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Effects of Toe-Strengthening Exercises on Medial Longitudinal Arch Height, Muscle Stiffness, and Functional Movement

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Abstract: Background: Prolonged training in combat boots can place significant stress on the medial longitudinal arch, potentially leading to lower-extremity muscle stiffness and an increased risk of injury. This study assessed the impact of toe-strengthening exercises on improving the lower-extremity function and functional movement in cadets undergoing training. Methods: Forty junior cadets (mean age: 22.6 years) participated in this study. The measurements included the medial longitudinal arch height, lower-extremity muscle stiffness, functional movement, and leg length. Results: Cadets who performed the toe exercises demonstrated improved lower-extremity muscle stiffness and functional movement performance (hurdle step, $p = 0.010$; rotary stability, $p = 0.001$). A significant correlation was observed between the exercise group and time (tibialis right, $p = 0.008$; tibialis left, $p = 0.028$). Conclusions: This study highlighted the potential of toe-strengthening exercises to enhance the lower-extremity function and reduce the risk of injury among cadets. However, challenges in identifying the medical history, past injuries, and specific areas of pain for each cadet were noted. These findings support the implementation of targeted toe exercises in military training programs to prevent injuries.

Keywords: toe exercise; medial longitudinal arch; lower-extremity muscle stiffness; functional movement; lower limb

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1. Introduction

The foot, as the distal part of the limb, supports the body weight, facilitates movement, and plays a critical role in locomotion. It consists of various anatomical structures, including bones, muscles, tendons, joints, ligaments, nerves, and blood vessels, and features three arch structures: the medial longitudinal arch (MLA), the lateral longitudinal arch, and the anterior transverse arch. These arches are crucial for shock absorption during activities such as walking and running [1]. In particular, the MLA is significant for forming the instep and primarily absorbing and dispersing shocks applied to the foot [2]. This arch facilitates proper lower-extremity function during the gait cycle and plays an essential role in shock absorption and propulsion during walking. Congenital deformities or acquired trauma affecting any element of the MLA can lead to varying degrees of clinical consequences [3].

The feet, used daily and subject to various stressors, are prone to numerous diseases due to morphological reasons, overuse, and other factors. Musculoskeletal injuries (MSKIs) to the foot are common, especially in soldiers, who frequently overuse their feet, accounting

for 80% of all injuries during military training [4]. Plantar fasciitis and Achilles tendonitis are particularly prevalent, with stress fractures also commonly originating in the feet [5]. Such damage often results from the stiffness of soft tissues, including muscles and fascia, due to the prolonged use of heavy shoes and overuse [6,7]. Overuse or weakening of the internal and external foot muscles can lower the height of the MLA, increasing tension in the foot's muscles and connective tissues [8].

For healthy foot function, it is important to maintain the height of the medial longitudinal arch. It is known that the foot's intrinsic muscles interact with the extrinsic muscles, fascia, and ligaments to maintain arch height and contribute to stability [9]. Due to their characteristics, soldiers spend a long time wearing hard combat boots. However, due to the military performing combat and missions, not many studies have verified the efficacy of toe exercises in soldiers and compared them to human asymmetry, and studies conducted especially on Asian soldiers have not been documented to the best of our knowledge. Therefore, this study assessed the impact of toe-strengthening exercises on improving the lower-extremity function and functional movement in cadets undergoing training.

The hypotheses of this study are as follows.

1. Cadets living in combat boots will have a difference in the height of the medial longitudinal arch and an imbalance in the lower extremities.
2. Toe exercises will alleviate the height and muscle tension of the medial longitudinal arch, causing positive changes in improving the lower extremity imbalance.

2. Materials and Methods

2.1. Participation

Before commencing this study, approval was obtained from the Institutional Bioethics Committee of the Air Force Aerospace Medical Center (ASMC-23-IRB-003), and the person in charge explained the research process to the participants, who then signed a consent form. This study was conducted according to the principles of the Declaration of Helsinki.

The participants in this study were 40 male 3rd-year cadets from the Air Force Academy, who voluntarily participated. These cadets were part of the 2023 summer military training program (lasting 4 weeks). The inclusion criteria were as follows: (1) those who were not excluded from the 3rd-year summer military training program (4 weeks), and (2) those who could perform the toe-strengthening exercises. The exclusion criteria were as follows: (1) those who experienced cardiovascular or cardiopulmonary dysfunction, (2) those who had experienced musculoskeletal injuries over the past six months, and (3) those who were participating in other types of lower body strengthening exercise programs. The sample size was calculated using G* Power software, version 3.1.9.7 (Heinrich Heine University, Düsseldorf, Germany). By setting $\alpha = 0.05$ and $\beta = 0.80$, the sample size was calculated to be 34 people. Allowing for possible dropout, 40 people were recruited. They were randomly grouped by selecting a piece of paper from an opaque box with A and B written on it: A, control (Con), n = 20; B, toe-strengthening exercise (Ex), n = 20. During participation, there were no withdrawals from the experiment. The intraclass correlation coefficient (ICC) of the NDT was the following: single measure during non-weight-bearing ICC (2,1) = 0.955, $p < 0.001$; average measure during non-weight-bearing ICC (2,1) = 0.984, $p < 0.001$; single measure during weight-bearing ICC (2,1) = 0.986, $p < 0.001$; and average measure during weight-bearing ICC (2,1) = 0.995, $p < 0.001$. The characteristics of the study participants are shown in Table 1.

Table 1. Participant characteristics: baseline characteristics of the exercise and control groups (mean ± SD), including age, height, weight, BMI, and leg length.

Variable	Ex (n = 20)	Con (n = 20)	t	*p*
Height (cm)	173.26 ± 4.25	174.18 ± 4.47	−0.663	0.988
Weight (kg)	71.21 ± 7.36	69.92 ± 8.87	0.498	0.797
Skeletal muscle mass (kg)	33.75 ± 3.75	34.00 ± 4.14	−0.204	0.809
Fat mass (kg)	11.87 ± 2.67	10.27 ± 3.69	1.569	0.509
Body fat (%)	16.61 ± 2.88	14.50 ± 4.25	1.839	0.281
Body mass index (kg/m^2)	23.70 ± 2.05	23.02 ± 2.57	0.916	0.376

Values are means ± SDs; EX, exercise group; CON, control group.

2.2. Toe-Strengthening Exercise Program

The toe-strengthening exercise program is shown in Figure 1. The toe-strengthening exercise program (type of exercise, exercise intervention, repetitions, and sets), modified from our previous study [10,11], consisted of 3 items with 5 sets per exercise item, conducted 3 times a week for 4 weeks [11,12]. Before the start of the exercise, direct training was conducted on the exercise method. In the Toe-Curl Exercise (A), while the subject was sitting, the heel was placed on the floor, the instep was bent about 30°, and all the toes were kept flexed for 5 s, and then returned to the original state. In the Toe-Spread Exercise (B), the participants were asked to place their heels on the floor in a sitting state, bend their insteps about 30°, keep all the toes apart for 5 s, and then return to their original position. In the Toe-Spread-Out Exercise (C), the subject sat on a chair, dorsiflexed the ankle joint by 30°, stretched all the toes, and put the fifth toe laterally, and the first toe inward on the ground for 5 s [13]. All the exercises were performed in 5 sets of 10 repetitions, 3 times a week for 4 weeks.



Figure 1. A toe-strengthening exercise program designed to enhance the medial longitudinal arch and improve lower extremity function: (**A**) (**a**) 30 degree dorsiflexion, (**b**) hold for 5 s after toe flexion, (**c**) return to original state, Toe-Spread Exercise; (**B**) (**a**) 30 degree dorsiflexion, (**b**) hold for 5 s after toe spread, (**c**) return to original state, Toe-Spread-Out Exercise; and (**C**) (**a**) relax, (**b**) lifting the toe, (**c**) flexing little toe toward lateral side, (**d**) hold for 5 s after flexing great toe toward medial side.

2.3. Medial Longitudinal Arch (MLA) Height Measurement

The MLA height was measured using the navicular drop test (NDT). The NDT was first described by Brody in 1982 as a means of quantifying the amount of foot pronation in runners [14]. The NDT is a representative measurement method that can determine the damage and weakness of the musculoskeletal system that reduces the height of the MLA [15]. The intraclass correlation coefficient of the NDT was ICC (2,1) = 0.955, $p < 0.001$ for the single measure, and ICC (2,1) = 0.984, $p < 0.001$ for the average measure during non-weight-bearing. During weight-bearing, the single measure ICC (2,1) = 0.986, $p < 0.001$, and the average measure ICC (2,1) = 0.995, $p < 0.001$ were found.

For the specific weight-bearing measurement, the participants sat on a chair, spread their feet shoulder-width apart, flexed the knee joint 90°, and maintained the neutral position of the subtalar joint. For all the measurements, the average value was determined after measuring three times each on the left and right sides using a Martin-type anthropometer (PMII, TTM, Tokyo, Japan) [16].

2.4. Lower-Extremity Muscle Stiffness

The lower-extremity muscle stiffness was measured using a muscle tone measuring instrument (Myoton AS, Tallinn, Estonia) (Figure 2). The MyotonPRO is a device suitable for measuring the energetic stiffness of soft tissue [13]. The measurement targets were the tibialis anterior, fibularis longus, gastrocnemius, Achilles tendon, and plantar fascia [10]. The tibialis anterior, fibularis longus, and plantar fascia were measured in the supine position, and the gastrocnemius and Achilles tendons were measured in the prone position [17]. The average value was used after three measurements and remeasured when the error range was 3% or more. Among the five measurement variables (frequency, stiffness, decrease, relaxation, and creep) of the MyotonPRO, the stiffness, which represents biomechanical characteristics, was used as data.



Figure 2. MyotonPRO device used for measuring lower-extremity muscle stiffness. The MyotonPRO provides quantitative data on muscle stiffness, which is crucial for understanding the biomechanical properties of the muscles and their response to training interventions.

2.5. Functional Movement Screen (FMS) Measurement

Before the Functional Movement Screen (FMS) measurement, participants were trained in 7 movements. Using a dedicated kit (Functional Movement Screen Test Kit, Functional Movement Systems, Inc., Chatham, VA, USA), 7 movements (deep squat, hurdle step, inline lunge, shoulder mobility, active straight leg raise, trunk stability push up, rotary stability) were measured. The FMS score was given out of 21 points by assigning 0 to 3 points for

each motion. For all the measurements, the average value was used after measuring twice and recording using two cameras (front and side) [15].

2.6. Leg Length Measurement

The functional/structural leg length test was used to measure the leg length. The study participants were asked to spread both legs about 15 to 20 cm apart in a supine position with light clothing and keep their legs stretched. The functional leg length test was measured from the belly button to the medial malleolus, and the structural leg length test was measured from the anterior superior iliac spine (ASIS) to the medial malleolus [12]. The average value was used after measuring three times each on the left and right sides using a Martin-type anthropometer (PMII, TTM, Tokyo, Japan).

2.7. Statistical Analysis

All the results are reported as the mean ± standard deviation. All the data were analyzed using SPSS version 26.0 (SPSS Inc., Chicago, IL, USA). First, a two-way repeated ANOVA was conducted to determine the difference between the groups and time. A Scheffe test was used for the post hoc analysis. Statistical significance was accepted at $p < 0.05$.

3. Results

A total of 40 male cadets (exercise group, n = 20; control group, n = 20) participated in this study. The characteristics of the participants are listed in Table 1. The intraclass correlation coefficient (ICC) of the NDT was the following: single measure during non-weight-bearing ICC (2,1) = 0.955, $p < 0.001$; average measure during non-weight-bearing ICC (2,1) = 0.984, $p < 0.001$; single measure during weight-bearing ICC (2,1) = 0.986, $p < 0.001$; and average measure during weight-bearing ICC (2,1) = 0.995, $p < 0.001$.

3.1. Results of the Medial Longitudinal Arch (MLA) Height Measurement

The results of the MLA height measurements are shown in Table 2. The measurements indicated that the exercise group exhibited an increased MLA height under the non-weight-bearing and weight-bearing conditions. However, these differences were not statistically significant. The group engaging in toe exercises exhibited an increased height in the MLA under both non-weight-bearing and weight-bearing conditions, although these differences were not statistically significant.

Table 2. Medial longitudinal arch (MLA) height: changes in the MLA height (non-weight-bearing and weight-bearing) for the exercise and control groups before and after the intervention, with *p*-values for the group and time comparisons.

Variable	Group	Pre	Post	Group and Time	*F*	*p*
NWL	EX (n = 20)	54.80 ± 4.11	57.05 ± 3.36	G: T:	0.037 0.817	0.848 0.369
	CON (n = 20)	55.05 ± 4.67	55.45 ± 4.07	G × T	2.438	0.123
NWR	EX (n = 20)	54.95 ± 3.81	57.30.3.31	G: T:	0.063 1.713	0.803 0.194
	CON (n = 20)	55.90 ± 4.59	55.91 ± 4.21	G × T	1.713	0.194
WL	EX (n = 20)	49.90 ± 3.16	51.40 ± 3.56	G: T:	2.482 0.600	0.119 0.441
	CON (n = 20)	49.20 ± 4.89	49.15 ± 4.84	G × T	0.685	0.410
WR	EX (n = 20)	49.85 ± 2.94	51.40 ± 3.80	G: T:	1.990 1.063	0.162 0.306
	CON (n = 20)	49.15 ± 4.88	49.50 ± 4.58	G × T	0.424	0.517

Values are means ± SDs; EX, exercise group; CON, control group; NWL, non-weight load left; NWR, non-weight load right; WL, weight load left; WR, weight load right; G, group; T, time; G × T, group and time.

3.2. Results of the Lower-Extremity Soft Tissue Stiffness Measurement

The results for the lower-extremity soft tissue stiffness measurement are shown in Table 3. Significant differences were observed in the left tibialis anterior for group × time (p = 0.008); right tibialis anterior for time (p = 0.015) and group × time (p = 0.028); left plantar fascia between the groups (p = 0.001) and group × time (p = 0.003); and right plantar fascia for between the groups (p = 0.019) and group × time (p = 0.005). Other factors generally showed lower stiffness levels in the exercise group; however, these differences were not statistically significant.

Table 3. Lower-extremity muscle stiffness: muscle stiffness measurements in both groups pre- and post-intervention, with significant group × time interactions.

Variable (Stiffness, N/m)	Group	PRE	POST	Group and Time	*F*	*p*
Tibialis Anterior (Left)	EX (n = 20)	545.50 ± 47.24	493.85 ± 46.48	G	0.001	0.978
				T	3.795	0.055
	CON (n = 20)	515.75 ± 47.63	524.20 ± 56.33	G × T ##	7.345	0.008
Tibialis Anterior (Right)	EX (n = 20)	539.60 ± 48.07	485.90 ± 45.55	G	2.854	0.095
				T **	6.183	0.015
	CON (n = 20)	533.30 ± 47.30	530.55 ± 60.69	G × T #	5.037	0.028
Fibularis Longus (Left)	EX (n = 20)	483.05 ± 50.40	449.01 ± 47.54	G	1.799	0.184
				T	3.213	0.077
	CON (n = 20)	454.11 ± 44.45	447.87 ± 58.58	G × T	1.492	0.226
Fibularis Longus (Right)	EX (n = 20)	481.50 ± 63.73	436.55 ± 61.99	G	0.834	0.364
				T	2.553	0.114
	CON (n = 20)	445.70 ± 55.57	447.95 ± 55.75	G × T	3.119	0.081
Gastrocnemius (Left)	EX (n = 20)	332.25 ± 45.55	303.45 ± 41.74	G	1.277	0.262
				T	2.737	0.102
	CON (n = 20)	330.55 ± 41.9	327.15 ± 45.42	G × T	1.703	0.196
Gastrocnemius (Right)	EX (n = 20)	343.85 ± 36.47	313.65 ± 36.97	G	0.039	0.844
				T	2.176	0.144
	CON (n = 20)	325.30 ± 45.50	328.60 ± 43.36	G × T	3.376	0.070
Achilles Tendon (Left)	EX (n = 20)	627.85 ± 77.47	613.75 ± 68.02	G	0.001	0.979
				T	0.873	0.353
	CON (n = 20)	628.45 ± 73.64	612.37 ± 71.43	G × T	0.004	0.950
Achilles Tendon (Right)	EX (n = 20)	628.41 ± 66.74	591.60 ± 59.07	G	1.980	0.164
				T	2.409	0.125
	CON (n = 20)	635.45 ± 73.11	626.25 ± 65.40	G × T	0.867	0.355
plantar Fascia (Left)	EX (n = 20)	487.30 ± 44.88	457.31 ± 38.47	G +++	10.969	0.001
				T	0.001	0.973
	CON (n = 20)	489.90 ± 45.10	519.25 ± 45.56	G × T ##	9.273	0.003
plantar Fascia (Right)	EX (n = 20)	486.25 ± 51.33	459.35 ± 44.51	G+	5.735	0.019
				T	0.112	0.738
	CON (n = 20)	481.30 ± 46.02	515.35 ± 48.72	G × T ##	8.175	0.005

Values are means ± SDs; +++ $p < 0.001$ by groups; ** $p < 0.01$ by time; # $p < 0.05$, ## $p < 0.01$ by time; EX, exercise group; CON, control group; G, group; T, time; G × T, group and time; stiffness, N/m.

3.3. Results of the FMS and Leg Length Measurements

The results of the FMS and leg length tests are shown in Table 4. For deep squats, a statistically significant difference was observed over time (p = 0.045). The hurdle step showed significant differences between the groups (p = 0.010), time (p = 0.003), and group × time (p = 0.010). The active straight leg raise showed significant differences between the groups (p = 0.021) and time (p = 0.008). Other factors indicated that the exercise group scored

higher in the inline lunge than the control group; however, these differences were not statistically significant.

Table 4. Functional Movement Screen (FMS) and leg length: FMS scores and leg length results for the exercise and control groups pre- and post-intervention, highlighting significant changes between groups and over time.

Variable	Group	PRE	POST	Group and Time	*F*	*p*
Deep Squat	EX (n = 20)	1.80 ± 0.83	2.10 ± 0.64	G	1.201	0.277
				T *	4.143	0.045
	CON (n = 20)	1.95 ± 0.75	1.60 ± 0.59	G × T	0.025	0.876
Hurdle Step	EX (n = 20)	1.00 ± 0.001	1.60 ± 0.59	G $^{++}$	6.946	0.010
				T **	9.701	0.003
	CON (n = 20)	1.55 ± 0.51	1.60 ± 0.50	G × T $^{\#\#}$	6.946	0.010
Inline Lunge	EX (n = 20)	1.10 ± 0.31	1.50 ± 0.51	G	1.652	0.203
				T	2.937	0.091
	CON (n = 20)	1.45 ± 0.60	1.45 ± 0.60	G × T	2.937	0.091
Shoulder Mobility	EX (n = 20)	1.80 ± 0.69	1.95 ± 0.60	G	11.700	0.001
				T	1.547	0.217
	CON (n = 20)	2.30 ± 0.86	2.55 ± 0.68	G × T	0.097	0.757
Active Straight Leg Raise	EX (n = 20)	1.50 ± 0.83	2.15 ± 0.67	G $^{+}$	5.592	0.021
				T **	7.303	0.008
	CON (n = 20)	1.40 ± 0.50	1.55 ± 0.60	G × T	2.853	0.095
Trunk Stability Push-Up	EX (n = 20)	1.40 ± 0.50	1.65 ± 0.58	G	16.334	0.001
				T	1.281	0.261
	CON (n = 20)	2.10 ± 0.79	2.20 ± 0.83	G × T	0.235	0.629
Rotary Stability	EX (n = 20)	1.15 ± 0.48	1.90 ± 0.59	G	1.361	0.247
				T ***	12.249	0.001
	CON (n = 20)	1.65 ± 0.48	1.65 ± 0.48	G × T $^{\#\#\#}$	12.249	0.001
Total Score	EX (n = 20)	9.75 ± 1.61	12.85 ± 1.75	G $^{++}$	7.756	0.007
				T ***	21.545	0.001
	CON (n = 20)	12.05 ± 2.52	12.95 ± 1.66	G × T $^{\#}$	6.517	0.013
Functional Leg Length (Left)	EX (n = 20)	98.85 ± 2.53	98.22 ± 1.96	G	0.580	0.449
				T	0.448	0.505
	CON (n = 20)	98.27 ± 2.89	98.07 ± 2.17	G × T	0.154	0.696
Functional Leg Length (Right)	EX (n = 20)	99.02 ± 2.41	98.10 ± 2.27	G	0.455	0.502
				T	1.095	0.299
	CON (n = 20)	98.22 ± 2.80	98.42 ± 2.06	G × T	0.195	0.660
Structural Leg Length (Left)	EX (n = 20)	93.65 ± 2.87	92.72 ± 2.30	G	0.932	0.338
				T	0.021	0.886
	CON (n = 20)	93.40 ± 3.05	93.15 ± 2.59	G × T	0.307	0.581
Structural Leg Length (Right)	EX (n = 20)	93.55 ± 3.13	92.80 ± 2.50	G	0.681	0.412
				T	0.681	0.412
	CON (n = 20)	93.87 ± 3.30	93.55 ± 2.62	G × T	0.106	0.745

Values are means ± SDs; $^{+}$ $p < 0.05$, $^{++}$ $p<0.01$, by groups; *$p < 0.05$, ** $p < 0.01$, *** $p < 0.01$ by time; $^{\#}$ $p < 0.05$, $^{\#\#}$ $p < 0.01$, $^{\#\#\#}$ $p < 0.001$ by time; EX, exercise group; CON, control group; G, group; T, time; G × T, group and time.

4. Discussion

This study investigated the efficacy of toe exercises in relieving muscle tension and improving lower limb imbalance among Air Force cadets undergoing 4 weeks of military training while wearing heavy combat boots. The toe exercises significantly contributed to the local stabilization of the foot owing to their anatomical and biomechanical contributions [18]. The MLA, a key structure in the foot, plays a critical role in shock absorption and proper lower-extremity function during the gait cycle [2]. Both extrinsic and intrinsic

foot muscles (IFMs) support the MLA within the active subsystem [19]. Specifically, IFMs such as the abductor hallucis, flexor digitorum brevis, and quadratus plantae play essential roles in directly stabilizing the arch by maintaining its height and flexibility [20].

The short-foot exercise (SFE) is a well-recognized exercise for strengthening the IFMs, involving the contraction of these muscles to pull the first metatarsophalangeal joint toward the calcaneus, thereby raising the MLA without flexing the toes [21]. Numerous studies have proposed SFE muscle-strengthening exercises as an effective approach to managing flat foot deformities [22]. Previous research has demonstrated that strengthening the foot muscles can reduce the navicular drop (ND) and improve the arch height, which is essential for distributing loads and absorbing shocks during movement [23].

Additionally, exercises targeting foot muscles can enhance performance in functional balance and reach challenges, which are critical for military personnel, who engage in rigorous physical activities [2]. Consistent with previous findings, this study confirmed that the height of the MLA improved in the group that performed toe exercises, although no statistically significant difference between the groups was observed. This result, although not statistically significant, is considered positive given the short duration of 4 weeks and the limited number of participants.

In the toe exercise group, the stiffness levels in the tibialis anterior and plantar fascia improved following the exercise regimen. The tibialis anterior is crucial for the dorsiflexion of the foot, and the plantar fascia is vital for supporting the arch and absorbing impact [24]. The alleviation of stiffness in the tibialis anterior and plantar fascia is primarily achieved through the restoration of mechanical elasticity and the improvement of neuromuscular coordination [25]. The stiffness of fascial and muscular tissues is mainly attributed to abnormal collagen fiber arrangement and reduced blood flow, both of which necessitate sustained mechanical stretching and exercise for resolution [26]. During this process, the realignment of collagen fibers is promoted, and the local blood flow increases, enhancing the oxygen supply and the removal of metabolic waste products [27].

Additionally, as neuromuscular coordination improves, tissue tension is relieved and functional recovery is facilitated. Toe-strengthening exercises can mitigate fascial stiffness by maintaining the arch of the foot and enhancing the functional roles of muscles associated with the plantar fascia [11]. These exercises activate the intrinsic muscles of the foot, reducing the tension on the plantar fascia and reinforcing the structural stability of the foot [28]. Through muscle activation, the pressure distribution across the foot becomes more balanced, reducing the excessive mechanical stress on the fascia and muscles, thereby contributing to the alleviation of stiffness [29]. Consequently, toe-strengthening exercises play a crucial role in reducing stiffness in the tibialis anterior and plantar fascia and improving biomechanical function during gait. The foot, with its intricate array of joints and articulations, plays a pivotal role in running and sprinting mechanics. Within this complex system, the IFM functions as a crucial local stabilizer that is integral to the active and neural subsystems, which are collectively referred to as the foot core [30]. These muscles play a key role in supporting the MLA, providing flexibility, stability, and shock absorption, and partially controlling pronation [31].

The FMS measurement results also support these findings. Lower-limb movements (deep squat, hurdle step, active straight leg raise) in the FMS showed that the toe exercise group demonstrated improved scores post-exercise. The FMS is a tool that focuses on exercises requiring mobility and stability. The improved FMS scores suggest an increased training effect in terms of injury prevention and exercise function [15]. Particularly, previous study confirmed the correlation between the G-test results of Air Force cadets, FMS, and lower extremity imbalance [32,33]. Therefore, the implementation of toe exercises for Air Force cadets with observed improved outcomes holds significant clinical importance.

In several previous studies, the effects of the short foot exercise, toe curl, and toe spread out exercise were verified as exercises to strengthen the intrinsic and extrinsic muscles of the foot, and the short foot exercise and toe spread out exercise activate the abductor muscle and the toe curl exercise is known to be mainly prescribed in the field of sports and

rehabilitation because it activates the toe flexor muscles to prevent lowering of the medial longitudinal arch and is effective in improving balance ability [34]. In this study, while the short duration and limited sample size of the study may have constrained the statistical significance of some findings, the observed trends suggest that toe exercises can positively influence the MLA height, lower-extremity stiffness, and functional movement. For further follow-up studies, it is necessary to develop an exercise manual optimized for soldiers' activities by dividing the type, frequency, time, and period of toe exercise. Further research with larger sample sizes and extended durations is warranted to substantiate these findings and fully elucidate the clinical benefits of toe exercises in the context of military training.

This study has some limitations, including the inability to thoroughly assess each cadet's medical history, past or present injuries, and specific pain areas. Future research should address these limitations by including a comprehensive medical history and a detailed analysis of pain and injuries. These follow-up studies can lead to more comprehensive and meaningful results by increasing the number of participants and adding an analysis of female cadets, further informing injury prevention strategies for military training.

5. Conclusions

This study provided valuable insights into the effects of toe exercises on the MLA, lower-extremity muscle stiffness, and limb imbalance. Although the sample size of the study was limited and did not encompass the entire cadet population, this is a pioneering approach to these specific physical metrics in cadets. The findings demonstrated significant improvements in muscle stiffness among those who performed toe exercises. Therefore, we recommend that the frequency and time of exercise are at least three times a week, at least 30 min, and people without certain conditions change in just four weeks. However, people with certain conditions are advised to exercise for at least eight weeks. In subsequent studies, it is necessary to advance further research by increasing the number of participants, such as diversifying the group of participants and measuring females. In addition, additional research is needed by differentiating the time and exercise intensity to efficiently identify toe-strengthening exercises in soldiers.

Author Contributions: All the authors were well informed of the WMA Declaration of Helsinki—Ethical Principles for Medical Research Involving Human Subjects—and confirmed that this study firmly fulfilled the Declaration. None of the authors has financial or private relationships with commercial, academic, or political organizations or people that may have improperly influenced this study. Overall planning of the research, data acquisition, analysis, and interpretation, and major drafting and revision of manuscript submission were performed by D.-H.J. Contributing to the data acquisition, analysis, and interpretation were H.-M.J. and D.-J.P. Provision of the anatomical and clinical opinion for conceptualization, overall organization, and direct supervision of the research were undertaken by J.-Y.S. and K.-L.L. All authors have read and agreed to the published version of the manuscript.

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References

1. Standring, S. *Gray's Anatomy: The Anatomical Basis of Clinical Practice*, 42nd ed.; Elsevier: Amsterdam, The Netherlands, 2020.
2. Zhao, X.; Tsujimoto, T.; Kim, B.; Tanaka, K. Association of arch height with ankle muscle strength and physical performance in adult men. *Biol. Sport* **2017**, *34*, 119–126. [CrossRef] [PubMed]
3. Babu, D.; Bordoni, B. Anatomy, Bony Pelvis and Lower Limb: Medial Longitudinal Arch of the Foot. In *StatPearls [Internet]*; StatPearls Publishing: Treasure Island, FL, USA, 2022.
4. Hearn, D.; Rhon, D.; Goss, D.; Thelen, M. Evaluation of a novel field expedient musculoskeletal readiness screening tool in an Army Basic Training population. *Mil. Med.* **2017**, *182*, e1862–e1868. [CrossRef] [PubMed]
5. Hauschild, V.D.; Barnes, S.; Hauret, K.; Lee, T.; Forrest, L.; Jones, B.H. The Etiology of Injuries in US Army Initial Entry Training. *US Army Med. Dep. J.* **2018**, *22*, 22–29.
6. Chiou, S.S.; Turner, N.; Zwiener, J.; Weaver, D.L.; Haskell, W.E. Effect of boot weight and sole flexibility on gait and physiological responses of firefighters in stepping over obstacles. *Hum. Factors* **2012**, *54*, 373–386. [CrossRef] [PubMed]
7. Mei-Dan, O.; Kahn, G.; Zeev, A.; Rubin, A.; Constantini, N.; Even, A.; Nyska, M.; Mann, G. The medial longitudinal arch as a possible risk factor for ankle sprains: A prospective study in 83 female infantry recruits. *Foot Ankle Int.* **2005**, *26*, 180–183. [CrossRef] [PubMed]
8. Okamura, K.; Kanai, S.; Oki, S.; Tanaka, S.; Hirata, N.; Sakamura, Y.; Idemoto, N.; Wada, H.; Otsuka, A. Does the weakening of intrinsic foot muscles cause the decrease of medial longitudinal arch height? *J. Phys. Ther. Sci.* **2017**, *29*, 1001–1005. [CrossRef]
9. Kirby, K.A. Longitudinal arch load-sharing system of the foot. *Rev. Esp. Podol.* **2017**, *28*, e18–e26. [CrossRef]
10. Mulligan, E.P.; Cook, P.G. Effect of plantar intrinsic muscle training on medial longitudinal arch morphology and dynamic function. *Man. Ther.* **2013**, *18*, 425–430. [CrossRef]
11. Fraser, J.J.; Hertel, J. Effects of a 4-week intrinsic foot muscle exercise program on motor function: A preliminary randomized control trial. *J. Sport Rehabil.* **2019**, *28*, 339–349. [CrossRef]
12. Woerman, A.L.; Binder-Macleod, S.A. Leg length discrepancy assessment: Accuracy and precision in five clinical methods of evaluation. *J. Orthop. Sports Phys. Ther.* **1984**, *5*, 230–239. [CrossRef]
13. Orner, S.; Kratzer, W.; Schmidberger, J.; Grüner, B. Quantitative tissue parameters of Achilles tendon and plantar fascia in healthy subjects using a handheld myotonometer. *J. Bodyw. Mov. Ther.* **2018**, *22*, 105–111. [CrossRef] [PubMed]
14. Brody, D.M. Techniques in the evaluation and treatment of the injured runner. *Orthop. Clin. N. Am.* **1982**, *13*, 541–558. [CrossRef]
15. Allen, M.K.; Glasoe, W.M. Metrecom measurement of navicular drop in subjects with anterior cruciate ligament injury. *J. Athl. Train.* **2000**, *35*, 403–406. [PubMed]
16. Cook, G.; Burton, L.; Hoogenboom, B. Pre-participation screening: The use of fundamental movements as an assessment of function. *N. Am. J. Sports Phys. Ther.* **2006**, *1*, 62–72.
17. Haun, C.; Brown, C.N.; Hannigan, K.; Johnson, S.T. The effects of the short foot exercise on Navicular Drop: A critically appraised topic. *J. Sport Rehabil.* **2020**, *30*, 152–157. [CrossRef]
18. McKeon, P.O.; Fourchet, F. Freeing the foot: Integrating the foot core system into rehabilitation for lower extremity injuries. *Clin. Sports Med.* **2015**, *34*, 347–361. [CrossRef]
19. McKeon, P.O.; Hertel, J.; Bramble, D.; Davis, I. The foot core system: A new paradigm for understanding intrinsic foot muscle function. *Br. J. Sports Med.* **2015**, *49*, 290. [CrossRef]
20. Headlee, D.L.; Leonard, J.L.; Hart, J.M.; Ingersoll, C.D.; Hertel, J. Fatigue of the plantar intrinsic foot muscles increases navicular drop. *J. Electromyogr. Kinesiol.* **2008**, *18*, 420–425. [CrossRef]
21. Kelly, L.A.; Cresswell, A.G.; Racinais, S.; Whiteley, R.; Lichtwark, G. Intrinsic foot muscles have the capacity to control deformation of the longitudinal arch. *J. R. Soc. Interface* **2014**, *11*, 20131188. [CrossRef]
22. Hara, S.; Kitano, M.; Kudo, S. The effects of short foot exercises to treat flat foot deformity: A systematic review. *J. Back Musculoskelet. Rehabil.* **2023**, *36*, 21–33. [CrossRef]
23. Park, D.J.; Lee, K.S.; Park, S.Y. Effects of two foot-ankle interventions on foot structure, function, and balance ability in obese people with pes planus. *Healthcare* **2021**, *9*, 667. [CrossRef] [PubMed]
24. Hamill, J.; Knutzen, K.M. *Biomechanical Basis of Human Movement*; Lippincott Williams & Wilkins: Philadelphia, PA, USA, 2006.
25. Fort-Vanmeerhaeghe, A.; Romero-Rodriguez, D.; Lloyd, R.S.; Kushner, A.; Myer, G.D. Integrative neuromuscular training in youth athletes. Part II: Strategies to prevent injuries and improve performance. *Strength Cond. J.* **2016**, *38*, 9–27. [CrossRef]
26. Nordez, A.; Gross, R.; Andrade, R.; Le Sant, G.; Freitas, S.; Ellis, R.; McNair, P.J.; Hug, F. Non-muscular structures can limit the maximal joint range of motion during stretching. *Sports Med.* **2017**, *47*, 1925–1929. [CrossRef] [PubMed]
27. Tondon, A.; Kaunas, R. The direction of stretch-induced cell and stress fiber orientation depends on collagen matrix stress. *PLoS ONE* **2014**, *9*, e89592. [CrossRef]
28. Lee, E.; Cho, J.; Lee, S. Short-foot exercise promotes quantitative somatosensory function in ankle instability: A randomized controlled trial. *Med. Sci. Monit. Int. Med. J. Exp. Clin. Res.* **2019**, *25*, 618. [CrossRef]
29. Sulowska-Daszyk, I.; Mika, A.; Oleksy, Ł. Impact of short foot muscle exercises on quality of movement and flexibility in amateur runners. *Int. J. Environ. Res. Public Health* **2020**, *17*, 6534. [CrossRef]
30. Riddick, R.; Farris, D.J.; Kelly, L.A. The foot is more than a spring: Human foot muscles perform work to adapt to the energetic requirements of locomotion. *J. R. Soc. Interface* **2019**, *16*, 20180680. [CrossRef]

31. Kim, E.K.; Kim, J.S. The effects of short foot exercises and arch support insoles on improvement in the medial longitudinal arch and dynamic balance of flexible flatfoot patients. *J. Phys. Ther. Sci.* **2016**, *28*, 3136–3139. [CrossRef]
32. Jeong, D.H.; Lee, D.R.; Lee, K.L.; Sung, J.Y. Gravitational acceleration test results according to functional movement screen and morphological symmetry results of air force cadets. *Symmetry* **2023**, *15*, 804. [CrossRef]
33. Sung, J.Y.; Jeong, D.H.; Lee, K.L. Analysis of the relationship between body imbalance characteristics and physical ability in air force cadets: Physical function and gravity acceleration resistance. *Sci. Rep.* **2024**, *14*, 19795. [CrossRef]
34. Matsumoto, S.; Fujita, D.; Osaka, H. Intrinsic Foot Muscle Training Affects Plantar Pressure Distribution during A Single-group Clinical Trial. *Kawasaki J. Med. Welf.* **2019**, *24*, 71–76.

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