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Research Article

Ancient Mnemonic in New Format—Episodic Memory Training With the Method of Loci in a Smart Phone Application

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Abstract

Objectives: Episodic memory is age-sensitive but can be strengthened by targeted training interventions. The method of loci (MoL) is a classic mnemonic which if successfully implemented greatly improves memory performance. We developed and investigated the effects of a MoL training program implemented in a smart phone application (app) with the aim of studying usage of the application, training effect and its modifiability by age, predictors for MoL proficiency, transfer effects to a face-name memory task, and perceived benefit in everyday memory.
Method: A total of 359 adults participated. Instruction and training of the MoL, transfer test (face-name paired associates cued recall task), and surveys were performed in an in-house developed app.
Results: The app interested people across the adult life span. Older adults practiced the most, whereas younger and young-old participants showed the highest level of MoL proficiency. Level of proficiency was modulated by amount of practice, but in the oldest participants this effect was less pronounced. Greater self-rated health was associated with higher level of proficiency. No transfer effect was observed. Among those who answered the survey, about half expressed that MoL training had benefitted memory in their everyday life.
Discussion: App-based memory training in the MoL can be delivered successfully via an app across the adult life span. Level of performance reached in training is variable but generally high, and mainly influenced by amount of training and age of the participants. Our data suggest plasticity across the life span, but to a lesser degree for adults between 70 and 90 years.

Keywords: Face-name memory, Serial recall, Transfer

Episodic memory—the ability to encode and retrieve information tied to a specific time and place (Tulving, 2002)—is age-sensitive (Rönnlund et al., 2005) but differs considerably across individuals (Habib et al., 2007; Josefsson et al., 2012). Certain lifestyle factors seems to reduce memory decline (Hertzog et al., 2008; Nyberg & Pudas, 2019), which suggests that such decline is malleable and possibly mitigated by targeted memory training interventions. Teaching strategies for structuring encoding and retrieval can lead to increased episodic memory performance in younger as well as older adults (e.g., Derwinger et al., 2003; Gross et al., 2012; Hulicka et al., 1967; Shing et al., 2010; Verhaeghen et al., 1992).

A classical mnemonic is the method of loci (MoL) (Bower, 1970; Higbee, 2001; Yates, 1966). Orators in ancient Greece and Rome used this technique to translate information to be remembered into easily visualized "things" and imagined placing them at specific places (loci) along familiar paths (e.g., a walk through their home). While performing the speech, the orator walked the same imaginary path, recollecting the content. Contemporary use of the MoL takes place at memory competitions where remarkable amounts of information are memorized by memory athletes. Athletes report that such feats are the result of extensive practice, typically on the MoL, rather than innately better memory faculties (Maguire et al., 2003; Von Essen, 2018). This is supported by research showing that memory athletes do not have higher cognitive abilities overall (Maguire et al., 2003; Ramon et al., 2016), and that young adults who practice to a high proficiency in MoL display changes in brain connectivity that resemble those of memory athletes (Dresler et al., 2017).

Several studies have shown beneficial effects of MoL training also among older adults (meta-analyses: Gross et al., 2012; Verhaeghen et al., 1992). However, a consistent observation has been a magnification of age differences after MoL training (Baltes, 1987; Baltes & Kliegl, 1992; de Lange et al., 2018; Nyberg et al., 2003), such that older adults improve to a lesser degree and the age difference is greater after compared to before training. One interpretation of this magnification effect is that older age puts constraints on plastic changes in relation to learning and using a mnemonic skill. Indeed, it has been argued that biological factors might exert a limiting effect on the magnitude of plasticity in older age (Hessel et al., 2018). Alternatively, factors related to comprehension and compliance may favor younger adults (cf., de Lange et al., 2018), rather than the potential for plasticity per se. In this study, the overall aim was to evaluate a training program for the MoL across the adult life span. To provide the possibility of extended practice, the training intervention was delivered in a smart phone application (app) format. This format allowed "unlimited" training at one's own pace. Thus, a first goal of the study was to examine the amount of practice with the app in different age groups. A second aim was to study level of performance reached in the practiced task, and to examine age-related differences in MoL proficiency in relation to training dose. We expected that MoL proficiency would scale with amount of practice, and a critical issue was whether this would be seen across age groups.

A third aim was to study whether individual differences affected MoL proficiency after training. Apart from age, imagery ability and cognitive factors (Sanchez, 2019; Verhaeghen & Marcoen, 1996) have previously been related to MoL gain. Self-rated health has also been demonstrated to be related to gain in a similar visualization strategy (Rebok et al., 2013). While physical activity has not been investigated as a predictor for training success in MoL, it was correlated with gain in a combined cognitive-physical training intervention (Rahe et al., 2015).

A fourth aim was to investigate whether practicing the MoL would also lead to transfer effects to a non-trained task. Typically, the degree of transfer is low (Gross et al., 2012; Lustig et al., 2009; Rebok & Balcerak, 1989; Rebok et al., 2007), and seen for tasks where the strategy can easily be applied, such as shopping lists (Anschutz et al., 1985). Transfer can also be expected if there is an overlap between training and transfer tasks with regard to underlying cognitive processes and brain regions (Dahlin et al., 2008). Practicing MoL engages the hippocampus and surrounding structures (Nyberg et al., 2003), likely as a result of a demand to "bind" the loci and the to-be-remembered information. Indeed, Jones and colleagues (2006) demonstrated a relationship between medial-temporal lobe brain activity during the successful use of the MoL and the performance on memorizing weakly associated word pairs. Here, we examined another task that requires binding of information, associating faces with names (Salami et al., 2012). We hypothesized that MoL training would transfer to face-name memory, possibly as a function of MoL proficiency. Lastly, we investigated whether practicing the MoL was perceived to benefit everyday memory.

Method

Participants

Participants were recruited through ads around Umeå municipality, on university homepages, in mailing lists, through social media channels, and in local and nationwide daily newspapers. Interested participants were directed to a webpage to read about the study and to sign up. Of 730 persons receiving an invitation, 359 completed the transfer pretest at level 5 in training (meaning practicing a minimum of four trials) and were included in the final sample (see Figure 1). The whole study was performed in an app on the participants' phones. To activate it, participants were prompted to a menu step where information was provided about purpose and method; that participation was voluntary; contact information; and that participation could be withdrawn at any time. They were instructed to read the information thoroughly before entering a personal username and activation code provided per email and ticking "I consent" (see Figure 2A). Data were collected via the university's data collection platform in accordance with GDPR. Participants' data were assigned a separate randomized digit-letter code in the database. The study was approved by the Regional Ethical Review Board in Umeå (ref.: 2018/373-31).

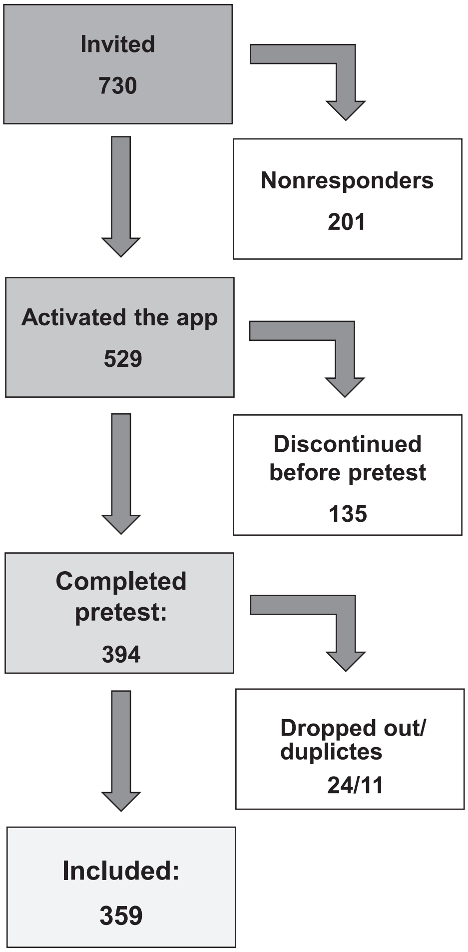

Figure 1. Recruitment flow chart. Inclusion into the study was defined by completing the first paired associates face-name test (transfer test 1) which was administered in the beginning of training at level 5, which means performing a minimum of four training trials.

For the purpose of comparing age groups, participants were divided into three age groups prior to analysis: younger 20–54, young-old 55–69, and old-old 70–90 years. The division was based on the fact that episodic memory declines with age and in line with previous studies (e.g., Brooks et al., 1999). While the exact onset of episodic memory decline varies between studies, it has been suggested to remain unaffected up to the age of 60 with an accelerating decline starting after the age of 70 (Rönnlund et al., 2005). Background characteristics of the total sample and the three age groups are presented in Table 1.

Materials and Procedure

The app was developed by the research group together with the ICT Services and System Development Department at Umeå University.

Participants received information about how to get started with the memory training per email. They were instructed that they needed to watch instruction videos learning a memory strategy and to practice with the app

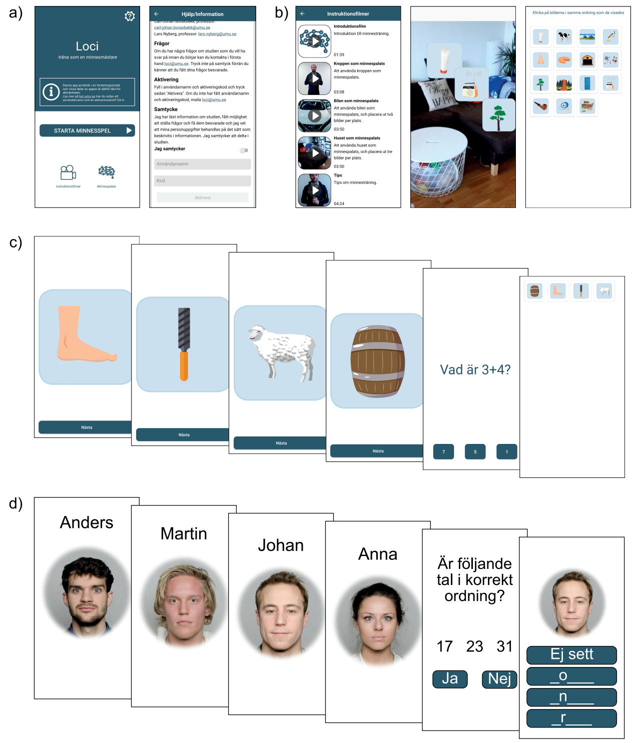

Figure 2. Loci memory training app. (**A**) Front screen instructing participants that the app is locked and that they need to go to the consent form to unlock it. Consent form with instructions about the study and activation with username and code. (**B**) Instruction video interface and example from instruction video "the house as a memory palace" with subsequent memory test. Idriz demonstrates how method of loci (MoL) can be used to visualize a tube of toothpaste being emptied over a radio standing on the sofa when a pine tree grows from it. (**C**) Training task, distraction task "what is 2 + 5?" and response screen. The task is to memorize the pictures with the MoL and when all items have been shown, to touch the pictures on the response screen in the correct order. The sequence is self-paced by pressing "nästa" ("next"). (**D**) Transfer test: Faces with names presented one by one for 3 s each with 1-s interstimulus interval (ISI); distraction task "Are the following numbers in the correct order?" and response screen shown until an answer has been given. The task is to memorize the names together with the faces and when all faces have been shown, to choose from a list "Ej sett" ("Not seen") or to choose (in this case) _o___ for Johan. Faces from the Oslo Face Database (Chelnokova et al., 2014). Full color version is available within the online issue.

for a duration of 3 months, preferably each day, and to try to reach as high as possible in the memory training game. They were told to perform memory tests at different occasions during training and answer short surveys, all within the app.

Background questions and predictor variables

After activating the app, a survey appeared. It consisted of questions about year of birth, gender, years of education; and hours per week of easier (e.g., gardening, walking, or slower cycling) and heavier (e.g., running, weight training, or other activity making you sweat) physical activity. Further, questions about general health compared to others of the same age, memory ability compared to others of the same age, and memory ability compared to 5 years

Table 1. Participants' Characteristics

	All included	Younger	Young-old	Old-old	Not included
Age range	20–90	20–54	55–69	70–90	20–85
n	359	132	133	94	159
Age (years)	58.82 (13.76)	43.55 (7.90)	63.02 (4.41)	74.33 (3.88)	56.55 (14.62)
Gender (women/men/other)	237/121/1	82/49/1	96/37/0	59/35/0	87/71/1
Education (years)	16.31 (3.32)	16.72 (2.83)	16.08 (3.39)	16.06 (3.83)	16.60 (3.68)
General health comp. to others of same age[a]	2.47 (0.93)	2.69 (0.84)	2.35 (0.97)	2.33 (0.93)	2.57 (0.92)
Memory ability comp. to others of same age[a]	2.97 (0.92)	3.12 (0.97)	3.00 (0.77)	2.74 (1.00)	3.09 (0.91)
Memory ability comp. to 5 years ago[a]	3.55 (0.87)	3.55 (0.87)	3.65 (0.75)	3.38 (1.00)	3.58 (0.76)
Hours easy physical activity per week	7.16 (6.04)	6.80 (7.18)	7.06 (4.77)	7.81 (5.84)	6.84 (5.39)
Hours hard physical activity per week	2.45 (2.58)	2.94 (2.96)	2.17 (2.25)	2.18 (2.35)	2.19 (2.04)
Vividness of visualization[b]	1.73 (0.90)	1.90 (0.90)	1.67 (0.96)	1.56 (0.74)	1.67 (0.84)

Notes: Means (and *SD*s) of survey items in total sample, age groups, and those not included in analysis (discontinued before pretest, and dropouts) respectively. [a]Rated on a 5-point Likert scale: 1 = much better, 2 = somewhat better, 3 = about the same, 4 = somewhat worse, 5 = much worse. [b]Imagine a bag of apples hanging on a door knob. How well can you imagine it 1 = as vivid as normal seeing, 2 = very vivid, 3 = somewhat vivid, 4 = vague, 5 = no picture at all, I only "know" that it is there. Outliers in years of education (four had entered 40 years or above) were replaced by mean value for that group.

ago were rated on a 5-point Likert scale (1 = much better, 2 = somewhat better, 3 = about the same, 4 = somewhat worse, 5 = much worse). Lastly, vividness of visualization was rated (*Try to see for your inner eye a plastic bag with apples hanging on a knob on your front door. How vividly can you see it?* 1 = Perfectly clear and as vivid as normal vision, 2 = Clear and reasonably vivid, 3 = Moderately clear and vivid, 4 = Vague and dim, 5 = No image at all, you only "know" that you are thinking of an object). Rating scale was adopted from Marks (1973).

Instruction videos—MoL

To continue and further unlock the app, participants were required to view six instruction videos (see Figure 2B). The memory training game (described below) could not be launched before the instruction videos had been viewed. The basics of the MoL was explained in the first video—that items to be remembered should be visualized at specific places along a path in a familiar environment called a memory palace.

The three videos that followed demonstrated how the body, the house, and the car, respectively, could be used as memory palaces, and how one, two, or three items could be placed at each loci in those palaces. Each video ended with a sequence memory test where the pictures from the demonstrations were presented simultaneously and had to be touched in the correct order to unlock the next video.

The two last videos contained training and motivation tips. The films and optional written instructions were available in the app throughout the study period.

Memory training game

Participants practiced the MoL by playing a memory training game which consisted of a sequence memory task (see Figure 2C) and they were instructed to use the MoL for encoding and retrieval.

When starting the first training session, a dialogue box urged the participants to ensure that they had understood the MoL, and to otherwise re-watch the videos and/or read the instructions. In the game, pictures were presented one by one on the screen. The sequence was self-paced by pressing "next," so that time for visualization was tailored to each individuals' current performance. After the whole sequence had been presented, all pictures were displayed simultaneously, and the task was to touch the pictures in the correct order. Upon starting the training, only level 1 was unlocked, which represented performing the training task with a picture sequence two items long, and passing it meant reaching level 2. Thus, reaching level 5 in training means being able to memorizing a sequence five items long. A level was passed if no more than five errors were made. After passing a level, the next was unlocked. If the level was not passed, the participant instead continued to practice on the same level. Thus, training difficulty level was adjusted to the performance of each individual. The lower levels were kept unlocked throughout the study, so that difficulty could also be self-adjusted downwards. Maximum level was 99 (which would imply remembering 100 items in sequence).

Transfer test

To test whether proficiency in MoL transferred to face-name memory, an in-house constructed face-name paired associates cued recall memory test was included (Figure 2D). It was administered at three different occasions during training. The first time, which was the pretest, it was administered when level 5 had been reached in training, thus when the MoL just had been learned but not practiced to a large extent. The second time when (if) level 25 had been reached, and the third when (if) level 45 in training had been reached. The two latter were chosen in order to test for transfer effects after reaching a moderate and high proficiency in the MoL. Faces with names above them were presented sequentially for 3 s each, with an interstimulus interval (ISI) of 1 s. Faces were from the Oslo Face Database (Chelnokova et al., 2014), and names from a list of the most common Swedish names. Unique names and faces were presented in each version of the test. Different number of faces (20 in the first, 30 in the second, and 40 in the third) were presented in the three versions of the test. This design choice was made to make room for improvements and at the same time not making the task too hard at pretest. The task was to memorize each face /name combination. After completing the whole sequence, a short distractor task was presented, in which participants judged whether three numbers were in the correct order. In the recall phase, all original and 50% new faces were presented sequentially, without names, in a self-paced manner, thus yielding 30 items in the first (20 old plus 10 new), 45 items in the second (30 old plus 15 new), and 60 items in the third (40 old plus 20 new). The task was to pick the correct name from one of three alternatives which had the correct second letter—for example, _n____ for Anders, or if the face was not recognized, to choose "Not seen."

End survey

Directly after the training period, a short survey was presented with questions about the participants' opinions on the training, whether it had influenced memory in everyday life (yes/no) and a possibility to add comments. All participants received an email thanking them for their participation.

Statistical Analysis

Statistical analyses were performed using IBM SPSS Statistics package 26.

To examine differences in amount of practice in the three age groups, we performed a one-way analysis of variance (ANOVA) with age group as between-groups factor and amount of practice—number of practiced trials—as dependent variable.

To examine how amount of practice and age affected level of performance in the MoL training task, we performed a 5 x 3 ANOVA. We divided participants into five groups depending on how many trials they had completed. Thus, Amount of training group: [(i) under 11; (ii) 11–30; (iii) 31–50; (iv) 51–100; and (v) over 100 practiced trials], and Age group: [younger 20–54, young-old 55–69, and old-old 70–90 years] were between-groups factors, and longest recalled sequence during practice was the dependent measure.

To test for transfer effects, we first performed a mixed ANOVA on the group of participants who reached level 25 (triggering the second transfer test) and then on the group that reached level 45 (third transfer test) with age group as between-subjects factor, testing time as within group factor, and percent correct recall (hits) as the dependent measure.

Following significant interaction effects in the ANOVAs, we performed Bonferroni corrected post hoc analyses and pairwise comparisons.

To examine whether individual differences in predictors (health, memory ability, physical ability, and vividness of visualization) influenced level of performance, multiple linear regression analysis was performed.

Results

App Usage

The app interested people ranging from 20 to 90 years of age. Of 359 participants, 227 (63.2%) were over 55 years old, and of those 94 (26.2%) were between 70 and 90 years of age (see Figure 3A; Table 1). There was a significant main effect of age group on amount of training $F(2, 356) = 12.8$, $MSE = 3355.8$, $p < .001$, $\eta^2 p = .067$. Subsequent pairwise comparisons revealed significant differences between all three age groups, ps <.05, such that the younger group practiced the least and the old-old group the most (Figure 3B).

Training Results

A 3 (age group) × 5 (amount of practice) ANOVA revealed a significant main effect of age group on max level reached in training, $F(2, 344) = 13.43$, $MSE = 141.0$, $p < .001$ $\eta^2 p = .072$, as well as a main effect of amount of practice, $F(4, 344) = 67.9$, $MSE = 141.0$, $p < .001$, $\eta^2 p = .44$. Further there was a significant group by practice interaction effect, $F(8, 344) = 5.02$, $MSE = 141.0$ $p < .001$, $\eta^2 p = .10$. Post hoc pairwise comparisons between age groups revealed significant differences between the old-old group and the other two groups, respectively, such that the younger and the young-old group reached a higher level of performance, p <.01. No difference between the younger group and the young-old group, $p = 1.0$ was observed. Post hoc pairwise comparisons between the five amount of practice groups (across age groups) were all significant, such that higher dose was associated with higher level of performance, ps < .001. Pairwise comparisons for each age group and for each amount of practice group were also conducted (Figure 3C; p-values in Tables 2 and 3). These comparisons revealed that among the younger and the young-old participants, there were significant differences between almost all amount of practice groups, such that smaller increases in amount of practice lead to better MoL proficiency, whereas for the old-old group, there were no significant differences in MoL proficiency among the three groups with most training, no difference between the three groups practicing 11–30, 31–50, and 51–100, and no difference between the two groups with the least practice <11 and 11–30.

Furthermore, significant age differences were seen for those who practiced 51–100 times and above 100 times (Table 3), but not among participants with less practice. Thus, after extensive practice, the two younger groups reached a significantly higher level than the old-old.

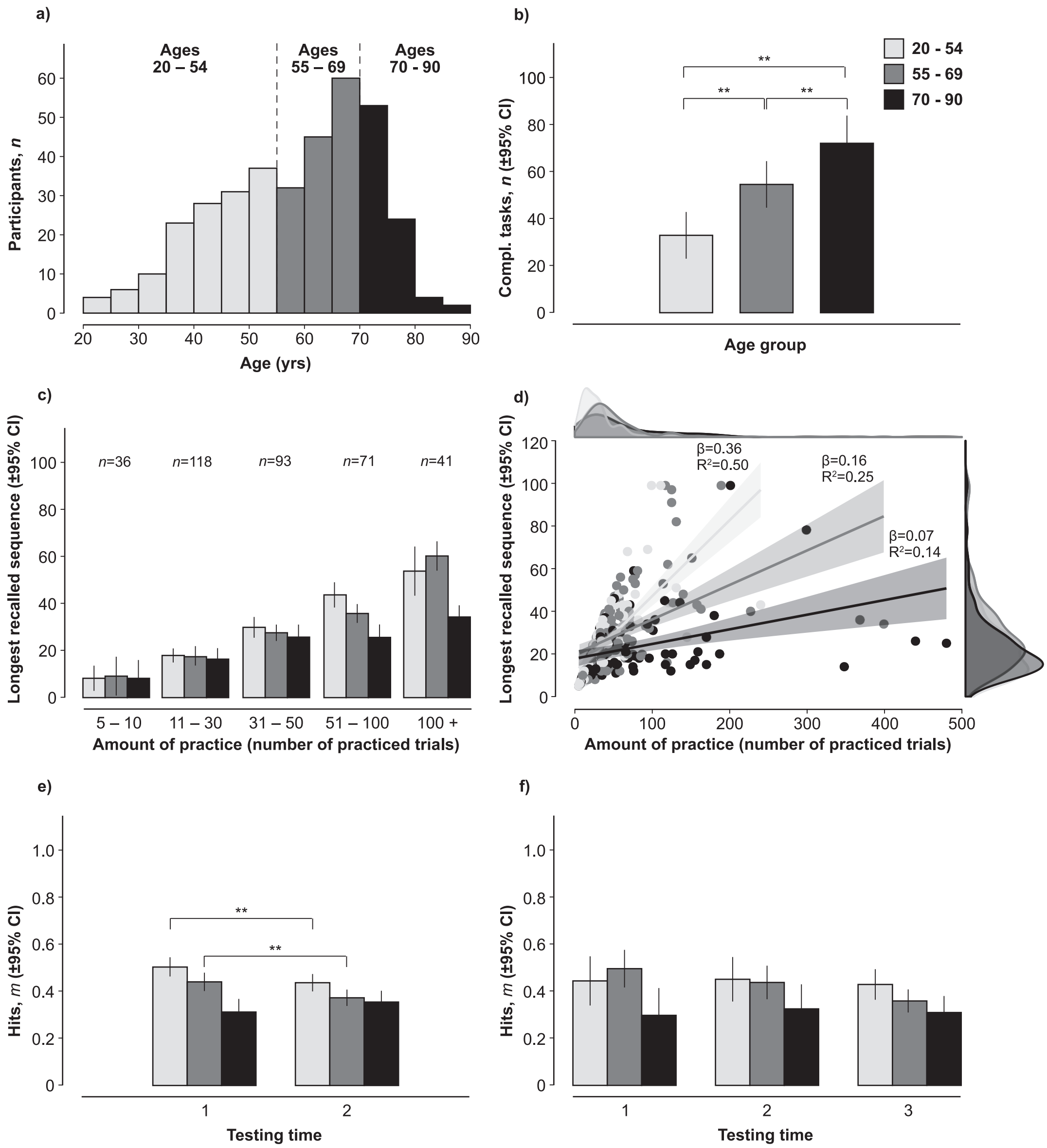

Figure 3. Results. (**A**) Age distribution. (**B**) Means and 95% confidence intervals of amount of practice (number of practiced trials) in the three age groups, respectively. Significant comparisons marked with asterisks. $^{**}p < .01$. (**C**) Means and 95% confidence intervals of maximum level of performance in method of loci (MoL) reached in training for the three age groups depending on amount of practice. *p*-Values for all comparisons are presented in Tables 2 and 3. (**D**) Amount of practice plotted against max level of performance in MoL reached training for the three age groups together with a visualization of the density of data and the respective R^2 values, β values, and confidence intervals for each linear fit line. (**E**) Means and 95% confidence intervals of percent correct answers in transfer test 1 (pretest) and 2 (at level 25 in training), $n = 165$. Significant comparisons marked with asterisks. $^{**}p < .01$. (**F**) Means and 95% confidence intervals of percent correct answers transfer test 1 (pretest), 2 (at level 25 in training), and 3 (level 45 in training), $n = 36$. None of the comparisons were significant.

To display the variation in training response in the three age groups, the level reached in training was plotted as a function of amount of practice, in Figure 3D, where each age groups' regression fit line and respective confidence intervals together with and R^2 and β-values are presented. The amount of variance explained by the respective linear relationship was .50 for the younger group, .24 for the young-old group, and .14 for the old-old group. Thus, the relationship was strongest for the younger group and weakest for the oldest group. Note one small subgroup of participants ($n = 6$) who showed a very high performance after training by recalling the maximum training level of 100 pictures in the correct serial order, and five participants who practiced between 350 and 500 trials without reaching above 40 correct recalled pictures.

Individual Predictors of Level Reached After MoL Training

Next we performed a regression analysis with the survey items as predictors (cf., Table 1) and MoL proficiency as

Table 2. *p*-Values From Pairwise Comparisons Between Amount of Practice Groups for Each Age Group

Age group	Amount of practice	51–100	31–50	11–30	<11
Young	100+	.91	**.00**	**.00**	**.00**
	51–100		**.00**	**.00**	**.00**
	31–50			**.00**	**.00**
	11–30				**.02**
Young-old	100+	**.00**	**.00**	**.00**	**.00**
	51–100		**.03**	**.00**	**.00**
	31–50			**.00**	**.00**
	11–30				.67
Old-old	100+	.22	.20	**.00**	**.00**
	51–100		1.00	.12	**.00**
	31–50			.09	**.00**
	11–30				.78

Note: Amount or practice represents number of practiced trials in the app. Pairwise comparisons were corrected with Bonferroni for multiple comparisons. Significant comparisons are printed in bold. Mean values are presented in Figure 3C.

Table 3. Pairwise Comparisons Between Age Groups for Each Amount of Practice Group

Amount of practice	Age	Young-old	Old-old
Under 11	Young	1.00	1.00
	Young-old		1.00
11—30	Young	1.00	1.00
	Young-old		1.00
31–50	Young	1.00	.70
	Young-old		1.00
51–100	Young	.06	**.00**
	Young-old		**.01**
Over 100	Young	.90	**.00**
	Young-old		**.00**

Note: Amount or practice represents number of practiced trials in the app. Pairwise comparisons were corrected with Bonferroni for multiple comparisons. Significant effects are printed in bold. Mean values are presented in Figure 3C.

the dependent variable. The regression model was significant (p = .048; R^2 = .035). General health compared to others of the same age was the only significant predictor, β = .15, with higher rated health associated with better performance.

Transfer Effects

A total of 165 persons reached transfer test 2 at level 25 in training. The analysis showed significant main effect of age group, $F(1, 162) = 15.04$, $MSE = 0.03$, $p < .001$, $\eta^2p = .16$ and testing time $F(1, 162) = 5.59$, $MSE = 0.013$, $p = .019$, $\eta^2p = .033$, as well as an interaction effect $F(2, 162) = 6.41$, $MSE = 0.013$, $p = .002$, $\eta^2p = .073$. Pairwise comparisons showed that both middle-aged and young-old groups *decreased* performance from pretest to transfer test 2 ($ps < .05$), while the old-old group performed at the same level (see Figure 3E).

A total of 36 persons reached transfer test 3 at level 45. There was a significant main effect of age group, $F(2,33) = 3.89$, $MSE = 0.038$, $p = .031$, $\eta^2p = .19$, but no main effect of testing time, $p = .11$ and no interaction effect ($p = .076$). Pairwise comparisons revealed significant overall differences between old-old and young-old, $p = .48$, but not between old-old and younger, $p = .056$, or younger and young-old, $p = 1.0$. Thus, overall, younger performed better on the face-name test, but there was no effect of MoL training on face-name performance (see Figure 3F).

Descriptive Statistics of Everyday Memory and App-Use

There were 175 participants (49%) who answered the end survey. Of those, 100 (56%) answered that they had definitely or to some degree benefitted in everyday life from partaking in training. These individuals were distributed across the different age groups with 30 individuals in the old-old group (17%), 45 in the young-old group (25%), and 25 in the younger group (14%). The comments showed that using the technique for shopping lists or similar activities were the most common. Other participants commented that the progress in training had changed their view on their own memory capacity, and that the training had increased their ability to concentrate and their self-confidence.

Discussion

The overall aim of this study was to evaluate the effects of a training program for practicing the MoL memory technique in a smart phone app across the adult life span. The app interested people from 20 to 90 years of age. Older adults participated to a high degree and practiced the most. That also older adults are willing to use a smart phone app for learning a mnemonic strategy without the aid of an experimenter is encouraging, and corroborates a recent study showing comparable feasibility and similar results between a web-based and a classroom-based memory training program for older adults (Rebok et al., 2020). It is also in line with reports showing high and increasing use of mobile technology among older adults (Davidsson & Thoresson, 2017). M-health was recognized by the World Health Organization already in 2011 (World Health Organization, 2011), and due to the time-consuming nature of memory training, the development of mobile solutions for cognitive health is pivotal for future research as well as clinical and everyday settings.

As for level of performance reached after MoL training, the younger (20–54) and the young-old group (55–69) did not differ in terms MoL proficiency after training. This finding suggests that plasticity in MoL may be unaffected among older adults in this age segment but that it decreases in older adults above the age of 70. The differences in adherence to training allowed us to further study how MoL proficiency was affected by differences in training dose in different age groups. MoL proficiency scaled with amount of practice, such that more practice was associated with higher MoL performance in the younger and young-old groups. This is indicative of intact plasticity. In the old-old group aged 70–90 years, there was a less strong relation between training dose and level reached, and there were no differences in max levels after 31–50, 51–100, or 100+ trials, suggesting reduced plasticity in this oldest age group. The typical finding in the literature regarding dose and training response is that dose is correlated with gain, but that more training does not ameliorate differences in memory performance between young and old adults (e.g. Baltes & Kliegl, 1992; Jones et al., 2006). Our study is in line with such findings, but with the important caveat that the young-old performed on the same level as the younger adults independent of training dose. In a study by Brooks and colleagues (1999), additional training in the MoL reduced differences between young-old (55–69 years) and old-old (70–88 years). The authors argued that while mnemonic training might not be sufficient for older adults to reach the same proficiency as younger adults, it may support older-old adults so that they approximate the performance of younger-old participants, a pattern that was not confirmed in our data. Within the ACTIVE study, older adults aged 65–93, who adhered to training and thus received a higher dose, benefitted more from training than those with less adherence. Adherence had no effect on memory trajectory over time (Rebok et al., 2013). Our results add to the literature by showing that increases in MoL training leads to better performance among young and young-old but not among old-old adults, who after 100+ training trials were at the level of proficiency reached by the younger adults after 31–50 trials. This is an important with respect to the design of future memory training regimens since it indicates how much MoL training is needed to reach different levels of proficiency in different age groups.

The predictive value of self-rated memory capacity, health, physical activity, and vividness of visualization was weak overall, explaining only a small portion of the total variance in MoL performance. Among the predictors, self-rated health compared to others of the same age emerged as the only predictor reaching statistical significance. This observation is in line with results from the ACTIVE memory training program (Rebok et al., 2013). Despite the allegedly superficial character (often, like here, inferred from ratings on one single question), self-rated health has previously been shown to predict a number of long-term outcomes, including cognitive status (Bond et al., 2006), and even mortality (Schnittker & Bacak, 2014).

Regarding transfer to face-name memory, we found no effect from MoL training to the face-name memory task. Not when measured at training level 25 nor at level 45, corresponding to a moderate and high MoL skill, respectively. This was contrary to our hypothesis, but nevertheless in line with much previous research. The issue of transfer is a long-standing question with conflicting findings (Bottiroli et al., 2017; Derwinger et al., 2003; Rebok & Balcerak, 1989; Richardson, 1995). When learning a mnemonic such as the MoL, transfer could be expected to occur both through application of the strategy in new tasks and settings (Anschutz et al., 1985), or through strengthening underlying processes (Dahlin et al., 2008). Not even in the relatively high proficiency of remembering 45 items in sequence did MoL training transfer to face-name memory. In fact, a significant *decrease* was observed between test one and two which we regard as a spurious finding possibly driven by weaker overall performance as list length increased. Future studies should include transfer tests with stronger, and perhaps graded, processing overlap with the practiced task.

Over half of those who completed the post-training survey expressed improvement of their everyday memory after MoL training—most commonly by using MoL for shopping lists. The training was also reported to strengthen their ability to focus and increased their self-confidence. Given the aging population worldwide, there is a need to find cost-effective solutions for memory training and it is essential that such strategies can and will be applied in everyday life (Anschutz et al., 1985; Bottiroli et al., 2017; see Hudes et al., 2019 for a meta-analysis). Our results suggest that teaching the MoL through an app might be a potential candidate for strengthening everyday behavior, which merits future studies investigating this issue in more detail (e.g., factors promoting everyday use).

Limitations of this study include the difficulty of knowing for certain that the person signing up is the person practicing by herself at all times, although we took preventive measures such as providing a personal activation code. We consider this quite unlikely as our experience is that individuals sign up to train their own memory and they also provided information on how the app facilitated their everyday life.

We used different maximum levels in the three versions of the transfer test; hence factors such as fatigue due to longer testing times could have affected test performance in test occasions 2 and 3.

The self-paced manner in the MoL training task was chosen to give all participants enough time to visualize the items at the places in their memory palaces, and thus to comply with the instructions to apply the MoL. Together with the increase in task difficulty over time, while also allowing self-adjustment to a lower level, this permitted individualization of training so that each participant practiced on a difficulty level that they mastered, without making it boring for those who needed less time for visualization. This should however be considered when interpreting the results, since it means that the training conditions were not identical over time and between groups.

In this study, no control group was included. The focus was on testing how age and amount of practice affected MoL proficiency and transfer, which made a design with a control group less straightforward. There is an ongoing debate over the use of control groups in memory training studies, but a control group would undoubtedly have enabled us to control for factors unspecific to MoL practice. It also deserves to be mentioned that the sample signing up for the study were comparably highly educated, which might limit generalizability of the results. We did not measure maintenance of training effects over time, and thus do not know whether the practice effects would change over time. In a study by Gross and colleagues (2014), one fourth of older adults who learned and practiced the MoL continued to use it for memory tasks 5 years posttraining. Future studies could aim at investigating such sustained use after app-based memory improvement programs and its relation to memory performance, in lab as well as everyday settings.

A concern from previous studies (Nyberg et al., 2003; Singer et al., 2003) is that older adults may have difficulties to adhere to strategy. This could be an issue also here but was minimized by keeping written and video instructions available at all times during training. Regarding the perceived improvement of everyday memory, we caution that the response rate was only 49% and we cannot rule out the possibility that this subsample may overly represent those who perceived benefits.

To conclude, our results suggests that instruction and practice in an episodic memory technique—the MoL—can be delivered via a smart phone application across the adult life span, that it interests people of all ages, and that older adults practiced the most. The level of performance reached in training was variable and mainly affected by amount of training and age. Level reached in MoL was affected by dose such that those who practiced more had better proficiency in MoL. This effect was the same for the younger and young-old, but much less pronounced for the old-old participants, indicative plasticity reductions above the age of 70. To some degree, self-rated health status was indicative of training outcome. An encouraging finding was that about half of the participants expressed that they had benefitted in everyday life from learning and practicing the MoL mnemonic. This indicates that app-based MoL practice can potentially be used to compensate for everyday life-related memory problems and merits further investigation in future studies.

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Conflict of Interest

I. Zogaj works professionally as a memory trainer and runs a company focusing on memory training, but has no financial or other interest in the app, which is the intellectual property of L. Nyberg through his position at Umeå University. No other potential conflicts of interest are present.

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