The Global Journal of Sport and Exercise Science (GJSES)
Vol. 1, Number 1 (2025)
p-ISSN: 3080-0307
DOI (Crossref): https://doi.org/10.63750/w0pndm42

Received on: 21 SEPTEMBER, 2025 Accepted on: 30 SEPTEMBER, 2025 Published on: 30 SEPTEMBER, 2025

Role of Minimalist Footwear on Stability, Change of Direction, and Force Production: A Randomized Crossover Trial

Logan Allen[1] , Justin Kiliam[2]

[1] Liberty University, United States, lallen74@liberty.edu
[2] Liberty University, United States, jrkilian@liberty.edu

ABSTRACT

The purpose of the present study was to examine the acute effects of minimalist footwear (MFW) on participants' ability to stabilize, change direction, and produce force. A randomized crossover design was used. Eighteen subjects participated. Participants tested in MFW and traditional running shoes (RS) and were randomly assigned an order. The protocol included a warm-up, limits of stability assessment, pro-agility test, modified t-test, countermovement, and isometric mid-thigh pull. No significant differences were found ($p \leq 0.05$), and the effect sizes were trivial to small. For the limits of stability assessment, time (ES = 0.350) and backward (ES = 0.229) had small effect sizes with MFW performing better and right had a small effect size (ES = 0.287) with RS performing better. Every other variable for the limits of stability had a trivial effect size. For the pro-agility assessment there was a small effect size (ES = 0.429) with MFW performing better. For the modified t-test assessment there was a small effect size (ES = 0.411) with MFW performing better. For the countermovement jump, every variable had a trivial effect size. For the isometric mid-thigh pull, peak force (ES = 0.216), time to peak force (ES = 0.316), and rate of force development 0 – 50 ms (ES = 0.246) had a small effect size. Rate of force development 0 – 100 ms had a trivial effect size with MFW performing better. In conclusion, this indicates that MFW may not acutely influence stability and may positively influence change of direction and force production.

Key Words: Minimalist Shoes, Anaerobic Performance, Sports Performance, Agility

Corresponding Author:
Logan Aleen
Libertiy University, United States
Email: lallen74@liberty.edu

1. Introduction:

Footwear that is lightweight and flexible with a low stack height and heel-to-toe drop has been defined as minimalist footwear (MFW) (Linares-Martín & Rico-González, 2023). The purpose of MFW is to closely mimic the biomechanics of being barefoot while protecting the wearer from unsanitary conditions and sharp objects (Linares-Martín & Rico-González, 2023). Key features of MFW that allow for mimicked biomechanics are a wide toe box that allows for natural toe splay and little to no added support. To date, most literature that has examined the effects of MFW has analyzed variables, such as running economy and running biomechanics (Linares-Martín & Rico-González, 2023; Ridge et al., 2019; Sinclair, 2017; Sinclair et al., 2016). For example, Hanson et al. found that both treadmill and over ground running were more efficient when running barefoot than in traditional running shoes (RS). Participants running barefoot had a lower VO2 and lower heart rate when running at 70% of their maximum VO2max velocity when compared to participants running in RS (Hanson et al., 2011). Hanson concluded that this was likely due to the lack of cushion allowing the ground reaction force to be delivered directly to the ground without any dissipation (Hanson et al., 2011). Minimalist footwear has also been indicated to alter gait. Prior research has suggested that MFW can reduce the impact that occurs immediately upon landing and reduce patellofemoral forces while running (Sinclair, 2017; Sinclair et al., 2016). These adaptations are likely due to changes in gait from a heel strike to a midfoot or forefoot strike. A heel strike distributes ground reaction force directly to the ankle and then up the kinetic chain, whereas a mid or forefoot strike allows the food to absorb and dissipate some of the ground reaction force before transferring it to the ankle and up the chain (Sinclair, 2017; Sinclair et al., 2016).

Minimalist footwear has also been indicated to develop the strength of the intrinsic and extrinsic foot musculature. Ridge at al. indicated that walking in MFW is a sufficient stimulus to strengthen the foot musculature (Ridge et al., 2019). Curtis et al. went a step further and indicated that wearing MFW throughout the day, but not taking a specific number of steps, was a sufficient stimulus to increase strength (Curtis et al., 2021). Increased foot strength is advantageous because weak foot musculature is correlated with foot pain and deformities such as plantar fasciitis, hallux valgus, claw toe, hammer toe, and pes planus (Allen & Gross, 2003; Latey et al., 2017; Mickle et al., 2009; Myerson & Shereff, 1989; J. Sullivan et al., 2015). Increases in foot strength are advantageous from a performance perspective because increased foot strength has been correlated with improved balance and forward jump distance (Quinlan et al., 2022). However, there is a paucity of research examining the effects of MFW on non-aerobic variables related to athletic performance such as stability, change of direction, and force production.

Several studies have researched the effects of footwear on balance and stability. One study found that eight weeks of barefoot training could improve stability and agility in athletes (de Villiers & Venter, 2014). However, the intervention was barefoot not MFW. Despite this difference, previous research has confirmed the similarity in performance between barefoot and MFW (LaPorta et al., 2013). Another study examined the effects of youth aged nine to twelve years who experienced improvements in balance after nine months of wearing MFW. Participants were provided shoes to wear during the school day and instructed to wear them for three days per week, equating to eighteen hours of wearing MFW per week (Quinlan et al., 2022). A different study took a sample of participants that were 19 – 50 years of age and found that thick-soft soled shoes destabilized participants during a beam walk (Robbins et al., 1994). Overall, thick-soft soled shoes have been indicated to reduce stability and reaction time, likely due to less mechanical support than hard soled shoes (Aboutorabi et al., 2016; Hosoda et al., 1997; Perry et al., 2007). A recent review indicates that MFW can improve balance, foot strength, function, and reduce pain across the lifespan (Davis et al., 2021). While there is evidence that MFW can improve balance across the lifespan most of the literature has been done in geriatrics (Sassi et al., 2009; Scanlan et al., 2021) and youth (Quinlan et al., 2022), little has been done in young, college-aged adults.

Similar to stability, little research has been done on the effects of MFW on change of direction. It is well established that shorter stride lengths can improve change of direction ability (Goodman, 2008). It is also well established that barefoot training can elicit changes in gait patterns, including, a shorter stride length, higher stride frequency, and shorter ground contact time (Graham et al., 2018; Linares-Martín & Rico-González, 2023). Research has indicated that training for at least five weeks in MFW can improve performance in the AFL agility test, t-test, pro agility test, 505 agility test, 10 m sprint, and 20 m sprint (de Villiers & Venter, 2014; Graham et al., 2018).

While there is some literature on the effects of MFW on stability and change of direction, very little has been done examining force production including, countermovement jumps and isometric mid-thigh pulls. Previous literature has suggested that vertical jump velocity, power, and height are improved when barefoot or wearing MFW (LaPorta et al., 2013; Than et al., 2022). Likewise, other research has indicated that wearing MFW can improve standing long jump performance in youth (Quinlan et al., 2022). To the authors knowledge, only one study has been published comparing the effects of barefoot to RS in terms of an isometric mid-thigh pull. Price et al. found that the barefoot group produced a higher peak force and rate of force development (RFD) than the shod group (Price et al., 2019). Another study examined a similar topic, the authors compared barefoot to shod conditions in a conventional deadlift. The authors found a significant effect between shoe conditions with barefoot having a significantly higher RFD (Hammer et al., 2018). One other study examined the differences between deadlifts with various levels of stability. The participants performed three tests; each test was done with shoes. One test done on the ground, one on a T-Bow, and one on a Bosu. The authors found that a more stable foundation allowed for greater production of maximal strength and muscle activity (Chulvi-Medrano et al., 2010).

The purpose of the present study was to examine the acute effects of MFW on the ability of participants to stabilize, change direction, and produce force. The hypothesis was that participants wearing MFW would have an improved ability to stabilize, change direction, and produce force. The hypothesis was based on the premise that due to the lack of cushion MFW may have two effects on performance. First, the lack of cushion may allow for greater proprioceptive feedback, having less material between the foot and the ground may allow the foot to better sense and react to disturbances. Potentially allowing for greater stability and balance. Second, the lack of cushion may have a reduced time required to compress under load. Potentially allowing for more efficient force transfer into the ground, enabling quicker changes of direction.

Surface mechanomyography (MMG) records low-frequency oscillations produced by muscle fibers during muscular contractions (Orizio et al., 1993). MMG is described as the mechanical counterpart to neural activation (Coburn et al., 2004), and the amplitude of the signal can be influenced by active stiffness modulated by motor unit (MU) recruitment and firing rates of the active MUs (Coburn et al., 2005). It is suggested that MMG amplitude (MMG_{RMS})-force relationships may allow for easier interpretation of MU recruitment and firing rate behavior than electromyographic amplitude (EMG_{RMS}), as the MMG signal is not influenced by as many non-physiological factors (Farina et al., 2010). Therefore, MMG_{RMS}-force relationships are commonly used to assess MU control strategies across various muscles (Orizio et al., 1990; Akataki et al., 2003; Sontag et al., 2021), contraction intensities (Trevino & Herda, 2015), and muscle actions (Coburn et al., 2005; Akataki et al., 2001; Dalton & Stokes, 1991).

MMG_{RMS}-force/torque relationships for the vastus lateralis (VL) and biceps brachii (BB) have previously differentiated sexes during high-intensity linearly increasing muscle actions of the knee extensors and elbow flexors, respectively (Sontag et al., 2021; Nonaka et al., 2006). It has been suggested that differences in the patterns of response may indicate divergent MU control strategies when modulating force, such as the greater increase in MMG_{RMS} during force production displayed by males suggests a greater reliance on MU recruitment (Hill et al., 2018). However, previous findings suggest that muscle morphology may influence MMG_{RMS}-force relationships as well. For example, Nonaka et al. (2006) reported males, who possessed larger muscle cross-sectional area (mCSA) of the BB compared to females, exhibited greater MMG_{RMS} values during a linearly increasing muscle action to 80% maximal voluntary contraction (MVC). More recently, Sontag et al. (2021) and Trevino et al. (2023) reported greater slopes calculated from the log-transformed MMG_{RMS}-torque relationships of the VL during a linearly increasing muscle action of the knee extensors to 70% maximal voluntary contraction (MVC) for individuals with larger mCSA and pennation angle, respectively. However, sex comparisons for MMG_{RMS} of the BB have yet to be investigated during moderate-intensity contractions, when the population of activated MUs would express type I- more so than type II-muscle fiber twitch characteristics (Trevino et al., 2016). Therefore, it remains unknown if sex-related differences exist at lower contraction intensities (≤ 70% MVC). Furthermore, differences in MU control strategies exist during MU activation and deactivation due to differences in the recruitment and derecruitment thresholds, and MU firing rates (De Luca et al., 1982; Herda et al., 2015; Jesunathadas et al., 2010). However, no study has examined if sex-related differences exist for MMG_{RMS}-force relationships during linearly decreasing muscle actions. Therefore, information is lacking regarding the mechanical behavior of the BB for males and females during moderate-intensity muscle actions of the elbow flexors, and for MU deactivation altogether.

Due to the relatively large amount of individual variability when analyzing MMG_{RMS}-force/torque relationships via polynomial regression and analysis of variance (ANOVA) models of composite MMG_{RMS} values at distinct %MVC levels (Herda et al., 2009), it has been suggested these relationships should be inspected on a subject-by-subject basis (Farina et al., 2004; Orizio et al., 1989; Zwarts & Keidel, 1991) as the individual patterns may not be accurately represented by the group means (Ryan et al., 2008). Subsequently, Herda et al.

(2009) applied a natural log transformation to the MMG_{RMS}-force/torque relationship for each contraction to calculate slope values (*b* terms) and y-intercepts (*a* terms) to examine individual patterns. For instance, the log-transformation procedure generates the equation: $Y = a \cdot X^b$, where $Y = MMG_{RMS}$, X = force/torque, a = gain coefficient, and b = exponential coefficient. The *a* term (anti-log of the *y*-intercept) can be viewed as a "gain factor" since the exponential model forces the *a* term through the zero, and it reflects a downward or upward shift in MMG_{RMS} without altering the linearity of the relationship. Conversely, the 95% confidence intervals (CIs) calculate around the group means for the *b* terms (slope) provide additional information regarding the linearity of the original MMG_{RMS}-force/torque patterns. For example, the relationship is linear if the 95% CI include 1. Furthermore, 95% intervals that are less than 1 but greater than 0 indicate a nonlinear relationship with downward deceleration, as the rate of change is greater for the force/torque than MMG_{RMS}. During linearly increasing muscle actions up to moderate- and high-intensity targeted forces/torques (60 - 90% MVC), the *b* terms have successfully discriminated the mechanical behavior of the VL between chronic training statues, and males and females (Trevino & Herda, 2015; Herda et al., 2010; Trevino et al., 2023; Sontag et al., 2021). However, no study has used the *a* and/or *b* terms to investigate the influence of sex on MU activation and deactivation strategies for the BB.

Therefore, the purpose of this study was to examine mCSA, the log-transformed MMG_{RMS}-force relationships of the BB between males and females during the linearly increasing and decreasing segments of a 40% MVC and 70% MVC isometric trapezoidal muscle action of the elbow flexors and MMG_{RMS} at steady force. We hypothesized that the males would possess greater: mCSA of the BB, *b* terms during the linearly increasing and decreasing segments of the 40% and 70% isometric trapezoidal muscle actions, as well as MMG_{RMS} at steady force during both intensities.

2. METHODS:

This investigation was a randomized crossover trial. The study design was selected so that each participant could act as their own control. The cross-sectional design was used to examine the acute effects of MFW. Eighteen participants partook in two testing sessions with one week between each session. The testing sessions occurred during the same time of day. During one testing session the participants wore MFW and the other testing session they wore RS. Conventional running shoes in the present study were defined as shoes that are designed for running, have a heel-to-toe drop of ≥4 mm, and a stack height of ≥10 mm. Heel-to-toe drop is defined as the difference in height off the ground from the heel to the toe. Stack height is defined as the average distance in height that the foot sits off the ground.

3. Subjects

Eighteen subjects participated aged 18 – 24 years old (n = 18). Thirteen males (n = 13) participated, and 5 females (n = 5) participated. The inclusion criteria were that all participants must be healthy and free of injury. Participants were excluded if they had an injury that would influence or limit their participation in any way and if they were under 18 years of age. Prior to participation, all participants were informed of the procedures and requirements of the study and filled out a PAR-Q and consent form that was approved by the universities Institutional Review Board. The participants were randomly assigned a testing order. Half the participants testing in MFW first (provided by the investigators) and RS second (provided by the subjects according to the previously defined parameters for conventional running shoes), and half did the opposite.

4. Procedures

The participants completed the PAR-Q and consent form prior to the first testing session. The warmup and testing procedure were identical between testing sessions, the only difference between sessions was the shoes that the participants were wearing. The testing sessions started with a standardized warm up. The warmup included a five-minute ride on an Echo Bike at a self-selected pace. The bike ride was followed by 10 yds of heel scoops and 10 yds of a lunge and twist. Once the warmup was completed the participants began the testing battery.

Every test in the testing battery was completed a total of three times. The first trial was a familiarization trial, and those results were not recorded. The familiarization trial was used to familiarize participants with the test, ensure they understood the instructions, and could perform the test properly. The second and third trials were both recorded, and the best trial was used for statistical analysis. The testing battery included a limits of stability assessment, a pro-agility, a modified t-test, and countermovement jump, and an isometric mid-thigh pull.

The limits of stability assessment was performed on a Biodex Balance System (Biodex model I0046257, Shirley, NY, USA). The Biodex Balance System has a computer screen located in front of the participant that has eight dots that form a circle around a dot in the center. Once the test begins a cursor appears where the participants center of gravity is. Then a random dot on the outer ring starts flashing red. The participants were instructed to shift their weight to move their curser to the red flashing dot. Once the participants reach the red flashing dot the computer will make them return to center and then another random dot will start flashing. This is repeated until the all the dots have been reached. The test provides ten variables including the time to completion, an overall score, and a score for the eight different directions. Higher scores indicate better performance other than time in which a better performance will result in a lower time. The scores are on a scale of 0 to 100.

The following assessment was the pro-agility assessment. The protocol that was performed for the pro-agility assessment has been utilized in prior research (Fields et al., 2023; Stewart et al., 2014). All participants started by going left first. The test was performed on a rubber floor. The timing was done by hand, and the same assessor timed all the trials. The pro-agility assessment has been shown to be a highly reliable and valid measure of change of direction ability (Stewart et al., 2014).

After the pro-agility was the modified t-test. The modified t-test is similar to the standard T-test, although it is modified to half-scale. The modified t-test has been indicated to have high relative and absolute reliability (Sassi et al., 2009; Scanlan et al., 2021). Like the pro-agility, participants started by going left fist and the test was performed on a rubber floor. The timing was done by hand, and the same assessor timed all the trials.

Next was the countermovement jump. The countermovement jump was performed using Hawkin Dynamics force plates (Hawkin Dynamics, Westbrook, ME). Participants were instructed to step onto the force plates with a different foot on each force plate and to stand still to establish a quiet phase. Once the quiet phase was established the participants were instructed to jump as high as possible while keeping their hands on their hips. A countermovement jump with no arm swing was performed to isolate lower-extremity function and reduce any variables that could stem from using an arm swing (Heishman et al., 2020).

5. Statistical Analysis

Statistical analysis was performed via JASP (JASP version 0.19.3, Amsterdam, NL). A paired samples T-test was performed for each test to compare differences between the two conditions. The alpha level was set to ($p \leq 0.05$). A Shapiro-Wilk test was performed to test for normality. A student T-test was used for any data that was normally distributed, and effect size was determined by Cohen's D. For data that was not normally distributed a Wilcoxon signed-rank T-test was performed and effect size was determined by matched rank biserial correlation. Only two variables were not normally distributed, isometric mid-thigh pull peak force and isometric mid-thigh pull RFD 0 – 50 ms. For those two variables median was used for analysis rather than mean. The mean is greatly affected by skewed data and is not favorable for skewed distributions, whereas, the median is less effected by skewed data (Khorana et al., 2023). Therefore, the median was used for the variables that were not normally distributed. Descriptive statistics and statistical power were also retrieved. The effect size categories were categorized as trivial < 0.2, small = 0.2 to 0.49 medium = 0.5 to 0.79, large = 0.8 to 1.29, and very large ≥ 1.3 (G. M. Sullivan & Feinn, 2012).

6. Results

No significant differences were found ($p \leq 0.05$). Although, a trend did present itself, MFW performed better on 13 out of the 20 variables. Out of the seven variables that RS performed better on six of the seven were on the limits of stability assessment and one was on the isometric mid-thigh pull. However, when non normative distributions are accounted for, and the median is used rather than the mean for those variables, MFW performed better on 14 out of the 20 variables. Of the six variables that RS performed better on, all six were from the limits of stability assessment. Minimalist footwear performed better for every variable on the pro-agility, modified t-test, countermovement jump, and isometric mid-thigh pull assessments. Descriptive statistics can be found in Table 1. Assumption checks to test for normality can be found in Table 2. The normally distributed data can be found in the paired samples T-test located in Table 2 and the non-normally distributed data can be found in the Wilcoxon signed-rank T-test located in Table 3.

Although no significant differences were found, there were some notable effect sizes. For the limits of stability assessment, time had a small effect size (ES = 0.350), backward had a small effect size (ES = 0.229), and right has a small effect size (ES = 0.287). Every other variable for the limits of stability had a trivial effect size. For the pro-agility assessment there was a small effect size (ES = 0.429). For the modified t-test assessment there was a small effect size (ES = 0.411). For the countermovement jump, every variable had a trivial effect size. For the isometric mid-thigh pull, peak force had a small effect size (ES = 0.216), time to peak force had a small effect size (ES = 0.316), RFD 0 – 50 ms had a small effect size (ES = 0.246), and RFD 0 – 100 ms had a trivial effect size.

Table 1: *Descriptive Statistics*

TABLE 1: *DESCRIPTIVE STATISTICS*

		Minimalist Footwear			Traditional Running Shoes		
TEST	Variable	Median	Mean	Std. Deviation	Median	Mean	Std. Deviation
LIMITS OF STABILITY	Time (Sec.)	36.000	36.167	4.409	38.500	38.167	6.205
	Overall	67.500	67.000	9.683	65.000	67.222	10.724
	Forward	77.000	72.944	19.166	75.500	72.444	26.075
	Backward	82.500	75.444	24.435	66.000	67.389	25.025
	Right	76.500	76.000	16.723	83.500	81.667	12.889
	Left	73.000	76.111	16.673	76.500	76.722	16.914
	Forward Right	68.500	69.722	15.974	68.500	69.833	14.151
	Forward Left	80.000	75.500	13.789	77.500	71.778	17.900
	Backward Right	63.000	62.611	18.974	64.500	64.389	17.150
	Backward Left	68.500	66.667	17.078	71.500	68.778	16.494
PRO AGILITY	Time (Sec.)	5.140	5.134	0.407	5.275	5.233	0.457
MODIFIED T-TEST	Time (Sec.)	6.840	6.673	0.741	7.070	6.871	0.790
COUNTERMOVEMENT JUMP	Jump Height (In.)	12.055	12.092	2.466	11.895	12.046	2.327
	Force at Minimum Displacement (N)	1751.500	1828.167	592.889	1617.500	1812.500	597.847
	Peak Braking Force (N)	1751.500	1830.278	591.184	1622.000	1820.111	605.842
	Peak Propulsive Force (N)	1894.500	1928.556	577.459	1671.500	1917.222	557.677
ISOMETRIC MID-THIGH PULL	Peak Force (N)*	2316.500	2212.833	570.417	2273.000	2218.833	591.378
	Time to Peak Force (Sec.)	2.540	2.481	1.027	2.960	2.955	1.408
	Rate of Force Development 0-50 ms (N/s)*	3500.000	4766.667	4415.454	3320.000	3752.222	2235.964
	Rate of Force Development 0-100 ms (N/s)	3145.000	3837.222	2561.249	3725.000	3590.000	1881.817

* INDICATES A VARIABLE THAT WAS NOT NORMALLY DISTRIBUTED

Table 2: Student Paired Samples T-Test

MEASURE 1	MEASURE 2	P	COHEN'S D
TIME MFW	Time RS	0.155	0.350
OVERALL MFW	Overall RS	0.915	0.026
FORWARD MFW	Forward RS	0.936	0.019
BACKWARD MFW	Backward RS	0.345	0.229
RIGHT MFW	Right RS	0.240	0.287
LEFT MFW	Left RS	0.886	0.034
FORWARD RIGHT MFW	Forward Right RS	0.978	0.007
FORWARD LEFT MFW	Forward Left RS	0.432	0.190
BACKWARD RIGHT MFW	Backward Right RS	0.774	0.069
BACKWARD LEFT MFW	Backward Left RS	0.686	0.097
PRO AGILITY MFW	Pro Agility RS	0.086	0.429
MODIFIED T-TEST MFW	Modified T-Test RS	0.099	0.411
CMJ JUMP HEIGHT MFW	CMJ Height RS	0.827	0.052
CMJ JUMP FORCE AT MIN. DISP. MFW	CMJ Force at Min. Disp. RS	0.787	0.065
CMJ PEAK BRAKING FORCE MFW	CMJ Peak Braking Force RS	0.860	0.042
CMJ PEAK PROPULSIVE FORCE MFW	CMJ Peak Propulsive Force RS	0.823	0.054
IMTP TIME TO PEAK FORCE MFW	IMTP Time to Peak Force RS	0.197	0.316
IMTP RFD 0-100 MS MFW	IMTP RFD 0-100 ms RS	0.686	0.097

NOTE. STUDENT'S T-TEST.
KEY: MFW = MINIMALIST FOOTWEAR; RS = RUNNING SHOES; CMJ = COUNTERMOVEMENT JUMP; IMTP = ISOMETRIC MID-THIGH PULL; RFD = RATE OF FORCE DEVELOPMENT

Table 3: Wilcoxon Signed-Rank Paired Samples T-Test

MEASURE 1	**MEASURE 2**	**P**	**RANK-BISERIAL CORRELATION**
IMTP PEAK FORCE MFW	IMTP Peak Force RS	0.442	0.216
IMTP RFD 0-50 MS MFW	IMTP RFD 0-50 ms RS	0.372	0.246

NOTE. WILCOXON SIGNED-RANK TEST.
KEY: MFW = MINIMALIST FOOTWEAR; RS = RUNNING SHOES; IMTP = ISOMETRIC MID-THIGH PULL; RFD = RATE OF FORCE DEVELOPMENT

DISCUSSION

The limits of stability assessment had small effect sizes for time, backward, and right. Minimalist footwear performed better on time and backward but worse on right. However, this made no difference in the overall score and none of the results were statistically significant. Likewise, the forward and left scores showed no significance or effect size. It would be reasonable to assume that if a shoe performed better going to the right it would also perform better going to the left, but this is not the case. The difference in backward and forward may be due to the heel-to-toe drop. However, no difference is seen in forward, which indicates that the difference backward may have been a fluke. The small effect sizes, but lack of statistical significance, indicates that there may be a difference, but the sample size was too small. The sample of eighteen participants had a power of 0.625. Had the sample had been larger (n = 27), it would have achieved a power of 0.8. Overall, the results of the present study showed that MFW's mean values showed that MFW performed better four out of ten variables. The median value performed better on five out of ten variables and was equal on another variable.

A recent review by Davis et al. suggests that MFW can improve balance throughout the lifespan. Although, the studies within the review had varying methods and amount of exposure to MFW making it difficult to determine a superior method (Davis et al., 2021). This effect seems to be the quite prevalent in older populations that are at risk of falling (Cudejko et al., 2020). Indeed, to reduce the risk of falls, it is recommended that older individuals wear thin, hard-soled shoes, matching the definition of MFW (Aboutorabi et al., 2016). One study by Robbins et al. examined the effects of footwear on stability in young men aged 19-50, and found that thick-soft soled destabilized participants (Robbins et al., 1994). Another study by Quinlan et al. had kids aged nine to twelve wear MFW for nine months and found that MFW improved balance in children (Quinlan et al., 2022). Thick-soft soled shoes have been indicated in other literature by Hosoda et al. and Perry et al. to reduce reaction time and the ability to react to disturbances in stability (Hosoda et al., 1997; Perry et al., 2007). Soft soled shoes may lead to instability because they offer less mechanical support compared to hard soled shoes (Menant et al., 2008).

The inconsistency between the present research and the other literature could stem from the lack of a longitudinal intervention. Perhaps, changes in balance and stability are adaptations that occur due to the strengthening of the foot musculature, increased proprioception, or other physical adaptations to the footwear that is being used. Increased proprioception has been a suggested benefit of wearing MFW and that having an increased proprioceptive ability will play a role in stability (Jenkins & Cauthon, 2011). Likewise, de Villers & Venter indicated that eight weeks of barefoot training can improve stability and agility in athletes (de Villiers & Venter, 2014). Therefore, a longitudinal intervention may be needed for future research.

Both the pro-agility assessment and modified t-test assessment had small effect sizes with MFW performing better for both tests. However, these results were not statistically significant. Previous research done by Graham et al. indicated that training in MFW for five weeks can improve performance in the AFL agility test, T-test, and the Pro Agility test in athletes (Graham et al., 2018). Similarly, de Villers & Venter suggested that eight weeks of barefoot training improved performance in the 505 agility test, 10 m sprint, and 20 m sprint in netball athletes (de Villiers & Venter, 2014). One crucial difference between the present research and the research done by Graham et al. and de Villers & Venter was that the present research tested for acute differences, whereas the referenced studies used an intervention. The intervention period may have elicited greater differences by giving the athletes more time to adapt. While there was a small difference acutely, the adaptations that are stimulated by training barefoot or in MFW may be more noteworthy. Indeed, previous research has indicated that barefoot training stimulates changes in stride kinematics, including a shorter stride length, higher stride frequency, and shorter ground contact time (De Wit et al., 2000).

Similarly, shorter stride lengths can improve change of direction ability (Goodman, 2008). There is a paucity of research related to examining MFW in terms of athletic performance.

Minimalist footwear performed better on every variable of the countermovement jump. However, the effect sizes were trivial and not statistically significant. Previous literature has reported similar results. LaPorta et al. indicated that vertical jump velocity, power, and height was improved when wearing MFW or barefoot compared to tennis shoes (LaPorta et al., 2013). Similarly, Than et al. found that vertical jump height was greater when barefoot compared to RS (Than et al., 2022). These results are theorized to be due to the cushion in the shoe dispersing the ground reaction force, therefore preventing direct application of the force into the ground (LaPorta et al., 2013). However, the cushion dispersing the ground reaction force may not be the only factor. A study by Quinlan et al. found a correlation between greater toe flexor strength and a greater standing long jump (Quinlan et al., 2022). Although, this study was done in kids and a horizontal jump was performed rather than a countermovement jump, it indicates that increases in foot strength—particularly great toe flexor strength—may improve performance. However, there is a lack of research comparing MFW or barefoot to shod conditions in terms of a countermovement jump. More research is needed both acutely and longitudinally.

Minimalist footwear performed better on every variable of the isometric mid-thigh pull. The mean was used for time to peak force and RFD 0 – 100 ms. The median was used for peak force and RFD 0 – 50 ms because the results were non-parametric. Peak force, time to peak force, and RFD 0 – 50 ms all had a small effect size, whereas RFD 0 – 100 ms had a trivial effect size. Similarly, research by Price et al. found that performing an isometric mid-thigh pull barefoot produced a higher peak force and RFD than RS (Price et al., 2019). However, to the author's knowledge the study be Price et al. is the only other research that has examined the effects of shoe conditions on the isometric mid-thigh pull. Although, one study by Hammer et al. performed a similar study, the authors examined the effects of footwear during a conventional deadlift. The authors found that deadlifting barefoot resulted in a significantly higher RFD (Hammer et al., 2018). This supports the common belief and anecdotal evidence that lifting barefoot or in MFW can provide a more stable surface to lift from and that cushioned shoes slow RFD because the cushion must be compressed prior to the force being transmitted into the floor (Hammer et al., 2018; Price et al., 2019).

In support of a stable surface, a study by Chulvi-Medrano et al., examined the effects of both an isometric mid-thigh pull and a deadlift using three conditions, on the ground, on a T-Bow , and on a Bosu. All the testing was done with RS. The authors found a significant effect on force produced and muscle activity, with the stable ground condition performing significantly better (Chulvi-Medrano et al., 2010). While a T-Bow and Bosu are extreme examples, the cushion in common maximalist shoes is likely having a similar effect. Using a thin-hard soled shoe will likely be more stable which will allow for potentially greater force production and muscle activity. However, while there is a plethora of research on the deadlift and its variations, very few studies have been performed investigating the effects of MFW or barefoot conditions on the isometric mid-thigh pull or deadlift.

In conclusion, the results did not support the hypothesis that participants wearing MFW would have an improved ability to stabilize and supported the hypothesis that participants wearing MFW would have an improved ability to change direction and produce force. While there was a clear trend in the data, it is important to note that the results were not statistically significant, and the effect sizes were small to trivial.

Conclusion

The present research observed that MFW performed better for every variable on the pro-agility, modified t-test, countermovement jump, and isometric mid-thigh pull assessments. Minimalist footwear performed better on four out of the ten variables on the limits of stability assessment. For the limits of stability this indicates that MFW may not influence stability, at least acutely. The remaining tests indicate that MFW may positively influence change of direction and force production as indicated by the pro-agility, modified t-test, countermovement jump, and isometric mid-thigh pull. However, there was no statistical significance, and the effect sizes were trivial to small. Due to the randomized crossover design, the present study was limited to testing for acute effects. While MFW may positively influence change of direction and force production acutely, there is likely a greater effect when exposure is multiplied out over time due to training adaptations and an increased training stimulus.

REFERENCES

- Aboutorabi, A., Bahramizadeh, M., Arazpour, M., Fadayevatan, R., Farahmand, F., Curran, S., & Hutchins, S. W. (2016). A systematic review of the effect of foot orthoses and shoe characteristics on balance in healthy older subjects. *Prosthetics and Orthotics International, 40*(2), 170–181. https://doi.org/10.1177/0309364615588342
- Allen, R. H., & Gross, M. T. (2003). Toe flexors strength and passive extension range of motion of the first metatarsophalangeal joint in individuals with plantar fasciitis. *The Journal of Orthopaedic and Sports Physical Therapy, 33*(8), 468–478. https://doi.org/10.2519/jospt.2003.33.8.468
- Camara, K., Coburn, J., Dunnick, D., Brown, L., Costa, P., & Galpin, A. (2016). An examination of muscle activation and power characteristics while performing the deadlift exercise with straight and hexagonal barbells. *The Journal of Strength and Conditioning Research, 30*, 1183–1188. https://doi.org/10.1519/JSC.0000000000001352
- Chulvi-Medrano, I., García-Massó, X., Colado, J. C., Pablos, C., de Moraes, J. A., & Fuster, M. A. (2010). Deadlift muscle force and activation under stable and unstable conditions. *The Journal of Strength & Conditioning Research, 24*(10), 2723. https://doi.org/10.1519/JSC.0b013e3181f0a8b9
- Cudejko, T., Gardiner, J., Akpan, A., & D'Août, K. (2020). Minimal shoes improve stability and mobility in persons with a history of falls. *Scientific Reports, 10*(1), 21755. https://doi.org/10.1038/s41598-020-78862-6
- Curtis, R., Willems, C., Paoletti, P., & D'Août, K. (2021). Daily activity in minimal footwear increases foot strength. *Scientific Reports, 11*, 18648. https://doi.org/10.1038/s41598-021-98070-0
- Davis, I. S., Hollander, K., Lieberman, D. E., Ridge, S. T., Sacco, I. C. N., & Wearing, S. C. (2021). Stepping back to minimal footwear: applications across the lifespan. *Exercise and Sport Sciences Reviews, 49*(4), 228. https://doi.org/10.1249/JES.0000000000000263
- de Villiers, E., & Venter, R. (2014). Barefoot training improved ankle stability and agility in netball players. *International Journal of Sports Science and Coaching, 9*, 485–496. https://doi.org/10.1260/1747-9541.9.3.485
- De Wit, B., De Clercq, D., & Aerts, P. (2000). Biomechanical analysis of the stance phase during barefoot and shod running. *Journal of Biomechanics, 33*(3), 269–278. https://doi.org/10.1016/s0021-9290(99)00192-x
- Fields, J. B., Kuhlman, N. M., Jagim, A. R., Dulak-Sigler, C., & Jones, M. T. (2023). Analysis of accumulated workloads and performance testing across a collegiate women's lacrosse season. *The Journal of Strength & Conditioning Research, 37*(11), 2213. https://doi.org/10.1519/JSC.0000000000004551
- Goodman, C. (2008). Improving agility techniques. *NSCA's Performance Training Journal, 7*(4), 10–12.
- Graham, S., Zois, J., Taylor, S., & McLaughlin, P. (2018). Effects of a five-week minimalist shoe plyometric training program on change-of-direction performance. *Journal of Australian Strength and Conditioning, 26*, 28–35.
- Gundersen, A. H., van den Tillaar, R., Falch, H. N., Fredriksen, A. B., & Larsen, S. (2022). A biomechanical comparison between conventional, sumo, and hex-bar deadlifts among resistance trained women. *The Journal of Strength & Conditioning Research.* https://doi.org/10.1519/JSC.0000000000005011

- Hammer, M. E., Meir, R. A., Whitting, J. W., & Crowley-McHattan, Z. J. (2018). Shod vs. barefoot effects on force and power development during a conventional deadlift. *The Journal of Strength & Conditioning Research, 32*(6), 1525. https://doi.org/10.1519/JSC.0000000000002246
- Hanson, N. J., Berg, K., Deka, P., Meendering, J. R., & Ryan, C. (2011). Oxygen cost of running barefoot vs. running shod. *International Journal of Sports Medicine, 32*(6), 401–406. https://doi.org/10.1055/s-0030-1265203
- Heishman, A. D., Daub, B. D., Miller, R. M., Freitas, E. D. S., Frantz, B. A., & Bemben, M. G. (2020). Countermovement jump reliability performed with and without an arm swing in NCAA Division 1 intercollegiate basketball players. *The Journal of Strength & Conditioning Research, 34*(2), 546. https://doi.org/10.1519/JSC.0000000000002812
- Hosoda, M., Yoshimura, O., Takayanagi, K., Kobayashi, R., Minematsu, A., Nakayama, A., Ishibashi, T., & Wilson, C. K. (1997). The effect of various footwear types and materials, and of fixing of the ankles by footwear, on upright posture control. *Journal of Physical Therapy Science, 9*(1), 47–51. https://doi.org/10.1589/jpts.9.47
- Jenkins, D. W., & Cauthon, D. J. (2011). Barefoot running claims and controversies: A review of the literature. *Journal of the American Podiatric Medical Association, 101*(3), 231–246. https://doi.org/10.7547/1010231
- Khorana, A., Pareek, A., Ollivier, M., Madjarova, S. J., Kunze, K. N., Nwachukwu, B. U., Karlsson, J., Marigi, E. M., & Williams III, R. J. (2023). Choosing the appropriate measure of central tendency: Mean, median, or mode? *Knee Surgery, Sports Traumatology, Arthroscopy, 31*(1), 1795. https://doi.org/10.1007/s00167-022-07204-y
- LaPorta, J. W., Brown, L. E., Coburn, J. W., Galpin, A. J., Tufano, J. J., Cazas, V. L., & Tan, J. G. (2013). Effects of different footwear on vertical jump and landing parameters. *Journal of Strength and Conditioning Research, 27*(3), 733–737. https://doi.org/10.1519/JSC.0b013e318280c9ce
- Latey, P. J., Burns, J., Hiller, C. E., & Nightingale, E. J. (2017). Relationship between foot pain, muscle strength and size: A systematic review. *Physiotherapy, 103*(1), 13–20. https://doi.org/10.1016/j.physio.2016.07.006
- Linares-Martín, J. Á., & Rico-González, M. (2023). Influence of minimalist footwear in middle and long distance runners' physical fitness, biomechanics, and injury incidence: A systematic review. *Strength & Conditioning Journal, 45*(3), 309. https://doi.org/10.1519/SSC.0000000000000748
- Malyszek, K. K., Harmon, R. A., Dunnick, D. D., Costa, P. B., Coburn, J. W., & Brown, L. E. (2017). Comparison of Olympic and hexagonal barbells with midthigh pull, deadlift, and countermovement jump. *The Journal of Strength & Conditioning Research, 31*(1), 140. https://doi.org/10.1519/JSC.0000000000001485
- Menant, J. C., Perry, S. D., Steele, J. R., Menz, H. B., Munro, B. J., & Lord, S. R. (2008). Effects of shoe characteristics on dynamic stability when walking on even and uneven surfaces in young and older people. *Archives of Physical Medicine and Rehabilitation, 89*(10), 1970–1976. https://doi.org/10.1016/j.apmr.2008.02.031
- Mickle, K. J., Munro, B. J., Lord, S. R., Menz, H. B., & Steele, J. R. (2009). ISB clinical biomechanics award 2009: Toe weakness and deformity increase the risk of falls in older people. *Clinical Biomechanics, 24*(10), 787–791. https://doi.org/10.1016/j.clinbiomech.2009.08.011
- Myerson, M. S., & Shereff, M. J. (1989). The pathological anatomy of claw and hammer toes. *JBJS, 71*(1), 45.

- Perry, S. D., Radtke, A., & Goodwin, C. R. (2007). Influence of footwear midsole material hardness on dynamic balance control during unexpected gait termination. *Gait & Posture, 25*(1), 94–98. https://doi.org/10.1016/j.gaitpost.2006.01.005
- Price, T., Davis, I., & Rhodes, J. (2019). Comparison of shod vs. barefoot effects on output and development of force during an isometric hex bar deadlift. https://doi.org/10.13140/RG.2.2.26079.41124
- Quinlan, S., Sinclair, P., Hunt, A., & Yan, A. F. (2022). The long-term effects of wearing moderate minimalist shoes on a child's foot strength, muscle structure and balance: A randomised controlled trial. *Gait & Posture, 92*, 371–377. https://doi.org/10.1016/j.gaitpost.2021.12.009
- Ridge, S. T., Olsen, M. T., Bruening, D. A., Jurgensmeier, K., Griffin, D., Davis, I. S., & Johnson, A. W. (2019). Walking in minimalist shoes is effective for strengthening foot muscles. *Medicine & Science in Sports & Exercise, 51*(1), 104–113. https://doi.org/10.1249/MSS.0000000000001751
- Robbins, S., Waked, E., Gouw, G. J., & McClaran, J. (1994). Athletic footwear affects balance in men. *British Journal of Sports Medicine, 28*(2), 117–122.
- Sassi, R. H., Dardouri, W., Yahmed, M. H., Gmada, N., Mahfoudhi, M. E., & Gharbi, Z. (2009). Relative and absolute reliability of a modified agility t-test and its relationship with vertical jump and straight sprint. *The Journal of Strength & Conditioning Research, 23*(6), 1644. https://doi.org/10.1519/JSC.0b013e3181b425d2
- Scanlan, A. T., Wen, N., Pyne, D. B., Stojanović, E., Milanović, Z., Conte, D., Vaquera, A., & Dalbo, V. J. (2021). Power-related determinants of modified agility t-test performance in male adolescent basketball players. *The Journal of Strength & Conditioning Research, 35*(8), 2248. https://doi.org/10.1519/JSC.0000000000003131
- Sinclair, J. (2017). The influence of minimalist, maximalist and conventional footwear on impact shock attenuation during running. *Movement & Sport Sciences - Science & Motricité, 95*, 59–64. https://doi.org/10.1051/sm/2016010
- Sinclair, J., Richards, J., Selfe, J., Fau-Goodwin, J., & Shore, H. (2016). The influence of minimalist and maximalist footwear on patellofemoral kinetics during running. *Journal of Applied Biomechanics, 32*(4), 359–364. https://doi.org/10.1123/jab.2015-0249
- Stewart, P. F., Turner, A. N., & Miller, S. C. (2014). Reliability, factorial validity, and interrelationships of five commonly used change of direction speed tests. *Scandinavian Journal of Medicine & Science in Sports, 24*(3), 500–506. https://doi.org/10.1111/sms.12019
- Sullivan, G. M., & Feinn, R. (2012). Using effect size—Or why the P value is not enough. *Journal of Graduate Medical Education, 4*(3), 279–282. https://doi.org/10.4300/JGME-D-12-00156.1
- Sullivan, J., Burns, J., Adams, R., Pappas, E., & Crosbie, J. (2015). Musculoskeletal and activity-related factors associated with plantar heel pain. *Foot & Ankle International, 36*(1), 37–45. https://doi.org/10.1177/1071100714551021
- Than, C. A., Seidl, L. A., & Beck, B. R. (2022). Comparative acceptability of weightbearing physical activity in sporting footwear versus barefoot in habitually shod individuals. *Journal of the American Podiatric Medical Association, 112*(3), 20–148. https://doi.org/10.7547/20-148