Elevate Series

CRITICAL PUBLIC HEALTH
2025, VOL. 35, NO. 1, 2598419
https://doi.org/10.1080/09581596.2025.2598419

RESEARCH ARTICLE

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Acute effect of dual-task endurance exercise on cognitive functions and myocardial oxygen consumption; a randomized, controlled trial

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ABSTARCT

Dual-task exercise and its impacts on cognitive function have gained increasing attention in recent years. Targeted aerobic exercise, cardiovascular responses, and the associated improvements in cognitive performance appear promising for mitigating certain cognitive disorders, although the optimal protocol remains unclear. In this randomized controlled trial, 34 participants meeting inclusion criteria were allocated into either a standardized aerobic exercise group (BSAEgr, $n=18$) or a dual-task aerobic exercise group (BIDAgr, $n=16$). Cognitive status was assessed with the Montreal Cognitive Function Assessment Scale (MOCA), and reaction time performance was measured using the Nelson Reaction Test (NRT). Cardiovascular responses including systolic blood pressure, diastolic blood pressure, pulse rate, and the double product formula were evaluated before and after the intervention. The findings demonstrated that dual-task aerobic exercise led to greater improvements in cognitive function compared to standardized aerobic exercise. Significant improvements were observed in MOCA scores, NRT distance, and NRT outcome measures within the dual-task group ($p<0.005$). These results provide preliminary evidence that incorporating dual-task elements into aerobic training may enhance both cognitive and cardiovascular outcomes, suggesting potential applicability in preventive and rehabilitative settings.

ARTICLE HISTORY
Received 19 December 2024
Accepted 27 November 2025

KEYWORDS
Dual-task; cardiovascular; cognitive function; exercise

Introduction

There are studies on the effects of exercise on cognitive performance in diseases that cause some cognitive disorders in healthy individuals. Exercise-induced brain changes are associated with changes in the strength of brain oscillations (Jiang et al., 2019). By increasing the integration of attention and executive functions and functional connections of the default mode network while simultaneously inculcating moderate-intensity aerobic exercise there is an observation of improved cognitive status and modulated functional brain networks in older adults (Chao et al., 2020). High-intensity acute exercise also improves reaction time and it is another indicator of cognitive status. Acute exercise triggers molecular changes and increases vascular endothelial growth factor and brain-derived neurotrophine factor, which contribute to brain plasticity (Loprinzi & Caplan, 2025). Cognitive activation during exercise is beneficial for improving cognitive functions (Brustio et al., 2018; Techayusukcharoen et al., 2019). Epidemiologic studies have shown that DT training can achieve better results on physical and cognitive performance than single cognitive and motor tasks (Donnezan et al., 2018). DT training may induce the combined effects of physical exercise and cognitive training (Law et al., 2014).

A motor-cognitive task involves performing two different independent tasks simultaneously, such as walking while solving simple arithmetic problems. Dual-tasks should be created by including both motor and cognitive tasks (Xiao et al., 2023). More studies are needed to establish an optimal study protocol in this field.

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Motor-Cognitive DT exercises encourage the brain to make connections between the two tasks, which are related to executive functions. High-intensity acute exercises contribute to the prefrontal activity of the brain (Loprinzi & Caplan, 2025). Neuroimaging methods have shown that executive functions are intensely related to the prefrontal cortex. Similar studies have also indicated that DT exercises facilitate prefrontal cortex activity (Kim & Park, 2023).

Aerobic training is characterized by the execution of cyclic exercises performed with large muscle groups contracting at mild to moderate intensity over a long period of time (Quevedo-Jerez et al., 2021). Aytürk (2019) stated that aerobic exercises basically aim to increase cardiovascular endurance and should be performed rhythmically for at least 20–60 minutes at an intensity above the anaerobic threshold, with the participation of at least 50% of the body mass, reaching 60–90% of the maximum heart rate or 50–85% of the maximum oxygen capacity. Examples of aerobic exercise include cycling, dancing, walking, jogging/long-distance running, swimming and walking. These activities are best accessed through aerobic capacity, defined by the American College of Sport Medicine (ACSM) as the product of the oxygen supply capacity of the cardiorespiratory system and the oxygen utilization capacity of skeletal muscles. The benchmark measure for aerobic capacity is peak oxygen consumption (VO2), which can be measured by graded exercise ergometry, treadmill protocols with an oxygen consumption analyzer, or mathematical formulas (Patel et al., 2017).

Aerobic training, especially high-intensity training, increases parasympathetic contribution to the sympathovagal system, and smoking may have a decreasing effect on the effects of aerobic training (Kim et al., 2017).

Increased systolic blood pressure (SBP) and heart rate (HR) are predictors of death and disability in the general population. The double product (DP), the product of blood pressure (BP) and HR, is an index of myocardial oxygen consumption. DP correlates with myocardial oxygen consumption and its physiological use has been validated during exercise testing in patients with ischemic heart disease. Simply put, a weakening in coronary blood flow will also reduce DP as it can cause myocardial necrosis (Schutte et al., 2013). Double Product (DP), calculated as the product of systolic blood pressure and heart rate, is a widely used non-invasive index of myocardial oxygen consumption and cardiac workload. It reflects the hemodynamic stress imposed on the heart and has been validated as a surrogate marker of myocardial oxygen demand in exercise testing and cardiovascular research (Schutte et al., 2013; Teli et al., 2016).

Creteur (2008) emphasized that tissue hypoperfusion is a common pathophysiological process leading to multiple organ dysfunction and death, that an important goal of hemodynamic monitoring is the early detection of inadequate tissue perfusion and oxygenation, and that the use of simple, non-invasive monitoring techniques has the advantage of facilitating earlier initiation of treatment.

Cardiac rehabilitation exercises in cardiovascular patients have been shown to have positive contributions to cortical functions. Cardiac rehabilitation has been found to increase cortical functions and prefrontal cortex oxygenation (Moriarty et al., 2020).

There is also evidence of a relationship between cardiovascular autonomic function and diseases in which the central nervous system is structurally affected, such as Alzheimer's disease. In Alzheimer's disease, cognitive function, particularly in the areas of memory, is reported to be associated with cardiovascular autonomic function. Specifically, lower cognitive performance has been found to be associated with significantly higher cardiovascular sympathetic and lower parasympathetic function in Alzheimer's disease (Nonogaki et al., 2017).

In studies on the negative effects on cognitive functions after cardiovascular surgery, it has been reported that postoperative cognitive dysfunctions (POCD) is mostly transient, but in some cases the problem is permanent. It is also stated that there is no study developed by modern medical methods (Szwed et al., 2012).

There is also evidence in the literature that long-term cognitive impairment develops after heart attacks. It has been reported that there is insufficient research on the extent to which cerebral hypoxia, especially during a heart attack, affects cognitive functions and how to combat this situation (Hagberg et al., 2022).

The relationship between cardiovascular function and cognitive function should not be interpreted as solely due to cardiovascular problems reducing cortical oxygenation. Decreased cortical and cognitive function, as in Alzheimer's disease, also adversely affects neuronal stimulation of the heart. Although the

evidence is not satisfactory, it has been reported that cardiovascular automatic function is associated with poor cognitive performance in patients with atrial fibrillation (Hämmerle et al., 2022).

In other words, improving cardiovascular functions positively affects cognitive functions and improving cognitive functions supports cardiovascular functions. However, regardless of the reason, there is a consensus that cognitive rehabilitation improves cognitive functions in adults (Ball et al., 2002). In addition, after epidemics, conditions such as covid syndrome have been identified to have adverse effects on multiple systems, especially on neurological and cardiovascular systems (Fedorowski et al., 2024; Leng et al., 2023).

As it is understood, affecting cardiovascular functions may affect the oxygenation of the brain and cause negative changes in cognitive and motor functions. Again, in cases where the central nervous system is affected, changes in cardiovascular functions are observed due to the influence of autonomic functions. Studies have tried to determine the causes of the existing effects and to determine their correlations with existing conditions. In particular, aerobic exercises, high intensity exercises, high intensity aerobic exercises, DT exercises have been considered separately. For example, there are not many studies that examine the effects of high-intensity exercise on heart health while simultaneously examining how it contributes to cognitive status, or that try to understand the effects of DT paradigms created using high- and low-intensity exercises on heart and cognitive health.

However, DT performance may vary depending on variables such as age, gender, occupation, general fitness level, general cognitive status, and general ability level. Therefore, in order to make a taxonomy of DT paradigms, it is necessary to take into account the results of many studies using various DT paradigms with individuals of different age groups, diseases, performance levels, genders and physical characteristics.

In addition, increasing medical costs around the world today, especially in neurological and cardiovascular segments of healthcare, emphasizes the need for shorter-term and more system-effective therapy or rehabilitation. Hence the urgency embedded in current circumstances (e.g. after epidemics such as covid; quality of life standards; and, the gradual decrease in personal time) can be reallocated for exercise or treatment. In this way, the aim of this study is to produce therapeutic approaches for patients with either or both cognitive and cardiovascular problems and to effectively contribute to the DT taxonomy. In this context, this study was designed to highlight only the acute outcomes of a single exercise session. Long-term adaptations, while well documented, are cited only where they provide context and do not imply that the present findings extend beyond acute responses. Accordingly, the acute responses assessed in this study are framed as indicators of prescription safety and immediate cognitive and cardiovascular outcomes of DT endurance exercise.

Materials and methods

Study design

This study was a prospective, single-center, randomized, controlled trial with confidential allocation. The study was conducted with healthy individuals. Participants were recruited through a public announcement. Volunteers provided written informed consent and underwent a preliminary assessment to determine their eligibility based on the inclusion criteria. Data collection began in July 2024 with eligible participants. The study was conducted under the oversight of the Istanbul Gedik University Ethics Committee (Protocol Number: E-56365223-050.02.04-2023.137548.177-551) and registered on the ClinicalTrials.gov website (Registration Number: NCT06461130). It adhered to the principles outlined in the Declaration of Helsinki. Written informed consent was obtained from all participants prior to their inclusion in the study.

Participants

Considering that the effect size that can be obtained from the study may be at a high level (dz = 0.3) as a result of the power analysis, it was calculated that at least 34 people should be included in the study in order to obtain 95% power at 95% confidence level. Forty-seven people were included in the

study and 13 of them were excluded. The subjects who met the inclusion criteria were randomized into 2 groups. Randomization was done online (http://www.randomization.org/). The study groups consisted of 2 arms as double-leg standardized aerobic exercise (BSAEgr) ($n = 18$) and double-leg DT aerobic exercise (BIDAgr) ($n = 16$) (Figure 1). Inclusion criteria were healthy individuals aged 18–40 years, volunteering to participate in the study, no comorbidity, no orthopedic, neurologic, cardiopulmonary systemic comorbid disease, and participants who had not been involved in another clinical trial in the last one month. Exclusion criteria were as follows: Participants who had undergone hip, pelvic, knee, ankle surgery, sensory loss, participants with height inequality, vestibular disorders, pregnancy, participants with known balance disorders in the last three months due to concussion, presence of systemic disorders (diabetes, blood pressure, etc.), bronchodilator drug users, neurological disease, and psychological well-being were excluded.

Demographic characteristics: Age, height, weight, waist and Hip Circumference (HC), diagnosis, complaints, additional diseases, discomforts experienced in the last 4 weeks, family history, cardiovascular problems, presence of recurrent infections, and medications used were categorized.

Procedures

Double leg bicycle ergometer aerobic training group only

In double leg cycling training, both legs were exercised on a bicycle ergometer, starting with a 5-minute warm-up (25% work power) on the ergometer before the application, with a training that lasted for a total of 20 minutes and was performed at 70% intensity continuously. It ended with 5 minutes of cooling down. Individuals were required to maintain a pedaling frequency of 50 rpm set externally with a metronome. As soon as the training was completed, the pre-intervention assessments were repeated and the acute effect was evaluated. Dyspnea and lower extremity muscle fatigue and pain was evaluated before and after the training with the Modified Borg Scale, and heart rates and oxygen saturations were measured with finger pulse oximetry before and after the training. The training was followed in this way and there was no risk (Bjørgen et al., 2009; Wickerson et al., 2021). Systolic and diastolic blood pressure, as well as heart rate, were measured using a validated digital sphygmomanometer immediately before and

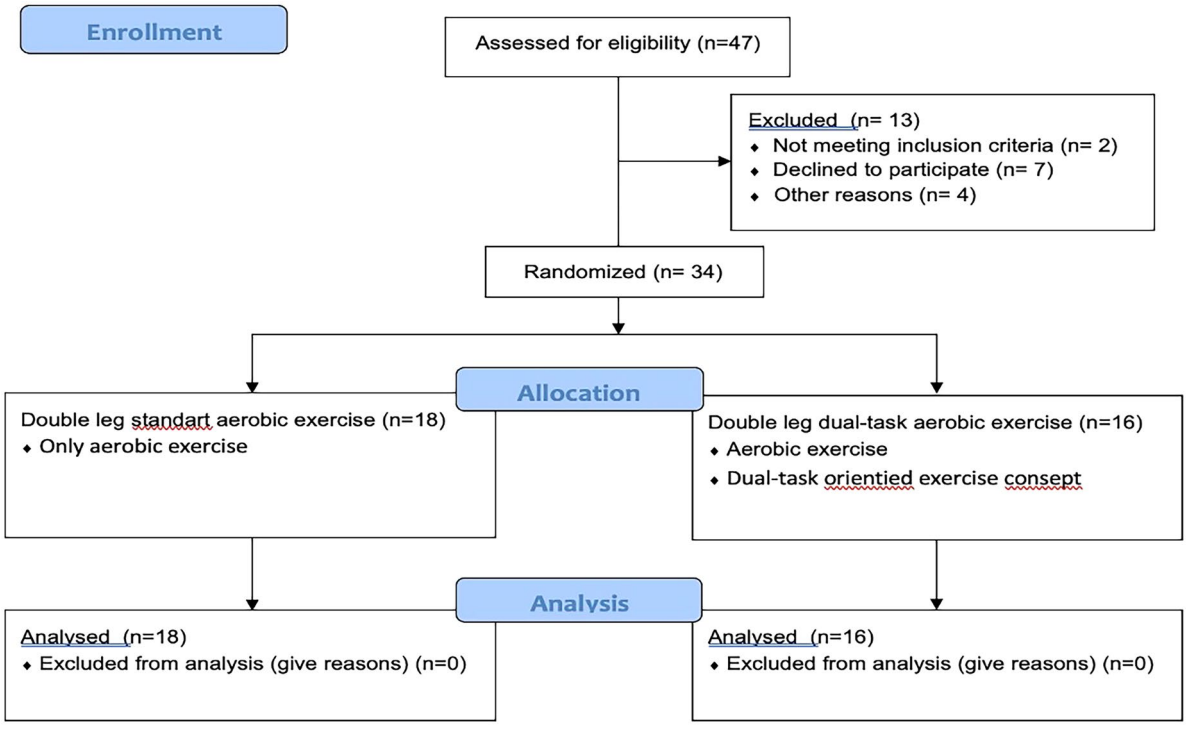

Figure 1. Study flow chart.

immediately after the intervention, with the participant seated and rested for at least five minutes in both conditions. This ensured that all cardiovascular parameters were obtained at comparable time points.

Bicycle ergometer aerobic training group with double leg DT

Dual-task. Aerobic training on a bicycle ergometer + serial sevens in the DT condition, participants completed the exercise while simultaneously performing a series of sevens cognitive tasks. Specifically, we instructed participants to serially subtract sevens from a prescribed three-digit number (in the range 100–300) and read the calculations aloud while performing aerobic exercise. The serial sevens task measures participants working memory while simultaneously increasing demands on cognitive focus and attentional capacity and is regularly used alongside walking to create a true motor and cognitive DT (Montero-Odasso et al., 2012). Cognitive performance, which is a secondary outcome measure calculates the percentage accuracy of the serial seven responses given during each trial by recording the number of responses and the number of errors (Tamura et al., 2018). Here a set number between 100 and 300 and counting back 7 times was put in place. We calculated the error percentage as above.

Montreal cognitive function assessment scale (MOCA). This test assesses visuospatial (5 points), naming (3 points), attention (6 points), language (3 points), abstract (2 points), memory (5 points), orientation (6 points) abilities. Possible scores range from 0 to 30 points, with higher scores indicating better cognitive function (Yang et al., 2021). Mone et al. (2022) pointed out in their study that a score below 26 indicates cognitive impairment.

Nelson reaction test (NRT). The NRT was used to measure reaction time. Measurements were taken in a quiet environment with adequate lighting. The measurements were taken with the subject standing and balancing on both feet. Five measurements were taken from the subject's dominant hand using the Nelson Reaction Time Scale, and the best score was recorded. After the athlete and participant's concentration was focused on the center point of the ruler during the measurement, the ruler was released without any signal to the athlete or participant. The value at the top of the ruler, held between the index finger and thumb, was read and recorded. Reaction times were calculated by substituting it into the formula below (Koç & Gökdemir, 2008).

$$\text{Time} = 2 \times \text{Distance the ruler falls} / \text{square root of Gravitational Velocity}$$

$$\text{Time} = 2 \times \text{Distance(cm)} / \text{square root of } 980\,\text{cm}$$

Indirect assessment of myocardial muscle oxygenation with the Double Product Formula: Double product (DP) is an increasingly used surrogate measure of myocardial oxygen demand and cardiac workload. It is SBP multiplied by heart rate (HR). The strong association of DP with left ventricular mass has identified it as a predictor of cardiovascular risk in hypertensive patients (Teli et al., 2016).

$$\text{Double Product Formula} = \text{Heart rate(HR)} \times \text{SBP} / \%$$

Our aim in using this formula is to see whether there is a difference in the cardiovascular oxygenation of nicotine addicted and non-nicotine addicted people during exertion and whether the heart is adequately nourished.

Statistical analysis

All statistical analyses were performed using SPSS version 22.0 (IBM Corp., Armonk, NY, USA). The normality of the data distribution was assessed with the Shapiro–Wilk test, which indicated that the data were not normally distributed. Therefore, nonparametric tests were employed. Comparisons of categorical variables between groups were conducted using the Chi-square test, while comparisons of quantitative variables were examined using the Spearman correlation test. Between-group comparisons were carried out with the Mann–Whitney *U* test (Table 1). A significance level of $p < 0.05$ was considered statistically significant.

Power analysis: Statistical power analysis was performed based on the study by Tonelli et al. (2022). In this analysis, t tests- Means- Means were used to obtain a margin of error alpha of 0.05, effect size of 0.8 and power of 0.8: Wilcoxon-Mann-Whitney (two groups) test was used. The analysis showed that 14 participants from each group were sufficient. Power analysis was performed with G-Power (Ver. 3.1.9.7) program.

Results

Comparisons of categorical variables between groups were conducted using the Chi-square test, while comparisons of quantitative variables were examined using the Spearman correlation test. Between-group comparisons were carried out with the Mann–Whitney U test (Table 1).

Comparisons of quantitative descriptive variables

According to the results of the analysis of the demographic information of the participants, it is understood that there is no significant difference between the groups. In addition, there is no statistically significant difference between the groups in terms of age, gender and smoking. No statistically significant difference was found in the comparison of quantitative descriptive variables ($p > 0.05$) (Table 2). There was no statistically significant difference in the comparison of categorical descriptive variables ($p > 0.05$).

Comparison of MOCA, NRT, SBP, DBP, DP measurements before and after according to groups

In the comparisons of MOCA, NRT, SBP, DBP, DP measurements before and after according to the groups; a statistically significant difference was found between the groups in MOCA before and after, NRT

Table 1. Comparisons of quantitative descriptive variables.

	Group	*n*	Mean ± Ss	Median	*U*	*p**
Age	Aerobics only	18	30.88 ± 6.21	33.5	107.5	0.206
	DT	16	27.56 ± 6.8	26		
Lenght	Aerobics only	18	1.64 ± 0.07	1.64	124	0.489
	DT	16	1.67 ± 0.1	1.645		
Weight	Aerobics only	18	69.33 ± 11.16	67	112.5	0.277
	DT	16	65.62 ± 10.27	63		
BMI	Aerobics only	18	25.53 ± 3.92	25.6	96	0.098
	DT	16	23.28 ± 2.84	22.95		
Number of cigarettes per day	Aerobics only	7	15.57 ± 7.57	20	14	0.307
	DT	6	11 ± 6.06	11		
Year of smoking	Aerobics only	7	7.85 ± 7.67	6	21	1
	DT	6	7.16 ± 3.18	7.5		
Waist circumference	Aerobics only	18	85.88 ± 12.03	88	93	0.078
	DT	16	79.06 ± 10.65	79.5		
HC	Aerobics only	18	100.83 ± 8.72	101.5	129	0.604
	DT	16	99.62 ± 5.83	101		

*Mann-Whitney *U* test.

Table 2. Comparisons of categorical descriptive variables.

	Group			
	Aerobics only	DT	χ^2	*p**
Gender				
Woman	12 (%66.7)	9 (%56.3)	0.389	0.393*
Male	6 (%33.3)	7 (%43.8)		
Education status				
Middle school	2 (%11.1)	2 (%12.5)	0.756	0.685
Associate degree	7 (%38.9)	4 (%25)		
License	9 (%50)	10 (%62.5)		
Cigarette smoking				
Yes	7 (%38.9)	6 (%37.5)	0.007	0.607*
No	11 (%61.1)	10 (%62.5)		

*Chi-Square test.

distance before and after, NRT result before and after measurements ($p < 0.05$). In the MOCA variable, the mean score of the DT group was higher in both before and after measurements. In the NRT *distance variable*, the mean score of the DT group was higher in the pre and only the aerobic group in the post measurement. In the NRT *outcome variable*, the mean score of the DT group was higher in the pre and aerobic group in the post measurement (Table 3).

Correlational analysis of quantitative descriptive variables and MOCA, NRT, SBP, DBP, DP measurements

MOCA, NRT, SBP, DBP, DP measurements of patients show a low level and a negative correlation was found between age and measurements before and after MOCA; a low level and negative correlation between BMI variable and measurement after MOCA; and a low level positive correlation between HC measurement and measurement after SBP ($p < 0.05$) (Table 4).

In the correlational analysis of BMI and HC measurements

A positive, high level and statistically significant relationship was found ($p < 0.05$) (Table 5).

Comparison of the differences of MOCA, NRT, SBP, DBP, DP measurements before and after according to the group

In the comparisons of the differences of MOCA, NRT, SBP, DBP, DP measurements before and after according to the groups, a statistically significant difference was found between the groups in MOCA, NRT distance, NRT result measurements ($p < 0.05$). In the MOCA variable, the mean difference score of the DT group was higher. In the NRT distance variable, only the DT aerobic group had a lower mean difference score. In the NRT outcome variable, only the DT aerobic group had a lower mean difference score (Table 6). To enhance the interpretability of the results, a figure has been added to visualize the main findings. Figure 2 illustrates the pre- and post-intervention changes in

Table 3. Comparison of MOCA, NRT, SBB, DBP, DP measurements before and after according to groups.

	Group	*n*	Mean ± Ss	Median	*U*	*p**
MOCA (B)	Aerobics only	18	24.11 ± 3.01	24.5	73	**0.014**
	DT	16	26.68 ± 2.9	27.5		
MOCA (A)	Aerobics only	18	24.22 ± 3.04	24	26	**<0.001**
	DT	16	29.12 ± 1.82	30		
NRT distance (B)	Aerobics only	18	18.88 ± 5.3	17.5	37	**<0.001**
	DT	16	26.25 ± 2.11	26		
NRT distance (A)	Aerobics only	18	24.38 ± 3.61	25	46	**0.001**
	DT	16	19.18 ± 3.6	18.5		
NRT conclusion (B)	Aerobics only	18	1.21 ± 0.33	1.118	37	**<0.001**
	DT	16	1.67 ± 0.13	1.661		
NRT conclusion (A)	Aerobics only	18	1.55 ± 0.23	1.597	46	**0.001**
	DT	16	1.22 ± 0.23	1.182		
SBP (B)	Aerobics only	18	113.61 ± 12.26	112.5	102	0.147
	DT	16	119.43 ± 10.83	119		
SBP (A)	Aerobics only	18	118.05 ± 15.07	118	101	0.138
	DT	16	124.93 ± 10.58	123		
DBP (B)	Aerobics only	18	70.16 ± 10.51	70.5	90.5	0.065
	DT	16	75.62 ± 6.81	76.5		
DBP (A)	Aerobics only	18	72.16 ± 10.16	73	102.5	0.151
	DT	16	77.62 ± 9.83	78		
Pulse (B)	Aerobics only	18	84.44 ± 16.65	79.5	126	0.534
	DT	16	85.37 ± 16.12	86.5		
Pulse (A)	Aerobics only	18	89.33 ± 14.67	84.5	137.5	0.822
	DT	16	89.06 ± 18.02	89		
DP (B)	Aerobics only	18	95.62 ± 19.32	92.31	113	0.285
	DT	16	102.37 ± 22.8	97.88		
DP (A)	Aerobics only	18	105.15 ± 18.87	107.76	127	0.558
	DT	16	111.24 ± 24.7	113.19		

*Mann-Whitney *U* test. Before (B), After (A).

Table 4. Correlational analysis of quantitative descriptive variables and MOCA, NRT, SBP, DBP, DP measurements.

		MOCA (B)	MOCA (A)	NRT distance (B)	NRT distance (A)	NRT conclusion (B)	NRT conclusion (A)	SBP (B)	SBP (A)	DBP (B)	DBP (A)	PULSE (B)	PULSE (A)	DP (B)	DP (A)
Age	*r*	**−0.349**	**−0.418**	−0.188	0.065	−0.188	0.065	0.176	0.101	0.281	−0.004	−0.027	−0.015	0.033	0.031
	p	**0.043**	**0.014**	0.288	0.715	0.288	0.715	0.319	0.571	0.108	0.984	0.880	0.932	0.855	0.862
BMI	*r*	−0.220	**−0.400**	−0.232	0.147	−0.232	0.147	0.135	0.278	0.040	0.064	−0.077	−0.071	−0.012	0.062
	p	0.211	**0.019**	0.186	0.407	0.186	0.407	0.447	0.111	0.822	0.721	0.665	0.691	0.946	0.730
Number of cigarettes per day	*r*	−0.364	−0.362	−0.108	0.273	−0.108	0.273	0.050	−0.140	0.243	0.359	0.379	0.440	0.366	0.371
	p	0.222	0.224	0.726	0.366	0.726	0.366	0.870	0.648	0.423	0.228	0.201	0.132	0.218	0.212
Year of smoking	*r*	0.004	0.096	−0.182	0.259	−0.182	0.259	0.434	0.002	0.513	0.433	0.089	0.050	0.271	0.003
	p	0.991	0.754	0.551	0.393	0.551	0.393	0.138	0.996	0.073	0.139	0.771	0.872	0.370	0.991
Waist circumference	*r*	−0.137	−0.282	−0.238	0.068	−0.238	0.068	0.329	0.306	0.196	0.073	−0.219	−0.264	−0.034	−0.079
	p	0.440	0.106	0.175	0.701	0.175	0.701	0.057	0.078	0.266	0.682	0.213	0.132	0.851	0.656
HC	*r*	−0.117	−0.221	−0.102	0.059	−0.102	0.059	0.264	**0.352**	0.206	0.197	−0.165	−0.179	−0.027	0.000
	p	0.512	0.209	0.564	0.742	0.564	0.742	0.131	**0.041**	0.241	0.264	0.351	0.310	0.878	0.999

Spearman Correlation test. Before (B), After (A), Body Mass Index (BMI).

Table 5. Relational analysis of BMI and HC measurements.

		HC
BMI	*r*	0.832
	p	**<0.001**

Spearman correlation test.

Table 6. Comparison of the differences of MOCA, NRT, SBP, DBP, DP measurements before and after according to the groups.

	Group	*n*	Mean ± Ss	*U*	*p**
MOCA difference	Aerobics only	18	0.11 ± 1.68	39	**<0.001**
	DT	16	2.43 ± 1.97		
NRT distance difference	Aerobics only	18	5.5 ± 4.37	0	**<0.001**
	DT	16	−7.06 ± 3.04		
NRT result difference	Aerobics only	18	0.35 ± 0.28	0	**<0.001**
	DT	16	−0.45 ± 0.2		
SBP difference	Aerobics only	18	4.44 ± 11.1	133	0.704
	DT	16	5.5 ± 10.71		
DBP difference	Aerobics only	18	2 ± 10.12	136	0.782
	DT	16	2 ± 7.46		
Pulse difference	Aerobics only	18	4.88 ± 7.51	120	0.406
	DT	16	3.68 ± 5.71		
DP difference	Aerobics only	18	9.52 ± 14.74	134	0.730
	DT	16	8.86 ± 12.51		

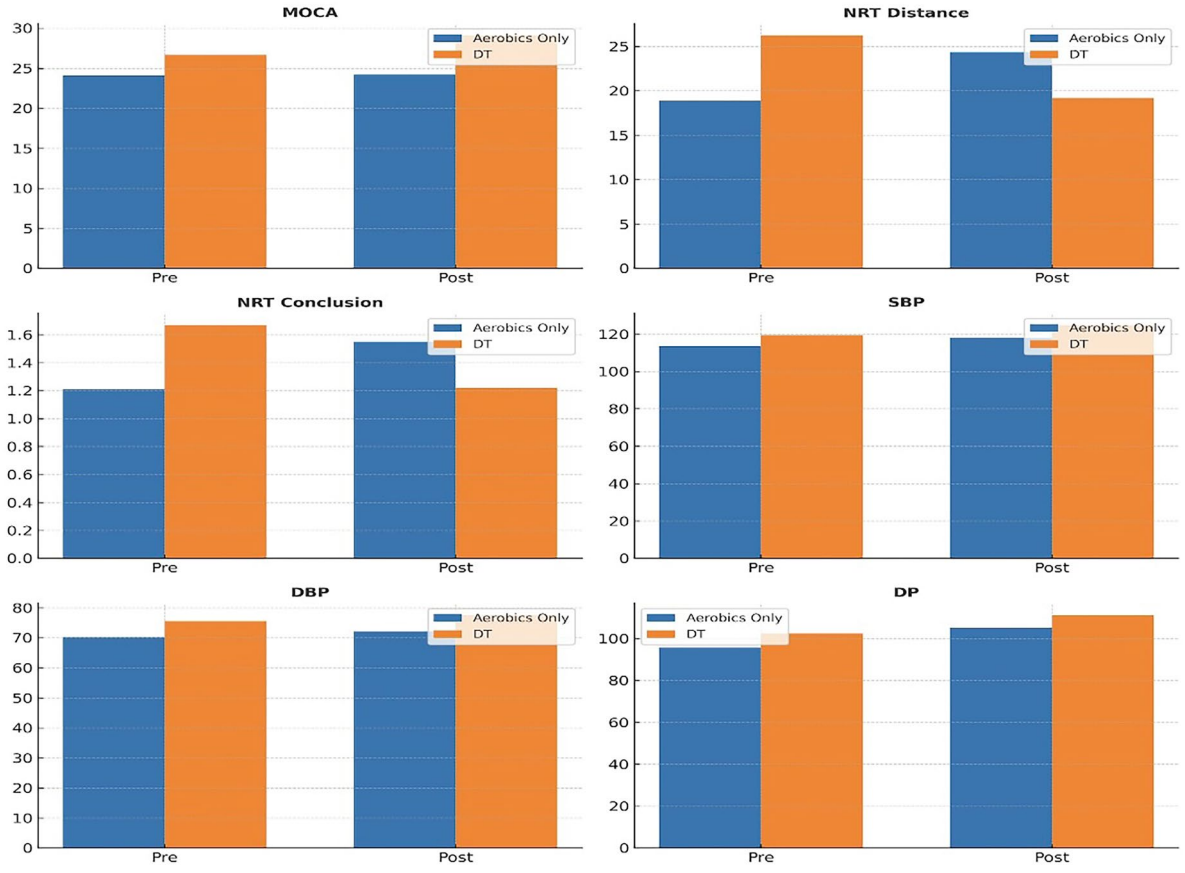

Figure 2. Pre- and post-intervention changes in cognitive and cardiovascular parameters (aerobics only vs DT group).

MOCA, NRT, and cardiovascular parameters (SBP, DBP, DP) for both the aerobic-only and DT groups. The graphical representation highlights the significant improvements observed in cognitive outcomes for the DT group.

Discussion

The various health benefits of physical activity are widely recognized, and the specific effects of aerobic and DT exercise on cardiovascular health and cognitive function have received increasing attention. Although smoking is generally known to have negative effects on health, the results of our study suggest that smoking does not play a significant modulatory role on acute exercise effects. This indicates that the effect of smoking on acute exercise responses is limited, at least in terms of the parameters examined. However, when its long-term health effects are considered, the negative effects of smoking on both cardiovascular health and cognitive functions are well documented (Bendikaite & Vimantaite, 2020; Khadanga et al., 2022).

The influence of gender on physiological and cognitive responses is complex, and in the present study we did not observe a significant modulating effect of gender on acute exercise effects. This suggests that acute exercise responses are largely independent of sex differences. However, there is evidence in the existing literature for long-term effects of gender on exercise adaptations. There are also studies showing that women and men may respond differently to exercise-induced cardiovascular and cognitive improvements (Booth & Katic, 2013; Hausmann, 2021; Röding et al., 2009).

BMI has a significant impact on an individual's overall health and particularly on their cardiovascular and metabolic risk profile. However, the effects of BMI on long-term cardiovascular health and cognitive functioning are well documented, especially in terms of obesity-related risk factors. Increasing BMI negatively affects brain oxygenation by affecting cardiovascular parameters such as SBP, DBP and cardiovascular output. This results in decreased performance in mental arithmetic and mathematical tasks. Increased risk of comorbidities and decreased fitness level explain the negative effect of obesity on cognitive functions (Alosco et al., 2015; Kibler et al., 2020).

In this study, no significant modulating effect of BMI on acute exercise responses was found, indicating that exercise effects may be independent of BMI in terms of the parameters examined. However, there was a negative relationship between BMI and MOCA scores, a positive relationship between BMI and HC and a positive relationship between HC and SBP. It was also shown that there was a low level significant negative relationship between age and BMI and cognitive functions. While an increase in BMI negatively affects cognitive functions, an increase in HC negatively affects cardiovascular health. This suggests that there may be complex links between cognitive function and general physiological and cardiovascular health.

DT exercises offer a challenge beyond traditional aerobic exercise by encouraging individuals to perform physical and cognitive tasks simultaneously. The finding that this approach has more pronounced positive acute effects on cognitive function than standard aerobic exercise suggests the potential for a comprehensive impact on cognitive and physical health. At the same time, there are studies in the literature showing that central nervous system diseases negatively affect cognitive health which can negatively affect cardiovascular health, and cardiovascular problems negatively affect cognitive health. This appears to be an observation of cybernetic activity worth adding to the literature.

The effects of DT exercises on cognitive functions promote synaptic plasticity by increasing the activation of various regions of the brain. This is in line with findings on the potential of DT exercises to improve cognitive functions (Li et al., 2022). These studies suggest that DT exercises may specifically target cognitive domains such as attention, processing speed and working memory (Moreira et al., 2021).

The improvement of reaction time can be considered as an indicator of the positive effects of DT exercises on cognitive functions. Improvement in reaction time indicates an increase in cognitive processing speed and attention, which may improve performance in daily life activities and complex tasks. Studies support that DT exercises may lead to improvements in cognitive functions by shortening reaction time (Wolkorte et al., 2014; Xu et al., 2015).

Several DT studies in the literature have shown that this type of exercise can be particularly effective in preventing cognitive decline in older adults. DT walking exercises have been found to have positive effects on cognitive flexibility and attention in older adults. Similarly, it has been shown that DT exercises can improve processing speed and memory functions (Iersel et al., 2008; Theill et al., 2011). The results of our study confirm that DT aerobic exercises provide more favorable acute effects on cognitive functions compared to aerobic exercises alone and establish a positive relationship with cognitive functions

by improving reaction time. These findings emphasize the potential use of DT exercises to support cognitive health in the aging process, cardiovascular diseases, mild cognitive impairments and many other conditions where cognitive function is affected. Our findings are consistent with Chao et al. (2020), who reported that the cognitive demands of exercise modulate neuroplastic outcomes. They also align with Kim and Park (2023), who suggested that combining physical and cognitive tasks yields superior clinical benefits. Additionally, Loprinzi and Caplan (2025) demonstrated that acute exercise intensity effects on cognition can vary, which contextualizes the heterogeneous outcomes observed in the literature and underscores the relevance of our acute-focus design.

The novelty of our study lies in its exclusive focus on the acute effects of dual-task (DT) endurance exercise on both cognitive and cardiovascular parameters. Unlike most prior investigations that examined long-term or training adaptations, our findings specifically highlight the immediate cognitive and cardiovascular responses to a single DT session in healthy young adults. Furthermore, by integrating surrogate myocardial oxygen consumption (via Double Product) with validated neurocognitive assessments (MOCA and NRT), we provide a multidimensional analysis rarely reported in the literature. This dual assessment underscores the complex interaction between cardiovascular workload and cognitive performance and offers new insights into the short-term safety and efficacy of DT interventions in non-clinical populations.

Although more advanced techniques such as direct VO_2 analysis or ergospirometry may provide a more precise quantification of myocardial oxygen consumption, we intentionally selected the Double Product (DP) as a surrogate marker due to its non-invasive, cost-effective, and clinically validated nature. Previous research has demonstrated that DP strongly correlates with myocardial oxygen consumption and cardiovascular risk, making it a widely accepted index in both exercise physiology and clinical cardiology (Creteur, 2008; Schutte et al., 2013; Teli et al., 2016). Therefore, while we acknowledge the limitation of not using direct gas analysis, the inclusion of DP still adds value to the study by providing a reliable and practical estimate of cardiac workload in real-world exercise settings.

In recent years, the effects of physical exercise on both cardiovascular health and cognitive functions have been intensively investigated. In particular, acute increases in myocardial oxygen consumption and their potential relationship with cognitive functions have been emphasized (Li et al., 2022). Our findings show that neither type of exercise caused significant acute increases in myocardial oxygen consumption. According to the results of our study, acute aerobic exercise did not cause a statistically significant change in myocardial oxygen consumption and blood pressure, whether performed as a DT or alone. These findings are not consistent with the literature. However, increased myocardial oxygen consumption in the acute phase indicates a rapid adaptation of the cardiovascular system to exercise and a process that requires the heart to consume more oxygen to meet increased metabolic demands. This suggests that the intensity and type of exercise are critical factors for its effects on cardiovascular health (Brown et al., 2023; Gaalema et al., 2021). It is known that cardiovascular health problems can have negative effects on cognitive functions. Conditions such as hypertension, atherosclerosis and heart disease can affect blood flow to the brain and lead to impaired cognitive function (Arakaki et al., 2023; Harrison et al., 2018). However, both exercise groups were effective in increasing cognitive performance independent of cardiovascular parameters. Although the findings obtained in our study do not support the literature showing the relationship between cardiovascular health and cognitive functions, it suggests that more comprehensive studies on the effects of acute aerobic exercise on cardiovascular and cognitive health are needed. Considering the relationships between BMI increase and HC, HC and SBP, the relationship between BMI and cognitive scores, and the positive effects of DT aerobic exercise on all cognitive scores, it can be concluded that there is a complex relationship between cardiovascular health and cognitive health and that physical exercise, especially DT aerobic exercise, may potentially have positive effects on these two domains. These results must be interpreted strictly as acute responses to a single bout of exercise. While chronic adaptations to repeated training sessions are widely reported, they represent fundamentally different mechanisms and timescales. In this manuscript, any mention of long-term effects serves solely to contextualize our findings and should not be understood as an extension of our results beyond the acute timeframe. Our interpretations remain restricted to immediate responses observed after a single session, whereas references to chronic outcomes are explicitly used only to

contrast the short-term scope of this trial with the broader exercise literature. They should be understood as preliminary indicators of exercise safety and immediate cognitive-cardiovascular effects, rather than evidence of long-term adaptation.

Study limitations

Our work has some limitations. We think that one of them is the limited number of participants. Another limitation of the study is that a mental state assessment method such as Mini Mental State Examination (MMSE) can be used in addition to other assessments. Another limitation of this study is the relative heterogeneity of the sample in terms of age range, sex distribution, and smoking status. Although all participants were healthy young adults without comorbidities, variability in demographic and lifestyle factors may have influenced the magnitude of acute responses. While this heterogeneity may enhance the external validity of the findings by reflecting a broader real-world population, it also reduces the internal control of the trial. Future studies should therefore consider recruiting more homogeneous cohorts (e.g., single-sex groups, non-smokers only, or narrower age ranges) to provide greater methodological precision and to clarify whether specific subgroups respond differently to dual-task interventions (Booth & Katic, 2013; Hausmann, 2021; Röding et al., 2009). Although adjusted p values were applied, future studies with larger sample sizes may further validate these results using alternative correction procedures (e.g., Bonferroni or FDR). A further limitation of this study is the use of a parallel-group design rather than a crossover design. While crossover trials can reduce inter-subject variability and are often preferred for examining acute responses, we chose a parallel approach to minimize participant burden, prevent potential carry-over effects, and align with logistical constraints of the intervention setting. This methodological decision should be considered when interpreting our findings, and future studies would benefit from employing a crossover design to strengthen internal validity.

Additionally, several other limitations should be acknowledged. First, the absence of blinding may have introduced potential bias, as participants were aware of their group allocations. Second, the generalizability of our findings is limited since the study included only healthy young adults; thus, results may not extend to older populations, clinical groups, or different cultural contexts. Third, there is inherent physiological variability in individual responses to acute exercise, influenced by factors such as baseline fitness level, circadian rhythms, and lifestyle variables, which could not be fully controlled. Fourth, the single-center design may restrict the external validity of the findings. Finally, some variables such as smoking status relied on self-report, which may be subject to reporting bias. Future studies should therefore address these factors to strengthen internal validity and enhance generalizability.

Conclusions

This study examined the acute effects of aerobic and DT exercise, together with the modulatory roles of demographic and physiological factors such as smoking, gender and BMI. The findings showed that both types of exercise had no effect on myocardial oxygen consumption. Smoking, gender and BMI also showed no significant modulatory effect. These results suggest that acute exercise responses are largely independent of the demographic and physiologic factors examined.

The positive acute effects of aerobic and DT exercises on cognitive functions emphasize the potential of DT exercises to improve cognitive functions. DT exercises were found to positively correlate with cognitive functions by improving reaction time. These findings point to the potential of structured exercise to support cognitive health and prevent cognitive decline during the aging process.

Our findings demonstrate the complexity of acute and long-term exercise responses and that these responses may vary according to individual health status.

This study can serve as a basis for future research to gain a deeper understanding of the interactions between structured exercise, cognitive and cardiovascular health and thus in developing effective interventions or strategies for enhancing the quality of research in these areas. Future studies should expand our understanding in health and exercise science by evaluating the effects of these factors on exercise responses from a long-term perspective.

Author contributions

Conceptualization: E. A; Methodology: E. A, and A. A; Software: E. A; Validation: E. A; Formal analysis: E. A and A. A; Investigation: E. A; Resources: E. A and A. A; Data curation: E. A and A. A; Writing - original draft: E. A and A. A; Writing - review & editing: E. A; Visualization: E. A and A. A; Supervision: E. A. All authors critically reviewed the article and approved the final manuscript.

Disclosure statement

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

Funding

This study has not any funding.

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Data availability statement

The data that support the findings of this study are available from the corresponding author, EA, upon reasonable request.

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