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Training and transfer effects of long-term memory retrieval training

Xiaofeng Ma[a,b], Haobo Zhang [a,b], Xin Zhao[a,b] and Aibao Zhou[a,b]

[a]School of Psychology, Northwest Normal University, Lanzhou, People's Republic of China; [b]Key Laboratory of behavioral and Mental Health, Gansu Province, People's Republic of China

ABSTRACT

Long-term memory retrieval ability and working memory can share attention control ability. Based on cognitive plasticity, a hypothesis that cognitive training could improve long-term memory retrieval efficiency and that this could transfer to retrieval involving working memory was proposed. 60 undergraduates were randomly assigned to a group of training and an active control group; all the participants completed the same tasks in the same order before and after the training, the tasks included a long-term memory retrieval access task, a intelligence test, a switching task, a working memory updating task, a response inhibition task and an interference control task. The statistics results indicate that cognitive training can improve long-term memory retrieval efficiency and has a transfer effect on working memory updating, interference control and switching ability, but not on response inhibition or intelligence. This reveal the plasticity of long-term memory retrieval and its influence on working memory.

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Introduction

Long-term memory retrieval ability is regarded as the ability to retrieve relevant information from one's long-term memory; furthermore, it is assumed to be an important component of higher-order cognitive ability, thereby playing a significant role in cognitive tasks (Cowan, 2010). When solving problems present in intelligence tests – such as Raven's Progressive Matrices – participants are required to test all hypotheses before identifying the best solution. Given that one's working memory (WM) can, on average, only store four items simultaneously, extra information can be converted into long-term memory (Cowan, 2010). Therefore, in order to solve inference problems, one needs to efficiently retrieve the relevant information from one's long-term memory (Shelton et al., 2010).

Defects in long-term memory retrieval abilities are an important cause of forgetting. Researchers believe that information stored in one's long-term memory does not not disappear, but instead is caused by problems of the long-term memory retrieval process. Therefore, one's retrieval ability is a significant sub-ability relating to long-term memory (Juola et al., 1971; Nobel & Shiffrin, 2001; Shiffrin & Atkinson, 1969). However, few studies explore how an individual's long-term memory retrieval ability can be improved.

Generally speaking, cognitive training is a commonly used method for improving cognitive ability (Dennis, 2002). Related research provides support for the effectiveness of cognitive training. Studies have found that WM, which is an important part of individuals' higher-order cognitive abilities (Baddeley, 1992, 2003), can be improved via cognitive training, and that the training effect can be transferred to other cognitive abilities related to WM (Melby-Lervag & Hulme, 2013; Minear et al., 2016). Specifically, Klingberg et al. (2002) found that an individual's WM and fluid intelligence improved significantly after receiving cognitive training. Xin et a.l (2011) also found that individuals' performance in active memory tasks (tasks for evaluating WM) and fluid intelligence improved after receiving cognitive training. It is worth noting that an individual's higher-order cognitive ability includes long-term memory retrieval capabilities (Wang et al., 2017).

In light of the above, two queries arise: 1) can cognitive training improve an individual's long-term memory retrieval ability? And 2) can the training effects be transferred to other cognitive abilities?

CONTACT Haobo Zhang psyzhanghaobo@126.com; Aibao Zhou zhouab@nwnu.edu.cn
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A large number of studies indicate that the improvement of WM via cognitive training lies in improving individuals' attention control ability (e.g. Engle, 2018; Xin et al., 2011). "Attention control ability" refers to the ability to assign attention to relevant information and the process of cognitive performance, while keeping irrelevant information inhibited (Posner & Digirolamo, 1998). Unsworth et al. (2013) propose that WM and long-term memory retrieval are likely to share attention control ability resources. Unsworth (2019) further states that the dependence of WM and long-term memory on individuals' attention control ability is highly similar within the study sample. The key process of long-term memory is inherent to the long-term memory retrieval process (Juola et al., 1971; Nobel & Shiffrin, 2001; Shiffrin & Atkinson, 1969). As such, WM and long-term memory retrieval not only share attention control ability resources, but also have highly similar dependences on attention control. The foregoing illustrates that long-term memory retrieval ability can be improved through cognitive training. In addition, the dynamic model of individual differences in WM – as proposed by Unsworth and Engle (2007) – states that the efficiency with which an individual can retrieve information from secondary memory will affect their WM capability. According to this model, individual differences of WM comprise two parts: the individual's ability to retain information in primary memory (PM), and the efficiency of retrieving information from secondary memory (SM). Specifically, an individual's WM has the capacity to store part of the information as processed by an individual. Due to the limited capacity of WM, however, extra information will be transferred to an individual's secondary memory. When the cognitive task requires additional information from one's secondary memory, the individual has to retrieve the information efficiently in order to ensure the successful completion of the task. The above process shows that one's long-term memory retrieval ability plays an important role in WM; furthermore, it provides a confident and theoretical basis for the present study to regard WM for its main transfer ability. Consequently, we hypothesise that one's long-term memory retrieval ability can be effectively improved via cognitive training, and that improvements can be transferred to one's WM.

The research adopts the modified Posner task (see more information in Wang et al., 2017) to train individuals' long-term memory retrieval abilities. Compared to traditional long-term memory retrieval tasks, the greatest advantage of the modified Posner task is that it can precisely reflect the process of long-term memory retrieval while avoiding interference from other memory processes, such as the coding process of memory (Lilienthal et al., 2013; Mogle et al., 2008; Unsworth, 2010); therefore, it is guaranteed that the task is specifically targeted at the process of long-term memory retrieval. The response time of the Posner task is usually used to evaluate the efficiency of individuals' memory retrieval. Wang et al. (2017) used a modified Posner task to explore the significant and independent contributions of individuals' long-term memory retrieval ability in terms of fluid intelligence. The task includes 4 levels: tasks at Level 1 and Level 2 include lower grade retrieval tasks (retrieving physical properties or implications concerning items, such as whether the items share a meaning), whereas tasks at level 3 and level 4 require retrieval at a higher grade (retrieving the conceptual information of items, such as whether the items have the same odd-even property). The present study uses the tasks at levels 1 and 2 for training purposes and makes use of tasks at levels 3 and 4 to evaluate the training results. If the training effect of lower-level tasks can be transferred to higher-level tasks, evidence can be gleaned for the notion that the improvement of one's retrieval efficiency is caused by the improvement of one's long-term memory retrieval ability, rather than effects from practising or other simple memory reflections.

Attention control ability mainly functions via one's central executive function (Engle, 2018; Xin et al., 2011) – tasks of executive function are used to assess the transfer effect of WM. According to the three-factor model of executive function, executive function mainly consists of switching capacity, updating capacity, and inhibition capacity, which includes one's interference control ability and response inhibition ability (Miyake et al., 2000). The final assessment tasks used in this study included the interference control task, response inhibition task, WM updating task, and switching task. In addition, Shelton's study indicates that long-term memory retrieval efficiency plays a significant role in fluid intelligence testing (Shelton et al., 2010), and that long-term memory retrieval is an independent and effective predictor of fluid intelligence (Wang et al., 2017). As such, general non-verbal fluid intelligence tasks were chosen in order to explore whether long-term memory retrieval can improve one's fluid intelligence.

The research plans to randomly assign participants to either the training group (of adaptive long-term memory retrieval) and the active control group. Adaptive training tasks consist of many non-repetitive stimulating materials; as such, each exercise can make use of different materials in order to guarantee the effectiveness of the training. Existing research on cognitive training indicates that training can be more effective if the tasks are difficult enough to arouse participants' attention (Lövdén et al., 2010); however, tasks should not be too difficult (Benikos et al., 2013). Therefore, the difficulty of the training tasks used in this study could be reduced or increased in accordance with the participants' performance. The control group completed another task in the same environment – sand painting (Zhao & Jia, 2018; Zhao et al., 2018) – which is irrelevant to memory retrieval. The above measures were taken to minimise the influence of irrelevant variables as much as possible.

Method

Participants

The minimum number of subjects required was 46, as calculated by G*power (parameters: effect size=0.3, alpha=0.05, power=0.8). Thus, we recruited 60 college students ($M = 19.92$, $SD = 1.89$) whose native language was Chinese. 30 subjects were assigned to the training condition and 30 subjects served as controls. There were no significant differences in any pre-training task scores between the two conditions (Table 3). One participant in each condition was excluded from data analysis because they failed to comply with the experimental rules. In the end, data of 29 subjects from each condition were entered into the statistical analysis. All subjects reported normal or corrected vision and no history of psychosis or neurological disorders. The study was approved by the local ethics committee and all experimental operations were conducted by following the approved guidelines, all participants signed informed consent and received cash compensation.

Material

Pre- and post-training tasks

Posner Task. This task measured long-term memory retrieval ability, referring to Level 3 and 4 tasks used in Wang et al. (2017). Stimuli comprised a rule and character-pairing consisting of Arabic numerals 1∼9 and Chinese number 一∼九. Subjects had to make a response in accordance with the character-pairing by pressing the "J" or "F" on the keyboard if the character-pairing conformed the rule or not, respectively. The rules of third and fourth levels both are: whether the parity was the same, the only difference is that the third level character-pairing consisted of Chinese characters or numbers (e.g. (1,2), (一,二)), while the fourth level character-pairing consisted of Chinese characters and numbers (e.g (1,二)., (一,2)). When the character-pairings were both odd or even, press the "J" key (e.g (1,9)., (1,九)); when there was an odd number and an even number, press the "F" key (e.g (1, 2)., (1, 2)). There were two types of character-pairing: (1) Number-number pairing; (2) Number-Chinese character pairing. On each trial, a rule was first presented in the center of the screen; after reading the rule, the subjects had to press the "space" key, then a red fixation cross was presented for 500ms, followed by a character-pairing stimuli (response window). After the response, the next trial started immediately. After 16 practice trials, the main task was initiated, which comprised 32 trials. The stimulus presentation sequence was random. The dependent measure was the accuracy of the reaction and the mean reaction time (RT) of the correct reaction, the higher the accuracy and the faster the RT, the better the long-term memory retrieval ability.

Stroop color–word interference Task. This task was used to measure interference control. The stimuli comprised Chinese characters (Hanzi) and strings (# # # #). Participants had to press the key based on the color of Hanzi and strings, rather than the meaning of that. Pressing "F" for red and "J" for green on a keyboard. The task contained three kinds of trials: congruent, incongruent, and neutral. On congruent trials, the Hanzi referring to the word "green" was printed in green and the character representing "red" was printed in red. On incongruent trials, the "green" Hanzi was printed in red and the "red" Hanzi was printed in green. Finally, on neutral trials, the symbols "####" were either printed in green or red. Each trial started with a fixation cross that was presented for 500ms, followed by a blank screen presented for 1000ms. Thereafter, the target stimulus (colored Hanzi or strings) was presented for 1500ms, followed by a blank screen that was presented for a variable duration lasting between 600ms and 1000ms. The next trial began immediately thereafter. The task comprised 18 practice trials and three blocks, each of which has 36 trials. The subject could have a break between the blocks. Each block contained 12 congruent, 12 incongruent, and 12 neutral trials. The task lasted about 15 min. The dependent measure was the mean RT on the different trial kinds, we computed the interference index by computing the mean RT of incongruent trials minus the mean RT of neutral trials. A high index score represents weak interference control.

Flanker Task. The task was used to measure interference control ability. Stimuli comprised five arrows presented in the center of the screen. If the direction of the middle arrow was pointing to the left, the subjects had to press the "F" key, and if the direction was pointing to the right, the subjects had to press the "J" key. The task comprised trials of two kinds: congruent (→→→→→or←←←←←) and incongruent (→→←→→or←←→←←). For each trial, a fixation cross was first presented for 500ms, followed by a blank screen that was presented for a variable duration lasting between 300ms and 500ms, then the stimulus was presented for 1500 ms (response window), after that was a 1000 ms blank screen. The next trial began immediately thereafter. The task comprised 5 blocks, each of which has 32 trials (16 congruent trials), the first block is the practice block, and the later four blocks are the main task. If the participants wanted to have a break, the task would be interrupted between the blocks. The tasks lasted about 15 min. Based on the mean RT of different kinds of trials, we computed the interference index by computing the mean RT of incongruent trials minus the mean RT of congruent trials. The higher the index score, the weaker the interference control ability.

Go/nogo task. This task was used to assess response inhibition. Subjects were required to respond to the target stimulus by pressing the key (Go trial), but not to the nontarget stimulus (Nogo trial). The task consisted of three blocks, one practice block and two experimental blocks. The practice block consisted of 60 trials. The two experimental blocks each contained 120 trials (70% of Go trials and 30% of Nogo trials), in random order. When the correct rate of the practice block reached ≥85%, the experimental blocks started. In each trial, the fixation cross was first presented for 500ms, followed by the alphabetic stimulus that was presented for 600 ms. The subject had to press the "J" key to the letter Y, but not to the letter X. Then a blank screen that was presented for 1000ms. The next trial began immediately. The task lasted for about 15 min. The dependent measure was the difference score: the proportion of hits (correct response to go trial) minus the proportion of false alarms (incorrect response to no-go trial). The higher the score, the stronger the inhibition ability.

Numerical WM updating: easy and difficult task. These tasks were used to evaluate WM updating ability. A series of single numbers from 0 to 9 were presented in the center of the screen. The length of the digital sequence varied with the type of trial; there were four types of trials with 5, 7, 9, or 11 digits. The number of occurrences of each trial type was the same and presented in random order. Participants had to remember the last three numbers in sequence. For example, if the number presented was 7-5-4-1-5-2-1, participants should remember 7-75-754-541-415-152-521. Finally, when blank bars were presented on the screen, participants had to use the keyboard to enter the last three digits presented (that is, 5-2-1). Each trial began with the "+" fixation point, which was presented for 500ms. Subsequently, the number was displayed, and the empty screen was displayed during the trial. The duration of the empty screen varied from between 800 ms to 1200 ms. The presenting time (PT) of each number distinguishes the difficulty of the task. We defined 1750ms as a simple task and 750ms as a difficult task. Easy tasks consisted of three blocks; the first block was a practice block, comprising eight trials, each of which occurred twice randomly. Both the main task and the difficult tasks included two test blocks, each comprising 12 trials. Each participant completed an easy task before the difficult task. The evaluation index was proportion of correct responses.

Switching task. The task was used to measure the ability to flexibly switch between tasks. The stimuli comprised red or blue numbers 1–9 (excluding number 5). The subjects need to judge the size or parity of each number. The specific rules depend on the color of the number. In Task A, if the color of the number is red, a size judgment should be made (magnitude task). If the number was > 5, then "A" should be pressed. If the number was < 5, then "L" should be pressed. In Task B, if the color of the stimulus number was blue, a parity judgment should be made (parity task). If the number was odd, then "A" should be pressed. If the number was even, "L" should be pressed. The participants first performed two task blocks (task A and task B) until the correct rate reached 75%. Then, they completed 20 experimental blocks: 10 single-task blocks, each comprising 8 trials, and 10 mixed-task blocks, each comprising 17 trials. The order of blocks was random, but there were restrictions on combining two single and two mixed task blocks. On each trial, the fixation cross was first presented for 1400 ms, then, the stimulus was presented until the subject responded. The next trial began immediately thereafter. The task lasted about 20 min. The dependent measure was the switching cost: median RT on switch trials minus mean median RT on non-switch trials. The greater the switching cost, the worse the switching ability.

Raven's Standard Progressive Matrices. The Raven's Standard Progressive Matrix (RSPM; Leavitt, 2011) test was used to measure fluid intelligence. The test comprised a series of diagrams or designs with a missing part. The subject needed to select the right part from the multiple options given below to complete the picture presented above. Sixty items were divided into two equal parts by title. Participants were asked to complete the even-numbered items in the pre-training test and the odd-numbered items in the post-training test. Each subject was given a limited time (20 min) to complete the test. The dependent measure was the proportion of correctly solved items.

Training task

The training task was adapted from level 1 and level 2 tasks used by Wang et al. (2017). Materials comprised two rules and character-pairing consisting of Arabic numerals (1~9) or Chinese-characters (一~九). The task involved responding to the character-pairing according to the given rules. If the character-pairing conformed to the rules, pressing the "J", if it did not conform to the rules, pressing the "F". Rules include: (1) Whether the physical properties are the same (e.g. (1-9), pressing the "J"; e.g (1-九)., pressing the "F"); (2) Whether the meaning are the same (e.g (4–四)., pressing the "J"; e.g (4-3)., pressing the "F"). The training task contained different difficulty levels. There were 32 trials in each difficulty level (16 trials in each of the two rules, and half of them conformed to rules). On each trial, a rule was first presented in the center of the screen. After reading the rule, the subjects had to press the "space" key, then a fixation cross was presented for 500ms, followed by a random character-pairing (response window), the next trial began immediately thereafter. Each subject had 10 opportunities to complete the training task every day, and the entire lasted about 25 min.

The training task was carried out in the form of self-adaption, which refers to the adjustment of task difficulty according to the performance of the subject (the number of wrong trials in each difficulty level). There were 10 difficulty levels in the task, which controlled by the time of stimulus presentation. See Table 1 for specific difficulty levels.

Procedure

In the pre-training session, all subjects completed one task that evaluated the transfer effect every day. The task sequence was as follows: Long-term Memory Retrieval Efficiency Assessment Task, Raven's Standard Progressive Matrices, Flanker Task, Stroop color–word interference Task, Numerical WM updating (easy, difficult), Go/nogo Task, Switching Task. After that, the training condition carried out about 25 min of training every day for 12 days. The active control condition carried out sand-painting task at the same time and place every day. Sand-paining is part of the Buddhist tradition and involves the individual to evenly spread fine colored sand on a sticky drawing paper containing templates. These templates, consisting of complex geometric patterns, have to be completed stepwise. Completion of the painting requires much patience and endurance. All participants performed the same tests, in the same order and with the same inter-session interval as used in the pre-training session (post-training assessment).

Score Standard

Each participant in the training condition would begin training at the first difficulty level (1200ms). In each difficulty level, if the number of wrong responses was less than or equal to 3, they would progress to the next difficulty level. If the number of wrong responses was greater than or equal to 4, they would remain in the present difficulty level for retraining. There were two opportunities for

Table 1. Specific difficulty level.

Difficulty level	Duration (ms)
1 (easiest)	1200
2	1100
… …	… …
9	400
10 (hardest)	300

retraining. If they were still unable to pass, they would drop to the previous difficulty level. There were 10 opportunities for each subject every day. Finally, the last difficulty level of the subject would be recorded. The next time the same subject was trained, they would start from the last recorded difficulty level. The results of the subjects' daily training were determined by their final difficulty level on that day. For example, on the first day, if a subject progressed to the third difficulty level (1000ms), his or her score was 3. On the second day, if he or she progressed from the third difficulty level to the fifth difficulty level (800ms), his or her score was 5.

Statistical analysis

For the Stroop and Flanker task, error trials and trials with an RT < 200 ms were excluded prior to the RT analyses. For Go/nogo task, Trials with an RT of < 150 ms were excluded from the analyses. For the switching task, RT ≥ 4000 ms and error trials were excluded prior to the analyses. In a first analysis, we computed Pearson's correlation among the performance measures of the various tasks taken from the pre- training tests, to examine whether assessment is effective (there should be a significant correlation between tasks that assess the same capacity). Prior to performing the main analyses, we first tested whether there was a difference between the trained and control participants on any of the pre-training tests, which was not the case (all *ps* > 0.05). After that, we used a analysis of variance (ANOVA) to examine the training data. Finally, for the transfer effect, condition (training vs. control) and session (pre- vs. post-training) were used in the ANOVA. Significant interactions were followed up by analysis of covariance (ANCOVA). An alpha level of $p<0.05$ was adopted throughout. Partial eta-squared (ηp^2) was used as an effect size estimate.

Results

Correlation analysis on pre-training performance data

Table 2 shows the correlations among the scores on the pre- training task performance measures. In order to demonstrate the effectiveness of the measurement, there should be a significant correlation between tasks that assess the same capacity. There is a significant positive correlation between the response time and the proportion correct of the long-term memory retrieval ability assessment task. There is also a significant correlation between the two WM updating tasks (easy and difficult). Although the correlation between the Stroop task and Flanker task is not significant, the correlation between the two is much greater than that with other measures. These results suggest our assessment is reliable.

Long-term memory retrieval training

The daily mean score of participants in the training condition, the mean difficulty levels reached after training, is shown in Figure 1. The results showed that with the increase of training sessions, the mean difficulty level increased from 3.6–8.4, $F(1,29) = 233.75$, $p< 0.001$, $\eta p^2 = 0.89$, indicating that the participants in training condition completed the training as required and made progress.

Transfer effect

Table 3 shows the conditions' mean score on the performance measure of the different transfer tasks (including near and far transfer) during the pre- and post-training sessions. Details of the overall ANOVAs on the pre- and post-training performance measures are presented in Table 4.

Table 2. Pearson's correlation among pre- training task performance measures.

	1	2	3	4	5	6	7	8	9
1. Posner Task (RT)	-								
2. Posner Task (correct proportion)	0.30*	-							
3. Raven	−0.17	−0.09	-						
4. Stroop	0.12	0.03	−0.15	-					
5. Flanker	0.07	−0.09	−0.06	0.18	-				
6. Updating-easy	0.01	−0.16	0.06	0.17	0.07	-			
7. Updating-difficult	0.12	−0.13	0.07	−0.02	0.13	0.48**	-		
8. Switching	0.20	0.21	−0.21	0.02	−0.01	−0.02	0.07	-	
9. Go/nogo	0.03	0.01	−0.04	0.12	0.10	0.14	−0.24	−0.22	-

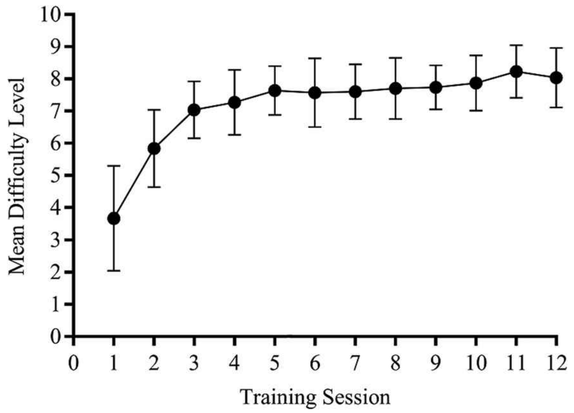

Figure 1. Mean (±SD) difficulty level reached by participants in training condition on each of the 12 training sessions.

Posner task

ANOVA using the RT of the posner task on the pre- and post-training sessions revealed significant main session and training condition × session interaction effects. The interaction effect reflected a significantly shorter RT at post-compared to pre-training test for the trained participants, $F(1,56) = 19.1$, $p<0.001$, $\eta p^2=0.25$; but not control participants, $F(1,56) = 1.78$, $p=0.19$, $\eta p^2=0.03$. Moreover, when controlling for the pre-training performance difference between the training and control conditions, the trained participants had a shorter RT during the post-training test than the control participants, ANCOVA, $F(1, 55) = 11.62$, $p<0.001$, $\eta p^2 = 0.17$.

The ANOVA using the proportion correct of the posner task on the pre- and post-training sessions did not reveal any significant effects.

These results suggest that training improves the long-term memory retrieval efficiency. Participants in training condition can retrieve the required target information more quickly from long-term memory system, rather than participants in control condition.

Raven task

ANOVA using the Raven scores did not reveal any significant effects. These results suggest no beneficial training effect on general IQ as measured by the Raven test.

Stroop task

ANOVA using the Stroop interference score on the pre- and post-training sessions revealed a significant training condition × session interaction effect. The interaction effect reflected a significantly lower interference score at post-compared to pre-training test for the trained participants, $F(1,56) = 7.31$, $p=0.09$, $\eta p^2=0.12$; but not control participants, $F < 1$. Moreover, when controlling for the pre-training performance difference between the training and control groups, the trained participants had a lower interference score during the post-training test than the control participants, ANCOVA, $F(1, 55) = 4.69$, $p<0.05$, $\eta p^2 = 0.08$. These results suggest some evidence for a positive transfer effect of the long-term memory retrieval training on interference control capacity as measured with the Stroop task.

Table 3. Descriptive statistics (mean and SD) for the conditions' pre- and post-training transfer task performance measures.

Task	condition	Pre-training	Post-training
Posner Task	Training	1289.75 (345.18)	**933.27*** (271.92)
(response time, ms)	Control	1285.74 (342.72)	1167.7 (265.5)
Posner Task	Training	.85 (.10)	.85 (.04)
(correct proportion)	Control	.86 (.11)	.89 (.05)
Raven	Training	.91 (.05)	.91 (.07)
	Control	.89 (.06)	.88 (.05)
Stroop	Training	38.11 (22.93)	**19.53*** (29.2)
	Control	32.78 (22.03)	34.63 (34.7)
Flanker	Training	24.89 (16.36)	**14.38*** (9.94)
	Control	25.06 (14.23)	23.62 (16.22)
Go/nogo	Training	.87 (.07)	.87 (.07)
	Control	.87 (.06)	.88 (.07)
WM updating-easy	Training	.92 (.07)	**.98*** (.03)
	Control	.93 (.07)	.94 (.06)
WM updating-difficult	Training	.92 (.07)	.95 (.05)
	Control	.90 (.08)	.91 (.08)
Switching	Training	208.16 (102.32)	**120.65*** (80.55)
	Control	194.29 (94.65)	171.39 (82.7)

Table 4. Results of statistical analyses (ANOVAs) of transfer test data.

Task (dependent measure)	Factor	*dfs*	*F*	*p*	ηp^2
posner task (response time)	Condition	1, 56	3.05	0.09	0.05
	Session	1, 56	20.9	**<0.01**	0.27
	Condition×session	1, 56	6.52	**<0.05**	0.11
posner task (correct proportion)	Condition	1, 56	2.99	0.09	0.05
	Session	1, 56	1.34	0.25	0.02
	Condition×session	1, 56	1.24	0.27	0.02
Raven	Condition	1, 56	2.99	0.09	0.05
	Session	1, 56	1.34	0.25	0.02
	Condition×session	1, 56	1.24	0.27	0.02
Stroop	Condition	1, 56	0.67	0.42	0.01
	Session	1, 56	3.74	0.06	0.06
	Condition×session	1, 56	5.72	**<0.05**	0.09
Flanker	Condition	1, 56	2.26	0.14	0.04
	Session	1, 56	7.7	**<0.01**	0.12
	Condition×session	1, 56	4.49	**<0.05**	0.07
Go/nogo	Condition	1, 56	0.69	0.41	0.01
	Session	1, 56	0.83	0.37	0.02
	Condition×session	1, 56	1.76	0.19	0.03
WM updating-easy	Condition	1, 56	0.67	0.42	0.01
	Session	1, 56	21.51	**<0.01**	0.28
	Condition×session	1, 56	9.25	**<0.05**	0.14
WM updating-difficult	Condition	1, 56	3.76	0.06	0.06
	Session	1, 56	6.85	**<0.05**	0.11
	Condition×session	1, 56	1.03	0.32	0.02
Switching	Condition	1, 56	0.96	0.33	0.02
	Session	1, 56	14.52	**<0.01**	0.21
	Condition×session	1, 56	4.97	**<0.05**	0.08

Flanker task

ANOVA revealed significant main session and training condition × session interaction effects. The interaction effect reflected a significantly lower interference score at post-compared to pre-training test for the trained participants, $F(1,56) = 8.75$, $p<0.01$, $\eta p^2=0.14$; but not control participants, $F < 1$. Moreover, when also controlling for the pre-training performance difference between the trained and non-trained participants, the trained participants had a lower interference score during the post-training test than the control participants, ANCOVA, $F(1, 55) = 7.66$, $p<0.01$, $\eta p^2 = 0.12$. These results suggest some evidence for a positive transfer effect of the long-term memory retrieval training on interference control capacity as measured with the Flanker task.

WM updating task

An ANOVA using the data from the difficult task did not reveal any significant effects. However, an ANOVA on the data from the easy task revealed significant main session and training condition × session interaction effects. The interaction effect reflected a significant performance increase from pre- to post-training for the trained participants, $F(1,56) = 22.38$, $p<0.01$, $\eta p^2=0.29$; but not control participants, $F < 1$. Moreover, the training condition difference in post-training task performance was significant after controlling for pre-training task performance differences, ANCOVA, $F(1, 55) = 9.78$, $p<0.01$, $\eta p^2 = 0.15$. These results suggest marginal evidence for a benefit of the long-term memory retrieval training on updating task performance.

Go/nogo task

An ANOVA did not reveal any significant effects. These results suggest no beneficial training effect on response inhibition capacity as measured by the Go/nogo task.

Switching task

An ANOVA using the data from the switching task revealed significant main session and training condition × session interaction effects. The interaction effect reflected a significant performance increase from pre- to post-training for the trained participants, $F(1,56) = 13.11$, $p<0.01$, $\eta p^2=0.19$; but not control participants, $F < 1$. Moreover, when also controlling for the pre-training performance difference between the trained and non-trained participants, the trained participants had a lower switching cost during the post-training test than the control participants, ANCOVA, $F(1, 55) = 6.59$, $p<0.05$, $\eta p^2 = 0.11$.

These results suggest evidence for a benefit of the long-term memory retrieval training on for switching task performance.

Discussion

The present study examines the effect of a 12-session Posner long-term memory retrieval training program (relative to an active control group). The study examines the participants' performance in a trained task and activities that measure transfer effects of a variety of cognitive tasks. For the participants in the training group, we found improved performance in the trained task, reflected in the increasing difficulty level achieved by the participant (from 3.6–8.4). The training group also displayed better performances in long-term memory retrieval tasks in the post-test (when compared to the pretest); although there was no significant improvement in retrieval accuracy, the response time was significantly reduced. Evidence of beneficial transfer effects of the training program was also found for the Stroop, Flanker, WM updating (easy), and switching tasks. However, no significant transfer effects were observed for WM updating (difficult), Go/No-go, and fluid non-verbal intelligence tasks. These results indicate that long-term memory retrieval ability has a certain degree of plasticity and has a beneficial transfer effect for the WM partial sub-ability.

For the improvement of one's long-term memory retrieval ability after training, two possible causes have been identified. First, it might be assumed that the cognitive nervous system (which is closely related to the long-term memory retrieval process) has undergone certain changes, structurally or/and functionally. Studies show that the fundamental reason why cognitive training can improve a certain cognitive ability is that targeted training changes the cognitive nervous system on which the ability depends (Benloucif et al., 1995; Buonomano & Merzenich, 1998; Hallett, 2001; Mano et al., 2003; Neville & Bavelier, 1998). One's long-term memory retrieval ability, as an important cognitive ability, must follow the regularity. Related studies have found that the bilateral ventrolateral prefrontal cortex (Districts BA 6, 44, 45 and 47) and the dorsal prefrontal cortex (District BA 9/46) are significantly activated during the long-term memory retrieval process (Charan et al., 2003). Therefore, we speculate that the above-mentioned brain areas may undergo certain changes as a result of the training, which leads to the training effect. Second, the improvement of the core ability (attention control), which the memory retrieval process relies upon, also contributes to the training effect. During the training process, as the difficulty of the task continues to increase, higher requirements will be placed on the individual's attention control ability. In fact, the plasticity of one's attention control ability has been shown by a number of studies (Millner et al., 2012; Protopapas et al., 2014; Wilkinson & Yang, 2012). Therefore, we speculate that the improvement in one's attention control ability is also one of the contributing factors in support of the training effect.

The present study finds strong evidence that gains achieved via the training effect were transferred to Stroop, Flanker, WM updating (easy), and switching tasks. The specific discussion on the transfer effects are as follow.

First, the Stroop task (Stroop, 1992) and Flanker task (Eriksen & Eriksen, 1974) reflect an individual's interference control ability. Interference control, also known as attention control, is one of the inhibition function components, and is the ability to inhibit competition and stimulate interference (Nigg, 2000). Individuals displayed an inhibition of irrelevant external information (and the interference between items) when retrieving relevant information, resulting in greater concentration on the targeted item and rapid achievement of successful retrieval (Juola et al., 1971; Shiffrin & Atkinson, 1969; Unsworth et al., 2013). The data, therefore, suggest that the training of long-term memory retrieval can improve individuals' interference control ability.

Second, the "numerical updating task" used in the present study not only required participants to update interfering numbers that existed in their WM before new numbers were presented, but also required that the participants accurately retrieve the target numbers from their long-term memory during the recall phase. After training, the participants cannot only effectively suppress the disturbances (competing irrelevant numbers) and keep their attention on the target numbers, but could also efficiently and accurately retrieve the required numbers when recalling, indicating that the training effect can be transferred to the updating task. Although the score in the WM updating (difficult) task did not improve significantly, it still increased to some extent (average accuracy increased by 0.01). The reason for this may be that the refreshing of WM updating (difficult) is more difficult, thus requiring longer training to be able to have a significant migration effect.

For the switching task, the participants needed to retrieve the corresponding rules (provided before the task in accordance with different stimulus information) and respond after retrieving the property relevant to the stimulation (such as an odd-even property) of their long-term memory. This view is also supported by other researchers: Mayr and Kliegl (2000) show that the switching cost partly reflects the time required to retrieve appropriate task rules and information from one's long-term memory. Individuals' memory retrieval efficiency improved after training – as such, the participants' performance in the switching task was improved.

However, we did not observe evidence for the transfer effect on the Go/No-go task – which aims to assess individuals' response inhibition ability. Existing research only shows that interference control plays a significant role in long-term memory retrieval (Unsworth et al., 2013), but the role of response inhibition remains unclear. Although both interference control and response inhibition are sub-abilities of the inhibition function, the individual abilities represent different inhibition functions (Stahl et al., 2014) – response inhibition refers to the ability of ending a response in progress, or rejecting the launch of an inappropriate response (Nigg, 2000). Therefore, the finding that no beneficial transfer effect was observed on this task is not unexpected.

The above results regarding the transfer effect of WM are of great significance for understanding the dynamic model of individual differences in WM, as proposed by Unsworth and Engle (2007). This model suggests that individual differences in WM are possibly caused by individuals' maintenance of information in PM and the difference in the ability to retrieve information retrieval from SM (or long-term memory, LTM). There is no doubt that information maintenance needs attention control and that retrieving memories from SM or LTM requires an efficient memory retrieval ability. After receiving training, one's memory retrieval ability is improved, and individuals can retrieve the required information more rapidly and more accurately, thereby better completing WM tasks which require memory retrieval (eg. Updating task, switching task). At the same time, during the training process, the core ability (attention control) that the memory retrieval process relies on will be improved as well, so transfer effects are also observed in WM tasks that mainly involve an individual's attention control ability (eg. Stroop task, Flanker task). From this point of view, the results of the above-mentioned WM transfer effect are expected and provide new evidence for the dynamic model of individual differences in WM, as proposed by Unsworth and Engle (2007).

A slightly unexpected result was encountered, as we did not observe a significant transfer effect on the fluid intelligence test. This result could be due to various reasons. First, the participants in this research were undergraduates from 18 to 22 years old, and their cognitive development was at a stable stage. Compared to stable adulthood, childhood is the key stage of cognitive development (Cao et al., 2013; Davidson et al., 2006), and cognitive ability in this stage is more plastic and has a more extensive transfer effect (Karbach & Unger, 2014; Zhao et al., 2018). Second, Raven's Standard Progressive Matrices (RSPM) (Leavitt, 2011) were selected for the adult participants in this research, rather than Raven Advanced Progressive Matrices (RAPM) (Raven, 1983), which are more appropriate for adults, and this may have had a ceiling effect (e.g. Melby-Lervåg et al., 2016).

Overall, this study identified that individual long-term memory retrieval has plasticity and can transfer to WM with the training of an individual's long-term memory retrieval ability. The results support the hypothesis of the research; nonetheless, the research faces limitations. First, the research only used an immediate post-test, rather than a long-term tracking of the transfer of ability; it remains unclear whether the improvement of long-term memory retrieval efficiency (and its transfer to WM) is long-standing. Second, the sample size is small and the age group of the participants is young; as such, the research result needs to be verified with a larger sample size and among other age groups. Finally, in the current study, the possible explanation of the existence of cognitive neural plasticity is not verified directly. In future studies, researchers can further explore the neuromechanism of long-term semantic memory retrieval plasticity with functional magnetic resonance imaging, event-related potential, or other instruments in order to obtain more powerful evidence.

Conclusion

The present research carried out a 12-day adaptive training on individuals' memory retrieval ability.

The final result shows that after systematic cognitive training, long-term memory retrieval efficiency can be improved and can be transferred to working memory, and the transfer effect is significant on Stroop task, Flanker task, updating task (easy) and switching task.

Research involving human participants

The present study was approved by the local ethics committee and all experimental operations were conducted in accordance with the approved guidelines.

Informed consent

Informed consent was obtained from all individual participants included in the study.

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Data Availability Statement

Data sharing is applicable for the present study. Anyone can get the data from the supplementary documents.

Disclosure statement

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

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ORCID

Haobo Zhang http://orcid.org/0000-0001-7231-6862

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