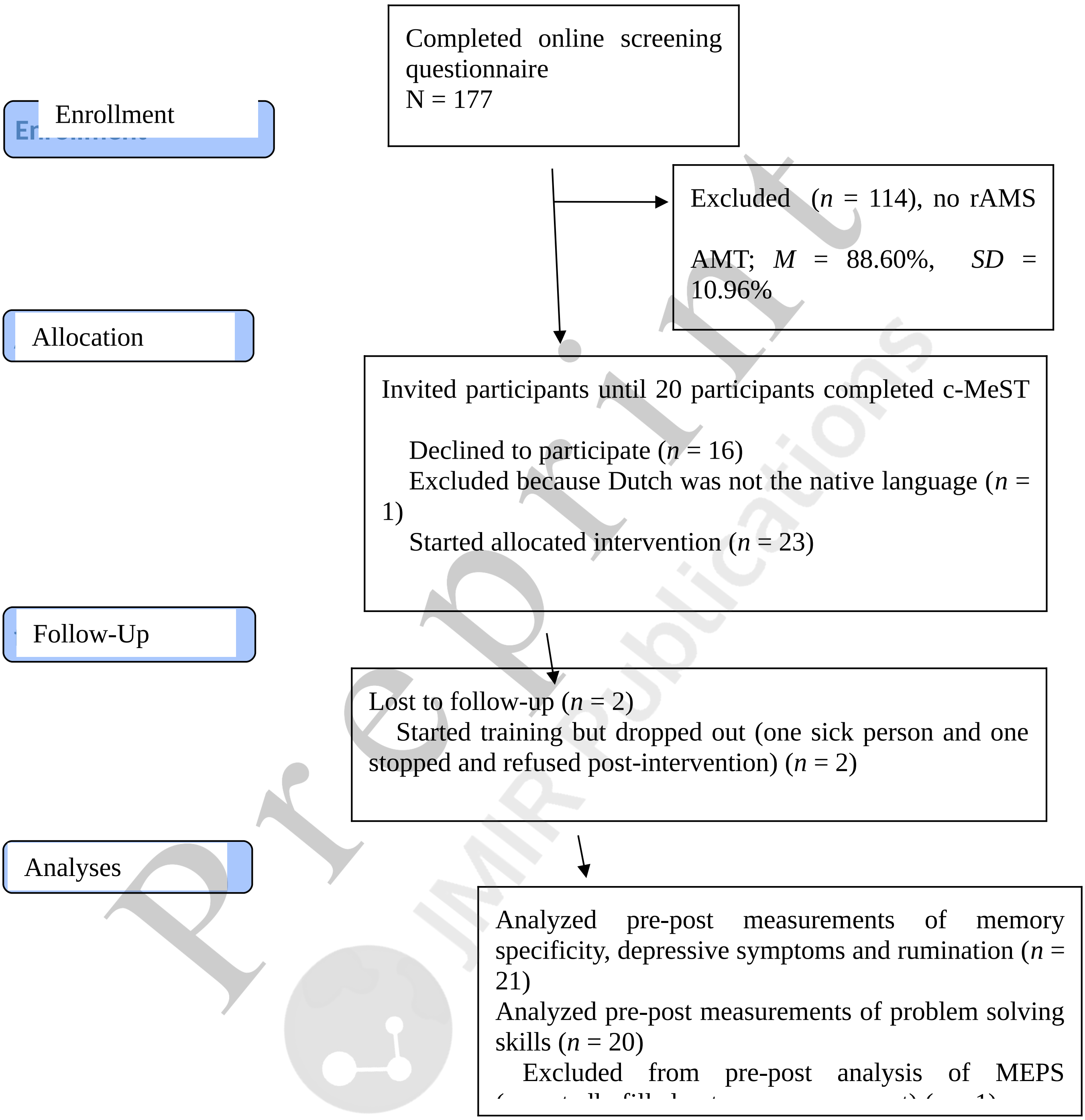

Figure 1. A flow diagram of the selection and inclusion process.

Participants in c-MeST (N = 21) were aged between 55 and 77 years (M_{age} = 67.05, *SD* = 6.55). Participants' age did not significantly correlate with memory specificity or any of the secondary measures (depressive symptoms, brooding and problem solving) at pre-intervention measurement (with the biggest correlation being a Kendall's tau correlation of -.25, *p* = .14 for brooding). Four participants reported mild depressive symptoms at the pre-intervention measurement (operationalized as a score of more than 5 on the PHQ-9) and one participant showed moderate depressive symptoms (> 10 on PHQ-9).

Treatment characteristics

Two participants did not complete c-MeST but did provide a post-intervention measurement: one participant stopped after four sessions and one after five sessions. One other participant was excluded from analyses of problem-solving skills as they inadvertently filled out the pre-intervention assessment several times and thus also completed both versions of the SAD-MEPS task, which made a valid post-intervention measurement impossible.

During c-MeST participants needed to click the ‘OK’ button after entering their memory so that the memory was automatically scored, before filling out the details tab. Sometimes participants did not click OK and switched immediately to the details tab, which led to missing values in 1.67% of all memories scored. Participants were also allowed to skip a trial if they found it too difficult; they did so in 11.31% of the provided trials at a first attempt.

Participants were instructed to train every other day, but they were free to complete the sessions at another pace if they wished to. For the 19 participants who completed all sessions, the duration varied from 13 to 29 days (M = 18.37, SD = 3.34). The number of days between the last session and the moment of the post intervention measurement varied as well, between 0 and 16 ($M = 3$, $SD = 3.76$).

Check on parallel versions

There were no differences between the sets used for the AMT and MEPS, counterbalanced between participants across timepoints, and so subsequent analyses do not use counterbalance as a between subjects factor (see MultiMedia Appendix 3).

Memory specificity

A Wilcoxon signed-rank test showed that participants’ memory specificity increased significantly, $Z = -3.70$, $p < .001$, between pre- (*Md* = 30.00%) and post-intervention (*Md* = 80.00%) as measured by the AMT, which can be regarded as a large effect size ($r = .57$).

Session-to-session analyses, based on first attempts of participants to retrieve a specific memory, showed that there was a significant improvement in the proportion of specific answers given by participants from the pre-intervention assessment (*Md* = 30.00%) to the end of the first session (*Md* = 81.82%), $Z = 3.95$, $p < .001$, $r = .61$. No further enhancement of specificity was observed throughout the remaining sessions (varying from *Md* = 72.73% for session 3 and 8 to *Md* = 81.82% for sessions 1, 2, 4 and 9), as illustrated in Figure 2 (and shown in Multimedia Appendix 2).

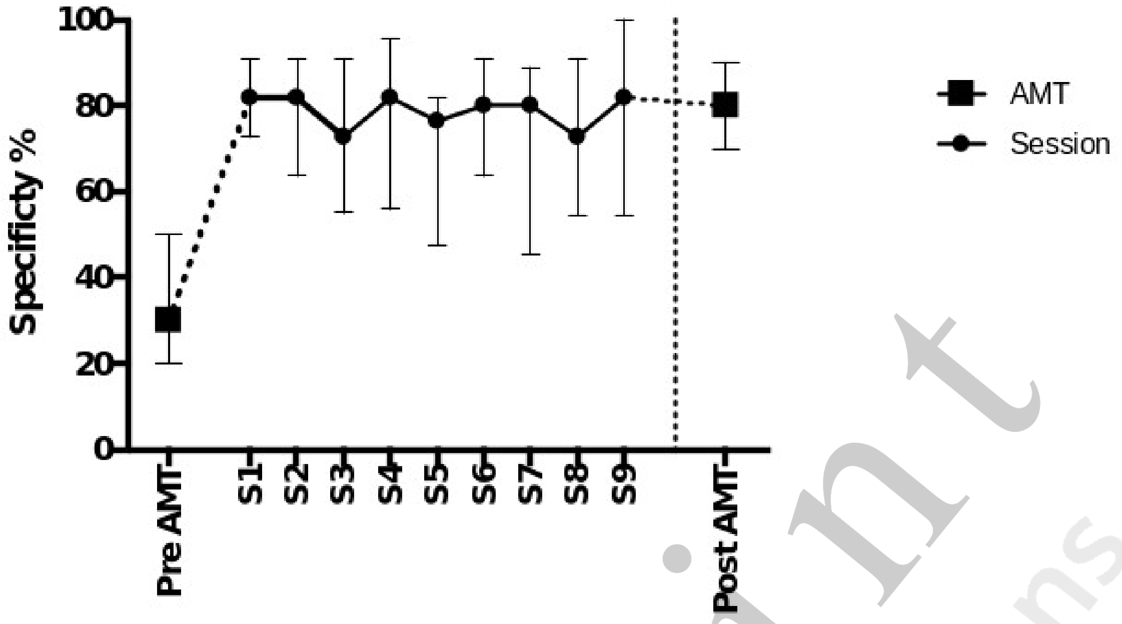

Figure 2. Median scores with an interquartile range (pc. 25 to pc. 75) of Autobiographical Memory Test (pre- and post- intervention measurements) and in between session-to-session scores on c-MeST.

As participants could give a correct answer in a second or even third attempt if they failed to do so on a first attempt, we examined whether participants were successfully able to respond to the feedback given to them after their failed first attempt and so report a specific memory in their second or third attempt. Comparing the mean proportion of specific memories given on *first* attempts and the mean across *all* attempts, this increased from 73.24% to 78.36%. A Wilcoxon signed-rank test revealed that this increase in memory specificity is statistically significant (Z = 6.29, p < .001), which can be regarded as a large effect size (r = .54). Feedback helped participants to retrieve more specific memories.

To check whether certain trials are particularly hard to complete for participants, scores (%) of participants for the four different trial types were compared: trials with (1) neutral, (2) positive, and (3) negative cue words and (4) and *memories of the day*. A Kruskal-Wallis Test showed that there was a significant difference in scores between different trials, $\chi^2(3) = 19.69$, p < .001, with mean rank scores for neutral cues of 362.81, for positive cues of 349.44, for negative cues of 320.68, and for *memories of the day* of 409.07. Post-hoc Mann-Whitney U Tests showed a statistically significant difference between scores on the *memories of the day* (Md = 100%) in comparison with exercises with neutral cues (Md = 66.67%; U = 14038.50, p = .014), positive cues (Md = 66.67%; U = 13509.50, p = .002), negative cues (Md = 66.67%; U = 12308.50, p < .001). Results indicate no significant differences in scores between types of cue words, but *memories of the day* can be regarded as the easiest type of trial.

In addition, analyses did not reveal that the number of days it took participants to fulfill the training (τ_b = .10, p = .59) or the number of days between the last session and the post-intervention measurement (τ_b = .16, p = .38) significantly influenced the difference between pre- and post-intervention measurements of memory specificity.

Changes in secondary outcomes

Participants reported low levels of depressive symptoms (*Md* = 3.00) and brooding (*Md* = 7.00) at pre-intervention measurement. As Table 1 shows, no significant change in reported depressive symptoms and brooding was evident by post-intervention. In addition, no significant change in problem solving skills (the number of means or the overall effectiveness of the solutions generated) was found between pre-intervention measurement and post-intervention measurement (Table 1). Exploratory analyses, in which no relevant association between change in memory specificity and change in secondary measures were found, are added as Multimedia Appendix 3.

Table 1. Medians, range and effect size using a Wilcoxon Signed Ranks Test for all variables at pre- and post- intervention assessment.

Variable	Pre		Post		Effect
	Md	Range (Pc. 25 – 75)	Md	Range (Pc. 25 – 75)	r
AMT[a]					
	30.00	20.00 – 50.00	80.00	70.00 – 90.00	-.57
PHQ-9[b]					
	3.00	.50 – 4.50	3.00	.00 – 4.50	-.09
RRS-5[c]					
	7.00	6.00 – 8.50	8.00	6.00 – 9.00	-.04
[d]MEPS (M) - Means					
	2.00	1.42 – 2.92	1.67	1.67 – 2.92	-.07
[d]MEPS - Effectiveness					
	4.50	3.33 – 5.33	4.83	3.67 – 5.33	-.03

[a]AMT = Autobiographical Memory Test
[b]PHQ-9 = Patient Health Questionnaire 9

[c]RRS-5 = The Ruminative Response Scale – Brooding subscale
[d]MEPS (M) = Mean End Problem-Solving Task.

Feasibility – training experiences

Overall, participants found the cue words used in each session to be of moderate difficulty (*M* = 6.16, *SD* = 2.18) and they experienced the classifier as correct more often than not (*M* = 7.29, *SD* = 1.89). The length of the sessions was experienced on average as 'just right' and 'a bit too long' (*M* = 3.52, *SD* = .80). Multimedia Appendix 4 shows mean scores on the three questions. For the open questions, five participants stated throughout the training that the rationale of the training was not clear, four participants experienced some technical problems and four participants reported that they got better at retrieving memories more quickly.

Discussion

This study examined the impact of online memory specificity training (c-MeST) on difficulty retrieving specific autobiographical memories amongst healthy older adults. This proof-of-principle study showed that translating MeST to an online application resulted in significant improvements in specificity.

Translating MeST to an online application dismantled MeST to its core mechanism. In comparison with in-person, group MeST as used by Leahy and colleagues [16], in c-MeST the introductory session and therapist-plus-group interaction are absent. Other study protocols [13] include psycho-education on memory problems in depression (Session 1) and psycho-education and exercises on how to notice when one is thinking on an overgeneral level in everyday contexts and how to tackle that (Session four). The results of the current study support the idea that mere memory specificity trials are sufficient to improve AMS, which is in line with previous examinations of c-MeST in the context of depression ([21] and personal communication by Martens, Barry, Takano, Onghena & Raes, 2018). Session-by-session scores revealed an increase in specificity between the online pre-intervention measurement and the end of the first c-MeST session. A similar finding emerged in the only other MeST or c-MeST investigation to quantify change in specificity on a session-to-session basis (personal communication by Martens, Barry, Takano, Onghena & Raes, 2018). Critically, this previous investigation used a face-to-face assessment (using a version of the AMT that included feedback) in their pre-intervention assessment and then an online assessment at the end of their first session. The authors concluded that the rapid improvement in specificity may have been due to a change in modality between measurements. The fact that this sudden increase in memory specificity is observed again, but now with an online pre-intervention assessment of specificity (without feedback) refute this suggestion. Instead, it seems that the effects of c-MeST on specificity are realized rapidly. For the current study, the addition of automated feedback in session in comparison to the pre-measurement, might have contributed to the sudden increase in memory specificity. However, it remains unclear what dosage of c-MeST (how many sessions) are required in order for these effects to endure once the intervention ends.

Some discrepancies between specificity measured within the AMT and within c-MeST are also of note. It could be that the difference in cue words between AMT and c-MeST might explain why c-MeST evoked more specific memories. First, it may be that the addition of neutral cue words and *memories of the day* to assessments of specificity in c-MeST make it easier for participants to retrieve specific memories. Also, by including participants with lower specificity scores than 70% at pre-intervention measurement, the increase in scores at a second measurement could be due to *regression to the mean* [32]. Future investigations should test these possibilities by comparing c-MeST to a control intervention and by testing differences in specificity across different cue types within the AMT *and* c-MeST. Another interesting route for future investigations is to include a measure of speed (or response time) for each memory retrieval. A decrease in the response time to retrieve a specific memory over the training may reflect an improvement in memory functions, which could better capture the training effect (or improvement trajectory) rather than the binary score of a specific memory.

Our hypothesis that c-MeST would lead to a decrease in depressive symptoms and rumination was not supported, but this may be due to floor effects for both variables. Participants' scores at the pre-intervention measurement of depressive symptoms (PHQ-9: $M = 3.19$; $SD = 2.96$) fall in the range of the scores found in the general population in this age range (from age 45 to >75: $M = 2.8$, $SD = 3.5$ to $M = 4.4$, $SD = 3.9$; [33]). Scores on the rumination brooding scale are also in line with those found in the general population ($M = 7.62$, $SD = 2.27$ compared to $M = 8.6$, $SD = 2.8$ in [34]) . Leahy and colleagues [17] reported similar findings. It might, therefore, be unrealistic to predict further improvements from these low levels. It is of note that amongst older adults who are vulnerable to subsequent increases in depression and impairments to quality of life and independence, the potential for c-MeST in preventing increases in these variables is worthy of further investigation.

No increase in problem solving skills was observed. This might indicate that c-MeST does not influence problem solving skills in healthy older adults with rAMS. This might also be explained by the use of an online version of SAD-MEPS, which is a test designed to be conducted face-to-face. After SAD-MEPS was used as a face-to-face measurement amongst people with depression [9], it was used as an online measurement amongst healthy students [35]. In both studies no statistically significant effects from pre- to post-intervention were observed in problem solving skills. Future studies could assess problem solving skills using measures which are more appropriate for online delivery or else the test should be conducted in-person. The use of an adapted version of MEPS, SAD-MEPS, may not have been optimal for a group of healthy older adults with rAMS and future research might use the standard MEPS.

The results of this study suggest that online remediation of rAMS is feasible for older adults. Participants considered the words as moderately difficult, the feedback from the classifier as correct, and the length of the sessions as tolerable. However, participants' varied in their preferences for session length and frequency. Given the nature of this research trial, we instructed participants to train 9 sessions of 11 trials in 17 days. However, outside of a research context participants should be able to train at their own pace. The software developed and tested here can enable participants to choose their own dosage and the frequency of training, which could further improve uptake and adherence. People also vary in scores for the four different kinds of trials. Future c-MeST could be personalized with an adaptive design, for example offering participants with low scores on one sort of cue words more of those similar trials. The software could also be combined with other instructions, such as those used in Life Review where specific memories are retrieved for particular life periods [18].

A limitation of this study is that the educational levels of participants was unknown. It can be assumed that the average educational level was above average as many participants were members of a university alumni group. Although internet use amongst older adults is generally high (in Belgium, 79% of older adults between 55 and 64 years have been reported to use the internet daily [36], education and income levels are also positively correlated with internet skills [37]. Future investigations should examine the feasibility of c-MeST amongst a more diverse socioeconomic range of participants than was used here. Another limitation is that we did not control for cognitive functioning. As previous research has indicated that specificity performance is associated with cognitive functioning such as executive functioning [38,39], future research should control for cognitive functioning.

However, for this proof of concept study, the feasibility of c-MeST is promising.

Conclusions

Online memory specificity training can effectively improve reduced autobiographical memory specificity amongst healthy older adults. Translating the in-group training to a computerized version resulted in a feasible, scalable, alternative, but no impact of this training on depressive symptoms, rumination or problem solving skills was found. Future investigations require follow-up assessments and control groups to assess the utility of c-MeST as an intervention for rAMS, and in the prevention of other negative outcomes such as increases in depression symptoms, amongst older adults.

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Conflict of Interest

The following facts which may be considered as potential conflicts of interest. Dr Raes is one of the developers of the original in-group face-to-face MeST. Dr Takano, Kris Martens and Dr Raes are the developers of the online, computerized MeST (c-MeST). Kris Martens and Dr Raes additionally receive payments for training workshops and presentations related to MeST. We wish to confirm that there are no other known conflicts of interest associated with this publication and there has been no significant financial support for this work that could have influenced its outcome.

Multimedia Appendix 1

Cue words used in assessments and training.

Multimedia Appendix 2

Specificity scores for each of the nine sessions of computerized memory specificity training.

Multimedia Appendix 3

Exploratory analyses.

Multimedia Appendix 4

Results for three feasibility questions.

Multimedia Appendix 5

The following raw data can be found as Supplementary File 5:

- Memory Specificity scores (AMT) of all participants
- For participants included in examination of c-MeST, per participant:
- Memory Specificity scores. Pre and post- intervention measurements (AMT)
- C-MeST scores. Amount of sessions and trials fulfilled, scores for each kind of trial, scores on first attempts, scores on all attempts, number of trials skipped.
- Impact of c-MeST on secondary measures. Pre - and post- intervention measurements of depressive symptoms (PHQ-9), brooding (RRS-5), problem solving (SAD-MEPS).
- Feedback of participants. Scores on three feedback questions.

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