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博　士　論　文

Effects of multicomponent attention training in a nonrandomized controlled trial of healthy adults

（健康成人を対象とした非ランダム化比較試験における多成分型注意力トレーニングの効果）

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Abstract

Cognitive training for healthy adults has a positive effect on maintaining or improving cognitive function; however, the cognitive domains best suited for intervention are still unclear. In this nonrandomized controlled trial, we examined changes in cognitive function due to multicomponent attention training for healthy adults. Nineteen healthy older adults and 20 younger adults participated in this study and were allocated to training and control groups for each age range. The training group received ten sessions of multicomponent attention training within two weeks. All subjects underwent neuropsychological tests initially and after two weeks. Both older and younger adults in the training group improved on their Symbol Digit Modalities Test results, and the improvement was larger in the younger than older adults. These results suggest that multicomponent attention training is helpful for improving cognitive function in both older and younger healthy adults.

Key Words

Attention, Cognitive training, Processing speed, Neuropsychological test

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Introduction

Cognitive decline along with aging affects multiple domains of cognitive function, including attention, working memory (WM), memory, and executive function[1-4], resulting in a reduction in the quality of independent life[5,6]. To maintain and improve cognitive function, diet[7], exercise programs[8], and socially active lifestyles[9] have been proposed for older adults, and cognitive interventions have also been reported to maintain or improve cognitive function in older adults[10,11]. Most of these reports focus on cognitive interventions for WM[12-14], memory[15,16], and executive function[17-19]. Although these cognitive functions include attentional components, interventions focused directly on attention have not been well-studied.

Attention-related interventions are crucial for various reasons. Aging studies find that attention is susceptible to the effects of aging[20,21], and a decline in attention may be predictive of progression to dementia in healthy older adults[22]. Early memory deficits in Alzheimer's disease may not be from impaired memory processes[23] but inadequate attention. Moreover, studies in the field of brain injury model cognitive processes as functionally hierarchical, where fundamental abilities such as arousal and attention are placed at lower levels as cognitive foundation[24,25]. Consistent with this model, attention leads to the performance of higher-order functions such as memory[26]. Additionally, Norman and Shallice proposed the Supervisory Attention System (SAS) to collect and monitor information and select appropriate actions[27] and observed that the malfunctioning of SAS induces a selection of wrong actions. These studies indicate that attention must perform efficiently and adequately for higher cognitive functions such as memory and executive functions to work effectively and suggest that attention training is vital for age-related cognitive decline.

Among the various types of training for attention, we focus on multicomponent attention training, which intervenes in each element of attention. Attention consists of multiple components[28,29], and Sohlberg et al. classified it into five: focused attention, sustained attention, selective attention, divided attention, and alternating attention[30]. They created Attention Process Training (APT)[31,32] that works on each component of attention and found the effects of APT on brain injury patients[33,34]. Attention research in the aging literature has focused on selective attention only[35-37], and to the best of our knowledge, no study has examined all five components.

In this study, based on a prediction that multicomponent attention training would also be effective in maintaining and improving cognitive function in healthy adults, we examined the effectiveness of multicomponent attention training in healthy adults. We administered ten sessions of multicomponent attentional training to healthy adults over a two-week period and used neuropsychological testing. We assessed 1) changes in cognitive function due to training in each age range and 2) whether the changes, if any, vary with age.

Methods

Participants

We recruited 39 healthy right-handed older adults (range: 55–75 years) and younger adults (range: 20–30 years) from the community and university for this study. Of these, 20 were younger adults (9 women; mean age 25.0 years; range: 21–30 years), and the remaining 19 were older adults (13 women; mean age 65.1 years; range: 59–72 years). All participants had no self-reported neurological or psychiatric disorders and had visual acuity of 20/25 vision or better (with correction). The older group had a score of 26 or higher on the Mini-Mental State Exam (MMSE)[37]. This study protocol was approved by the Ethics Committee of Kobe University Graduate School of Health Sciences (Approval Number: 496), and all subjects signed a consent form before participating in the study. Participants were assigned alternately to the control group (young n=10, old n=10) and the training group (young n=10, old n=9) in the order of their applications. There were no significant differences in age, gender, education history, or MMSE (older adults) between the training and control groups among both older adults and younger adults (Table 1).

Table 1. Baseline data of participants in the training and the control group

	Old Training (N=10)		Control (N=9)			Young Training (N=10)		Control (N=10)		
	Mean	SD	Mean	SD	*p*	Mean	SD	Mean	SD	*p*
Age (years)[a]	65.4	2.2	64.7	5.3	0.692	24.7	2.9	25.2	3.4	0.728
Gender (female)(%)[b]	7 (70%)		6 (66.7%)		0.876	6 (60%)		3 (30%)		0.178
Education (years)[a]	14.4	1.3	14.3	3.0	0.902	16.0	1.7	15.8	0.9	0.747
MMSE[a]	29.8	0.6	29.7	0.5	0.620					

a : Independent t-test.
b : Chi-squared test.

Training procedure

All participants were administered neuropsychological tests during the initial interview, and a baseline assessment was conducted. The training group completed a total of ten sessions of cognitive training, about 30 minutes a day, within two weeks (five sessions per week). APT studies have recommended intensive training and reported training effectiveness with seven to nine interventions per week[30,32]. However, because cognitive training for healthy older adults has been shown effective with one to two interventions per week[34,49], the training frequency was set at five times per week, with two days per week when training days could be skipped if necessary. The training period required two weeks to complete a minimum of ten training sessions, based on previous research[11] that a minimum of ten interventions is desirable to improve cognitive function due to intellectual training. The training tasks and answers were printed on paper. The first training task was conducted after the initial neuropsychological examination, during which the training procedure was explained. The second and subsequent training sessions were done on their own. To ensure that the training was accurate, participants were asked to email a photo of their forms after each training. Additionally, if they had any questions or concerns, they were asked to send the contents by email, and we responded as needed. The control group did not receive any training and spent their time as was typical for them. After a period of 14–16 days following the baseline assessment, all participants again underwent the same neuropsychological tests as those administered at the beginning.

Training task

The attention training in this study involved training to work on each attention component, and we performed various tasks related to selective, sustained, alternating, and divided attention (see Table 2). We arranged tasks progressively, i.e., from easy to difficult tasks in each session, and the subjects were requested to record the execution time at every training to visualize any changes. The number of assignments was designed to be completed in about 30 minutes per day. The difficulty level of the assignments was gradually increased over the course of five days; on the sixth day, it was returned to the same level as the first day, and thereafter, it was increased again. This is because we assumed that by lowering the difficulty level midway, it would be easier for the participants to continue working on the task, and fewer people would drop out.

Table 2. A description of multicomponent attention training

Exercise	Targeted ability	Description (contents)
Repeated subtraction	focused attention sustained attention	The same number is repeatedly subtracted from 100 until the remainder is zero or a number smaller than the number being subtracted. (Subtracted numbers changes to 1, 5, 2, 3, 7, as the difficulty level changes)
Find the differences	selective attention divided attention	Identify the differences between two similar pictures. (The difficulty level was gradually increased.)
Cancellation task	selective attention	Participants search for and cancel (strike out) targets (letters, geometric figures, numbers), which are intermingled among several distracters.
Flexible number (shape) cancellation	selective attention alternating attention	This task adds attention transformation to the cancellation task and needs to switch from one target to a different type of word or target on sound cue.
Paced Auditory Serial Addition Task (PASAT)	sustained attention divided attention processing speed	A random string of single-digit numbers (1–9) is played every 2 or 3 seconds. Add the next number to the one promptly preceding it and repeat that.

Neuropsychological tests

We conducted neuropsychological tests to evaluate the effects of multicomponent attention training. The Trail Making Test (TMT)[38)] is a well-known test to examine attention and executive functions and consists of two parts, TMT-A and TMT-B. TMT-A assesses selective attention, visual scanning, and processing speed, whereas TMT-B assesses divided attention, WM, and inhibition control. Interference and executive function were also evaluated by the difference score (TMT-B − TMT-A)[39,40)]. The Modified Stroop Test (MST) is a battery that primarily assesses the ability to inhibit stereotype[41,42)]; we used the MST that includes Japanese Kanji characters[43)]. Part A of this test assessed the speed of WM and visual search. Participants were presented with a piece of paper on which 24 dots colored blue, green, and yellow were randomly printed in six columns by four rows, and they were required to answer the color of the ink as completely and accurately as possible. Part B assessed WM and conflict monitoring. Participants were presented with a sheet of paper on which Chinese characters representing blue, green, and yellow were printed with ink that did not match the colors, and they were required to answer the ink colors as completely and accurately as possible. We assessed the inhibitory ability by looking at the difference between Part A and Part B[44)]. The Clinical Assessment of Attention (CAT) is a battery that assesses deficits in generalized attention and has been standardized and widely used in clinical settings in Japan[44,45)]. From these, we used Digit Span, Tapping Span, Visual Cancellation Task, and Symbol Digit Modalities Test (SDMT). Digit Span (forward and backward) was used to assess WM and immediate recall, whereas Tapping Span (forward and backward) was used to assess visual memory and WM. The Visual Cancellation Task (target: a letter) is a test to assess selective attention. A Cancellation task targeting a single Japanese "kana" letter was used and evaluated by the percentage of correct responses. SDMT was used to evaluate processing speed[46-48)]. Participants were required to write down as many numbers (between one and nine) corresponding to each symbol as possible in 90 seconds; their results were evaluated by the achievement rate (number of correct answers / 110) (%).

Statistical analysis

As a baseline evaluation of the first neuropsychological test, we conducted independent t-tests between the control and training groups (for the older and younger adults, respectively). Subsequently, group differences were analyzed by two-way repeated-measures analysis of variance (ANOVA), with Time (pre-and post-training) as the within-subjects factor and Group (control and training) and Age (old and young) as the between-subjects factors. To evaluate the training effects, we conducted a Time × Group analysis for both older and younger adults. To evaluate the effect of training on age, we conducted a Time × Age analysis for both the training and control groups. Statistical analysis was performed using IBM SPSS Version 24 for Windows, with all statistical significance levels set at 0.05.

Results

All participants in the training group completed the attention training, and no participant dropped out of the training. Baseline assessment of neuropsychological tests showed no significant difference between the training group and the control group in both the younger and older adults (All *ps* > 0.127, two-sided). The results of the neuropsychological tests before and after the training are reported in Table 3.

Training-induced changes in cognitive function

Table 4 reports the main effects and the interaction effects of the Time × Group analysis using repeated-measures ANOVA.

Table 3. Results of the pre and post-neuropsychological tests

	Old-training				Old-control				Young-training				Young-control			
	Pre		Post		Pre		Post		Pre		Post		Pre		Post	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
TMT-A	87.9	17.2	75.6	15.8	92.1	26.7	88.3	28.5	63.2	5.0	53.5	8.2	64.6	11.0	63.8	13.9
TMT-B	125.3	43.2	110.8	30.7	122.7	53.2	117.2	66.9	76.5	17.6	68.2	12.7	90.1	37.7	69.7	19.9
TMT B-A	37.4	33.3	35.2	21.3	30.6	32.1	28.9	45.6	13.3	16.4	14.7	11.3	25.5	34.1	0.9	0.2
MST (PART A)	14.3	2.4	14.1	2.0	16.4	3.8	16.5	3.9	13.8	2.7	12.0	2.2	12.2	2.4	11.1	0.3
MST (PART B)	24.9	6.1	23.5	4.3	28.0	6.0	26.2	5.8	18.5	3.2	16.3	3.9	17.4	3.2	15.8	2.7
MST (PART B - PART A)	10.6	5.0	9.4	3.3	11.6	2.8	9.7	2.8	4.8	2.2	4.3	2.6	5.2	2.1	4.7	2.2
Span (forward)	6.6	1.4	6.5	1.1	6.3	1.3	6.0	2.1	6.5	1.0	6.8	1.2	6.5	1.1	6.5	1.4
Span (backward)	5.0	1.3	5.4	0.9	5.4	1.4	5.4	1.4	4.7	1.0	5.9	1.6	5.6	1.6	5.5	1.2
Tapping Span (forward)	6.0	1.3	5.7	1.1	6.3	1.3	6.0	1.2	6.9	1.2	6.9	1.2	7.3	1.0	7.3	0.8
Tapping Span (backward)	5.9	1.6	6.0	1.5	5.7	1.2	5.8	0.7	6.0	0.7	6.4	0.7	5.9	1.2	6.8	0.4
Visual Cancellation	95.4	4.8	95.4	3.3	97.6	3.7	97.1	3.6	87.2	14.4	79.1	8.3	86.0	18.3	99.6	0.8
SDMT	54.5	8.8	59.5	9.4	48.1	9.4	50.9	10.0	67.3	11.5	75.2	12.7	61.7	7.8	65.6	6.9

TMT = Trail Making Test, MST = Modified Stroop Test, SDMT = Symbol Digit Modalities Test, TMT-A, TMT-B, MST (PART A), MST (PART B) = Completion time (seconds). Span (forward), Span (backward), Tapping Span (forward), Tapping Span (backward) = Number of digit correctly recalled. Visual Cancellation = Accuracy (%). SDMT = Achievement rate (number of correct answers / 110) (%).

Table 4. Results of repeated measures ANOVA (Group × Time)

	Old						Young					
	Main effects			Interaction effects			Main effects			Interaction effects		
	F	*p*		*F*	*p*		*F*	*p*		*F*	*p*	
TMT-A	4.116	0.058		1.133	0.302		4.426	0.050		3.097	0.095	
TMT-B	2.152	0.161		0.429	0.521		10.417	0.005	**	1.838	0.192	
TMT B-A	0.082	0.778		0.001	0.973		2.752	0.114		3.700	0.070	
MST (PART A)	0.011	0.916		0.233	0.635		12.048	0.003	**	0.569	0.460	
MST (PART B)	3.001	0.101		0.039	0.847		14.284	0.001	**	0.348	0.563	
MST (PART B - PART A)	2.379	0.141		0.112	0.742		0.699	0.414		0.000	0.984	
Span (forward)	0.562	0.464		0.163	0.691		0.503	0.487		0.503	0.487	
Span (backward)	0.454	0.510		0.454	0.510		3.351	0.084		4.680	0.044	*
Tapping Span (forward)	2.669	0.121		0.007	0.932		0.000	1.000		0.000	1.000	
Tapping Span (backward)	0.113	0.741		0.000	0.986		6.528	0.020	*	0.966	0.339	
Visual Cancellation	0.081	0.779		0.169	0.686		0.378	0.081		0.783	0.169	
SDMT	91.317	<0.001	**	7.028	0.017	*	38.980	<0.001	**	4.465	0.049	*

Results of main and interaction effects evaluating whether post-training neuropsychological test results differ between control and training groups (in each age range). * $p < 0.05$, ** $p < 0.01$, TMT = Trail Making Test, MST = Modified Stroop Test, SDMT = Symbol Digit Modalities Test.

1) Older adults

The results of the repeated measures ANOVA (Table 4) to assess the effectiveness of the attention training showed a significant main effect of Time [$F(1, 17) = 91.317$, $p < 0.001$] in SDMT, with an improvement in SDMT scores from pre-to post-training in both the training and control groups. Notably, there was a significant interaction of Time × Group ($F(1, 17) = 7.028$, $p = 0.017$), with the training group showing significantly greater improvement in scores than the control group (Fig 1).

2) Younger adults

There was a significant main effect of Time [$F(1,18) = 38.980$; $p < 0.001$] in SDMT, and both control and training groups showed significant score improvements. As with the older adults, there was a significant interaction effect of Time × Group ($F(1, 18) = 4.465$, $p = 0.049$), with the training group scoring significantly better than the control group. Although there was no significant main effect on the Span (backward) results, there was a significant interaction effect of Time × Group ($F(1, 18) = 4.680$, $p = 0.044$), indicating greater performance improvement in the training group than in the control group (Fig 1).

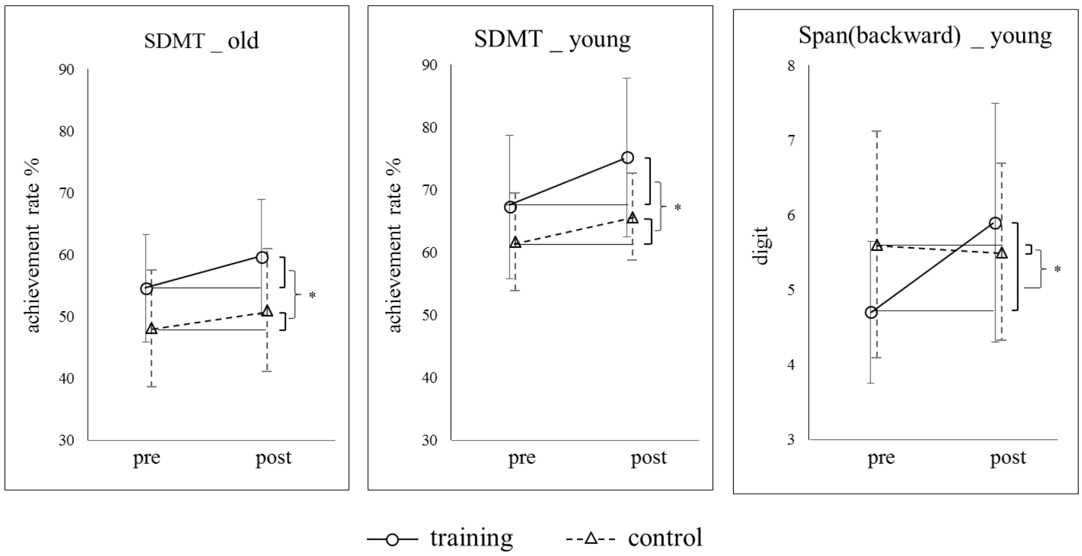

Fig 1. The neuropsychological tests that showed training-induced changes
(pre = pre-training, post = post-training) * $p < 0.05$

Effects of training on age

Table 5 reports the main effects and the interaction effects of the Age × Time analysis using repeated-measures ANOVA.

1) Training group

The results of a repeated-measures ANOVA (Table 5) assessing the effect of attention training on age showed a main effect of time, as the SDMT scores improved from pre-to post-training for both age ranges [$F(1, 18) = 130.935$, $p < 0.001$], and interaction of time and age ($F(1, 18) = 6.649$, $p = 0.019$) was found (Fig 2). These results showed that the improvement in SDMT scores after training was greater among younger adults than older adults.

2) Control group

There were no significant interactions.

Table 5. Results of repeated measures ANOVA (Age × Time)

	Training						Control					
	Main effects			Interaction effects			Main effects			Interaction effects		
	F	*p*		*F*	*p*		*F*	*p*		*F*	*p*	
TMT-A	9.859	0.006	**	0.133	0.720		0.604	0.448		0.241	0.630	
TMT-B	3.802	0.067		0.277	0.605		5.515	0.031	*	1.807	0.197	
TMT B-A	0.006	0.940		0.149	0.704		2.070	0.168		1.460	0.244	
MST (PART A)	6.420	0.021	*	4.141	0.057		1.894	0.187		2.927	0.105	
MST (PART B)	3.956	0.062		0.201	0.660		14.584	0.001	**	0.026	0.875	
MST (PART B - PART A)	0.709	0.411		0.136	0.717		5.370	0.033	*	1.815	0.196	
Span (forward)	0.327	0.574		1.309	0.268		0.280	0.604		0.280	0.604	
Span (backward)	7.200	0.015	*	1.800	0.196		0.028	0.869		0.028	0.869	
Tapping Span (forward)	0.574	0.458		0.574	0.458		0.746	0.400		0.746	0.400	
Tapping Span (backward)	0.719	0.408		0.259	0.617		3.461	0.080		2.107	0.165	
Visual Cancellation	0.022	0.884		0.000	1.000		0.055	0.818		1.685	0.212	
SDMT	130.935	<0.001	**	6.649	0.019	*	13.953	0.002	**	0.359	0.557	

Results of main and interaction effects evaluating whether the results of pre and post-training neuropsychological tests differ across age range (in each group). * $p < 0.05$, ** $p < 0.01$, TMT = Trail Making Test, MST = Modified Stroop Test, SDMT = Symbol Digit Modalities Test.

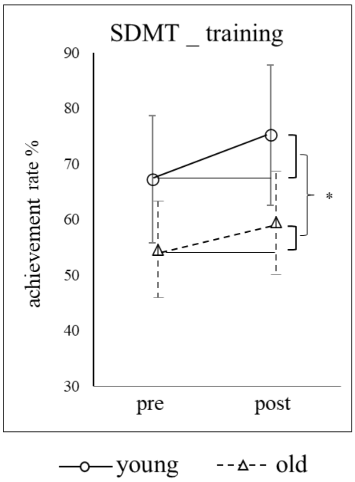

Fig 2. The neuropsychological tests in which the rate of change due to training differed between older and younger adults (pre = pre-training, post = post-training) * $p < 0.05$

Discussion

We conducted multicomponent attention training in healthy adults to investigate 1) changes in cognitive function due to training in each age range and 2) whether the training effects, if any, differed between younger and older adults. Our main finding was that SDMT, an assessment of processing speed, significantly improved for both age range in the training group. This finding indicates that multicomponent attention training may improve processing speed, located higher than attention in cognitive hierarchy[26)]. Because our training is based on APT, this finding is also consistent with the hypothesis that APT improves attention and enhances upper-level cognitive function[30,32)]. We speculate that multicomponent attention training improved each component, and thus the SAS worked adequately. The SAS monitors novel situations that cannot be resolved by a well-learned schema and prevents error or routine responses[27)]. Enhanced attention allows the SAS to manage and process information appropriately and may increase processing speed, which ranks higher than attention in the cognitive hierarchy. The finding also suggests that a transfer effect may have occurred. One of the criteria for the effectiveness of cognitive training is whether we found the transfer of training effects on different tasks within the same cognitive domain (near transfer) or other domains (far transfer)[49-51)]. SDMT primarily assesses processing speed. However, it also assesses elements of selective and divided attention[52)]. Because the attention elements were shared between the attention training and SDMT in this study, our finding indicates that near transfer may have occurred and improved the SDMT performance.

It is also noteworthy that the improvement in cognitive function was observed not only in older adults but also in younger adults. For effective cognitive training, it is essential to provide training tasks adjusted to each subject's appropriate cognitive function level[30,53)]; cognitive training suitable for older adults may be easy for younger adults and not effective for them. The attention training used in this study provided a variety of attention tasks organized so that each session was sequential from easy to difficult tasks, and we also demanded shorter task performance time. The intervention included not only easy tasks in each session but also difficult tasks for younger adults. Additionally, we expected that tasks that were easy for participants would be more difficult when performed quickly and accurately. Thus, attention training may have improved cognitive function in younger as well as older adults, as each session had tasks appropriate for both age ranges.

This central finding should take into account individual differences that affect training effects. SDMT, at pre-assessment in this study, tended to be higher in the training group than in the control group in both age ranges (Fig. 1), although this difference was not statistically significant. Our finding of greater cognitive plasticity with higher performance at the pretest is inconsistent with a study reporting that lower performance at the pretest was associated with greater training gains and greater transfer effects[54)]. However, performance at pretest and cognitive plasticity has been shown to be independent, and the impact of differences in pre-assessment on training effectiveness is not well understood. Therefore, to solve this issue, the sample size should be increased, and random sampling should be used to reduce the difference in prior ratings between the training and control groups.

Another finding is that the magnitude of the improvement in SDMT was more significant for the younger than older adults (Fig. 2). This result is consistent with the hypothesis that older adults preserve cognitive plasticity but are less marked than younger adults[53)]. It is speculated that the negative influence of age reduced cognitive plasticity, causing older adults to reach the performance limit earlier than younger adults[55)], leading to the age difference in training gains.

There were no significant differences in neuropsychological tests except for SDMT and span (backward). As the Cancellation task was an evaluation for patients with attention disorders, which is an easy evaluation for healthy adults, a ceiling effect may have occurred. TMT, MST, and Digit span require executive function and memory. Since the training did not practice these cognitive functions, it may not have led to an improvement in untrained cognitive functions (far transfer). It is noteworthy that span (backward), an assessment of auditory memory, showed improvement in the younger adults but not older adults. PASAT, the only auditory task in training, may be too difficult for older adults to improve their auditory memory. This result reaffirms the importance of providing training tasks that are appropriate to the level of cognitive function.

We are able to draw meaningful implications from these findings. The multicomponent attention training may lead to improvement in processing speed in healthy older adults. The goal of aging research is to improve the daily living abilities of older adults. As processing speed is correlated with efficient execution of daily life activities[56)], the improvement of processing speed by attention training in this study may lead to an improvement in activities of daily living.

Limitations

There are some limitations to this study. First, the small sample size and the short training period may have resulted in localized changes due to training effects. Next, the assignment of participants to the training and the control groups was not randomized; instead, the participants were assigned in the order of application. Last, although the current study focused on each component of attention, it was not possible to assess which training was effective, selective attention training or multicomponent attention training. Therefore, we believe that further research should examine which attention training is more effective in a larger randomized sample and for a more extended training period.

Conclusion

The present study shows that multicomponent attention training improves processing speed in both older and younger healthy adults. This result suggests that the intervention can improve attention and promote the ability to manage and process information appropriately.

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