The effects of minimalist footwear on stability, change of direction, and power production: a randomized crossover trial

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ABSTRACT

Prior research indicates that minimalist footwear (MFW) enhances foot strength. The purpose of this study was to determine the effects of MFW on lacrosse athletes' ability to stabilize, change direction, and produce force. It was hypothesized that that athletes wearing MFW will have an enhanced ability to stabilize, change direction, and produce force. Eighteen male athletes participated in a randomized crossover design, alternating between MFW and regular shoes (RS). The protocol included a warm-up, limits of stability assessment, pro-agility test, modified T-Test, vertical jump, and maximal velocity trap-bar deadlift. A paired-sample *t*-test was used. For the limits of stability assessment significant differences were found for time, forward, and forward left. Minimalist footwear performed better for time (p = 0.04, ES = 0.60) and forward left (p = 0.02, ES = 0.58), whereas RS performed better for forward (p = 0.03, ES = 0.56). The vertical jump peak force showed significant differences in trial one (p = 0.05, ES = 0.53) and trial two (p = 0.04, ES = 0.57) for the right foot with MFW producing more force in both trials. No significant differences were found in the pro agility, modified T-test , or the maximal velocity deadlift. Although, for the maximal velocity deadlift, the MFW group produced more force and had a quicker time to peak force from both the right and left leg during both trials compared to the RS group. In conclusion, the differences in peak force during the vertical jump and the maximal velocity deadlift, but no differences in the pro agility and modified T-test, indicate that the effects of MFW may be more prominent during activities that require force production and not a change of direction.

Keywords

minimalist shoes, barefoot shoes, sports performance, balance, agility

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Introduction

Minimalist footwear (MFW) has been defined as lightweight, flexible shoes with a low stack height and low heel-to-toe drop, meaning they provide little to no added support to the foot (Linares-Martín & Rico-González, 2023). They tend to be thin with a wide toe box, which allows natural toe splay. The goal of MFW is to mimic the biomechanics associated with being barefoot while providing sufficient protection to the plantar surface of the foot so the perception of being barefoot can be experienced without some of the inherent risks, such as cuts and infections due to sharp and/or unsanitary conditions (Linares-Martín & Rico-González, 2023). To date, most of the research completed on MFW has been conducted studying topics such as running economy and biomechanics (Linares-Martín & Rico-González, 2023; Ridge et al., 2019; Sinclair, 2017; Sinclair et al., 2016).

Conclusions from previous literature have indicated various alterations to running kinetics and kinematics associated with MFW (Linares-Martín & Rico-González, 2023; Sinclair, 2017; Sinclair et al., 2016). Runners that run in MFW typically have a midfoot or forefoot strike whereas, runners that run in RS typically have a heel strike (Sinclair, 2017; Sinclair et al., 2016). The strike pattern that a runner uses can influence the ground reaction forces that they experience when running. One study compared MFW to conventional and maximalist running shoes regarding an impact transient. An impact transient is a rapid spike in a ground reaction force graph that occurs immediately after landing. The maximalist and conventional running shoe groups ran with a heel strike and had a large impact transient, whereas the MFW group ran with a forefoot or midfoot strike and did not have a discernable impact transient (Sinclair, 2017). Another study that compared the same three groups as the previously mentioned study indicated that runners in maximalist and conventional running shoes that ran with a heel strike had significantly higher patellofemoral forces than the MFW group that ran with a forefoot or midfoot strike (Sinclair et al., 2016). The reduction in patellofemoral forces is most likely due to the metatarsal and the tarsal joint's ability to absorb force. A rearfoot strike distributes force from the ankle to the knee and then the hip, whereas a midfoot or forefoot strike allows the metatarsal and the tarsal joints to absorb some of that force before it is transferred up the kinetic chain (Sinclair, 2017).

Another common use for MFW is to develop the strength of the intrinsic and extrinsic foot musculature. One study indicated that walking in MFW is enough to increase the strength of the foot musculature (Ridge et al., 2019). Likewise, a recent study indicated that simply wearing MFW during the day but not taking a specific amount of steps was also effective for strengthening foot musculature (Curtis et al., 2021). Wearing MFW has also been indicated to improve balance, forward jump distance, and increase foot strength (Quinlan et al., 2022). Developing the strength of the foot musculature is desirable because previous literature indicates that weak feet are associated with foot pain and foot deformities such as hallux valgus, claw toe, hammer toe, and pes planus (Latey et al., 2017). It is theorized that strong feet will have a greater ability to provide a strong foundation. It is further theorized that a strong foundation will allow athletes to more confidently apply force to the ground, allowing for improved acceleration, change of direction, and force production.

Lacrosse is often considered one of the most strenuous team sports, it is a fast-paced game that requires both aerobic and anaerobic fitness (Aben et al., 2023). During a game, lacrosse athletes are required to make quick transitions repetitively and abruptly change speed, direction, or both. Athletes move continuously with repetitive accelerations and sprints. While lacrosse athletes benefit from developing a large aerobic base, the primary plays within the game are anaerobic (Fields, Jones, et al., 2023). Lacrosse requires frequent changes of direction, jumps, cuts, and the stability to move efficiently. Little research has been conducted analyzing the acute effects of MFW on stability, change of direction, and force production on athletes, leaving a gap in the literature.

Previous research has indicated that there is a dose-dependent response to the thickness of cushion in a shoe and the amount of instability a person experiences. However, the literature in this area is not very conclusive with some research indicating that wearing MFW or being barefoot will increase stability (de Villiers & Venter, 2014; Hosoda et al., 1997; Perry et al., 2007; Robbins et al., 1994) and some research indicating the opposite (Smith et al., 2015). Longitudinal studies have indicated that MFW can significantly improve performance on the AFL agility test, the T-test, and the pro agility test (de Villiers & Venter, 2014; Graham et al., 2018).

While there have been a few studies that examined the longitudinal effects of MFW, no studies have been done examining the acute effects of MFW on stability, change of direction, and force production to the authors' knowledge. The present research is the first to examine the acute effects of MFW. Similarly, this is the first research that has been done examining the effects of MFW on Men's Collegiate Lacrosse Association Division 1 athletes.

Previously mentioned literature has indicated the acute benefits of MFW on stability. Although, the literature on stability is inconclusive. Other literature that was previously mentioned has indicated improvements in change of direction and force production with repeated exposure to MFW. However, no studies have examined the acute effects of MFW on change of direction and force production. Therefore, the purpose of this study was to determine the acute effects of MFW on lacrosse athletes' ability to stabilize, change direction, and produce force. It was hypothesized that athletes wearing MFW would have an enhanced ability to stabilize, change direction, and produce force. This hypothesis was formed based on the premise that MFW, due to its lack of cushioning, may have two effects on performance. First, the lack of cushioning may allow for greater proprioceptive feedback. By placing less material between the foot and the ground the foot may be able to better sense the ground and have an enhanced ability to react to disturbances, potentially enabling better stability and balance. Second, the lack of cushioning may reduce the time required to compress the cushion under load and allow for more efficient force transfer into the ground, potentially enabling quicker changes of direction and more efficient force production.

Methods

Eighteen Men's Collegiate Lacrosse Association (MCLA) Division 1 athletes participated in the study (N = 18). The inclusion criteria were that all participants must be rostered athletes in the 2023-2024 season, communicate their shoe size, and be able to provide a regular pair of running shoes. The inclusion criteria for a regular pair of running shoes was a shoe designed for running with a heel-to-toe drop of ⩾4 mm and a stack height of ⩾10 mm. Heel-to-toe drop is defined here as the difference in height off the ground from where the heel sits to where the toes sit. Stack height is defined here as the average distance between where the foot sits in the shoe and the ground. The exclusion criteria were if they had any injuries that would influence or limit their ability to participate in the selected tests or were under 18 years of age. All participants were informed of the procedures of the study and filled out a PAR-Q and consent form before participation. The PAR-Q and consent form were both approved via Liberty University's Institutional Review Board.

For this study, a randomized crossover design was chosen so that each subject could act as their control. Eighteen collegiate athletes participated in two testing sessions, once in each condition (MFW and RS). The cross-sectional design was used to analyze the immediate effects of the shoes rather than the long-term effects of wearing MFW.

Each athlete participated in two testing sessions. All participants were randomly assigned groups via a random team generator (www.randomlists.com). Group one received the MFW in the first testing session and tested in RS in the second session. Group two completed testing in the opposite sequence. The testing sessions occurred one week apart. The shoes were provided by Xero Shoes, which included an HFS model that was size-to-participant matched (Xero Shoes, Denver, CO).

Upon arrival at the laboratory on the first day, participants signed a PAR-Q and a consent form. Once the forms were completed, all participants completed a standardized warm-up assigned by the team's strength and conditioning coaches. Following the completion of the warm-up, all participants were instructed and familiarized with the testing battery. The testing battery included a limits of stability assessment, a pro agility test, a modified T-test, a vertical jump, and a maximal velocity trap bar deadlift that was loaded with an amount equivocal to the athlete's body mass. A trap bar deadlift was chosen based on the existing familiarity of the exercise to limit performance decrements from an unfamiliar variation of the lift. An open trap bar (Kabuki Strength, Clackamas, OR) was used for the deadlift. Trap bar deadlifts have been growing in popularity within the athletic population. Their increase in popularity is likely due to literature that measured a different pattern of muscle activation compared to traditional barbell deadlifts. The different pattern results in the trap bar deadlift variation being more effective for training maximal power, force, and velocity (Camara et al., 2016; Gundersen et al., 2022).

Participants were informed about the limits of stability assessment procedure before testing. The participants were not permitted to practice the limits of stability assessment to minimize any learned effects. Similarly, the participants performed only one trial on the limits of stability assessment. Every participant was tested one week apart. The assumption was that the participants would have a very minimal learning effect doing only one test at a time a week apart. Likewise, the counterbalanced design was used to offset any learning effects that may have occurred. The same assessor was present and responsible for operating the Biodex machine for every testing session to increase intra-rater reliability.

The limits of stability assessment was performed using a Biodex Balance System, a device used to assess and improve balance and neuromuscular control (Biodex model I0046257, Shirley, NY, USA). The Biodex Balance System consists of a circular foot pad, safety handles and a screen. The screen has a cursor that represents the participants center of pressure on the platform. Participants were instructed to stand in the center of the foot pad so that the cursor that represents their center of pressure was in the center of the screen. Once the participant was positioned correctly the test would begin. Once the test starts, nine targets would appear on the screen, eight in a circle around the participant's cursor and one target under the participant's cursor. The eight targets in the circle were in different directions from the participants cursor, these targets included: forward, backward, right, left, forward right, forward left, backward right, and backward left. A random target would start flashing red. The participant would lean in the direction of the flashing target until it stops flashing and the center target starts flashing, the participants were required to go back to the center target after each of the targets in the circle. The targets in the circle flashed in a random order. The test was completed after the participant had leaned in the direction of all eight targets. The Biodex Balance System provides a score for all eight directions based on how well the participant was able to lean in that direction, this is a measure of their stability, efficiency, and quickness. An overall score is also provided and the time to completion is also recorded. The Biodex Balance System uses a 0 - 100 scoring system where higher scores indicate better balance and stability. The only variable that doesn't use a score is time, it is also the only variable where a lower value is desired.

Next, participants performed the pro agility assessment. The pro agility was performed adhering to the same protocol as previously published methods (Fields, Kuhlman, et al., 2023; Stewart et al., 2014). However, unlike the published protocols that used cones to mark the course, the present study used tape to mark the ground. The timing for this test was measured with Freelap timing gates (Freelap, Alachua, FL). This test was done on a rubber floor. Participants performed one familiarization trial followed by two maximal effort time trials that were recorded via the Freelap timing gates. One of two different assessors performed the PA. Both assessors used the Freelap timing gates, which are electronically timed and reduced the likelihood of interrater variation.

After completing the pro agility, athletes performed the modified T-test. The modified T-test is a half-scale version of the original T-test. Previous literature has indicated that the modified T-test has a high relative and absolute reliability (Sassi et al., 2009; Scanlan et al., 2021). The half-scale version was used due to its sport specificity. In lacrosse, athletes rarely sprint and change direction at the scale of the full-scale T-test. Instead, a half-scale version has a greater similarity to how the athletes run and change direction on the field. The modified T-test was performed adhering to the same protocol as previously published methods (Sassi et al., 2009; Scanlan et al., 2021). However, unlike the published protocols that used cones to mark the course, the present study used tape to mark the ground. The timing for this test was measured using hand timers. This test was completed on a rubber floor. Participants performed one familiarization trial followed by two maximal effort time trials. The same assessor was present and responsible for timing every testing session to increase intra-rater reliability.

Following the modified T-test was the vertical jump. For the vertical jump, participants performed two max effort attempts. For the vertical jump, the participants were instructed to stand on the force plates with each foot on a different force plate. The participants were then instructed to stand still to establish a quiet phase. Once the quite phase was established the participants were instructed to jump as high as possible. The participants were allowed to swing their arms. No familiarization trial was performed because the athletes were already familiar with the movement and testing protocol before testing. Ground reaction forces were collected at a sampling rate of 1,000 Hz, using AMTI force plates (AMTI model OR6-7-2000, Watertown, MA, USA)**.** The same assessor was present and responsible for capturing data from the force plates for every testing session. The collected data was analyzed using Vicon Nexus software (Vicon, Centennial, CO, USA).

The last assessment in the testing battery was the maximal velocity deadlift. For the maximal velocity deadlift, participants performed two attempts. The participants were instructed to stand in the middle of the trap bar with one foot on each force plate and to stand still to establish a quiet phase. Then the athletes were instructed to lift the bar as quickly and as explosively as possible. No familiarization trial was performed because the athletes were already familiar with the movement before testing. Before the maximal velocity deadlift, participants were weighed using a Health O Meter 500KL Scale (Health O Meter, McCook, IL). Participant weights were measured so that the trap bar could be loaded with 100% of body mass, including the weight of the trap bar itself. The weight was rounded to be within the nearest 2.27 kilograms (5 pounds) of the participants' weight using standard rounding rules. The participants were instructed to lift the bar as quickly as possible. Ground reaction forces were collected at a sampling rate of 1,000 Hz using AMTI force plates, model OR6-7-2000 (AMTI model OR6-7-2000, Watertown, MA, USA)**.** The same assessor was present and responsible for capturing data from the force plates for every testing session to increase intra-rater reliability. The collected data was analyzed using Vicon Nexus software (Vicon, Centennial, CO, USA).

Statistical analysis was performed via JASP (JASP version 0.18.3, Amsterdam, NL). A Shapiro-Wilk test was performed to test for normality. Paired samples *t*-tests were performed to test for differences between the two trials for all the variables obtained during the testing battery. For normally distributed data, a student-paired samples *t*-test was used, and effect size was determined by Cohen's D. For data that was not normally distributed, Wilcoxon signed rank paired samples were used, and effect size was determined by matched rank biserial correlation. For the data that was not normally distributed the median was used for analysis rather than the mean. The median is less affected by skewed data and is more favorable for skewed distributions than the mean, which is greatly affected by skewed data (Khorana et al., 2023). The alpha level set to determine significance was $p = 0.05$. The effect size (ES) categories used included: 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 (Sullivan & Feinn, 2012)

Results

For normally distributed data the mean and standard deviation was used for analysis, for not normally distributed data the median was used for analysis. The following descriptive statistics for the normally distributed data are reported as (MFW: mean ± standard deviation & RS: mean ± standard deviation). The following descriptive statistics for the not normally disturbed data are reported as (MFW: median & RS: median).

Limits of Stability

Every variable was normally distributed other than time. Significant differences were found between time, forward, and forward left. The Biodex Balance System uses a 0 - 100 scoring system for every variable other than time. A higher score and a quicker time are advantageous. For time, MFW performed better than RS (MFW: 38.5 s & RS: 43.5 s) ($p = 0.04$, ES = 0.60). For forward, RS performed better than MFW (MFW: 47.3 ± 23.9 & RS: 62.9 ± 17.2) ($p = 0.03$, ES = 0.56). For forward left, MFW performed better than RS (MFW: 56.9 ± 17.4 & RS: 45.2 ± 17.5) ($p = 0.02$, ES = 0.58). No significant differences were found between overall scores, backward, right, left, forward right, backward right, and backward left.

Pro Agility

No significant differences were found between trials 1 and 2 or the best times. The effect sizes were small to trivial. Trial 1 and the best times were normally distributed but trial 2 was not normally distributed.

Modified T-Test

No significant differences were found between trials 1 and 2 or the best times. The effect sizes were trivial. All the data was normally distributed.

Vertical Jump

The variables measuring peak force were not normally distributed and the variables measuring time to peak force were normally distributed. Significant differences were found between absolute peak force, trial one for the right foot and peak force, trial two for the right foot. For absolute peak force, trial one for the right foot, MFW produced more force than RS (MFW: 1051.8 N & RS: 1021.5 N) ($p = 0.05$; ES = 0.53). For absolute peak force, trial two for the right foot, MFW produced more force than RS (MFW: 1020.8 N & RS: 981.4 N) ($p = 0.04$; ES = 0.57). No statistically significant differences were found for absolute peak force from the left foot on trials one or two or time to peak force from either foot or either trial. No statistically significant differences were found for relative peak force for either foot or either trial. The effect sizes for the data that was not statistically significant were small to trivial. The collected data was analyzed using Vicon Nexus software (Vicon, Centennial, CO, USA).

Deadlift

Every variable was normally distributed other than peak force, trial one for the right foot and peak force, trial two for the left foot. No significant differences were found for peak force or time to peak force. The effect sizes ranged from small to trivial. The collected data was analyzed using Vicon Nexus software (Vicon, Centennial, CO, USA).

Overall, significant differences were found between the limits of stability assessment and the vertical jump. No significant differences were found in the pro agility, modified T-test , or the maximal velocity deadlift.

Discussion

The limits of stability assessment is a test that measures an individual's limits of stability. It measures how well a participant can lean in eight different directions, including forward, backward, right, left, forward right, forward left, backward right, and backward left. A score is subsequently reported for all eight directions as well as an overall score and the time to completion. During the limits of stability assessment, the MFW group performed better on time and on the forward left, whereas the RS group performed better on the forward condition. It is also important to note that the forward right condition saw no significant difference between groups. Due to the MFW group performing better on forward left, the RS group performing better on forward, and no difference on forward right, the logical conclusion is that statistical significance may have been incidental due to a lack of definitive trends in favor of either type of footwear. One potential factor that could have attributed to the difference could be the heel-to-toe drop on the RS that will slightly shift the weight forward and cause a slight forward lean compared to MFW, which does not have a heel-to-toe drop. The heel-to-toe drop in the MFW was zero. The heel-to-toe drop for the RS was ≥4 mm. To the authors knowledge no research has directly compared the degree of heel-to-toe drop and stability.

Similar to the results of the present research, previous research has indicated that thick and soft shoes destabilize participants in a dose-dependent manner, this indicates that as the degree of thickness and softness of the shoe increases, the more it will destabilize the participant (Robbins et al., 1994). Thick and soft shoes have also been indicated to reduce reaction time and decrease the ability to adapt to disturbances in stability, and wearing MFW may improve those abilities over time (Hosoda et al., 1997; Perry et al., 2007). Contrary to the present research, other research has indicated that static balance in RS is superior compared to MFW and barefoot and that static balance in MFW was also indicated to be similar to barefoot (Smith et al., 2015). Although, it is important to acknowledge that the participants will likely be the most stable in the footwear that they are familiar with. If the participants are unfamiliar with MFW and have never worn MFW before then they may not perform well. However, if stability between MFW and barefoot are similar, as Smith et al. indicated, then the athletes may be able to quickly establish a well performing static balance due to familiarity with walking barefoot. Correspondingly, it has been indicated that nine weeks of barefoot training can significantly improve stability in athletes (de Villiers & Venter, 2014). Comparing the present study to the studies referenced above highlights some discrepancies within the body of literature. More research is needed to clarify the effects of MFW on stability and balance.

Neither the pro agility nor the modified T-test saw any statistically significant differences. Both tests also reported small to trivial effect sizes. No trend could be found when examining each data set further. Other literature with longitudinal designs has indicated that training either barefoot or in MFW can significantly improve performance on the AFL agility test, the T-test, and the pro agility test marginally (de Villiers & Venter, 2014; Graham et al., 2018). This indicates that MFW may not acutely affect change of direction drills. However, a larger effect may be seen after regular training in MFW. The training effect has been attributed to an increase in foot and ankle strength that allows the athletes to more efficiently apply force into the ground and an increased proprioception (de Villiers & Venter, 2014). Therefore, the value of minimalist footwear appears to be in the adaptive response to regular exposure, rather than from any acute benefit.

The MFW group produced statistically more ground reaction force in the right foot for the vertical jump during both trials. Both statistically significant results also reported a medium effect size (Sullivan & Feinn, 2012). No statistically significant difference was found between either trial on the left foot. This may indicate the athletes are right leg dominant. Although the participants' dominant leg was not identified during data collection. For the left foot in trial one RS produced more force and in trial two MFW produced more force. Once again this was not statistically significant. The time to peak force was also not statistically significant for any metric. This indicates that MFW may allow athletes to produce more ground reaction forces but may not have an effect of the time to peak force. Although, the effect on ground reaction forces is not very conclusive. While there were a significant difference and a medium effect size for the right foot, there was no difference or trend that could be found for the left foot. Once again, perhaps the different results between left and right are due to the athlete's dominant leg. However, since the athlete's dominant leg was not recorded, more research is needed to further examine the relationship. Several studies indicate that MFW and barefoot perform better when performing a vertical jump (LaPorta et al., 2013; Than et al., 2022). In contrast, other literature has reported findings similar to those of the present study and showed no difference (Harry et al., 2015). These results are attributed to the to lack of cushion in the MFW and barefoot conditions. The added cushion in RS dissipates force and prevents that force from being directly applied to the ground. The dissipation of force likely has a negative effect on the vertical jump (LaPorta et al., 2013).

The maximal velocity deadlift did not report any statistically significant differences. However, further examination did reveal a trend in favor of MFW. During both trials, the MFW group produced more force from the right and left leg than the RS group. Likewise, the MFW group had a quicker time to peak force from both the right and left leg when compared to the RS group during both trials. This indicates that, although not significant, the MFW group was generally able to produce more ground reaction force and produce that force in less time, which aligns with prior research showing that performing a maximal velocity deadlift barefoot increases the rate of force development and mediolateral center of pressure excursion (Hammer et al., 2018). Another factor to consider is the stack height of the shoes. If athletes are barefoot, they will have to lift the bar at a shorter total distance than if they were doing the same lift but wearing thick shoes. If maximum weight is the goal, then perhaps barefoot would be superior due to the lesser amount of work (defined as work = force * displacement) needed to lift the bar. However, a shoe with a greater stack height may provide a better stimulus due to the greater amount of work needed to lift the same weight, assuming the thicker shoes are stable and do not influence the application of force from reduced stabilization (Valenzuela et al., 2021). An additional factor to consider is heel-to-toe drop. Increased heel-to-drop influences the kinematics and kinetics of the knee and ankle joints with a higher heel-to-toe drop resulting in greater knee flexion, reduced ankle flexion, and a more upright torso when squatting (Legg et al., 2017). Deadlifting in footwear with a high heel-to-toe drop may have a similar effect, resulting in greater knee flexion, reduced ankle flexion, and a more upright torso. However, no study has directly compared the effects of heel-to-toe drop on joint kinetics and kinematics during a deadlift. A greater heel-to-toe drop may also increase peak patellofemoral stress when running due to the increased knee extension moment (Zhang et al., 2022).

Overall, the hypothesis of the present research was partially correct. The hypothesis was correct for ground reaction force production. There was an observed difference in the athlete's force production, with MFW producing more force and achieving a quicker time to peak force. The hypothesis was incorrect for stability and change of direction ability. There were no observed differences in the athlete's stability or change of direction ability, regardless of shoe condition.

One strength of this study design was the use of MCLA Division 1 athletes who were familiar with many of the testing protocols before testing. This likely resulted in less of a learning effect between the two testing sessions. These athletes were beyond recreational levels of training and were involved in a sport-specific strength and conditioning program. Thus, their exercise technique and base level of conditioning increased the likelihood of valid assessments using the selected metrics.

Very few other studies have examined areas comparable to the topic of this study. The present research was the first to test the effects of MFW on MCLA Division 1 athletes. It was also the first to investigate the acute effects of MFW on athletes. One study examined the effects of wearing MFW for five weeks on change of direction performance via the AFL agility test, T-test, and pro agility (de Villiers & Venter, 2014). They found that a five-week plyometric training program in MFW improved the AFL agility, T-test, and pro agility performance. However, the T-test and pro agility performances were not statistically significant. Another study indicated that barefoot training for nine weeks improved the sprint speed, agility, and ankle stability of netball athletes (de Villiers & Venter, 2014). Prior research has also indicated that wearing MFW can increase foot strength when worn for at least eight weeks (Curtis et al., 2021; Ridge et al., 2019) and improve running economy (Lindlein et al., 2018; Ridge et al., 2015; Yang et al., 2020). Therefore, the cross-sectional observations of this study may be amplified by adaptive responses that occur from repeated exposure to the minimalist footwear.

It is also important to note that the tests that did not report significant differences show that while MFW may not improve performance, it did not hinder performance. The absence of a benefit or hinderance can be important because, for the tests that were not significantly different, the coach, athletes, or general population can base their selection of footwear on individual preference. However, for the significantly different tests, including the limits of stability assessment and the vertical jump, MFW performed better and may be a better choice for those exercises. In athlete or patient compliance, it may be recommended that MFW is the standard, as compliance may decrease if they are required to switch shoes frequently.

Future research is needed to examine the effects of long-term MFW use for the same tests used here. A longitudinal study design may elicit more differences than presented in this study. Future research is needed to replicate this study to see the effects in other populations, such as different teams, sexes, and the general population.

A limitation of this study is using Vicon Nexus software to analyze data acquired from the force plates, causing two potential limitations. The first limitation is that the Vicon Nexus software requires a visual analysis of peak force and time to peak force. To minimize the effects of this limitation, one analyst was responsible for analyzing all the force plate data. The second limitation is that the software could occasionally glitch and not collect data correctly. In cases where this occurred, that data was excluded from the study.

Another limitation is that some of the effects of MFW may take time to develop. A randomized crossover design such as the one used in this study does not have an intervention and, thus, has no time to adapt to the shoes. Multiple studies indicate that the adaptations due to wearing MFW may take anywhere from eight weeks to six months. However, full adaptations may take even longer (Curtis et al., 2021; Ridge et al., 2019). Additionally, the model of minimalist shoes was controlled for, but the running shoes were inspected and qualified based on generic designs that included a heel-to-toe drop via a cushioned heel. It is unlikely that the running shoe models would yield substantially different performance outcomes based on the similarities in the designs between manufacturers. However, the possibility of an influence must be acknowledged.

Conclusion

The observed differences in peak force during the vertical jump and the maximal velocity deadlift (maximal velocity deadlift was not statistically significant) but not the pro agility and modified T-test indicate that

MFW is acutely more influential during strength and force production and less influential on change of direction and agility. While the present research indicates an acute effect, it is reasonable to infer that repeated exposure to an acute effect could elicit a greater training stimulus which could benefit athletes over time. Therefore, it may be best to wear MFW when maximum strength and power are training priorities. However, minimalist shoes may not make a difference—either positive or negative—in change of direction drills. Practically speaking, for many sports, change of direction drills occur on grass or turf where cleats are primarily used, potentially making shoe selection an irrelevant consideration for these styles of drills. In conclusion, MFW may be best utilized during resistance training that is aimed for developing maximal strength and power.

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Data availability statement

All relevant data are within the paper.