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Association of Core Muscle Endurance with Weekly Workout Time, Speed, and the Symmetry of Frontal Core Motion during Indoor Walking and Cycling

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Abstract: This study investigated the factors that influence core muscle endurance, i.e., the symmetry of frontal core motion during indoor walking and cycling, the symmetry of lateral core muscle endurance, the symmetry of the hip abductor strength, the weekly workout time and fast walking and cycling speeds, while controlling for gender. Seventy-nine healthy young adults participated in this study. In a regression analysis, the core muscle endurance time was the dependent variable. The independent variables were the symmetry of frontal core motion (measured using a wireless earbud sensor during walking and cycling), the symmetry of side plank time and of hip abductor strength, the weekly workout time and fast walking and cycling speeds. In the multiple regression analysis, weekly workout time, fast walking speed, symmetry of frontal core motion during fast cycling and symmetry of lateral side plank time predicted core muscle endurance (adjusted R^2 = 0.42). Thus, clinicians and fitness personnel should consider the association of core muscle endurance with the symmetry of frontal core motion during cycling and the symmetry of side plank holding time, as well as with the weekly workout time and a fast walking speed, when designing core muscle exercise programmes.

Keywords: core muscle endurance; cycling; home workout; symmetry; walking

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1. Introduction

The body's core consists of the trunk, pelvic and hip regions, and these components form a kinetic chain with the extremities [1,2]. A better core performance results in a better sport performance, including a longer throwing distance and higher running speeds, as well as less injury, back pain and urinary incontinence [3–5]. Core performance has been evaluated using core muscle endurance tests, such as plank tests, to pre-screen for injuries of the lower extremities and to prescribe exercise programmes [6,7]. However, the measurement of the core muscle endurance time requires considerable effort and time, as well as a trained tester [8]. A model was developed to predict the endurance time in the performance of a side plank based on age, gender, body mass index and questionnaire-assessed variables [8]. There was a gender difference in lateral trunk endurance time, with males having greater holding times on both sides in side plank endurance tests than females [9]. However, there was no gender difference in trunk flexor endurance time [9].

Based on previous regression and correlation analyses, the weekly workout time is significantly associated with core muscle endurance; a longer weekly workout time had a positive correlation with better core muscle endurance [10]. Core muscle endurance is further related to the walking and indoor cycling speeds. Walking is the most popular physical activity worldwide [11], and indoor cycling was also very popular during the

COVID-19 pandemic worldwide [12]. Two studies showed that a core strengthening exercise programme can lead to improved cycling speed in cyclists and improved walking speed in patients with lumbar fusion, consistent with the association between core strength and speed performance [13,14].

The symmetry of core motion and lateral core muscle performance are the goals of rehabilitation during cycling and walking. Asymmetrical, increased lateral leaning of the trunk in the indoor cycling test is associated with a reduced activation of the core musculature, which increases the spinal load [15,16]. One study demonstrated asymmetrical pelvic tilt and hip rotation during indoor cycling in individuals with lower back pain and no leg length asymmetry, which was likely caused by a bilateral imbalance in the trunk muscles [15]. Another study revealed the asymmetrical activation of the lumbar multifidus in association with an asymmetrical lumbar rotation in the initial and final phases of indoor cycling in cyclists with lower back pain compared to healthy cyclists [17]. Asymmetrical lateral trunk leaning during walking has been also observed in people with knee osteoarthritis and patellofemoral pain [18]. With respect to the lateral core musculature, the weakness of the hip abductors may be related to asymmetrical lateral trunk leaning and pelvic drop during walking, resulting in the Trendelenburg gait [19]. In addition, asymmetrical lateral trunk leaning during walking affects the endurance of the lateral trunk muscles because their compensatory activation can be induced by weak hip abductors, in turn inducing their fatigue over time [20,21]. A prospective study also identified asymmetrical hip abduction strength as a potential risk factor for lower extremity injury [22].

Although symmetry is a desirable goal, its relationship to core muscle endurance during popular workouts, such as walking and cycling, or during performance tests, has yet to be investigated. Thus, this study included variables related to symmetry while performing workout activities, as well as previously identified variables, when investigating factors associated with core muscle endurance. The purpose of this study was to investigate factors that influence core muscle endurance, i.e., the symmetry of frontal core motion during indoor walking and cycling, the symmetry of lateral core muscle endurance, the symmetry of hip abductor strength, the weekly workout time, and indoor walking and cycling speeds, while controlling for gender. We hypothesised that core muscle endurance would have significant associations with the symmetry of core motion during cycling and walking, the hip strength, the lateral core muscle endurance bilaterally, the weekly workout time and the walking and cycling speeds.

2. Materials and Methods

2.1. Participants

This was a cross-sectional study with a convenience sample. The participants were recruited through online social media advertisements and via posters placed around a college campus and a local community in South Korea. The participants were interviewed by the researchers to confirm they met the inclusion criteria, which were as follows: age 19–30 years, body mass index <25 kg/m^2 and good health with no reported history of major physical discomfort or psychological symptoms that prevented their participation in the tests. This latter criterion was assessed by the following questions: "Do you suffer from any illness or injury of a physical or psychological nature that impairs your functioning in everyday life?"; "Have you ever had one of the following diseases or symptoms diagnosed by a doctor or self-reported: pregnancy, vertebral pathology (e.g., tumour, fracture or infection), cancer, lumbar surgery, psychiatric diagnosis, balance impairment related to dizziness, neurological disorder (e.g., spinal cord injury or central nervous system diseases), or chronic pain in the lower back and lower extremities for at least 3 months during the past year?"; and "Have you ever experienced discomfort while performing the plank or while walking or cycling quickly?" Only the participants who answered "no" to all questions were included in the study. All experimental procedures were explained prior to study participation, and written consent forms were obtained from all participants. This study was approved by the university's institutional review board (jjIRB-210114-HR-2021-0113).

2.2. Instruments

2.2.1. Strength Measurement System

A tensiometer (Smart KEMA pressure sensor; Factorial Holdings, Seoul, Korea) was used to measure the isometric strength of the hip abductor. The tensiometer measured 65 × 83 × 28 mm and weighed 110 g. To measure hip abductor strength, a 5 cm wide non-elastic strap was attached to the distal lower leg, with an absorber as a fixation point for firm attachment to the floor in the side-lying position. The sampling frequency was 10 Hz. The data were transferred to a Galaxy tablet (A6 10.1; Samsung, Seoul, Korea) via Bluetooth and analysed using Smart KEMA software (Factorial Holdings).

2.2.2. Wireless Earbud-Type IMU Sensor

Frontal core motion during walking and cycling was measured using a high-resolution inertial measurement unit (IMU; BNO080; CEVA Technologies, Rockville, MD., USA) consisting of an accelerometer and a gyroscope embedded into a wireless earbud (QCY-T6; Dongguan Hele Electronics Co., Ltd., Dongguan, China) that was worn on the participant's right side. The size and weight of the IMU sensor were 36 × 15 × 7.5 mm and 8.2 g, respectively. The orientation of the accelerometer was aligned with the gravitational axis corresponding to the standing position. The collected data were sent via Bluetooth to a computer. The sampling rate was fixed at 100 Hz. The recorded data were used to estimate the frontal core angle, calculated using Matlab (version R2018a; MathWorks, Natick, MA, USA). Prior to the calculation, the accelerometer output was filtered through a low-pass filter. Before the measurement was started, off calibration was performed automatically for 1 s. During the calibration period, 100 data samples were collected while the participant remained stationary.

2.3. Procedure

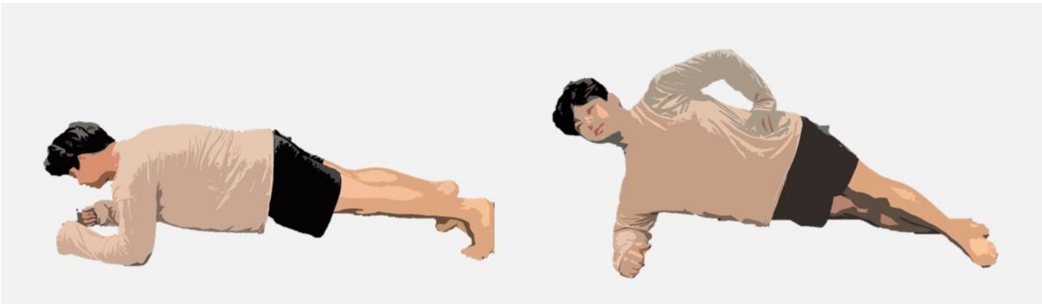
The experiments were conducted in a university laboratory in South Korea from February 2021 to January 2022. The experimental procedure consisted of four sessions that included the following: (1) baseline measurements and warm-up, (2) core muscle endurance test, (3) hip abductor strength test and (4) speed and frontal core motion tests during treadmill walking and indoor cycling. The experiment took about 80 min to complete, and each session took 20 min. The sequence of the experimental procedures after the warm-up was randomised using Excel (Microsoft Corp., Redmond, WA, USA), with a passive rest between sessions to minimise the fatigue effects arising due to repetitive exercising. The tests for strength, speed and frontal core motion were completed by one examiner, who was blinded to the core muscle endurance test.

2.3.1. Baseline Measurements and Warm-up

Baseline information on demographic characteristics (gender, height, weight, body mass index and weekly workout time) was collected. Each participant was asked to report the total weekly workout time including the number of days a week and the duration of each workout period [23]. Participants wore their own shoes and conducted a 5 min indoor cycling session for the warm-up, followed by 5 min of passive rest.

2.3.2. Core Muscle Endurance Test

The participants' core muscle endurance was assessed using the prone and side plank tests, with the order randomised to minimise the fatigue effects. The endurance times from the three plank tests (prone, left and right sides) were summed for data analysis [24]. In the prone plank test, the participants were prone, with their elbows in contact with the ground, such that the humerus was perpendicular to the horizontal plane, directly beneath the shoulders. The elbows were spaced shoulder-width apart, and the feet were close together. The participants were then instructed to raise the pelvis from the floor so that only the forearms and toes were in contact with the floor, while the shoulders, hips and ankles were maintained in a straight line (Figure 1a) [24]. In the side plank test, the participants lay on their sides with their legs extended. The upper foot was placed in front of the lower foot for support. Support was maintained using one elbow and one foot, and the hips were raised up from the floor, with the maintenance of a straight line along the lateral sides of the trunk and lower legs. The top arm was held across the chest with the hand placed on the opposite shoulder (Figure 1b) [21,25]. During the plank tests, the participants were asked to maintain the positions for as long as possible. The timer was stopped when the participant could no longer maintain a straight line between the trunk and the hip. Each plank test was performed once. To avoid muscle fatigue, a 5 min passive rest without any recovery exercise was allowed between each plank test.

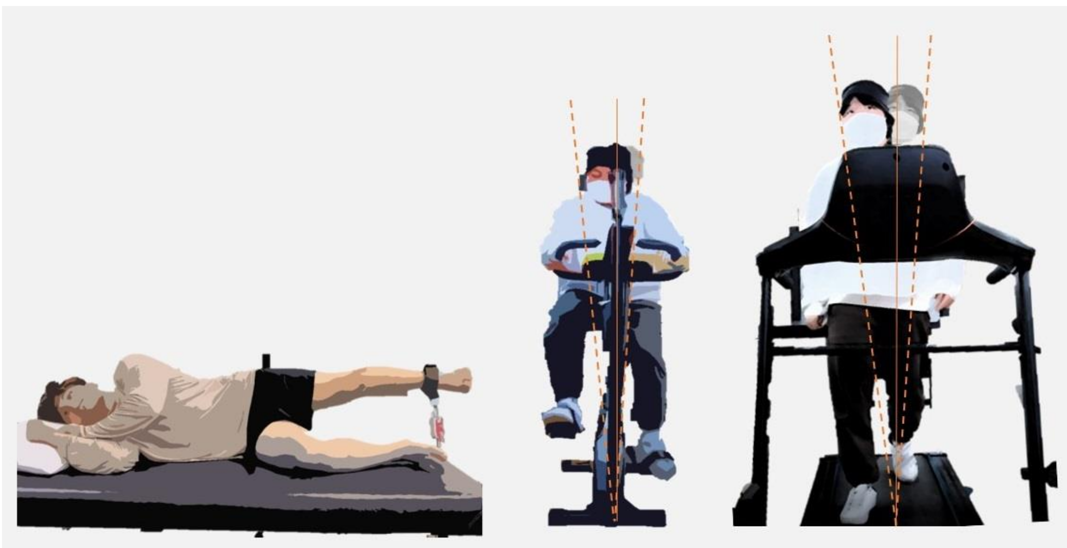


(**a**) (**b**)

Figure 1. Core muscle endurance tests: (**a**) prone plank test and (**b**) side plank test.

2.3.3. Hip Abductor Strength Test

The maximal isometric strength of the hip abductors was measured on each side using a tensiometer with a non-elastic band (smart KEMA pressure sensor; Factorial Holdings Co., Seoul, Korea), with participants lying on their sides. The pelvis was held to minimise compensatory pelvic elevation and rotation during the test. The participants were asked to extend the hip and knee on the tested side, with a 10° hip abduction. The hip and knee on the non-tested side were flexed slightly. The duration of the contractions was 5 s, and each contraction was repeated three times with a 30 s passive rest between repetitions. Both sides were tested, with a 5 min passive rest before switching the side (Figure 2a) [26].



(**a**) (**b**) (**c**)

Figure 2. Symmetry tests: (**a**) symmetry of abductor strength in both hips; (**b**) symmetry of frontal core motion using a wireless earbud sensor during indoor cycling at fast speed; and (**c**) symmetry of frontal core motion using a wireless earbud sensor during treadmill walking at fast speed.

2.3.4. Speed and Frontal Core Motion Tests during Treadmill Walking and Indoor Cycling

A wireless earbud-type IMU sensor was used in these tests because the wireless earbud is a popular wearable device that is commonly used to listen to music during workouts and because it is worn closer to the trunk than other popular wearable devices, such as smartwatches [27]. The assessment of core motion in the frontal plane using an earbud-type IMU sensor has been shown to be valid compared with the use of a 3D motion analysis system, and the data correlate with trunk motion during home workout activities [27]. Frontal core motion data were collected during 60 s of walking or cycling.

Indoor Cycling at a Fast Speed

The participants cycled at a self-selected fast speed on an indoor stationary bicycle. Each participant adjusted the cycle seat height to a comfortable position. Before data collection, the participants were allowed 3 min to become familiar with the self-selected fast speed. They were instructed to 'cycle as fast as possible' [28]. After a 60 s passive rest, the participants cycled for 1 min. During cycling, they held the front handlebars with both hands and fixed their gazes on the cycle's speedometer (Figure 2b).

Treadmill Walking at a Fast Speed

The participants walked for 3 min on a treadmill to determine their self-selected fast walking speed. The verbal instructions that they received were 'walk as fast as possible without running'. The participants switched the treadmill on and then gradually increased the speed by 0.5 km/h until their fast walking speed was selected [28]. After 60 s of passive rest, the participants walked on the treadmill for 1 min. While walking, they fixed their gaze on the front tablet at eye level (Figure 2c).

2.4. Data Analysis

Regarding the frontal core motion data, the middle 50 s of the 60 s walk or cycle were analysed, excluding the 5 s initial and final deceleration phases. A symmetry index (SI) was used to quantify the asymmetry of the right and left sides for the side plank test, hip abduction strength and frontal core motion during walking and cycling, using the formula [29]:

$$\text{Symmety Index} = 100 - \left| 100 \times \frac{Right\ side - Left\ side}{Right\ side + Left\ side} \right|$$

The SI was expressed as a percentage, with a value of 100 indicating absolute symmetry, and lower values indicating greater asymmetry between the right and the left sides.

2.5. Statistical Analysis

All variables were summarised with standard descriptive statistics, including the mean and standard deviation (SD). Normality was confirmed using the Shapiro–Wilk test. Independent t-tests or the Mann–Whitney U test were used to compare the variables between genders. Univariate regression analysis was used to examine the relationships between core muscle endurance time and each independent variable. i.e., gender, weekly workout time, fast walking and cycling speeds, SIs for hip abduction strength, side plank endurance time and frontal core motion during fast walking and cycling. A multiple regression analysis using stepwise selection was performed to determine which of the following factors had the greatest influence on core muscle endurance time after adjusting for gender: weekly workout time, fast walking and cycling speeds and SIs for hip abduction strength, SIs for side plank endurance time and SIs for frontal core motion during fast walking and cycling. All models were adjusted for gender. SPSS (version 25.0; IBM Corp., Armonk, NY, USA) was used for the statistical analyses. The alpha level was set to 0.05.

3. Results

This study enrolled 79 healthy young adults (31 males and 48 females, mean ± SD age, 21.80 ± 2.78 years; body mass index, 21.42 ± 2.11 kg/m^2). Table 1 presents the participants' characteristics and compares the variables between genders. The mean and SD for all variables were significantly greater for males than for females ($p < 0.05$), except the SI for frontal core motion during fast walking ($p = 0.18$). Table 2 provides the descriptive data for the right and left sides obtained before calculating the SIs using the formula.

Table 1. Descriptive statistics for variables by gender and overall.

Variables	Males (*n* = 31)	Females (*n* = 48)	Total (*n* = 79)	*p* Value
Core muscle endurance time, s	260.81 ± 63.29	185.99 ± 81.99	215.35 ± 83.33	0.01
Weekly workout time, min	365.32 ± 195.48	235.46 ± 264.56	286.40 ± 246.87	0.01
Fast walking speed, km/h	6.42 ± 1.20	5.24 ± 1.02	5.70 ± 1.23	0.01
Fast cycling speed, km/h	39.87 ± 3.87	35.61 ± 4.32	37.28 ± 4.63	0.01
SI * for the side plank endurance time, %	91.10 ± 8.48	86.02 ± 12.07	88.01 ± 11.03	0.04
SI for hip abduction strength, %	94.49 ± 3.55	91.65 ± 5.83	92.76 ± 5.23	0.04
SI for frontal core motion during fast walking speed, %	79.18 ± 18.40	70.25 ± 24.52	73.75 ± 22.62	0.18
SI for frontal core motion during fast cycling speed, %	75.71 ± 19.44	59.89 ± 30.13	66.10 ± 27.44	0.01

* SI, symmetry index. Values are presented as mean ± SD.

Table 2. Descriptive data on both sides for the variables that were calculated using the symmetry index.

Variables	Mean ± SD
Side plank endurance time (left/right), s	65.33 ± 31.50/64.14 ± 28.00
Hip abduction strength (left/right), kgf	11.44 ± 4.45/11.67 ± 4.50
Frontal core motion during fast walking speed (left/right), °	5.89 ± 3.30/5.91 ± 2.34
Frontal core motion during fast cycling speed (left/right), °	12.30 ± 18.30/12.51 ± 11.79

Table 3 presents the results of the univariate linear regression analyses. Gender was significantly associated with the core muscle endurance time. All other variables, except SI for frontal core motion during fast walking, were also significantly associated with the core muscle endurance time (Table 3).

Table 3. Results of univariate regression analyses with core muscle endurance.

Independent Variable	ß Coefficient *	95% CI	*p*
Gender	74.82	40.29, 109.35	0.00
Weekly workout time, min	0.16	0.09, 0.23	0.00
Fast walking speed, km/h	31.48	17.89, 45.07	0.00
Fast cycling speed, km/h	8.61	5.02, 12.20	0.00
SI # for hip abduction strength, %	4.96	1.52, 8.40	0.01
SI for side plank endurance time, %	2.92	1.34, 4.50	0.00
SI for frontal core motion during fast walking speed, %	0.62	−0.02, 1.45	0.14
SI for frontal core motion during fast cycling speed, %	0.94	0.29, 1.60	0.01

* ß coefficient represents the estimated change in seconds in core muscle endurance time for 1 unit. change in the independent variable. # SI, symmetry index.

Five models were built from the multiple stepwise regression analysis after adjusting for gender. The final model explained 42% of the variance in core muscle endurance and included four variables: weekly workout time, SI for the side plank endurance time, fast walking speed and SI for frontal core motion during fast cycling (Table 4). Three non-significant variables were not included in the final model: fast cycling speed (ß Coefficient = 0.14, $p = 0.18$), the SI for hip abduction strength (ß Coefficient = 0.14, $p = 0.14$) and the SI for frontal core motion during fast walking speed (ß Coefficient = 0.01, $p = 0.94$).

Table 4. Results of stepwise multivariate regression analyses with core muscle endurance, adjusted for gender.

Selected Variables in the Final Model	R^2	ΔR^2	Standardized ß *	t	*p*
Gender			0.16	1.54	0.13
Weekly workout time, min			0.33	3.61	0.00
SI # for the side plank endurance time, %	0.46	0.42	0.20	2.19	0.03
Fast walking speed, km/h			0.22	2.11	0.04
SI for frontal core motion during fast cycling speed, %			0.19	2.06	0.04

* Standardized ß coefficient represents the magnitude of the contribution that each predictor variable makes to maximally predicting the core muscle endurance time in the regression model. # SI, symmetry index.

4. Discussion

This study examined the associations between factors related to a home workout setting and core muscle endurance and identified predictors of core muscle endurance with adjustment for gender. Males had greater core muscle endurance, longer weekly workout times, higher speeds, higher SIs for side plank endurance time and greater hip abduction strength and frontal core motion during fast cycling than females (Table 1). A previous study also demonstrated gender differences; specifically, males had better hip muscle strength and core muscle endurance times [25]. In addition, univariate analyses showed significant relationships between gender and all variables, except for the symmetry of core motion during fast walking (Table 3). However, this gender difference did not remain after adjusting for other covariates, indicating the major confounder of the gender–core muscle endurance relationship (Table 4). In line with the current study, gender was a potential confounder in a previous multiple regression analysis of factors influencing back muscle endurance [10].

In the current study, symmetry of frontal core motion during fast cycling, symmetry of the side plank endurance time, fast walking speed and weekly workout time accounted for 42% of the variance in core muscular endurance (Table 4). In a previous regression model, perceived self-efficacy, sitting trunk angle, weekly workout time and duration of daily TV use accounted for 15% of the variance in back muscle endurance [10]. In another study, body mass index, fat mass and body fat percentage accounted for 29–37% of the variance in core muscular endurance [30]. Our study included variables related to the symmetry of core motion, symmetry of lateral core endurance and walking speed, which were not considered as independent variables in the previous regression analysis. This increased the power to predict core muscle endurance relative to previous studies.

The symmetry of frontal core motion during fast cycling (mean $\pm$ SD, 66.10 $\pm$ 27.44%) contributed to core muscle endurance (mean $\pm$ SD, 215.35 $\pm$ 83.33 s) (Tables 1 and 4). Among the cyclists (8 males and 10 females) participating in the previous study, asymmetrical lower lumbar rotation was observed at the initial and final phases of indoor cycling in those with lower back pain compared with healthy cyclists [17]. Asymmetrical activation of the multifidus in the lower lumbar region was also observed during indoor cycling in cyclists with lower back pain [17]. Asymmetrical trunk motion in the frontal plane might have occurred in association with asymmetrical core muscle activation in our study. Along with asymmetrical trunk motion and core muscle activation, asymmetrical pedalling was observed in non-professional and professional cyclists with low core stability and body asymmetry, as measured using a functional movement screening test [31,32]. The above findings, together with those of the current study, indicate that core muscle endurance can be predicted from the asymmetry of the trunk in the frontal plane during fast cycling.

The final regression model included the SI for side plank endurance time (Table 4). This result means that the side plank symmetry contributed significantly to the core muscle endurance time, in contrast to the findings of a previous study in which the symmetry of the side plank endurance time was not determined [25]. The difference between these studies is that the body was supported by the elbow and one foot in the latter [25] and by the elbow and both feet, with the top foot placed in front of the lower foot to provide additional support, in our study. In addition, the participants in the previous study were healthy, physically active Navy cadets [25]. The weekly workout times of our participants ranged from 0 to 1050 min (mean $\pm$ SD, 286.40 $\pm$ 246.87 min) and contributed significantly to the core muscle endurance time (Tables 1 and 4). Previous regression and correlation analyses support our finding that the weekly workout time is associated with core muscle endurance; specifically, a longer weekly workout time had a positive correlation with core muscle endurance [10]. Therefore, the symmetry of the side plank endurance time along with the weekly workout time should be considered when assessing the core performance.

In a multiple regression analysis, fast walking speed was identified as a factor influencing the core muscle endurance (Table 4). A previous study demonstrated that gradually increasing the walking speed to 2, 3, 4, 5 and 6 km/h induced a greater activation of the core muscles (the rectus abdominis and internal and external obliques), indicating that greater core muscle contraction is necessary when the walking speed is increased [33]. The results of this and previous studies suggest that fast walking can be achieved with the improvement of core performance [13,33]. Clinicians and sports trainers should thus recommend fast walking to improve core muscle endurance.

The limitations of this study must be taken into account. First, the participants were healthy and young. Whether the results of this study also apply to the core muscle endurance of participants of different ages or with musculoskeletal disorders is unclear. Second, both males and females were included in the current study, and there was a gender difference in core muscle endurance time, among other variables. Although the regression analysis was adjusted for gender, a future study should investigate the factors contributing to core muscle endurance in each gender. Lastly, the study's cross-sectional design hindered the determination of whether an improvement in walking speed or the symmetry of frontal core motion during cycling improves core muscle endurance.

5. Conclusions

This study showed that core muscle endurance times were related to fast walking speed, weekly workout time, symmetry of frontal core motion during fast cycling and symmetry of side plank endurance times. Given that symmetry, speed and weekly workout time are associated with the core muscle endurance time, healthcare providers should adequately evaluate the symmetry of frontal core motion during cycling and side plank endurance in individuals who want to improve their core muscle endurance, as well as the weekly workout time and fast walking speed.

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Institutional Review Board Statement: The study was conducted according to the guidelines of the Declaration of Helsinki and approved by the Institutional Review Board of Jeonju University (jjIRB-210114-HR-2021-0113).

Informed Consent Statement: Informed consent was obtained from all participants involved in the study.

Data Availability Statement: The data presented in this study are available on request from the corresponding author, as they contain data from human volunteers.

Conflicts of Interest: The authors declare no conflict of interest.

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