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Effects of a High-Intensity Interval Physical Exercise Program on Cognition, Physical Performance, and Electroencephalogram Patterns in Korean Elderly People: A Pilot Study

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ABSTRACT

Background and Purpose: The effects of high-intensity interval training (HIIT) interventions on functional brain changes in older adults remain unclear. This preliminary study aimed to explore the effect of physical exercise intervention (PEI), including HIIT, on cognitive function, physical performance, and electroencephalogram patterns in Korean elderly people.
Methods: We enrolled six non-dementia participants aged >65 years from a community health center. PEI was conducted at the community health center for 4 weeks, three times/week, and 50 min/day. PEI, including HIIT, involved aerobic exercise, resistance training (muscle strength), flexibility, and balance. Wilcoxon signed rank test was used for data analysis.
Results: After the PEI, there was improvement in the 30-second sit-to-stand test result (16.2±7.0 times vs. 24.8±5.5 times, p=0.027), 2-minute stationary march result (98.3±27.2 times vs. 143.7±36.9 times, p=0.027), T-wall response time (104.2±55.8 seconds vs.71.0±19.4 seconds, p=0.028), memory score (89.6±21.6 vs. 111.0±19.1, p=0.028), executive function score (33.3±5.3 vs. 37.0±5.1, p=0.046), and total Literacy Independent Cognitive Assessment score (214.6±30.6 vs. 241.6±22.8, p=0.028). Electroencephalography demonstrated that the beta power in the frontal region was increased, while the theta power in the temporal region was decreased (all p<0.05).
Conclusions: Our HIIT PEI program effectively improved cognitive function, physical fitness, and electroencephalographic markers in elderly individuals; thus, it could be beneficial for improving functional brain activity in this population.

Keywords: High-intensity Interval Training; Physical Fitness; Cognition; Electroencephalogram; Aging

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INTRODUCTION

Physical exercise is an important lifestyle intervention that counteracts the effects of cognitive aging.[17] A systematic review that assessed the relationship between various exercise dose measures and cognitive performance in older adults with and without cognitive impairment showed that performing exercise for at least 52 hours improves global cognition, attention, processing speed, and executive function.[8] In addition, there is supporting evidence that aerobic exercise, resistance (strength) training, mind–body exercises, or combinations of these interventions counteracts the effects on cognitive aging. However, a recent narrative review proposed a routine exercise regimen including all forms of exercise for both physical and cognitive health in advanced age, taking into consideration the fact that different mechanisms of neuroplasticity are involved in each mode of exercise.[9]

Additionally, intensity is an important exercise dose measure that should be included in practical prescribing guidelines for physical exercise to promote cognitive brain health. Exercise intensity is frequently measured using oxygen uptake (VO_2), heart rate (HR), or heart rate reserve (HRR). High intensity is classified into vigorous effort (60%–79% of peak VO_2, 70%–89% of peak HR, and 60%–84% of HRR) or arduous effort (≥80% of peak VO_2, ≥90% of peak HR, and ≥85% of HRR).[10-12] Moderate-intensity continuous training (MICT) regimens have been used in the majority of exercise intervention research studies, as reported by Sáez de Asteasu et al.[13] However, high-intensity interval training (HIIT) is more effective than MICT in improving cardiorespiratory fitness and vascular function in older adults.[14,15] Considering that the higher the intensity of exercise, the greater the release of growth factors (e.g., brain-derived neurotrophic factor),[16] HIIT can be expected to have prevalent impact on cognition, in comparison with moderate-intensity exercise in the elderly. Besides, HIIT is known to be safe for healthy older adults. Further, HIIT is preferred over MICT by healthy older adults.[17,18]

Only a few studies have indicated a significant impact of HIIT on cognition.[19-21] Fiorelli et al.[20] demonstrated that HIIT improved both attention and auditory memory, while MICT improved only auditory memory. Hoffmann et al.[21] also reported that HIIT decreased the severity of neuropsychiatric symptoms and enhanced the frontal lobe function task. However, the effects of HIIT interventions on functional brain changes in older adults remain unclear. Further, to date, none of the trials have included electroencephalographic markers. Therefore, this study aimed to evaluate the effect of a 4-week structured multimodal physical exercise intervention (PEI) program, including HIIT, on physical fitness, cognitive function, and electroencephalographic markers in older people in South Korea.

MATERIALS AND METHODS

Ethics statements
The study was approved by the Ajou University Hospital Institutional Review Board (approval number: AJIRB-MED-OBS-20-131). All potential participants gave written informed consent prior to enrollment in the study.

Study design and participants
This pilot study recruited individuals aged >65 years from a community health center in Dongtan, Gyeonggi-do, South Korea to participate in the 4-week PEI program. Only

individuals without dementia were eligible for inclusion in the study. The exclusion criteria were as follows: 1) a confirmed psychiatric diagnosis (e.g., major depressive disorder); 2) other neurodegenerative diseases (e.g., Parkinson's disease); 3) severe or unstable symptomatic cardiovascular disease; 4) a diagnosis of incurable malignancy within the previous 5 years; 5) angioplasty or a stent procedure within the previous year; 6) a z-score <−1.5 on the Korean version of the Mini-Mental State Examination (K-MMSE)[22]; 7) any other evidence of a severe or unstable physical condition; 8) severe visual or hearing loss or communication impairment beyond which validation of the intervention could not be performed; 9) illiteracy; 10) inability to participate thoroughly and safely in the research based on the investigators' opinion; and 11) enrollment in other interventional studies.

PEI protocols

The PEI program was conducted at the community health center for 4 weeks, three times/week, and 50 minutes/session. It was a multicomponent, structured program that consisted of aerobic exercise, resistance training, flexibility, and postural balance. Exercise movements were based on the pre-existing Korean physical exercise program developed for the Korean multidomain lifestyle intervention called the SoUth Korean study to PrEvent cognitive impaiRment and protect BRAIN health through lifestyle intervention in at-risk elderly people (SUPERBRAIN).[7] In this study, the PEI for SUPERBRAIN was revised to include HIIT. The current PEI was conducted in a group using floor plates on which numbers (0–9) were drawn, elastic bands, immobile chairs, and rope ladders. Two trained exercise experts guided the participants—one expert gave an order in front of the group and demonstrated the movement, while the other moved between participants, corrected movements, and assessed safety. During the PEI, participants were equipped with an HR belt (Zephyr™ HxM BT device; Zephyr Technology Corporation, Annapolis, MD, USA) mounted on their chest, so that each participant's real-time HR was monitored and displayed on a big screen that could be viewed by the participants.

Each 50-minute PEI session was organized into the following three parts: a 15-minute warm-up, the main part of the session of 23 minutes that included HIIT, and then a 12-minute warm-down exercise. During warm-up, aerobic exercises were performed, including exercise movements called number walking,[7] which included walking on a numeric floor mat according to the exercise professional's command, and music walking,[7] which comprised walking to the tempo of one popular Korean song with 150 beats/min for 3 minutes and 30 seconds. The main part of the PEI consisted of resistance exercise (RE), aerobic exercise called the ladder drill (LD), and step exercise (SE). Participants were encouraged to maintain their HR at a 75% higher value than their resting HR. RE and LD were performed in three sets each and alternately in each set. RE was performed for a total of 3 minutes per set, which included 2.5 minutes of a high-intensity workout and 0.5 minutes of recovery. LD was performed for a total of 3 minutes per set, i.e., 1.5 minutes each of a high-intensity workout and recovery. SE was a one-set exercise, in which participants went up and down the step platform as quickly as possible for 2 minutes. High-intensity training accounted for 14 minutes of the total 23 minutes of the main part of the exercise. The warm-down exercise comprised stretching exercises. The protocol and flow of the PEI are shown in **Fig. 1**.

Physical performance, cognitive function, and safety assessment

Before and after the 4-week PEI, three physical items (height, weight, and body mass index), and three physical fitness items (30-second sit-to-stand test for lower extremity strength, 2-minute stationary march for cardiopulmonary endurance, and T-wall test for coordination)
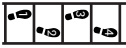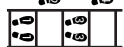
	Program description	%HRmax target	Duration (min)
Warm-up	♦ Number walking ♦ Music walking	57–63	15
Main exercise	**HIIT** - Perform 3 sets of RE (3 min/set) and LD (3 min/set) alternately, then move on to SE. - During the HIIT, take a short BR (30 sec) between RE and LD. RE Set 1 | BR | LD Set 1 | BR | RE Set 2 | BR | LD Set 2 | BR | RE Set 3 | BR | LD Set 3 | BR | SE		HIIT total 23
	♦ **RE** consisted of 3 movements. 1) Whole-body muscle strength with elastic band 　: Deadlift, bent-over row 2) Lower-body muscle strength 　: Squat, side leg raises, toe lifts 3) Upper-body muscle strength with elastic band 　: Chest fly, pulldown, biceps curls, shoulder front raises	64–76	**RE** 3 × 3 sets
	♦ **LD** consisted of 4 movements. 1) One-step 2) Two-step 3) Side-step 4) In-out-step	77–95	**LD** 3 × 3 sets
	♦ **SE** 　: Go up and down the 'step platform' as quickly as possible	>96	**SE** 2
Warm-down	Stretching	<57	12

Fig. 1. Protocol and flow of the 4-week PEI course.
PEI: physical exercise intervention, HIIT: high-intensity interval training, RE: resistance exercise, LD: ladder drill, SE: step exercise, BR: break.

were assessed. The 30-second sit-to-stand test and 2-minute stationary march are components of the physical fitness test battery for the Korean elderly in the Korean National Physical Performance Evaluation Program, which was devised by the National Project of the Ministry of Cultures, Sports, and Tourism of Korea.[23,24] The T-wall, the ultimate Exergame product, which incorporates movement, fitness, and reaction, was performed using TWALL-16-FIX (Motion Fitness LLC; Elk Grove Village, IL, USA). The T-wall test involved a special touch sensor to measure the reaction time across a surface. The light-emitting diode signals to the button to touch in a random sequence and speed. The participants were instructed to act and react as quickly as possible to turn the light off. As soon as they hit a button, another light turned on. The time taken for each individual to turn off a total of 100 lights and the number of mistakes made were recorded.[25] Cognitive function was evaluated before and after the 4-week PEI using the K-MMSE[22] and Literacy Independent Cognitive Assessment (LICA).[26] The safety of the PEI was monitored during the supervised sessions.

Electroencephalogram acquisition and analyses

Resting-state electroencephalography (EEG) was conducted before and after the PEI. EEG analysis included a condition with eyes closed for 3 minutes, and for data analysis, the following 19-channel referential montages were used: FP1, FP2, F7, F3, Fz, F4, F8, T3, C3, Cz, C4, T4, T5, P3, Pz, P4, T6, O1, and O2. For preprocessing, the EEG data were high-pass filtered offline above 1 Hz, low-pass filtered below 45 Hz, and recomputed to the common average reference. Artifacts were eliminated by visual inspection and advanced mixture independent component analysis (amICA).[27] After removing the artifacts from EEG signals, sensor-level analysis using EEGLAB-based spectopo function was performed on the following 8 spectral bands.: delta (1–4 Hz), theta (4–8 Hz), alpha 1 (8–10 Hz), alpha 2 (10–12 Hz), beta 1 (12–15 Hz), beta 2 (15–20 Hz), beta 3 (20–30 Hz), and gamma (30–45 Hz). All preprocessing steps, denoising using amICA, and extraction of sensor level features were completed using iSyncBrain® (iMediSync, Inc., Seoul, Korea; http://isyncbrain.com). The EEG band power was presented in a topographic map plotted with the built-in sLORETA function in iSyncBrain software (version 2.1).[28]

Statistical analysis

The clinicodemographic characteristics of participants were described using descriptive statistics. Continuous variables were presented as the mean±standard deviation. Changes in physical performance and cognitive function after the PEI were confirmed using the Wilcoxon signed rank test. EEG power spectra were examined by the paired t-test for comparisons between baseline and post-intervention iSyncBrain® results (iMediSync, Inc.).

Statistical analyses were performed using SPSS 26.0 (IBM Corp., Armonk, NY, USA). A p-value <0.05 was considered statistically significant.

RESULTS

In total, six individuals with a mean age of 77.0±4.7 years were enrolled. They had no prior complaint of cognitive impairment and had never undergone evaluation of cognitive function previously. There were 2 female participants, and the mean years of education of all participants was 14.3±6.0 years. Four participants had underlying diseases, such as diabetes mellitus and hypertension, but none of the participants had a history of taking medications related to cognitive function, including choline alfoscerate. The mean K-MMSE score at baseline was 25.7±2.3. All six participants completed the 12 PEI sessions, and achieved the targeted maximum HR percentage and HRR during the main part of the PEI (**Table 1**). There were no safety issues associated with the PEI program during the study period.

After the 4-week PEI, there were improvements in the physical fitness variables of the 30-second sit-to-stand test (16.2±7.0 times vs. 24.8±5.5 times, p=0.027), 2-minute stationary march (98.3±27.2 times vs. 143.7±36.9 times, p=0.027), and T-wall response time (104.2±55.8 seconds vs. 71.0±19.4 seconds, p=0.028). There were also improvements in the cognitive function variables, including the memory domain score (89.6±21.6 vs. 111.0±19.1, p=0.028), executive function domain score (33.3±5.3 vs. 37.0±5.1, p=0.046), and total score (214.6±30.6 vs. 241.6±22.8, p=0.028) in LICA (**Table 2**).

The EEG patterns were also improved after the PEI, as compared to those before the PEI. The beta power in the frontal region was significantly increased, while the theta power in the temporal region was significantly decreased (all p<0.05; **Fig. 2**).

Table 1. Participants' clinicodemographic characteristics

Variable	Participant 1	Participant 2	Participant 3	Participant 4	Participant 5	Participant 6
Age (yr)	73	82	81	77	79	70
Sex	Male	Male	Male	Female	Female	Male
Education (yr)	6	24	16	16	12	12
Underlying diseases	BPH	DM, HTN, L-HNP	-	DM, HTN, Dyslipidemia	-	HTN, BPH
BMI (kg/m²)	17.3	22.2	22.7	26.9	20.3	29.2
Clinical status	NC	NC	NC	MCI	MCI	MCI
K-MMSE score	29	28	25	23	25	24
Baseline HR (per 1 min, beats/min)	91	77	89	74	87	90
Average %HRmax during HIIT sessions	85.7±7.1	81.1±3.4	90.1±5.3	68.9±0.9	78.9±3.5	77.9±1.6
HRR reached	≥80%	≥90%	≥90%	≥90%	≥90%	≥90%

BPH: benign prostate hyperplasia, DM: diabetes mellitus, HTN: hypertension, L-HNP: lumbar-herniated nucleus pulposus, BMI: body mass index, NC: normal cognition, MCI: mild cognitive impairment, K-MMSE: Korean version of the Mini-Mental State Examination, HR: heart rate, %HRmax: maximum heart rate percentage, HRR: heart rate reserve.

Table 2. Changes in physical fitness and cognitive function after the 4-week PEI

Variable	Before the 4-week PEI	After the 4-week PEI	p-value
Physical performance			
30-sec sit-to-stand (times)	16.2±7.0	24.8±5.5	0.027
2-min stationary march (times)	98.3±27.2	143.7±36.9	0.027
T-wall, response time (seconds)	104.2±55.8	71.0±19.4	0.028
T-wall, correct response (times)	84.2±5.0	83.5±3.9	0.833
Cognition			
K-MMSE score	25.7±2.3	27.3±1.8	0.068
LICA, total	214.6±30.6	241.6±22.8	0.028
LICA, attention	9.0±2.4	9.2±1.8	1.000
LICA, memory	89.6±21.6	111.0±19.1	0.028
LICA, visuospatial function	29.0±1.2	30.0±0.0	0.102
LICA, language	42.0±2.8	42.7±2.4	0.673
LICA, executive function	33.3±5.3	37.0±5.1	0.046
LICA, calculation	11.7±0.4	11.8±0.3	0.414

Variables are shown as the mean±standard deviation.
PEI: physical exercise intervention, K-MMSE: Korean version of Mini-Mental State Examination, LICA: Literacy Independent Cognitive Assessment.

DISCUSSION

Our 4-week structured, multimodal PEI program, which included HIIT, was safe for older people. Importantly, the PEI program improved the electroencephalographic markers, physical fitness, and cognitive function of the elderly participants without dementia. We previously reported the feasibility and efficacy of structured and multimodal MICT for enhancing physical fitness and cognitive function in the Korean elderly without dementia.[7] However, considering that total hours, rather than exercise dose measures (i.e., the session duration, weekly minutes, frequency, or total weeks), were significantly correlated with improvements in cognition, the most important component to be considered for a practical exercise regimen was keeping the elderly interested in exercise for as long as possible. Thus, in this preliminary study, we revised our original PEI to include HIIT, which was also feasible and effective in the Korean elderly people.

HIIT consists of high-intensity exercise interspersed with active/passive recovery periods. A commonly used HIIT protocol is 4 intervals of 4 minutes (4×4 HIIT) at 85%–95% of maximum or peak heart rate (HRmax/peak), interspersed with 3 minutes of active recovery at 60%–70% HRmax/peak, 3 times per week for 12–16 weeks. The total duration of an HIIT session should be approximately 30–60 minutes, including warm-up and warm-down

[Topomap (Abs. power)–Theta band]

Unit: μV²
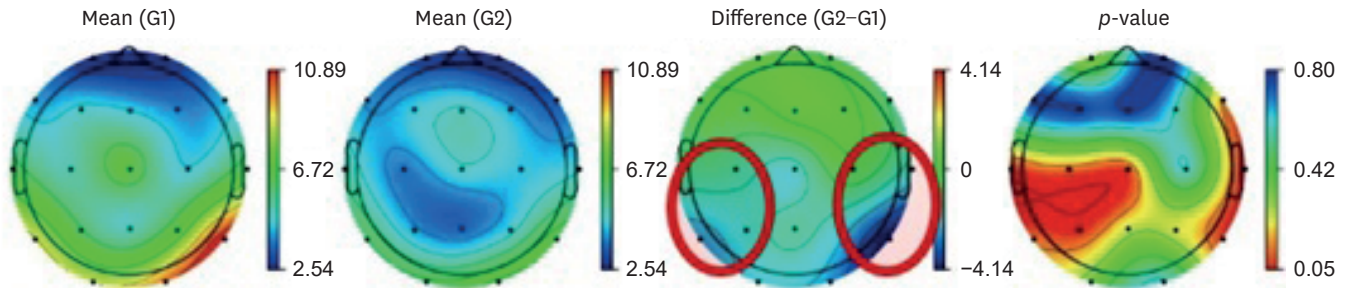
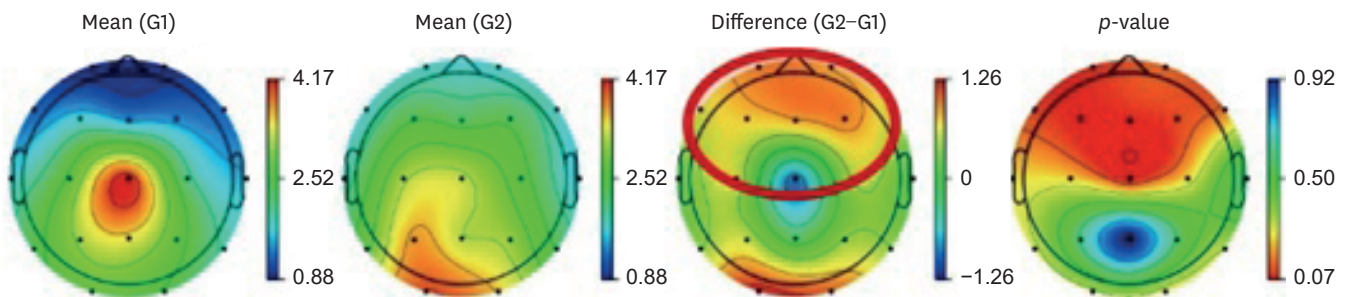[Topomap (Abs. power)–Beta1 band]

Fig. 2. Level of absolute power at theta and beta frequency bands at baseline (G1) and post-intervention (G2). The beta power in the frontal region is significantly increased, while the theta power in the temporal region is significantly decreased (all $p<0.05$).

exercises.[29,30] However, HIIT protocols vary in design and may differ with respect to the number of repetitions, interval duration, intensity, and recovery time between interval bouts, thus allowing for different training goals and fitness levels. Previous studies have suggested a range of workouts and recovery from 15 seconds up to 2–3 minutes for each interval, depending on the workout-to-recovery ratio used. The duration of exercise varied from 3 weeks to 24 weeks in other studies that specifically targeted adults with declined cognition. In addition, it is unclear whether the appropriate HIIT protocol differs by age. Although our PEI program that included HIIT was conducted for only 4 weeks and included 23 minutes of HIIT per session, it was beneficial for improving cognition, physical performance, and electroencephalogram patterns. Therefore, further study is needed to confirm the HIIT protocol that could be beneficial for cognition in elderly people.

Our study is significant as it showed beneficial electroencephalographic changes in elderly patients after they performed the PEI program that included HIIT. Although task-specific electroencephalographic changes at the moment of performing specific cognitive domain tasks have been studied in young adult men after HIIT,[31,32] the post-interventional resting-state electroencephalographic effect of HIIT has not been elucidated. In general, resting EEG findings change with aging, with gradual alteration in the spectral power profile. This indicates global slowing of background EEG, a significant decrease in the alpha amplitude, and increase in power and topographic location in the slower frequency ranges, delta, and theta,[33,34] which has also been observed in Alzheimer's disease (AD) patients.[35-37] Our electroencephalographic analyses revealed that after the PEI, the beta power in the frontal region was increased, while the theta power in the temporal region was decreased, which is in contrast to the EEG changes that occur during normal aging and AD. This suggests

that our PEI program, which included HIIT, can induce neurophysiological changes that counteract aging and neurodegeneration related to AD. In our study, improvements in memory, executive function, and physical performance, including the T-wall response time after HIIT, which has also been reported in previous HIIT studies,[38] matched well with EEG changes in the temporal and frontal areas.

There are some limitations to our study. First, the sample size was small as this was a preliminary study; hence, the results should be interpreted with caution. Second, further confirmatory research is required and it should include a control group. Third, there is a concern about the learning effect because the interval between baseline and post-intervention LICA was short. Thus, in the future study, it is necessary to adopt a cognitive evaluation tool with minimal concern regarding the learning effect or increase the interval. Finally, in the further study, it would be meaningful to plan a long-term evaluation to confirm the persistent effect after termination of the intervention.

In conclusion, our HIIT PEI program effectively improved cognitive function, physical fitness, and electroencephalographic markers in elderly individuals; thus, it could be beneficial for improving functional brain activity in this population.

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