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EngAge – A metacognitive intervention to supplement working memory training: A feasibility study in older adults

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ABSTRACT

Working Memory (WM) training has shown promise in supporting cognitive functioning in older adult populations, but effects that generalize beyond the trained task have been inconsistent. Targeting cognitive processes in isolation might be a limiting factor given that metacognitive and motivational factors have been shown to impact older adults' engagement with challenging cognitive activities, such as WM training. The current feasibility study implemented a novel metacognitive intervention in conjunction with WM training in older adults and examined its potential amplifying short- and long-term effects on cognitive and self-report outcomes as compared to WM or active control training alone. One-hundred and nineteen older adults completed a cognitive training over the course of 20 sessions at home. The cognitive training targeted either WM or general knowledge. In addition, one of the WM training groups completed a metacognitive program via group seminars. We tested for group differences in WM, inhibitory control, and episodic memory, and we assessed participants' perceived self-efficacy and everyday memory failures. At post-test, we replicated earlier work by demonstrating that participants who completed the WM intervention outperformed the active control group in non-trained WM measures, and to some extent, in inhibitory control. However, we found no evidence that the supplemental metacognitive program led to benefits over and above the WM intervention. Nonetheless, we conclude that our metacognitive program is a step in the right direction given the tentative long-term effects and participants' positive feedback, but more longitudinal data with larger sample sizes are needed to confirm these early findings.

Introduction

Working memory (WM), the ability to retain and simultaneously manipulate information, is a core cognitive mechanism involved in various complex cognitive tasks

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[50], including those of everyday functioning [9]. Critically, it is among the prominent factors accounting for individual differences in cognitive functioning across the life span [60,71]. In addition, WM displays age-related decline [10,57], which coincides with age-related changes in both, structural brain architecture as well as functional networks [2,46,53,61,63,65,67].

Given the importance of WM in everyday life, it is not surprising that there is thriving research aimed at developing WM training procedures capable of mitigating or slowing down age-related cognitive decline. Such programs target WM with the aim of not only improving older adults' WM performance, but also facilitating a more flexible use of general cognitive resources, which in turn, might lead to improvements in cognitive skills that rely on the integrity of WM processes [56,70,78]. Several *meta*-analyses have demonstrated that training WM can benefit healthy older adults in that they show substantial gains in measures that are similar to the trained tasks [39,80]; in addition, these gains are maintained for several months after training completion [30]. The evidence is less conclusive, though, with respect to improvements in outcome measures that are less related to the trained tasks (i.e., far transfer effects), with effect sizes that are typically smaller than those observed for more specific training gains [39,77]. Furthermore, the effects seem to be more mixed and less durable overall [30,80].

Thus, the efficacy of WM interventions in older adults is still a matter of debate, especially in terms of the generalizability of training benefits, and there is growing interest and research that is dedicated to better understand the factors that might impact efficacy. Along with pre-existing individual differences in cognitive ability [34,41,54] and dopaminergic functioning [3], recent work has highlighted participant motivation and engagement as well as growth mindset as key factors impacting adherence and learning outcomes [55,56,75,82]. For example, our group found that participant motivation, as characterized by engagement with a WM training task, was directly related to WM improvements in children with ADHD [37], as well as in young adults [34,51]. Thus, we and others have argued that motivation might be a critical factor contributing to training efficacy [38,51].

Several previous attempts have implemented "game-like" elements to improve participants' motivation and engagement while completing cognitive interventions (e.g., [20,40], however, most of such gamified interventions are not specifically designed for older populations [31,43]. In addition, they fail to trigger relevant metacognitive and emotional-motivational processes that have been shown to support intervention completion and training benefits [15,54,73]. In particular, it has been shown that metacognitive processes can influence how older adults perceive and regulate their cognitive functioning when dealing with cognitively demanding tasks [28].

Critically, older adults' knowledge and perceptions about memory and cognition are often affected by negative beliefs about their cognitive functioning and its age-related changes (e.g., believing that aging is associated with unavoidable losses, and that abilities are immutable rather than malleable [29]. Indeed, older adults are more likely to perceive their memory as functioning more poorly as compared to when they were younger, and they are also less likely to perceive that they have control over their cognitive functioning, in particular, memory and learning. Such negative views impact actual performance, which further leads to less confidence, self-efficacy, and motivation towards engaging in effortful cognitive tasks [27,29].

To disrupt such thinking patterns, several interventions that embrace metacognitive approaches (particularly those that include specific activities aimed at fostering metacognitive processes) have been developed, and there is recent *meta*-analytical evidence that such interventions are promising avenues to improve memory performance in adulthood and older age (see [74]. There are also promising effects for programs that combine metacognitive approaches with mnemonic strategy interventions that attempt to improve episodic memory performance through the teaching of mnemonic techniques. However, it is still unclear whether mnemonic strategies are easily generalizable beyond the specific context in which they are trained (see [74]. No studies to our knowledge have attempted to capitalize on metacognitive processes to supplement a WM intervention in older adults. Built upon existing research in the episodic memory domain, combining a metacognitive program with a WM intervention might be a promising avenue to amplify cognitive training benefits. Training-induced changes and transfer to non-trained cognitive functions might be explained not only by shared underlying brain networks, but also by common underlying neurotransmitter systems (e.g., [5,18]. In particular, the dopaminergic system is known to be implicated in WM performance, cognitive control, as well as learning and plasticity (e.g., [4,12]. Indeed, it has been demonstrated that WM training-related transfer is mediated by dopaminergic modulation of the prefrontal cortex, especially in older adults (e.g., [6,3,18,24,42,70]. Moreover, the dopaminergic system supports a range of motivational processes (e.g., effort, engagement, reward; [44,84], and has also been found to regulate metacognitive processes (e.g., [36]. Thus, the dopaminergic system acts as a critical interface in modulating interactions between cognitive and emotional-motivational processes [45].

To optimize WM training paradigms for older adults, the current study focuses on supplementing a previously successful WM intervention with activities that trigger metacognitive-motivational processes in order to capitalize on potential synergistic effects between benefits generated by the WM training as well as those generated by the added metacognitive-motivational component. The aim of the present study was therefore to examine the feasibility and efficacy of this novel training approach in an older adult population, with the hope of generating more pronounced benefits, as well as longitudinal effects by activating the relevant dopaminergic systems to optimally support WM functioning and training gains [35]. The metacognitive program - called EngAge - was designed to include specific activities aimed at challenging misconceptions about cognitive functioning and age-related changes, to enhance metacognitive knowledge and regulatory processes, as well as fostering positive attitudes, attributions, self-efficacy, and motivation towards engaging in demanding cognitively-stimulating activities to promote healthy aging (e.g., [74,83]. The metacognitive program was also thought to promote a growth mindset and improve engagement and persistence with the WM training program, which is essential given that training on n-back is often perceived as complex and demanding [87]. A growth mindset along with modified attributions and greater engagement could lead to more improvement during training and experiences of success (e.g. [34,75], which in turn, could further impact participant self-efficacy and confidence, as well as promote a sense of agency [8]. Importantly, the EngAge program was delivered in a group setting to further promote emotional-motivational processes by capitalizing on social support, which has been shown to promote cognition and successful aging [11,47,76].

The EngAge program was used in conjunction with a well-established, home-based n-back training regimen that was only minimally gamified [33]. To examine the potential additive and/or synergistic effects of the metacognitive program, the combined EngAge + WM intervention group was compared with a group that completed only the WM training, and an active control group that completed alternative tablet-based activities targeting general knowledge and vocabulary (Knowledge Builders; KB). The relative benefits of the interventions were assessed using non-trained WM measures, inhibitory control measures, as well as long-term memory measures. We also implemented a vocabulary measure and processing speed tasks as controls for which we did not expect any intervention-specific benefits. Furthermore, we administered self-report measures of memory self-efficacy and everyday functioning (self-reported cognitive failures) to capture benefits in the metacognitive domain.

We predicted that both the combined EngAge + WM and WM training groups would outperform the KB active control group in WM and inhibitory control measures, a finding which would both replicate and extend our previous work [33]. In addition, we tested whether the EngAge + WM training group would show even greater improvements and maintenance effects in cognitive outcomes as compared with the WM training group. Finally, we expected the EngAge + WM group to show the most pronounced benefits in self-reported memory self-efficacy and everyday memory functioning, given that these were the aspects that were specifically targeted by the metacognitive program.

Method

Participants

Healthy older adults were recruited from Southern California and Southeast Michigan via flyers distributed in the community, snowball sampling, and through an online registry aimed to connect researchers with individuals interested in participating in research (Content-to-Contact Registry; [26]). The current study builds upon our earlier study by adding new participants to an existing dataset using similar procedures [33], AsPredicted #7897; https://aspredicted.org/mp2jv.pdf).[1] Inclusion criteria were as follows: (i) age between 65 and 85 years; (ii) good physical and mental health status assessed by means of extensive demographic and health questionnaires, (iii) absence of diagnosed neurological disorders including mild cognitive impairment, (iv) a Mini Mental State Exam (MMSE; scores > 24) [23], (v) no depression or anxiety as assessed by the Geriatric Depression Scale (GDS; scores < 10) [86], and the Generalized Anxiety Depression Questionnaire (GAD; scores < 15) [79], and (vi) no current participation in other cognitive interventions.

Eligible participants were randomly assigned to two groups: the WM training group (n = 36); or the Knowledge Builders (KB) active control group (n = 35). Furthermore, we added a new study arm to test the novel combined intervention by recruiting a separate group of participants exclusively in Southern California, i.e., the EngAge + WM training group (n = 54). Five participants from the EngAge + WM group dropped out during the intervention, and another participant from the KB group was excluded because of missing demographic and baseline data (cf. Fig. S1; Supplementary Materials).

Participants were included if they completed at least 50% of the cognitive intervention (i.e., 10 sessions of WM or KB, respectively), and if they were in the EngAge + WM group, they also had to complete all group seminars (note though that a few participants changed their session dates due to scheduling conflicts). Research procedures were approved by two institutional review boards, and participants signed an informed consent.

Materials

The assessments used in this study are the same as used previously and therefore only briefly described in the following. For a full description of each of the cognitive outcome measures, see Jaeggi et al. [33] and Weaver and Jaeggi [85].

Cognitive assessments

Working Memory. We used three measures to assess WM: A Spatial n-back task (cf. [33]), the Symmetry span task (cf. [64]), as well as the Sternberg item-recognition task (cf. [32]). In the Spatial n-back, the primary dependent variable was the proportion of hits minus false alarms (pr) across all 2-back trials, although for completeness, we also report the reaction times (RT) for correct responses. In the Symmetry span task, the number of correctly recalled sets was used as the dependent variable. In the Sternberg task,

[1] We reused a subpopulation from a previous dataset [33]; data collection 2016–2018) given that we relied on the same procedures and outcome measures in the current study (data collection 2018–2020). Specifically, from the previous dataset, we included the 24 participants from the WM training group and the 24 participants from the KB group who completed the once-per-day training schedule. To address potential cohort effects, we recruited additional participants for the WM group (n=12), and the KB group (n=11), which we randomly assigned to their condition. We planned to recruit more participants to reach equal sample sizes across all three groups, however, this was cut short due to the COVID-related lockdown.

the primary dependent variable was RT for correct responses across all set sizes, and in addition, we also report accuracy.

Inhibitory Control. Our inhibitory control measures included the false alarm rates (errors) derived from the n-back task (cf. [33]), and the number of intrusions made in the visual long-term memory task (VLTM; cf. [59]). In addition, we used the D2 (cf. [13]), for which we used the total number of items completed minus any type of error (TN-E) as the dependent variable.

Episodic Memory. Episodic memory was assessed by a Meta-Memory task (cf. [48]), the VLTM (cf. [59]), and an applied memory task, the "Characterization of the Elderly on Daily Activities in the Real-World" (CEDAR; cf. [81]). We used the number of correctly recalled words across all lists in the Meta-Memory task as the dependent variable (cf. [58] for a report on the other variables). The dependent variable used in the VLTM task was the total number of correctly recalled items. In the CEDAR task, we used the average accuracy across subtasks.

Control Measures. We used the Mill-Hill Vocabulary Scale (cf. [62]), and two measures of processing speed, i.e., the Letter and Pattern Comparison task (cf. [19]). The dependent variables used were the total number of correct trials in the vocabulary task, and the total time in seconds to complete each of the processing speed tasks (letter and pattern comparison).

Self-Report assessments

Self-efficacy. We used the 11-item locus of control subscale of the Meta-Memory in Adulthood questionnaire (MIA; [21]) to assess participants' perceptions of control in memory-demanding situations. Statements such as "I can't expect to be good at remembering zip codes at my age" were presented. Participants were asked to select responses from a 5-point Likert scale ranging from "agree strongly" to "disagree strongly". Higher scores correspond to more negative perceptions of control of memory (Cronbach's Alpha: 0.68). Finally, a 10-item General Self-Efficacy survey (GSE; [72]) was utilized to assess individuals' perceptions of their ability to handle difficult situations. Statements such as "I can always manage to solve difficult problems if I try hard enough" were presented. Participants were asked to select from a 5-point Likert scale ranging from "not at all true" to "exactly true" and choose which response described them if they were in a similar situation. Lower scores corresponded to lower perceived ability or self-efficacy (Cronbach's Alpha: 0.89).

Cognitive Failures and Everyday Memory. We used a 40-item version of the Cognitive Failure Questionnaire-Memory and Attention Lapses (CFQ-MAL; [14]) to assess self-perceived frequency of cognitive failures that happen in everyday life. For example, participants were presented with questions such as "At the end of a conversation, do you realize that you forget to mention something you wanted to say?" Responses were selected from a 5-point Likert scale ranging from "never" to 'very often". Higher scores corresponded to greater frequency of cognitive failures (Cronbach's Alpha: 0.93). An adapted 13-item version of the Everyday Memory Questionnaire (EMQ; [69]) was utilized to assess self-perceived memory failures in everyday life. Participants were presented with statements such as "Forgetting important details of what you did or what happened to you the day before" and asked to select on average how often such incidents happen to them with five multiple choice responses to choose from ranging from "once or less in the past month" to "once or more in a day". Higher scores corresponded to a greater amount of memory failures (Cronbach's alpha: 0.76).

Procedure

Before and after the intervention period, participants came to the lab to complete a battery of behavioral tasks as well as questionnaires. In most cases, the research assistants who conducted the assessments were not involved in training, and thus, they were not aware of the conditions to which participants were assigned. Occasionally, other staff members who were involved in training conducted the testing due to unforeseen circumstances, but that was the exception. Participants were provided with electronic tablets to take home to complete daily activities. All participants were asked to complete 20 sessions of tablet-based cognitive training activities individually at home, roughly one session per day, with each lasting approximately 20 min. The tablet-based activities targeted either WM or general knowledge, depending on group assignment [33]. In addition, the EngAge + WM training group participated in three group seminars, each lasting two hours (cf. Fig. 1). Those three sessions were administered in conjunction with the WM intervention with the goal to foster metacognitive processes to promote learning and support the engagement with the WM training. Furthermore, the EngAge + WM training group completed a final 2-hour long group session ~ 4–5 weeks after training completion to further consolidate the knowledge acquired during the intervention (cf. Fig. 1). Participants were not aware that there were other training conditions. All participants were asked to complete a follow-up assessment session three months after training completion.

Unfortunately, due to the COVID-related pandemic and associated lockdown that did not allow for in-person testing, a subset of participants (n = 9) completed the 4th group seminar session via zoom, and furthermore, very few participants were able to conduct the follow-up assessment sessions (cf. Fig. S1). Also, in our earlier study [33], we did not implement the survey measures at post-test until later during data collection; in addition, many participants failed to complete all surveys at home, thus, our report of the survey data is provided for descriptive purposes only.

Metacognitive Program. Materials and content for the group seminars of the EngAge program were purposely designed to: 1) challenge erroneous and negative beliefs regarding cognitive aging and related changes, and promote awareness of one's own cognitive skills and their functioning; 2) promote a proactive attitude, a growth mindset, as well as confidence and control over one's own cognitive skills; 3) promote motivation toward embracing an "engaged" lifestyle and adopt best practices

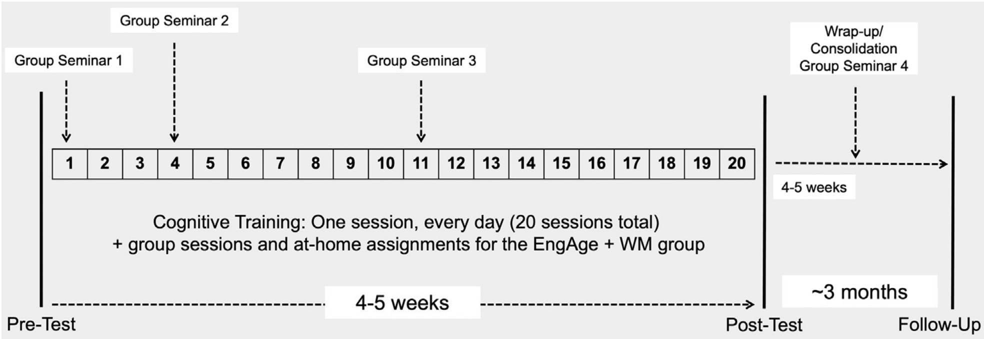

Fig. 1. Procedure. Each of the intervention groups was asked to complete 20 sessions of tablet-based training at home over the course of 4–5 weeks. Within a week of the first and last training session, as well as 3 months after training completion, participants underwent testing in the lab, and they were asked to complete self-report surveys via Qualtrics at home. The EngAge + WM group completed 4 additional in-person group sessions lasting 2 h each; three during the intervention period, and one final session $\sim$ 4–5 weeks after training completion. In addition, they were asked to complete assignments and reflections at home.

Table 1
EngAge - metacognitive-motivational program. Key concepts covered in each seminar.

Seminar 1	Seminar 2	Seminar 3
Cognitive Aging • Different memory systems and their sensitivity to the effects of aging → memory is not unitary. • What is active/healthy aging? • Cognitive failures in everyday life, and the role of attention and motivation.	**Mindsets** • Growth vs. fixed mindsets. Which one is endorsed during challenging situations? • Attributions for memory successes and failures. • Knowledge and beliefs about memory with aging. • Self-efficacy and trusting one's abilities.	**Importance of an engaged lifestyle** • Consequences of mentally engaged vs. disengaged lifestyles (cost/benefit analysis). • Benefits of engagement for well-being and brain health. • Importance of correct beliefs about memory performance and trusting one's abilities. • How to endorse an engaged lifestyle and strategies for choosing valuable and meaningful goals for oneself.

Note. The 4th seminar re-emphasized the three prior seminars, thus, no new concepts were covered.

and strategies to support cognitive functioning and healthy aging.

As is typical in such programs [74,83], each seminar provided theoretical explanations on given topics presented by the experimenters, supplemented with practical activities (e.g., brief tasks or questionnaires) and group discussions to provide participants with hands-on examples, as well as vicarious experiences and social stimulation. As for theoretical explanations, all sessions referenced research from various disciplines and included easily interpretable images, figures, and graphs to communicate the information.

Each of the seminars covered one topic. Table 1 provides an overview of the topics covered in each seminar; the slides and associated activities are available on the Open Science Framework (https://osf.io/fv86h/?view_only=858ad1c4c7b04ba0ae3c79de1edde8f7).

The first seminar focused on cognitive aging and memory systems. It illustrated how memory systems work, and which forms of memory are particularly sensitive to the effects of aging. Finally, other factors that impact one's ability to remember information, such as attention and motivation, were highlighted. The goal of this session was to emphasize that memory is not a unitary construct, but rather is comprised of several components that are differentially affected as one ages, and to stress that memory challenges are not inherently indicative of severe cognitive decline, but that such challenges are also related to attention, effort, and relevance of that information. During the session, participants completed various activities to demonstrate the different levels of difficulty amongst tasks that required the use of WM, recall, and recognition abilities. Discussion was always highly encouraged, and the goal was to relate the material to experiences in the participants' everyday lives.

The second seminar brought attention to the role of one's growth vs. fixed mindset [22] and how it can impact the engagement with mentally challenging situations (such as the daily WM training) and emphasized how one's beliefs and self-efficacy about one's abilities may lead to avoidance (or engagement) with these situations. Participants were also guided in reflections about the attributions they might make when encountering a memory success or failure, and in recognizing the importance of context, control, and effort [8]. The experimenter explained how knowledge and beliefs about our mental abilities are connected to self-efficacy, mindsets, and attributions of memory successes and failures. They were told that these factors all play a role in whether one chooses to avoid situations that require the use of memory or maintain motivation to engage despite the potential for failure.

In the third seminar, the importance of living an engaged lifestyle was discussed. In addition, participants were presented with a cost-benefit analysis towards

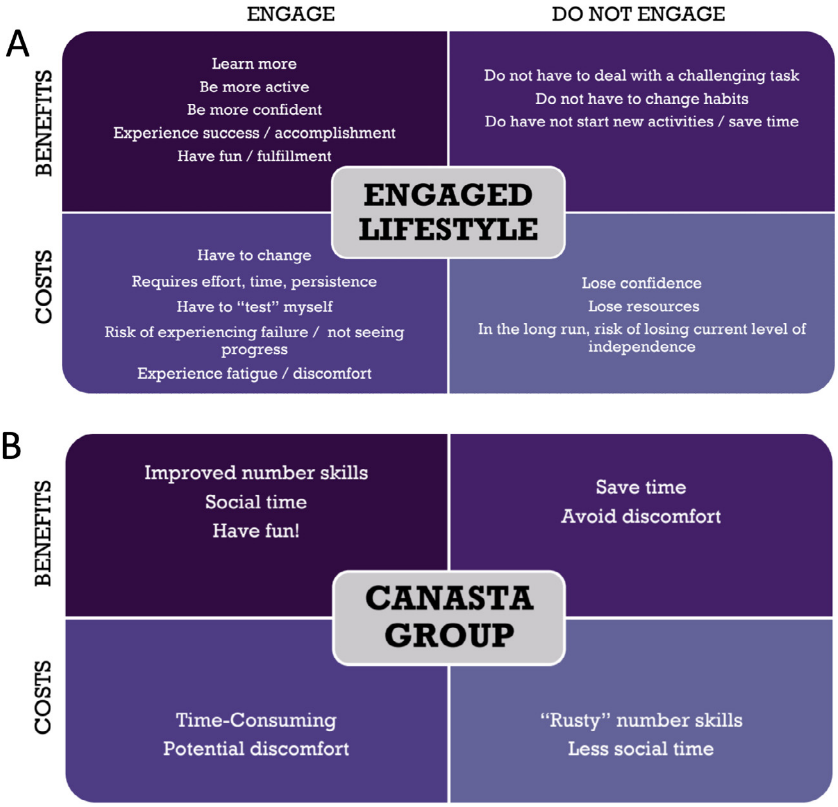

Fig. 2. Example for the cost-benefit analysis discussed in Seminar 3. A: General example to illustrate the costs and benefits of engaging in a mentally active lifestyle. B: Example for the costs and benefits of engaging in a specific activity (being part of a canasta group) generated by a participant.

engaging (or not engaging) in cognitively stimulating activities (cf. Fig. 2), which was inspired by motivational interviewing [17,49]. Other topics covered "risky aging" [1,25], and the neural benefits and compensatory scaffolding effects that may result with new learning and engagement [66]. Finally, participants were presented with strategies for choosing meaningful activities for engagement and successful aging utilizing the selection, optimization, compensation model (SOC; [7]).

The first seminar was held prior to starting the cognitive intervention and was intended to provide participants with relevant background knowledge about memory. Seminars 2 and 3 were scheduled during the WM intervention with the goal of providing participants with relevant metacognitive skills as they were dealing with the cognitive demands of the WM training. The fourth and last seminar was held after the intervention period, in which the content of the previous three seminars was revisited to consolidate the material, and thus, no new content was covered.

In order to keep the seminars engaging and interactive, they were limited to 4–5 individuals which allowed for a rich discussion amongst all participants. Each of the seminars was facilitated by two trained experimenters (one lead experimenter, and one co-lead), and these facilitators remained with the same cohorts of participants as much as possible to maintain the established rapport. In total, 7 experimenters were trained to facilitate the sessions using a script and a manual to ensure that all material was covered, and to maintain consistency in language. That said, almost all the seminars were led by one of the facilitators (ANW, i.e., there were 14 participant cohorts in total, 12 of which were led by ANW).

To supplement the in-person group seminars, participants were asked to complete short weekly homework assignments, which required them to reflect upon the main points of the session for that week in writing, and to complete an activity or questionnaire alluding to the material for the following week. Moreover, they were invited to keep a written journal – akin to a diary – in which they were asked to respond to a daily prompt asking them to reflect on how they were feeling that day, how they felt about their mental abilities that day, and to take note of situations that required the use of their memory, and of any difficulties they may have encountered. The prompts were always the same; however, participants were encouraged to include any information they felt was significant to them, including their experience with the WM training.[2]

To complete their at-home activities, participants were provided with binders that contained copies of the weekly session material, the homework assignments, as well as the reflection journal pages, which they were asked to take

[2] Qualitative analyses of the reflection journals will be reported elsewhere.

with them for each seminar in order to facilitate meaningful group discussions.

Working Memory Training. Participants in the WM and the EngAge + WM group completed a minimally gamified version of the n-back task on a tablet individually at home (see [33,34] for details). This task used pictures as stimuli that were presented one at a time (e.g., common objects, animals, or plants; presentation time: 1,000 ms; interstimulus interval: 2,500 ms). Participants were required to indicate whether a presented image was the same as the one presented n-trials previously. Each image could be either a target, a non-target, or a lure (i.e., an image that was presented n ± 1 trials back in the sequence). Participants completed 10 rounds per training session consisting of five target trials, 10 + n non-target trials, a variable number of lures (0, 2, or 6), and an additional filler trial at the beginning of each round. The task was adaptive and increased or decreased its difficulty by increasing or decreasing n and the number of lures as a function of participant's performance (accuracy) after each round [34], and participants also received feedback about their performance at that time. The dependent measure was the average level of n reached per training session.

Knowledge Builders Training. Participants in the control group used a tablet-based general knowledge program [34]. Participants were presented with general knowledge and vocabulary questions, along with four potential answer alternatives. Each selected response was followed by feedback on whether the answer was correct, and if it was incorrect, the question was presented again at the following session. This task was adaptive as well in that the difficulty of the questions corresponded with the level of success. Participants completed 10 rounds per training session (12 questions per round), which they completed individually at home. Although the emphasis of the task was on accuracy, participants were given 45 s to respond before the trial was marked as incorrect. The dependent measure was the average level reached per training session.

The training tasks (WM or KB, respectively) which also included a practice session were introduced in the lab as part of the first seminar in the EngAge + WM group, and as part of the pre-test assessment in the other two groups. All participants were told to complete one training session per day and to keep up a regular training schedule. The research team did not interact with the participants during training (except for the EngAge + WM group), but staff was available for questions and troubleshooting via email or phone. That said, participants rarely reached out, indicating that they were able to complete the assigned program independently and with minimal assistance.

Analytical approach

The data were analyzed using IBM SPSS statistics Version 27. We first tested for group differences at baseline (demographic variables and outcome measures). We then analyzed the training performance of the WM and EngAge + WM groups by comparing the performance of the first two sessions with the last two sessions (average n-back level) using paired t-tests [33]). For the outcome measures, we used a similar approach as in the earlier study [33]; specifically, we ran separate multivariate analyses of variance (MANOVAs) with intervention as between-group factor; in each of the MANOVAs, we included the measures within each of the three tested domains (WM, inhibitory control, episodic memory) as well as the control measures (vocabulary, processing speed) using gain scores (comparing pre vs. post, and pre vs. follow-up, respectively). In addition, we followed up the MANOVA with individual analyses of covariance (ANCOVAs) to capture more subtle differences between the intervention groups. Specifically, for each measure, we conducted ANCOVAs using intervention as a between-group factor and post-test (or follow-up test) as the dependent measure, with pre-test as the covariate. In case of significant intervention effects, we ran orthogonal Helmert contrasts, i.e., first comparing the two WM groups (WM and EngAge + WM) with the control group (KB), followed by a direct comparison between the WM and EngAge + WM group.

Results

Demographic information of the final analytical sample (N = 119; 76% women, M_{age} = 72.86 years, *SD* = 5.14) is provided in Table 2. Note that there were no group differences in any of the demographic variables with the exception of

Table 2
Demographic information as a function of intervention group.

	EngAge + WM (N = 49)		WM (N = 36)		KB (N = 34)		Group differences (*p*)
Women (#, percentage)	36	74%	27	75%	27	79%	0.88
Age (mean, SD)	72.63	5.17	72.89	5.72	73.15	4.55	0.90
SES (mean, SD)	6.93	1.47	7.10	1.65	6.97	1.21	0.88
Education (mean years, SD)	16.60	2.53	16.60	2.17	16.47	2.48	0.96
Vocabulary (Mill-Hill; mean, SD)	22.46	3.91	21.78	3.56	22.06	4.49	0.73
Health (mean, SD)	3.90	0.65	4.10	0.76	3.88	0.73	0.38
Cognitive status (MMSE; mean, SD)	28.71	1.54	29.06	1.14	28.35	1.74	0.15
Depression (GDS; mean, SD)	0.57	0.93	0.62	1.07	0.79	1.37	0.67
Anxiety (GAD; mean, SD)	0.49	0.88	1.03	1.84	1.56	1.85	0.009**

Note. SES was assessed on a self-report scale of 1–10 with higher values indicating more well off in comparison to others in the United States. Health was assessed on a scale of 1–5, with 5 indicating above average physical health in comparison to others their age. There were some missing data, because participants chose not to complete certain surveys, or the data were lost due to user error (SES = 13, Education = 2, Health = 6, GDS and GAD = 6; Vocabulary = 1).

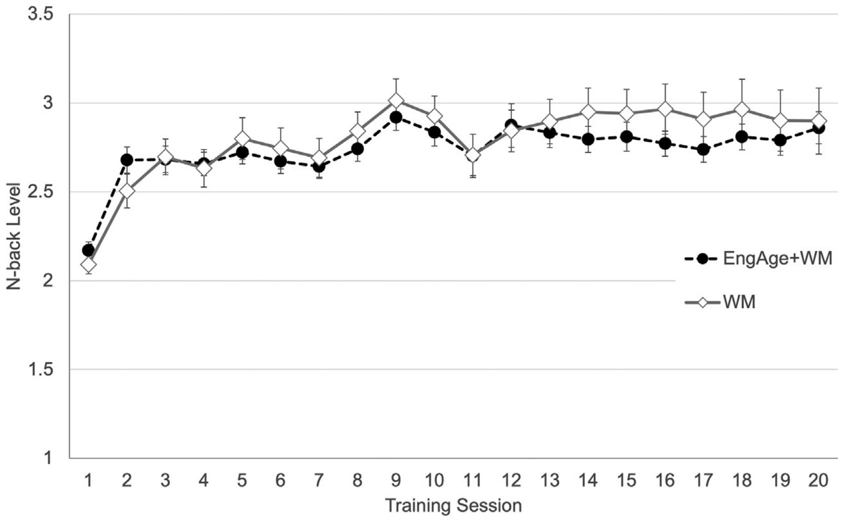

Fig. 3. Training performance. Average n-back level for each training session as a function of intervention group (tablet-based WM training).

self-reported anxiety ($F(2,112)$ = 4.95; p =.009, η_p^2 =.08). Post-hoc tests showed that the EngAge + WM group reported significantly lower levels of anxiety as compared with the KB group (p =.007), with no other group differences reaching significance; however, note that the reported anxiety level was very low overall. Furthermore, there were no significant group differences comparing the two cohorts (pre-existing dataset vs. newly recruited participants, including EngAge + WM group) in any of the demographic variables (all p >.07; uncorrected).

Training data

The two groups did not differ significantly from each other with respect to the number of completed WM training sessions (WM group: 20.42 (SD = 1.81), EngAge + WM group: 19.90 (SD = 4.25); $t(68.89)$ = -0.77; p =.45, d = 0.15), the training performance at the beginning of the intervention (average n-back level; first two sessions: WM group: 2.30 (SD = 0.41), EngAge + WM group: 2.42 (SD = 0.41); $t(83)$ = 1.40; p =.17; d = 0.31), and the improvement over time (difference between first and last two sessions: WM group: 0.57 (SD = 0.87), EngAge + WM group: 0.34 (SD = 0.50); $t(51.59)$ = -1.39; p =.17; d = 0.33). See Fig. 3 for a visualization of the training performance.

Cognitive outcome measures

Descriptive data for each test session as a function of intervention group, along with within-group changes (paired t-tests) and effect sizes (Cohen's d; change scores, accounting for re-test reliability; [16] are provided in Tables 3 and 4. There were no significant group differences in any of the measures at baseline, except for Symmetry Span ($F(2,116)$ = 3.19; p =.045, η_p^2 =.05), where the EngAge + WM group numerically outperformed the two other groups; however, none of the specific group comparisons were significant (all ps > 0.06).

Overall, the effect sizes for the WM as well as for the EngAge + WM group are larger than those observed in the KB control group, especially in the WM and inhibitory control domains (Tables 3 and 4).

The MANOVA with the WM outcome measures was significant at post-test for both accuracy (i.e., n-back, Symmetry Span, and Sternberg item-recognition; $F(6,194)$ = 2.696, p =.015; η_p^2 =.08) and reaction times (n-back and Sternberg: $F(4,200)$ = 3.430, p =.011; η_p^2 =.063). In contrast, the MANOVA was neither significant for inhibitory control (i.e., n-back false alarms, D2, and VLMT intrusions; $F(6,184)$ = 1.159, p =.17; η_p^2 =.047), nor for episodic memory (i.e., Meta-Memory, VLTM, and CEDAR; $F(6,202)$ = 0.309, p =.93; η_p^2 =.009), nor the control outcomes (i.e., vocabulary, letter comparison, and pattern comparison; $F(6,214)$ = 1.610, p =.15; η_p^2 =.043).[3]

Table 5 reports all individual ANCOVA results for the post-test. At post-test, we generally replicated our earlier study [33], that is, Helmert contrasts showed that the two WM groups outperformed the active control group in WM, which was expressed in all three primary outcome measures, the non-trained n-back task (accuracy; p =.001), the Symmetry Span task (p =.022), as well as the Sternberg task (RT correct; p =.003). In addition, the WM group outperformed the EngAge + WM group in the Sternberg task (p =.037). Although the overall MANOVA was not significant for inhibitory control, the ANCOVAs revealed that the two WM groups committed fewer n-back false alarms than the KB group (p =.004), and there was a trend for them to perform better than the KB group in the D2 (p =.056). However, in contrast to our expectations, there was no evidence that the EngAge + WM group significantly

[3] Given the pre-test differences in GAD and given the potential impact of subclinical affective symptoms and/or general cognitive status at baseline, we ran additional sensitivity analyses with GAD, as well as GDS, or MMSE as separate covariates (as these questionnaires were used for participant inclusion/exclusion); however, the pattern of MANOVA results remained the same.

Table 3
Descriptive data for the outcome measures as a function of intervention group and testing session (pre and post), as well as within-group comparisons (paired t-tests).

	Pre-Test			Post-Test				
	N	Mean	SD	Mean	SD	*p*	*r*	ES
EngAge + WM Training Group								
Working Memory Measures								
Spatial N-back (Acc)	40	0.63	0.18	0.80	0.13	**<0.001*****	0.54	**1.07**
Sternberg (Acc)	46	0.82	0.10	0.83	0.10	0.48	0.50	0.10
Symmetry Span (Acc)	48	17.88	7.29	19.90	5.68	**0.032***	0.59	**0.33**
Spatial N-back (RT, msec., correct)[a]	40	1126	197	1102	202	0.48	0.39	0.11
Sternberg (RT, msec., correct)[a]	47	1104	145	1042	144	**0.006****	0.45	**0.41**
Inhibitory Control Measures								
Spatial N-back (False Alarms)[a]	40	0.13	0.12	0.08	0.07	**0.004****	0.53	**0.46**
D2 (TN minus E)	45	406.78	85.67	433.09	81.61	**0.001*****	0.83	**0.53**
VLTM (Intrusions)[a]	48	2.10	2.31	2.23	1.78	0.73	0.22	-0.05
Episodic Memory Measures								
Meta-Memory (Recall)	43	21.14	6.12	22.37	7.00	0.23	0.52	0.19
VLTM (Recall)	48	11.18	6.50	14.57	6.78	**<0.001*****	0.54	**0.53**
CEDAR (Acc)	49	4.60	0.54	4.65	0.60	0.61	0.21	0.07
Control Measures								
Mill-Hill Vocabulary	46	22.43	4.01	22.74	3.50	0.43	0.75	0.12
Letter Comparison (RT, min.)[a]	49	3.07	1.00	2.85	0.63	0.09	0.46	0.25
Pattern Comparison (RT, min.)[a]	46	3.35	0.97	2.83	0.60	**<0.001*****	0.54	**0.63**
WM Training Group								
Working Memory Measures								
Spatial N-back (Acc)	33	0.58	0.21	0.73	0.20	**<0.001*****	0.80	**1.17**
Sternberg (Acc)	35	0.82	0.07	0.83	0.07	0.40	0.37	0.14
Symmetry Span (Acc)	34	14.59	8.16	16.12	7.16	0.25	0.52	0.20
Spatial N-back (RT, msec., correct)[a]	33	1201	316	1148	287	0.30	0.56	0.19
Sternberg (RT, msec., correct)[a]	35	1128	156	1040	144	**<0.001*****	0.86	**1.08**
Inhibitory Control Measures								
Spatial N-back (False Alarms)[a]	33	0.17	0.16	0.12	0.13	**0.006****	0.79	**0.51**
D2 (TN minus E)	34	395.00	73.79	426.38	69.87	**<0.001*****	0.88	**0.88**
VLTM (Intrusions)[a]	34	1.76	1.84	1.94	1.63	0.64	0.20	-0.08
Episodic Memory Measures								
Meta-Memory (Recall)	33	20.45	7.93	20.67	7.88	0.84	0.71	0.04
VLTM (Recall)	34	9.87	5.63	12.49	7.39	**0.006****	0.72	**0.51**
CEDAR (Acc)	36	4.49	0.53	4.70	0.48	**0.021***	0.49	**0.40**
Control Measures								
Mill-Hill Vocabulary	35	21.86	3.57	22.17	3.50	0.46	0.75	0.12
Letter Comparison (RT, min.)[a]	35	3.09	0.84	2.94	0.82	0.16	0.74	0.24
Pattern Comparison (RT, min.)[a]	35	2.90	0.81	2.77	0.72	0.09	0.84	0.29
Knowledge Builders Training Group								
Working Memory Measures								
Spatial N-back (Acc)	33	0.57	0.22	0.62	0.24	**0.028***	0.84	**0.38**
Sternberg (Acc)	34	0.81	0.10	0.83	0.05	0.20	0.47	0.25
Symmetry Span (Acc)	34	14.03	6.50	14.38	5.98	0.66	0.73	0.08
Spatial N-back (RT, msec., correct)[a]	33	1252	229	1249	257	0.93	0.64	0.02
Sternberg (RT, msec., correct)[a]	34	1124	126	1126	139	0.91	0.76	-0.02
Inhibitory Control Measures								
Spatial N-back (False Alarms)[a]	33	0.14	0.08	0.15	0.11	0.77	0.46	-0.05
D2 (TN minus E)	33	405.85	90.68	417.85	78.78	0.22	0.79	0.22
VLTM (Intrusions)[a]	33	1.76	1.94	2.27	1.91	0.15	0.47	-0.26
Episodic Memory Measures								
Meta-Memory (Recall)	33	21.61	9.44	21.76	9.39	0.92	0.55	0.02
VLTM (Recall)	33	10.62	5.44	13.52	7.85	**0.028***	0.46	**0.40**
CEDAR (Acc)	34	4.42	0.45	4.52	0.51	0.28	0.43	0.19
Control Measures								
Mill-Hill Vocabulary	34	22.06	4.49	22.29	4.58	0.61	0.83	0.09
Letter Comparison (RT, min.)[a]	34	3.11	0.69	2.95	0.77	0.06	0.80	0.34
Pattern Comparison (RT, min.)[a]	34	3.09	0.84	2.96	0.91	0.15	0.84	0.26

Note: r = re-test reliability; ES = Effect size (Cohen's d; accounting for re-test reliability). [a]Effect sizes for RTs and error rates are reversed in the table so that all positive effect sizes indicate performance improvements. *p <.05; **p <.01; ***p <.001 (2-tailed).

outperformed the WM group in any of the cognitive measures at post-test, except for pattern comparison, where the EngAge + WM group showed the most pronounced improvements (p =.017).

At the follow-up, we were underpowered to run MANOVAs given the participant attrition (cf. Table 4 and Figure S1); still, we are reporting the individual ANCOVAs in the Supplementary Materials for completeness

Table 4
Descriptive data for the outcome measures as a function of intervention group and testing session (pre and follow-up), as well as within-group comparisons (paired t-tests).

	Pre-Test			Follow-Up Test				
	N	Mean	SD	Mean	SD	*p*	*r*	ES
EngAge + WM Training Group								
Working Memory Measures								
Spatial N-back (Acc)	12	0.62	0.20	0.83	0.11	**<0.001*****	0.88	**1.85**
Sternberg (Acc)	12	0.81	0.10	0.85	0.06	0.10	0.58	0.51
Symmetry Span (Acc)	11	18.82	4.98	18.36	6.25	0.84	0.21	-0.06
Spatial N-back (RT, msec., correct)[a]	12	1192	226	1137	203	0.19	0.81	0.40
Sternberg (RT, msec., correct)[a]	12	1171	165	1039	103	**0.004****	0.66	**1.06**
Inhibitory Control Measures								
Spatial N-back (False Alarms)[a]	12	0.16	0.16	0.08	0.09	**0.013***	0.90	**0.86**
D2 (TN minus E)	13	414.77	77.01	448.69	63.07	**0.004****	0.90	**1.00**
VLTM (Intrusions)[a]	11	1.64	1.96	4.14	4.59	0.08	0.36	-0.58
Episodic Memory Measures								
Meta-Memory (Recall)	9	18.44	7.30	19.22	6.53	0.69	0.68	0.14
VLTM (Recall)	11	10.59	5.46	14.64	7.86	0.22	-0.15	0.39
CEDAR (Acc)	12	4.57	0.74	5.13	0.13	**0.023***	0.13	**0.76**
Control Measures								
Mill-Hill Vocabulary	13	23.69	3.55	22.85	3.83	0.20	0.82	-0.38
Letter Comparison (RT, min.)[a]	14	3.40	1.26	2.66	0.47	**0.033***	0.37	**0.64**
Pattern Comparison (RT, min.)[a]	12	3.45	1.01	2.41	0.46	**0.001*****	0.63	**1.28**
WM Training Group								
Working Memory Measures								
Spatial N-back (Acc)	15	0.57	0.24	0.72	0.21	0.09	0.00	0.47
Sternberg (Acc)	15	0.82	0.07	0.84	0.08	0.37	0.43	0.24
Symmetry Span (Acc)	15	15.07	8.07	17.60	8.72	0.39	0.14	0.23
Spatial N-back (RT, msec., correct)[a]	15	1191	312	1226	253	0.69	0.35	-0.11
Sternberg (RT, msec., correct)[a]	15	1134	145	1054	110	0.08	0.21	0.49
Inhibitory Control Measures								
Spatial N-back (False Alarms)[a]	15	0.17	0.20	0.09	0.08	0.20	-0.14	0.35
D2 (TN minus E)	16	400.56	82.23	443.50	77.49	**<0.001*****	0.89	**1.11**
VLTM (Intrusions)[a]	15	1.40	1.88	1.87	1.88	0.49	0.10	-0.18
Episodic Memory Measures								
Meta-Memory (Recall)	16	20.81	9.47	20.75	7.84	0.96	0.87	-0.01
VLTM (Recall)	15	9.47	6.15	12.67	7.49	0.07	0.60	0.51
CEDAR (Acc)	16	4.56	0.33	4.60	0.47	0.82	-0.37	0.06
Control Measures								
Mill-Hill Vocabulary	14	22.79	3.19	22.36	3.18	0.71	0.12	-0.10
Letter Comparison (RT, min.)[a]	21	3.06	0.64	2.89	0.71	**0.054**	0.85	**0.45**
Pattern Comparison (RT, min.)[a]	21	2.97	0.79	2.78	0.76	0.07	0.83	0.42
Knowledge Builders Training ***Group***								
Working Memory Measures								
Spatial N-back (Acc)	15	0.54	0.22	0.66	0.26	0.14	0.20	0.40
Sternberg (Acc)	14	0.80	0.09	0.84	0.13	0.46	-0.50	0.20
Symmetry Span (Acc)	15	12.00	6.93	15.87	8.06	0.054	0.56	0.54
Spatial N-back (RT, msec., correct)[a]	15	1299	234	1083	196	**0.023***	-0.15	**0.66**
Sternberg (RT, msec., correct)[a]	14	1146	109	1026	124	**0.023***	-0.12	**0.69**
Inhibitory Control Measures								
Spatial N-back (False Alarms)[a]	15	0.14	0.10	0.11	0.12	0.41	0.19	0.22
D2 (TN minus E)	13	380.23	49.41	418.23	53.61	**0.002****	0.78	**1.10**
VLTM (Intrusions)[a]	16	1.13	1.78	3.13	2.28	**<0.001*****	0.78	**−1.41**
Episodic Memory Measures								
Meta-Memory (Recall)	13	20.62	7.93	19.23	7.13	0.27	0.84	-0.32
VLTM (Recall)	16	10.72	6.44	14.56	7.08	0.09	0.20	0.45
CEDAR (Acc)	15	4.34	0.46	4.69	0.40	**0.044***	-0.05	**0.57**
Control Measures								
Mill-Hill Vocabulary	15	22.27	4.88	24.13	3.70	0.15	0.42	0.39
Letter Comparison (RT, min.)[a]	17	3.20	0.75	3.02	0.67	0.15	0.76	0.36
Pattern Comparison (RT, min.)[a]	16	3.22	1.00	3.13	1.08	0.68	0.72	0.11

Note: r = re-test reliability; ES = Effect size (Cohen's d; accounting for re-test reliability). [a]Effect sizes for RTs and error rates are reversed in the table so that all positive effect sizes indicate performance improvements. *p <.05; **p <.01; ***p <.001 (2-tailed).

(cf. Table S1). Unlike in our previous work [33], we observed very limited maintenance effects at follow-up, but still, we did observe longitudinal effects in favor of the EngAge + WM group. Specifically, the EngAge + WM group showed the most improvement from pre-test to follow-up in the applied episodic memory task (CEDAR;

Table 5
Intervention effects at post-test (ANCOVAs; intervention as between-group factor, post-test performance as the dependent measure; pre-test as the covariate).

Outcome Measure	df	*F*	*p*	*η2p*
Working Memory				
Spatial N-back (Acc)#	2, 103	6.73	**0.002****	**0.12**
Sternberg (Acc)	2, 114	0.02	0.98	0.00
Symmetry Span (Acc)	2, 115	4.52	**0.013***	**0.08**
Spatial N-back (RT)	2, 105	1.48	0.23	0.03
Sternberg (RT)#	2, 113	5.45	**0.006****	**0.09**
Inhibitory Control				
Spatial N-back (False Alarms)	2, 105	4.83	**0.010****	**0.09**
D2 (TN minus E)	2, 111	1.49	0.23	0.03
VLTM (Intrusions)	2, 114	0.45	0.64	0.01
Episodic Memory				
Meta-Memory (Recall)	2, 108	0.38	0.68	0.01
VLTM (Recall)	2, 114	0.39	0.68	0.01
CEDAR (Acc)	2, 118	0.80	0.45	0.01
Control Measures				
Mill-Hill Vocabulary	2, 114	0.06	0.95	0.00
Letter Comparison (Speed)#	2, 115	0.14	0.87	0.00
Pattern Comparison (Speed)#	2, 112	5.24	**0.007****	**0.09**

Note. p-values are 2-tailed (uncorrected). # = assumptions for ANCOVA (homogeneity of regression slopes) were not met, thus, the values for the session × group interaction (repeated measures ANOVA) are reported instead. *p <.05; **p <.01 (2-tailed).

p =.001). Furthermore, the EngAge + WM group continued to outperform the other two groups in processing speed (pattern comparison: *p* <.001; letter comparison: *p* =.014).

Self-report measures

Descriptive data for each testing session as a function of intervention group, along with within-group changes and effect sizes are provided in the Supplementary Materials (Tables S2 and S3). The intervention groups differed at baseline in two of the four measures: Meta-Memory ($F(2,99) = 5.47$, $p = .006$, $\eta_p^2 = .10$) in which the EngAge group reported lower self-efficacy than the WM group ($p = .004$), and Cognitive Failures ($F(2,101) = 5.54$, $p = .005$, $\eta_p^2 = .10$), in which the KB group reported more failures than both, the WM and EngAge + WM group ($p = .001$). The ANCOVA results are also provided in the Supplementary Materials (Tables S4 and S5). Essentially, we did not see evidence for any significant group differences in any of the self-report measures, neither at post-test, nor at follow-up.

Discussion

Our results replicate our earlier work by demonstrating that participants who trained with the WM task significantly improved their performance in the trained task [33]. Note that across both groups, we see a consistent dip in performance in Session 11 (Fig. 2), which can be attributed to the type of training material presented during that session (road signs with animal crossings that were hard to distinguish, as well as tools).

Importantly, we also broadly replicate the outcomes at post-test; specifically, participants who trained with the WM task outperformed the KB control group in non-trained measures within the WM domain, and to some extent, in measures of inhibitory control. Thus, our findings add to the accumulating research suggesting that targeted WM interventions can lead to benefits in non-trained cognitive domains in older adults [9,39,77].

The primary aim of the current feasibility study, though, was to test the potential enhancing effects of our EngAge program, a novel metacognitive intervention that was conducted in conjunction with WM training, on cognitive and self-report outcomes as compared to WM or active control training alone. The EngAge program was designed for healthy older adults with the intention to disrupt common dysfunctional perceptions of self-efficacy and control over one's own cognitive (memory) abilities, and to provide participants with resources to experience and practice alternative attributions, which in turn, should lead to more motivation to engage and persist in cognitive tasks that are effortful (i.e., [29,83]. We hypothesized that this additional focus on metacognitive processes, along with the social component of the training, would lead to stronger and more persistent outcomes [1,74]. However, contradicting our hypotheses, we found no evidence that the supplemental metacognitive program led to benefits over and above the WM intervention at post-test, with the only exception of one of the control measures (pattern comparison), where the EngAge + WM showed the most pronounced improvement.

We did observe long-term benefits in favor of the EngAge + WM group three months after training completion in some measures though (Table S1); but given the few participants who were able to complete the follow-up assessments due to the pandemic-related lockdown, those results are preliminary and should be interpreted with caution.

Similarly, we did not observe any significant intervention effects in the self-report measures, but at least descriptively, the EngAge + WM group showed the most consistent improvements in the intended direction (cf. effect sizes; Tables S2 and S3), in particular, in the two measures of self-efficacy (MIA and GSE). Nonetheless, several participants in the EngAge group reported that they tried to implement a few of the activities and concepts that were covered in their daily life. For example, in a reflection journal entry, one participant stated "I am trying to review to-do lists in my mind. I met a lot of new people over the weekend and focused on remembering their names. I did pretty well - once I knew I'd make a point of it". In addition, various participants expressed the use of more growth-mindset thinking over time in their reflection journal entries relating to both their memory in everyday life as well as their challenges with WM training. A participant stated in relation to their training "I had to struggle hard to quickly refocus and keep going. I am optimistic and believe that continued efforts will lead to improvement". Lastly, participants were taking note of their memory successes and failures of the day along with their attributions. For example, one participant discussing their memory success stated "I succeeded in remembering because 1. It was important, 2. I used reminder notes, 3. I was going to share info so I was committed to remembering". Overall, although there were limited data to observe in self-report outcomes, anecdotal evidence and qualitative data from their reflection journal entries suggest that participants found the seminars helpful.

Limitations and suggestions for future research

There are several factors that might have contributed to the lack of significant enhancing effects of the EngAge + WM program observed in our study:

First, in retrospect, we realized that certain program design decisions could benefit from a modification. For example, rather than conducting the metacognitive seminars *in conjunction* with the WM intervention, the group seminars might have been more beneficial if they were conducted separately from the training, ideally, *before* the tablet-based intervention. That way, participants could have spent more time to internalize the concepts that were covered in the seminars, instead of trying to go through everything at once: processing and practicing the metacognitive concepts, completing the reflections and homework assignments, in addition to completing the tablet-based training, which might have been too extensive. Another issue was that participants were asked to complete at-home assignments to keep reflecting on their own everyday functioning related to the themes emerged during the group sessions, which were then again discussed by the group; however, these activities were optional. Having a means to allow each participant to monitor their progress across the EngAge sessions (e.g., via individualized conversations) might have helped participants to fully benefit from the intervention (see also [29]).

Alternatively, some of the seminar contents might be more effective if they were delivered in a different order; in particular, the contents of one the key seminars, session 3, where the importance of leading an engaged lifestyle was discussed by means of a cost-benefits analysis (Fig. 2), might have been more beneficial at an earlier time in order to set the stage for engaging with the demanding WM training program. Overall, it might be that the number of sessions, their wealth of content and complexity, along with their organization were not suitable for our participants to fully reap the benefits from both the EngAge program as well as the concurrent WM training. Whether a larger number of shorter sessions, each focused on specific metacognitive aspects before the WM training, along with additional activities delivered during the WM training (booster sessions), would be a better solution to provide generalized and durable benefits on cognitive functioning should be tested in future studies.

Second, it became apparent over the course of the project that the selected self-report measures should be optimized for future assessments of the impact of the metacognitive program. Specifically, even though the effect sizes do look promising, the selected self-report questionnaires might not have fully captured the effects of the *meta*-cognitive intervention. For example, we exclusively relied on measures that we already implemented in our earlier study (GSE, MIA, CFQ-MAL, and EMQ; [33]). Although those measures are well-known measures of metacognitive processes in older adults (see [74]), these measures were likely neither exhaustive nor specific enough to assess all the metacognitive processes that were directly targeted by the EngAge program. For example, although we did implement measures of memory self-efficacy and cognitive failures, which were discussed in the first and second seminars, we did not include other outcome measures to capture motivation, engagement, or growth mindset, all of which were part of the seminar content. This issue was further exacerbated by the fact that many participants did not complete the surveys, which further decreased our power to detect any changes and/or benefits of the intervention.

Finally, and most importantly, the follow-up assessments, for which we expected the most pronounced effects of the EngAge program given the time it likely takes for participants to internalize the seminar content [83], were negatively affected by the COVID-related pandemic in that very few participants were able to complete those.

That said, despite the limited effects observed here, there is accumulating evidence indicating that approaches that go beyond targeting cognitive processes in isolation to also include metacognitive and/or motivational components might be beneficial to boost the effectiveness of cognitive training [52,68,74]. Our program seems to be a step in the right direction given the participants' positive feedback, but more work should be done to optimally implement the program so that participants can maximally benefit, and in particular, more longitudinal data with larger sample sizes are needed to establish these early findings.

Conclusions

To conclude, we replicated our earlier work in that our tablet-based WM intervention led to benefits beyond the trained task as compared to an active control intervention, in particular, in WM, and to a lesser extent, in inhibitory control. Unfortunately, due to a combination of factors, including the negative impact of the COVID-related pandemic, we were not able to demonstrate distinct support for beneficial effects of our metacognitive program over and above the WM intervention. However, given the encouraging data from some individual measures as well as the positive participant feedback, such a multi-component intervention approach, ideally implemented across multiple sites, clearly warrants further investigation.

CRediT authorship contribution statement

Susanne M. Jaeggi: Conceptualization, Formal analysis, Funding acquisition, Methodology, Resources, Supervision, Writing – original draft, Writing – review & editing. **Alexandria N. Weaver:** Conceptualization, Data curation, Formal analysis, Investigation, Project administration, Writing – original draft, Writing – review & editing. **Elena Carbone:** Conceptualization, Investigation, Methodology, Writing – original draft, Writing – review & editing. **Francesca E. Trane:** Investigation, Project administration, Writing – review & editing. **Rachel N. Smith-Peirce:** Data curation, Project administration, Writing – review & editing. **Martin Buschkuehl:** Conceptualization, Formal analysis, Methodology, Software, Writing – review & editing. **Christoph Flueckiger:** Conceptualization, Writing – review & editing. **Madison Carlson:** Investigation, Project administration. **John Jonides:** Conceptualization, Funding acquisition, Resources, Writing – review & editing. **Erika Borella:** Conceptualization, Methodology, Writing – review & editing.

Declaration of Competing Interest

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

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.nbas.2023.100083.

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