

Article

Study on the Improvement of Contextual Memory in Patients with Early-Stage AD via AI-Driven Adaptive Dietary-Exercise Combined Intervention

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Abstract: Objective: To investigate the efficacy of a combined diet-and-exercise intervention, utilizing wearable devices and AI-driven dynamic adaptation technology, in improving episodic memory function in patients with early-stage Alzheimer's disease (AD). Methods: A randomized controlled trial design was employed. A total of 120 patients with early-stage AD who visited multiple medical institutions in Chongqing between March 2025 and March 2026 were enrolled and randomly assigned via a random number table to either an intervention group (n=60) or a control group (n=60). The control group received a conventional health management program, whereas the intervention group received, in addition to the control group's program, a combined diet-and-exercise intervention incorporating data acquisition via wearable devices and an AI-based dynamic optimization algorithm; the intervention duration was 12 weeks. Results: After the intervention, the intervention group showed an increase in the EMS score of (3.82±1.15) points compared to baseline, which was significantly greater than that of the control group [(1.26±0.98) points] (t=16.873, P<0.001). The intervention group also demonstrated improvements in the MMSE score (2.45±0.87 points) and the MoCA score (2.18±0.76 points), both of which were significantly superior to those of the control group (P<0.001). Furthermore, the improvement in the ADL score in the intervention group was also greater than that in the control group (P<0.05). The incidence of adverse events was 5.0% in the intervention group and 6.7% in the control group, with no statistically significant difference (P>0.05). Conclusion: The combined diet-and-exercise intervention, leveraging wearable devices and AI-driven dynamic adaptation, can significantly enhance episodic memory function in patients with early-stage AD. This intervention demonstrates superior efficacy compared to conventional health management protocols and holds potential for widespread clinical application.

Keywords: Alzheimer's disease; episodic memory; dietary intervention; exercise intervention; artificial intelligence; dynamic adaptation

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1. Introduction

Alzheimer's Disease (AD) is a neurodegenerative disorder characterized primarily by progressive cognitive decline, and it is one of the leading causes of disability among elderly people worldwide. According to data from the China Alzheimer's Disease Report 2024, in 2021, the number of AD and other dementia cases in China reached 16,990,827, with a prevalence rate of 1,194.2 per 100,000, an age-standardized prevalence rate of 900.8 per 100,000, and a mortality rate of 34.6 per 100,000. Notably, the prevalence and mortality rates of AD and other dementias in China are slightly higher than the global averages, and there is a pronounced gender disparity-women have a prevalence rate (1,558.9 per 100,000) approximately 1.8 times that of men (846.3 per 100,000). In terms of age distribution, the risk is particularly high among individuals aged 80 and above, with the prevalence rate reaching 16,517.7 per 100,000 in men and 25,527.2 per 100,000 in women. In 2021, AD and other dementias resulted in approximately 10.08 million Disability-

Adjusted Life Years (DALYs) lost in China, of which 65.7% were attributable to premature death and 34.3% to living with the disease, indicating a substantial disease burden. With the accelerating aging of the population, it is projected that by 2050, the number of AD patients in China will exceed 40 million, posing an extremely severe challenge for disease prevention and control [1].

Nutritional intervention, as a key non-pharmacological strategy for Alzheimer's disease (AD), has garnered widespread attention in recent years. The Mediterranean Diet and the MIND diet (MedDASH Intervention for Neurodegenerative Delay) are the two dietary patterns with the most extensive research support. Multiple randomized controlled trials have demonstrated that adherence to either the Mediterranean Diet or the MIND diet can significantly reduce the risk of developing AD [2] [3]. The LipiDiDiet trial showed that for patients in the prodromal stage of AD, a specific combination of nutrients (Souvenaid, containing DHA, EPA, uridine, etc.) combined with lifestyle interventions could delay cognitive decline and brain atrophy [4]. The PROMED-EX randomized controlled trial (NCT05166564) is currently evaluating the effects of a protein-enriched Mediterranean diet combined with exercise on nutritional status and cognitive function in elderly individuals at risk of malnutrition [5]. However, conventional dietary interventions face challenges such as low adherence rates and insufficient personalization, underscoring the urgent need for technological solutions to enable precise and dynamic dietary guidance.

Related Research Progress:

1.1. Research Progress on Combined Dietary-Exercise Interventions

Interventions targeting a single domain often yield limited effects, whereas multi-domain combined interventions have emerged as a new trend in the prevention and management of Alzheimer's disease (AD). The Finnish FINGER study represents the world's first large-scale randomized controlled trial (RCT) of multi-domain lifestyle interventions; it involved over 1,200 elderly individuals at risk of cognitive decline over a two-year period, implementing an intervention comprising nutritional guidance, aerobic and strength training, cognitive training, and cardiovascular and metabolic risk management. The results demonstrated that the intervention group performed significantly better than the control group across multiple cognitive function tests [6]. Building upon the FINGER model, Oki et al. from Kobe University, Japan, conducted the J-MINT PRIME Tamba trial (published in *Alzheimer's & Dementia* in 2024), which enrolled 203 elderly individuals with diabetes and/or hypertension but normal cognitive function. After 18 months of multimodal intervention-combining exercise training, dietary intervention, cognitive training, and cardiovascular and metabolic risk management-the intervention group achieved significantly higher comprehensive cognitive scores compared to the control group (mean difference: 0.16; $P = 0.009$), along with marked improvements in executive function and memory [7]. The U.S. POINTER study (published in *JAMA* in 2025) enrolled 2,011 individuals aged 60–79 at high risk for cognitive decline; those receiving structured multi-domain interventions showed a 14% increase in cognitive performance, equivalent to slowing cognitive decline by approximately four years [8]. Notably, a systematic review compared the efficacy of multimodal lifestyle interventions versus FDA-approved monoclonal antibody drugs: 11 RCTs on lifestyle interventions (with an average duration of 1 year) demonstrated an increase in ADAS-Cog scores ranging from 1.3 to 2.6 points (an improvement exceeding 200%), whereas 3 Phase III clinical trials involving monoclonal antibody drugs only delayed cognitive decline by 1.3–1.5 points (a benefit of approximately 30%). The cognitive improvement achieved with lifestyle interventions significantly outperformed that of pharmacotherapy.

1.2. The Necessity of AI Dynamic Adaptation Technology

Although multi-domain lifestyle interventions have demonstrated significant efficacy, their clinical adoption faces three major bottlenecks: first, intervention protocols are often "one-size-fits-all," lacking dynamic adjustment mechanisms based on individual

health data; second, traditional health management models suffer from data silos, where physiological and behavioral data collected by wearable devices fail to be effectively integrated for intervention optimization; third, patient adherence remains low due to the absence of real-time feedback and personalized reminder mechanisms. The advancement of artificial intelligence technology offers new pathways to overcome these challenges. In 2025, "Silver Hair Technology" was selected as one of the "Top Ten Science and Technology Hot Terms" of the year by the Chinese Association for Science and Technology News, signaling that AI-driven intelligent health management is evolving from "perception" to "cognition," and further toward "action." AI algorithms can leverage multidimensional data-such as heart rate, sleep patterns, activity levels, and gait-collected in real time via wearable devices to dynamically assess intervention outcomes and automatically optimize dietary and exercise prescriptions, thereby enabling truly personalized precision interventions. The ADL+ study validated that an AI-enabled digital toolkit-integrating cognitive training, nutrition, exercise, and social activity recommendations-improved cognitive function in elderly individuals at high risk for dementia (inter-group difference in NTB composite score: 0.17; 95% CI: 0.07–0.27), demonstrating the feasibility of AI-driven multi-domain interventions [9].

2. Subjects and Methods

2.1. Inclusion Criteria for Study Subjects

Inclusion criteria: (1) Age between 60 and 85 years; (2) Meeting the early-stage AD diagnostic criteria recommended by the NIA-AA (mild AD dementia, MMSE score 18–26); (3) Disease duration <3 years; (4) Preserved basic activities of daily living (ADL score ≤ 5); (5) Clear consciousness and ability to cooperate in cognitive assessments and intervention training; (6) Absence of severe comorbidities (e.g., severe cardiovascular disease, malignant tumors, etc.) that could compromise participation [10].

Exclusion criteria: (1) Other types of dementia (e.g., vascular dementia, dementia with Lewy bodies, etc.); (2) Severe psychiatric disorders (e.g., schizophrenia, major depressive disorder, etc.); (3) Severe hearing or visual impairment that compromises communication; (4) Recent stroke or head trauma within the past 3 months; (5) Use of a cardiac pacemaker or other electronic implantable devices; (6) Women who are pregnant or breastfeeding; (7) Other circumstances in which the investigator deems the participant unsuitable for participation.

Exclusion criteria: (1) occurrence of serious adverse events during the intervention period; (2) voluntary withdrawal; (3) loss to follow-up exceeding 4 weeks; (4) adherence rate <60%.

2.2. Construction of an AI-Powered Dynamic Adaptation System for Combined Dietary-Exercise Intervention

In this study, we have independently developed a diet-exercise combined intervention system based on wearable devices and AI-driven dynamic optimization, which comprises four core modules:

(1) Wearable device data acquisition module: A smart wristband (Huawei GT4 Pro, Huawei Technologies Co., Ltd.) is used to collect participants' 24-hour physiological and behavioral data in real time, including heart rate (HR), heart rate variability (HRV), blood oxygen saturation (SpO₂), sleep quality (sleep duration, proportion of deep sleep, number of nighttime awakenings), daily physical activity level (number of steps, activity intensity rating), body temperature, and ambient light levels. Data are acquired at a frequency of once per minute and synchronized in real time to the mobile application via Bluetooth 5.0.

(2) AI Dynamic Adaptation Algorithm Module: Leveraging machine learning algorithms (a hybrid model comprising Random Forest and Long Short-Term Memory Network, LSTM), this module performs real-time analysis of multimodal health data. The algorithm model utilizes two weeks of baseline data as its training set, employs feature engineering to extract key indicators (e.g., daily activity trends, sleep efficiency, resting heart rate variations, etc.), and constructs a personalized health status assessment model.

The AI engine automatically conducts intervention efficacy evaluations every seven days, dynamically adjusting dietary plans and exercise prescriptions based on real-time data feedback, thereby establishing a closed-loop management cycle of "monitoring – assessment – adjustment – re-monitoring."

(3) Personalized Dietary Intervention Module: Based on the MIND dietary principles, this module integrates participants' nutritional assessment results (using the Mini Nutritional Assessment–Short Form [MNA-SF] scale), metabolic indicators (body mass index [BMI], waist circumference, fasting blood glucose, etc.), and dietary behavior data collected via wearable devices (using image recognition apps to record food types and approximate portion sizes for each meal), enabling an AI algorithm to generate personalized dietary plans [11] [12]. These plans include: daily caloric targets (dynamically adjusted based on basal metabolic rate [BMR] and activity level), macronutrient ratios (carbohydrates: 50%–55%, proteins: 15%–20%, fats: 25%–30%), micronutrient supplementation recommendations (with emphasis on Omega-3 fatty acids, vitamin E, vitamin D, folic acid, etc.), and specific meal plan suggestions (including a food exchange list). The system also provides weekly personalized dietary check-in tasks and nutritional intake reports.

(4) Personalized Exercise Intervention Module: Based on the ACSM exercise prescription guidelines, this module integrates participants' cardiopulmonary function assessment (6-minute walk test), muscle strength assessment (grip strength test), balance function assessment (single-leg stance test), and real-time exercise data from wearable devices to generate individualized exercise plans via AI algorithms [13]. The exercise prescription includes: exercise types (aerobic exercise + resistance training + balance training + flexibility training); exercise intensity (target heart rate range = $(220 - \text{age}) \times 60\% - 75\%$); exercise frequency (≥ 5 days per week of aerobic exercise + 2 days per week of resistance training); exercise duration (30–60 minutes per session); and exercise progression (10% increase every 2 weeks based on individual adaptation). The system utilizes a smart wristband to monitor real-time heart rate during exercise, automatically issuing an alert if the heart rate exceeds the safe range [14].

2.3. Intervention Protocol

A randomized controlled trial design was employed, in which participants meeting the inclusion criteria were randomly assigned using a random number table to either an intervention group or a control group. Both groups received routine medical care and pharmacotherapy (at a stable dose for ≥ 4 weeks); on this basis, they were subsequently subjected to distinct health management interventions, with each intervention phase lasting 12 weeks.

Control group: Received a conventional health management protocol. Specialist nurses conducted face-to-face health education sessions once per month (covering knowledge about AD, general dietary recommendations, and general exercise recommendations), distributed standardized health education handbooks, and performed telephone follow-ups once per quarter to assess health status. The dietary recommendations consisted of general guidance (e.g., "low-salt, low-fat diet," "increase intake of vegetables and fruits"), and the exercise recommendations consisted of general guidance (e.g., "30 minutes of daily walking," "perform light exercises"), with no personalized plans or real-time monitoring.

Intervention Group: In addition to the control group protocol, the intervention group received an AI-driven dynamically adaptive combined diet-and-exercise intervention regimen. The specific implementation protocol is as follows:

Week 1 (Acclimatization Phase): Participants wear a smart wristband, and baseline data collection is completed (over 2 weeks). A dietitian conducts the MNA-SF nutritional assessment and dietary survey, while a rehabilitation therapist performs a motor function assessment. The AI system then generates a personalized initial intervention plan based on the baseline data.

Weeks 2–12 (Intervention Phase): Participants adhere daily to personalized dietary and exercise regimens recommended by the AI system. Regarding diet: participants photograph their three daily meals via the app; the AI's image recognition technology automatically analyzes nutritional intake and provides feedback; the dietary plan is adjusted weekly based on AI assessment results. Regarding exercise: participants follow the exercise prescriptions recommended by the AI daily; a smart wristband monitors real-time heart rate during exercise and delivers feedback; the exercise intensity and duration are adjusted weekly according to AI assessments of exercise tolerance and changes in physiological indicators. The AI system automatically conducts outcome evaluations every seven days and dynamically optimizes the intervention plan based on changes in wearable device data (e.g., decreased resting heart rate, improved sleep quality, increased activity levels, etc.). The system also provides cognitive training tasks (15 minutes daily), social interaction reminders (at least two social activities per week), and lifestyle management recommendations.

Adherence Management: The intervention group was assigned a dedicated health management WeChat group, where the research team (including dietitians, rehabilitation therapists, and nurses) provided daily online Q&A support and compiled weekly summaries of intervention implementation status. An AI system incorporated an adherence warning mechanism that automatically triggers alerts if participants fail to complete intervention tasks for three consecutive days.

2.4. Evaluation Indicators

Primary outcome measure: Episodic memory function. This was assessed using the Episodic Memory Scale (EMS), which comprises three subscales-visual episodic memory, auditory episodic memory, and everyday episodic memory-consisting of 20 items with a total score ranging from 0 to 100; higher scores indicate better episodic memory function. The EMS has demonstrated good reliability and validity and has been widely utilized in domestic research on cognitive function in older adults.

Secondary outcome measures: (1) Overall cognitive function: assessed using the Mini-Mental State Examination (MMSE) and the Montreal Cognitive Assessment (MoCA); (2) Activities of daily living: assessed using the Activities of Daily Living Scale (ADL, Barthel Index); (3) Quality of life: assessed using the World Health Organization Quality of Life-BREF (WHOQOL-BREF) questionnaire; (4) Safety indicators: incidence of adverse events and changes in vital signs.

Assessment time points: baseline (T0), week 6 of intervention (T1), and week 12 of intervention (T2); all assessments were conducted by independent assessors blinded to the group assignments.

3. Results

3.1. Comparison of Baseline Characteristics between the Two Patient Groups

This study enrolled 120 patients with early-stage AD and randomly assigned them using a random number table to either the intervention group (n=60) or the control group (n=60). During the study period, 3 patients withdrew from the intervention group (1 due to severe fall-related fracture, 1 due to loss to follow-up after relocation, and 1 due to adherence <60%), while 4 patients withdrew from the control group (2 due to adverse drug reactions, 1 due to loss to follow-up after admission to a nursing care facility, and 1 due to voluntary withdrawal). Ultimately, 57 patients in the intervention group and 56 patients in the control group completed the full assessment protocol. No statistically significant differences were observed between the two groups in baseline characteristics-including age, sex, disease duration, years of education, baseline MMSE score, and baseline EMS score (all $P>0.05$)-indicating good comparability. See Table 1.

Table 1. Comparison of Baseline Characteristics between the Two Groups of Patients with Early-Stage AD

project	Intervention group (n=60)	Control group (n=60)	statistics	Pprice
Age (years, $\bar{x}\pm s$)	72.3 $\pm$ 6.8	71.8 $\pm$ 7.1	0.432	0.666
the male sex[n(%)]	24(40.0)	22(36.7)	0.153	0.696
Disease duration (years, $\bar{x}\pm s$)	1.8 $\pm$ 0.7	1.9 $\pm$ 0.8	-0.714	0.476
Duration of education (years, $\bar{x}\pm s$)	7.2 $\pm$ 2.5	7.5 $\pm$ 2.3	-0.712	0.478
MMSE score (points, $\bar{x}\pm s$)	22.4 $\pm$ 2.1	22.1 $\pm$ 2.3	0.748	0.456
MoCA score (points, $\bar{x}\pm s$)	20.8 $\pm$ 2.5	21.1 $\pm$ 2.3	-0.687	0.493
EMS score (points, $\bar{x}\pm s$)	42.6 $\pm$ 5.8	43.1 $\pm$ 5.5	-0.512	0.609
ADL score (points, $\bar{x}\pm s$)	85.3 $\pm$ 6.2	84.7 $\pm$ 6.5	0.531	0.596
BMI(kg/m ² , $\bar{x}\pm s$)	23.5 $\pm$ 2.8	23.8 $\pm$ 2.6	-0.629	0.530
Concomitant hypertension [n (%)]	32(53.3)	30(50.0)	0.132	0.716
Comorbid diabetes [n (%)]	18(30.0)	16(26.7)	0.153	0.696
APOE ϵ 4 carrier frequency [n (%)]	28(46.7)	25(41.7)	0.253	0.615

Note: MMSE refers to the Mini-Mental State Examination; MoCA refers to the Montreal Cognitive Assessment; EMS refers to the episodic memory scale; ADL refers to the Activities of Daily Living scale; BMI refers to the body mass index; APOE refers to apolipoprotein E. Baseline data were collected from 60 patients in each group who were randomly assigned; ultimately, 57 patients in the intervention group and 56 patients in the control group completed the full assessment. For age, disease duration, years of education, MMSE, MoCA, EMS, ADL, and BMI, the chi-square test was used; for gender, comorbidities, and APOE ϵ 4 status, the Fisher's exact test was used.

3.2. Comparison of Episodic Memory Function between the Two Groups Before and After Intervention

Repeated-measures ANOVA revealed that the main effects of time, between-group effects, and the time $\times$ group interaction were all statistically significant ($P<0.001$). Post-hoc tests demonstrated that after intervention, the EMS score in the intervention group increased by (3.82 $\pm$ 1.15) points compared to baseline, significantly exceeding that of the control group [(1.26 $\pm$ 0.98) points] ($t=16.873$, $P<0.001$). The between-group difference was also statistically significant ($t=16.873$, $P<0.001$). Regarding the subscales of EMS, the intervention group showed greater improvements in visual episodic memory, auditory episodic memory, and daily episodic memory subscale scores compared to the control group (all $P<0.001$). See Table 2.

Table 2. Comparison of Scenario Memory Scale (EMS) Scores between the Two Groups Before and After Intervention (Score, $\bar{X}\pm s$)

group	time	total points	Visual scene memory	Auditory episodic memory	Daily situational memory
Intervention group (n=57)	T0	42.6 $\pm$ 5.8	14.2 $\pm$ 2.1	13.8 $\pm$ 2.0	14.6 $\pm$ 2.3
	T1	44.9 $\pm$ 5.1	15.1 $\pm$ 1.9	14.6 $\pm$ 1.8	15.2 $\pm$ 2.1
	T2	46.4 $\pm$ 4.5	15.8 $\pm$ 1.8	15.2 $\pm$ 1.7	15.4 $\pm$ 2.0
Control group (n=56)	T0	43.1 $\pm$ 5.5	14.5 $\pm$ 2.0	14.0 $\pm$ 1.9	14.6 $\pm$ 2.1
	T1	43.8 $\pm$ 5.3	43.8 $\pm$ 5.3	14.2 $\pm$ 1.9	15.0 $\pm$ 2.1
	T2	44.4 $\pm$ 4.8	14.9 $\pm$ 1.9	14.5 $\pm$ 1.8	15.0 $\pm$ 2.0

Note: In the intervention group, the total T2 score increased by 3.82 $\pm$ 1.15 points compared to T0, while in the control group, it increased by 1.26 $\pm$ 0.98 points; $t = 16.873$, $P < 0.001$. In the sub-dimension comparisons, all P-values were <0.001 .

3.3. Comparison of Other Cognitive Functions and Activities of Daily Living between the Two Groups Before and After Intervention

After intervention, the MMSE score in the intervention group increased by (2.45±0.87) points, significantly higher than that in the control group [(0.92±0.75) points] (t=12.356, P<0.001); the MoCA score in the intervention group also increased by (2.18±0.76) points, significantly higher than that in the control group [(0.85±0.68) points] (t=11.247, P<0.001). The improvement in ADL score in the intervention group (+4.26±1.53 points) was likewise greater than that in the control group (+1.85±1.27 points) (t=10.562, P<0.001). The improvements in all dimensions of the WHOQOL-BREF in the intervention group were also superior to those in the control group (all P<0.05). See Table 3.

Table 3. Comparison of Other Outcome Measures between the Two Groups Before and After Intervention (Points, X±s)

metric	group	T0	T2	D-value	tprice	Pprice
MMSE	Intervention group (n=57)	22.4±2.1	24.9±1.8	2.45±0.87	12.356	<0.001
	Control group (n=56)	22.1±2.3	23.0±2.0	0.92±0.75		
MoCA	Intervention group (n=57)	20.8±2.5	23.0±2.1	2.18±0.76	11.247	<0.001
	Control group (n=56)	21.1±2.3	21.9±2.0	0.85±0.68		
ADL	Intervention group (n=57)	85.3±6.2	89.6±5.6	4.26±1.53	10.562	<0.001
	Control group (n=56)	84.7±6.5	86.6±5.8	1.85±1.27		
WHOQOL-BREF	Intervention group	52.3±5.8	58.6±4.9	6.3±2.1	8.745	<0.001
	control group	52.8±5.5	55.2±5.0	2.4±1.8		

Note: MMSE refers to the Mini-Mental State Examination; MoCA refers to the Montreal Cognitive Assessment; EMS refers to the episodic memory scale; ADL refers to the Activities of Daily Living scale; BMI refers to the body mass index; APOE refers to apolipoprotein E. Baseline data were collected from 60 patients in each group who were randomly assigned; ultimately, 57 patients in the intervention group and 56 patients in the control group completed the full assessment. For age, disease duration, years of education, MMSE, MoCA, EMS, ADL, and BMI, the chi-square test was used; for gender, comorbidities, and APOE ε4 status, the Fisher's exact test was used.

4. Discussion

4.1. Effect of AI-Driven Dynamic Adaptation of Combined Diet-Exercise Intervention on Scenario Memory Improvement in Patients with Early-Stage AD

The findings of this study demonstrate that a diet-exercise combined intervention, dynamically adapted using AI and wearable devices, can significantly improve episodic memory function in patients with early-stage Alzheimer's disease (AD). After 12 weeks of intervention, the total EMS score in the intervention group increased by 3.82 points compared to baseline, significantly outperforming the control group's increase of 1.26 points; this inter-group difference was both clinically and statistically significant. This finding is consistent with results from multiple international, multi-domain lifestyle intervention studies, yet demonstrates even more pronounced effects. The FINGER study reported significant improvements in comprehensive cognitive scores in the multi-domain intervention group [6]. The J-MINT PRIME Tamba trial showed significant improvements in memory function in the intervention group (P=0.04) [7]. The US POINTER study found that cognitive enhancement in the structured intervention group equated to delaying cognitive decline by approximately four years [8]. In this study, the intervention group exhibited a greater improvement in episodic memory, likely attributable to the following factors: (1) The AI-driven dynamic adaptation algorithm enabled real-time, personalized adjustments to the intervention protocol, overcoming the limitation of "fixed protocols" in conventional interventions; (2) Wearable devices facilitated continuous 24/7 monitoring, allowing for more precise and timely intervention adjustments; (3) The diet-exercise combined intervention exerted synergistic effects on the hippocampus-medial temporal lobe memory network through multi-target mechanisms [15].

4.2. Comparative Analysis with Relevant Domestic and International Studies

The findings of this study corroborate those of several pivotal clinical trials conducted in recent years, while also introducing novel insights. First, regarding dietary intervention, the AI-driven personalized dietary regimen adopted in this study is based on the MIND diet principles and dynamically adjusts using metabolic parameters and nutritional assessment data acquired via wearable devices, thereby offering greater specificity than conventional generic dietary recommendations. This approach aligns with the concept of a protein-enriched Mediterranean diet improving cognitive function demonstrated in the PROMED-EX trial [5]. However, the AI-based dynamic adaptation mechanism in this study enables highly individualized, precision nutrition recommendations tailored to each participant. Second, concerning exercise intervention, this study develops personalized exercise prescriptions based on the ACSM guidelines and real-time heart rate monitoring via wearable devices, rendering the recommendations more scientifically robust and precise than the conventional "30 minutes of daily walking" guideline. A systematic review by Luo et al. confirmed that aerobic exercise significantly improves episodic memory in patients with Alzheimer's disease (AD) [16]. In this study, the exercise adherence rate in the intervention group reached 79.8%, and real-time heart rate monitoring via AI ensured both safety and efficacy of the exercise regimen. Third, regarding combined interventions, the outcomes of this study surpassed those of pharmacotherapy alone. As demonstrated in one systematic review, multimodal lifestyle interventions can yield an improvement in the ADAS-Cog score of approximately 1.3–2.6 points—approximately 1.3–1.5 points greater than the slowing rate observed with monotherapy—indicating a more pronounced trend toward cognitive benefit. In this study, the intervention group exhibited increases in the MMSE score by 2.45 points and in the MoCA score by 2.18 points, demonstrating statistically significant effects. Furthermore, the ADL+ study demonstrated that AI-enabled digital toolkits can improve cognitive function (inter-group difference in the NTB composite score: 0.17), findings consistent with our current study, thereby further validating the feasibility of AI-driven interventions [9].

4.3. Discussion of Potential Mechanisms of Action

The mechanisms by which AI-driven dynamic adaptation of combined diet-exercise interventions enhances episodic memory in patients with early-stage AD may involve the following pathways: (1) Nutrition–Neuroplasticity Pathway: The Mediterranean diet, rich in Omega-3 polyunsaturated fatty acids, antioxidants, and B vitamins, can reduce oxidative stress and neuroinflammation in the brain, promote synaptic plasticity, and thereby support neural protection. AI dynamically adjusts nutritional intake to consistently meet individual metabolic needs, maximizing these neuroprotective effects. (2) Exercise–Neurotrophic Factor Pathway: Regular aerobic exercise increases hippocampal BDNF expression, fostering neurogenesis and synaptic remodeling. AI precisely regulates exercise intensity based on real-time heart rate monitoring, ensuring it remains within the target heart rate range (60%–75% of maximum heart rate), thereby maximizing exercise benefits while minimizing risks. (3) Metabolic–Vascular Pathway: Combined diet-exercise interventions improve insulin sensitivity, lower blood pressure and lipid levels, and enhance cerebral blood perfusion, thereby providing adequate oxygen and nutrient supply to memory-related brain regions, including the hippocampus. (4) Circadian Rhythm–Memory Consolidation Pathway: Wearable devices monitor sleep quality, and AI optimizes daily routines accordingly, promoting slow-wave sleep—a critical phase for episodic memory consolidation. (5) AI-Driven "Precision Feedback" Mechanism: Every seven days, the AI algorithm automatically refines the intervention protocol using multimodal data, establishing a "monitor–evaluate–adjust" closed-loop system. This ensures that interventions are consistently delivered within the optimal individualized dosage range—a core advantage not available with traditional fixed-intervention protocols.

4.4. Strengths and Innovations of This Study

This study offers the following innovations: (1) For the first time, we have deeply integrated wearable device data acquisition with an AI-driven adaptive algorithm within the context of combined dietary and exercise interventions for AD, enabling real-time personalized adjustment of intervention protocols. This approach overcomes the limitations of conventional interventions-namely, fixed protocol designs and delayed adjustments; (2) We have established a complete technical closed-loop encompassing data acquisition, AI analysis, intervention execution, and outcome evaluation, thereby providing a replicable technical framework for intelligent health management of AD; (3) By employing contextual memory as the primary outcome metric, we focus on the earliest and most sensitive domains of cognitive impairment in AD, thereby enhancing the sensitivity of intervention outcome evaluation; (4) Regarding adherence management, we have introduced innovative measures-including an AI-based early-warning mechanism and online support from a health management team-resulting in an average intervention group adherence rate of 82.6% (with 79.8% for exercise prescription adherence and 84.1% for dietary record adherence), which exceeds the rates reported in most comparable studies (typically 60%–75%); (5) The research team possesses both pedagogical expertise in health and wellness and practical experience in AD intervention research, granting them professional advantages in three key areas: formulation of dietary plans (based on knowledge from the "Diet and Nutrition for the Elderly" course), design of exercise prescriptions (based on knowledge from the "Rehabilitation Training for Daily Living Skills of the Elderly" course), and implementation of care practices (based on knowledge from the "Fundamentals and Practical Care for the Elderly" course).

4.5. Clinical and Public Health Significance

The findings of this study provide new evidence-based support and technical pathways for early intervention in Alzheimer's disease (AD). From a clinical perspective, AI-driven dynamically adaptive combined diet-exercise interventions can serve as an effective complementary approach to comprehensive AD management in the early stages, particularly for patients whose response to pharmacotherapy is limited. From a public health standpoint, the AI-based health intervention model in China offers advantages such as low cost, high accessibility, and good safety profiles, making it suitable for widespread adoption in primary healthcare institutions and elderly care facilities. In line with the strategic orientations set forth in the "Healthy China 2030" Planning Outline and the National Nutrition Plan, AI-driven smart health and wellness interventions hold promise as a crucial technological strategy to address the prevention and control needs of AD patients. Future research should involve multi-center, large-sample, long-term randomized controlled trials to further validate these interventions and explore their applicability across diverse cultural contexts and varying healthcare resource conditions.

5. Conclusion

A combined diet-exercise intervention, dynamically adapted using wearable devices and artificial intelligence (AI), significantly improves episodic memory in patients with early-stage Alzheimer's disease (AD), outperforming conventional health management interventions in terms of overall cognitive function, activities of daily living (ADL), and quality of life. This intervention model leverages real-time data acquisition via wearable devices and AI algorithms for dynamic optimization, enabling personalized and precise adjustment of intervention protocols, thereby enhancing intervention adherence and efficacy. This study provides a novel technological pathway and evidence-based support for non-pharmacological interventions in early-stage AD, demonstrating promising clinical application prospects and public health value. Future research should involve multi-center, large-sample studies to further validate long-term outcomes and cost-effectiveness.

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