

Variation of Kinematic and Dynamic Parameters with the Use of Minimalist Shoes in the Entry Phase of the Hammer Throw

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Abstract: This study investigates the biomechanical implications of footwear choice on the start phase of the hammer throw, aiming to determine whether minimalist footwear can be integrated into training without negatively affecting technical execution. A cohort of six trained hammer throwers performed the initial three rotations (start phase) under two different footwear conditions: standard World Athletics-approved throwing shoes and minimalist Fivefingers shoes by Vibram. Participants were divided between two motion capture laboratories for geographical reasons while ensuring consistent methodological application across environments. The objective was to assess whether the minimalist footwear—known to enhance activation of intrinsic foot musculature—alters key technical elements of the throwing motion. Analysis was structured around five biomechanically relevant instants within the entry phase, before the start of the turns, enabling comparison across footwear conditions of five parameters relative to the hammer head and the right foot motion, obtained using stereophotogrammetry (tangential hammer velocity, right joint movements and ground reaction forces). Preliminary results aim to determine whether the use of minimalist footwear brings an advantage to the throwers in the entry phase of throwing and whether it can be a useful tool for use in training.

1 INTRODUCTION

In hammer throwing, the entry phase represents one of the most critical phases for efficient execution. This phase occurs between the preliminary swings selection potentially influential on performance. As throw, the efficient transfer of force begins at highlighted in biomechanical analyses of hammer the ground level, where the foot plays a pivotal role in stabilizing and initiating rotational momentum (Dapena, 1986; Murofushi et al., 2005), and the rotational turns of the thrower-hammer system (Judge, 2000). During this phase, accelerating the hammer requires significant contribution from both

intrinsic and extrinsic foot muscles, making footwear may represent a possible alternative.

The choice of footwear for competition and training may therefore impact technique and Current World Athletics-endorsed throwing shoes have a rigid, heavy structure, while minimalist footwear may represent a possible alternative.

Minimalist footwear - characterized by minimal cushioning, flexible soles, and wide toe boxes - aims to replicate barefoot conditions with the potential to enhance natural foot movement, proprioception, and intrinsic muscle activation. Some research suggests that minimalist shoes may increase plantar flexor and intrinsic foot muscle strength compared to conventional footwear (Ridge et al., 2018), although

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such evidence is context-dependent and not specific to hammer throw.

While direct evidence regarding the use of minimalist shoes in hammer throwing is limited, the biomechanical demands of the entry phase suggest that such footwear could offer potential benefits. This phase requires precise footwork, rapid weight shifts, and finely tuned postural control—all of which depend heavily on foot muscle strength and sensory input. Despite its biomechanical complexity and critical role in initiating effective hammer acceleration, the entry phase remains underrepresented in the literature (Rozhkov et al., 2020). A recent review has further highlighted the scarcity of studies on this specific phase, underlining the need for more focused investigations (Castaldi et al., 2022).

It has been hypothesized that stronger foot muscles might improve stability and force transmission, while enhanced sensory feedback could help throwers in maintaining posture and control during the critical transition from preliminary swings to rotational turns. However, these potential benefits have not yet been verified in hammer throwers. Indeed, posture and proprioceptive control in the early phases of the throw are essential for maintaining optimal hammer trajectory and velocity (Brice et al., 2008; Bartonietz, 2008).

Additionally, by promoting more natural foot placement, minimalist shoes could influence elements such as the left foot's heel pivot and right foot's toe positioning during entry. Whether this translates into improved movement efficiency remains to be determined.

Therefore, this study analyses whether two different footwear types can modify technique or efficiency during the hammer throw entry phase.

2 METHODS

2.1 Participants

This research was approved by the University of Rome “Foro Italico” local institution Review Board (CAR 194/2024). Six hammer throwers (three men and three women, height 1.78 ± 0.08 m; body mass 80.7 ± 13.5 kg; age 21.0 ± 4.9 years) included in the top ten positions of the Italian U20, U23, or senior category rankings participated in the study. Data acquisition took place at the University of Rome “Foro Italico” laboratory (Rome) and at the Vibram Connection Lab (Milan).

2.2 Protocol

Two types of entry phases were analysed, without performing the throwing phase. The first (3gr) involved no pre-start of the hammer before the preliminary rotations, no displacement of the right foot at the end of the preliminaries, and an initial rotation on the heel of the left foot. The second (4gr) included a hammer pre-start before the preliminary swings, with the displacement of the right foot at the end of the preliminary swings and an initial rotation on the left forefoot. Each type of start was performed twice with both World Athletics approved throwing footwear (WA) and Vibram Fivefingers KSO Evo minimalist footwear (MS). MS is a very light and flexible minimalist shoe, while WA is a heavy and rigid shoe (fig. 1). Throwing with MS therefore allows more efficient use of the muscles of the foot and promotes the thrower's sensitivity. In contrast, with WA the sensitivity and use of the intrinsic foot muscles are less, but due to the greater stiffness of the shoe, reaction forces from the ground are transferred more and more efficiently to the thrower's body.



Figure 1: Marker protocol and shoes.

2.3 Data Acquisition

Two motion-capture system were used to measure movement kinematics: in lab1, an 8-cameras SMART-DX 4000 (BTS Sp.a.; @250 frame/s); in lab2, a 4-Vero and 5-Bonita infrared cameras (VICON®, Oxford Metrics, Oxford, UK; @200 frame/s). Two floor-embedded force plates were used to assess ground reaction force - GRF (lab1: BTS S.p.a 40x60cm., Milano, IT, lab2: Bertec Corp., Columbus OH USA, 40x40cm, both @1000 Hz). Data were processed using Vicon Nexus 2.10 (Vicon, Oxford, UK). Athletes were equipped with the Clinical Gait Model (CGM, v.2.5) protocol, while the

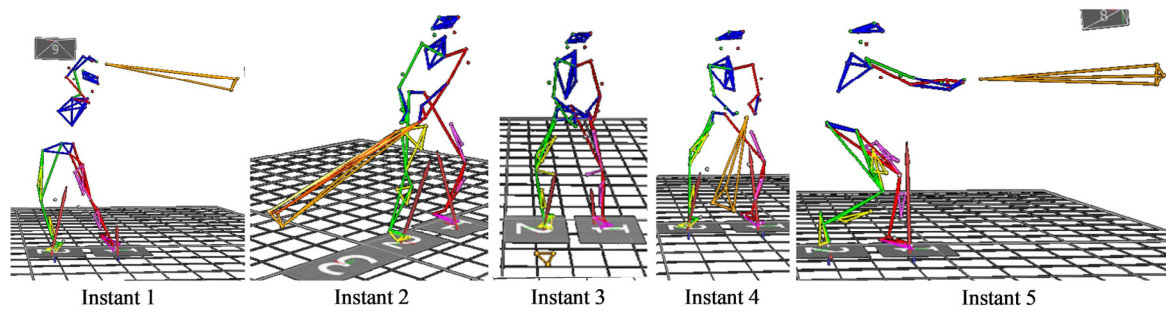


Figure 2: Key instants of the entry phase: the beginning of the active phase after the last preliminary turn Instant 1), the descending phase of the hammer on the right side of the thrower (Instant 2), the passage of the hammer in front of the thrower's right foot (Instant 3), the reaching of the low point of the hammer's path (Instant 4), and the end of the entry phase with the landing of the right foot from the ground (Instant 5).

hammer carried 4 markers: one at the beginning of the wire connected to the handle, and three applied on the maximal circumference at 120 deg respective separation (fig. 1). To minimize inter-laboratory differences, the same experimenter performed the anatomical calibration and sensors/markers placement in both laboratories.

2.4 Data Analysis

Raw marker trajectories and analogue signals were imported using ezc3d and organized into a nested structure grouped by subject, footwear condition ("WA" for World Athletics shoe, "MS" for minimal shoe), trial type (3gr, with rotation in the entry on the heel of the left foot and usually used for a three turn throw technique, or 4gr, with rotation on forefoot and usually used for a three turn throw technique), and repetition.

2.5 Key Instants

In the research five critical moments were defined to analyze motion (fig. 2): the point where HAMMER is furthest to the left of the thrower on the frontal plane (Instant 1, I1), the point at which LFMH, RFMH and HAMMER are on the same line (Instant 2, I2), the point at which LFMH, RFMH and HAMMER form a right angle on RFMH (Instant 3, I3), the lowest point of HAMMER relative to the ground (Instant 4, I4) and the point where the right foot loses contact with the ground (Instant 5, I5). The five key instants (I1–I5) were determined for each repetition using a combination of velocity thresholds and temporal heuristics using data from force platforms, right and left feet heel (RHEE, LHEE) and first metatarsal heads (RFMH, LFMH) and the hammer marker cluster, used to compute the implement's centroid.

2.6 Key Parameters

For every repetition, the CGM2.5 model was used to determine the plantar-dorsiflexion of both ankles (LAnkleAngles and RAnkleAngles) and the athlete's centre of mass (COM). The hammer centroid tangential velocity was computed relative to subject COM, along the X, Y, and Z axes. Ground reaction forces under the right (Rfoot) and left foot (Lfoot) were represented in a body frame perspective along the anteroposterior (AP), mediolateral (ML), and vertical (VERT) directions (i.e. force plate axes were assigned to anteroposterior or medio-lateral according to the feet orientation), and computed at the 5 key instants.

2.7 Statistical Analysis

Statistical analyses were conducted using Python libraries (statsmodels, scipy, and pandas). For each dependent variable, normality of residuals was tested using the Shapiro-Wilk test and the homogeneity of variances was evaluated using Levene's test. Descriptive statistics were computed using mean and standard deviation, for variables meeting both assumptions, and median and interquartile ranges (IQR) for non-normally distributed ones.

Prior to inferential analysis, extreme outliers were removed using a z-score threshold of ± 3 , and trials with missing data were excluded on a per-variable basis. Variables meeting Shapiro-Wilk and Levene assumptions were analysed using a two-way ANOVA, with shoe (WA vs MS) and trial (3gr vs 4gr) as fixed factors (table 1). If assumptions were violated, the non-parametric Scheirer-Ray-Hare test was applied. When main effects or interactions were statistically significant ($p < 0.05$), pairwise post-hoc comparisons were conducted using the Tukey HSD test to identify specific condition differences.

3 RESULTS

The analysis of ground reaction forces revealed significant differences for footwear type only for the left foot in the vertical direction at instants I1 and I4, AP direction at I3 and ML direction at I4 (fig. 3).

More significant differences were found across tasks in GRF, always for the left foot, at the instant I1 along the AP and vertical direction; at instant I2 along the ML and vertical ones; at instant I4 and I5 along the AP direction. In all cases 4gr task entailed greater forces (fig. 3).

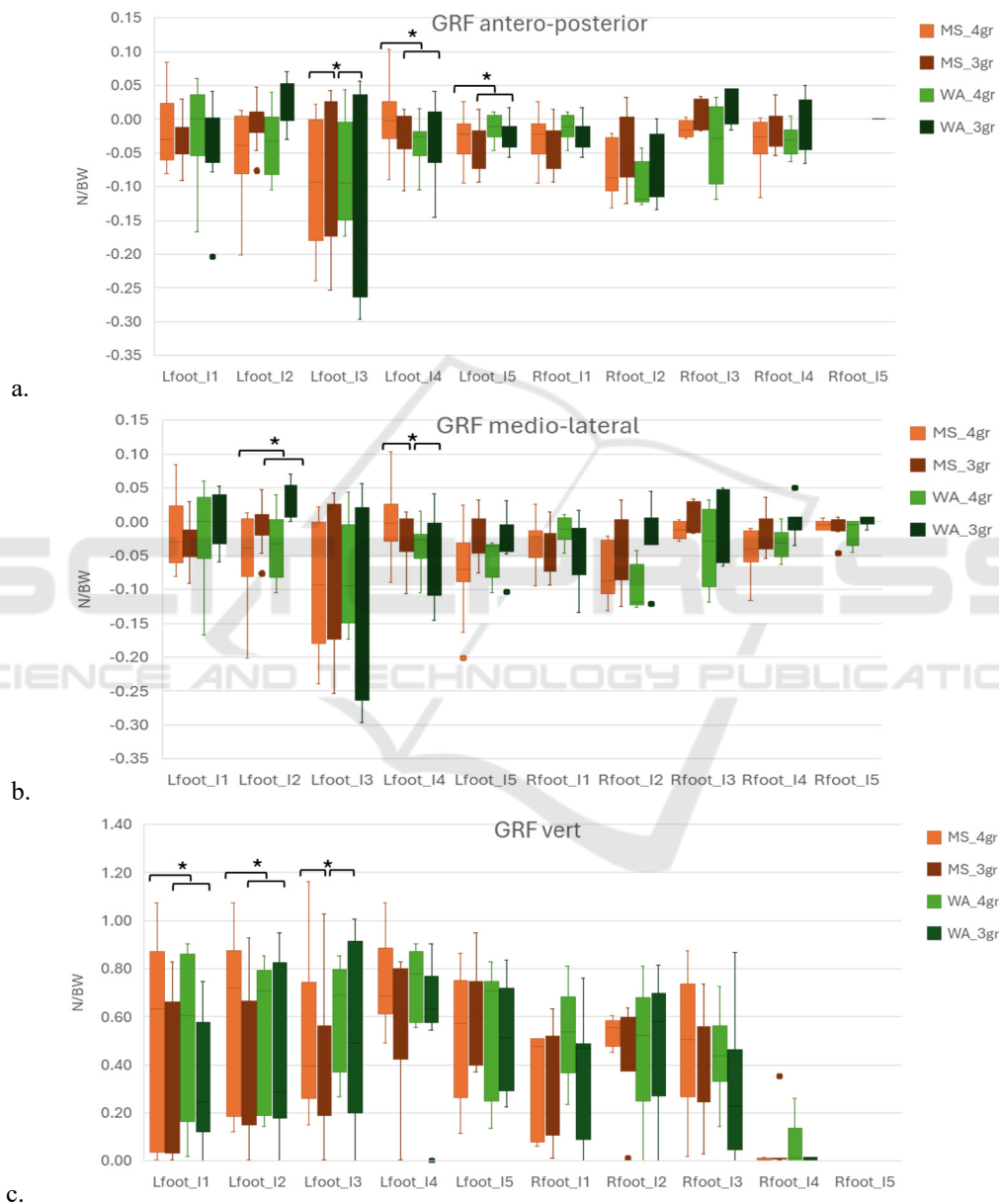


Figure 3: a. anterior-posterior (ap), b. medio-lateral, and c. vertical components of ground reaction force (GRF, normalized to body weight, BW) during contact of the right foot (Rfoot) and left foot (Lfoot) at the five moments of support (I1–I5). Four types of footwear are reported: Minimal Shoe (MS) and World Athletics approved footwear (WA), each tested on three (3gr) and four turns (4gr). The bars represent the median and interquartile range, while dots show the outlier. The symbols “*” highlight statistically significant differences between conditions ($p < 0.05$).

Table 1: Statistically significant differences.

variable	Test	p shoe	p trial	descriptive
Lfoot_I2_ml [N/BW]	Two-way ANOVA	0.17	0.01	mean=-0.18 sd=0.51
Lfoot_I4_ml [N/BW]	Two-way ANOVA	0.01	0.32	mean=-0.24 sd=0.47
Lfoot_I1_ap [N/BW]	Two-way ANOVA	0.20	0.00	mean=-0.17 sd=0.51
Lfoot_I3_ap [N/BW]	Two-way ANOVA	0.01	0.34	mean=-0.24 sd=0.47
Lfoot_I4_ap [N/BW]	Two-way ANOVA	0.67	0.00	mean=-0.41 sd=0.44
Lfoot_I5_ap [N/BW]	Two-way ANOVA	0.63	0.00	mean=-0.40 sd=0.44
Lfoot_I1_vert [N/BW]	Two-way ANOVA	0.02	0.02	mean=-0.43 sd=0.20
Lfoot_I2_vert [N/BW]	Scheirer- Ray-Hare	0.58	0.02	median=-0.23 IQR=0.68
Lfoot_I4_vert [N/BW]	Scheirer- Ray-Hare	0.04	0.15	median=-0.37 IQR=0.47
Lank_I5 [deg]	Scheirer- Ray-Hare	0.82	0.24	median=3.8 IQR=4.8
Rank_I1 [deg]	Two-way ANOVA	0.04	0.41	mean=14.1 sd=15.6
Rank_I2 [deg]	Two-way ANOVA	0.03	0.50	mean=16.1 sd=14.8
Rank_I3 [deg]	Two-way ANOVA	0.05	0.70	mean=14.1 sd=14.8
Rank_I4 [deg]	Scheirer- Ray-Hare	0.04	0.40	mean=14.5 sd=17.5
Rank_I5 [deg]	Two-way ANOVA	0.04	0.15	mean=14.7 sd=14.3
vel_I3 [m/s]	Scheirer- Ray-Hare	0.57	0.05	median=44.1 IQR=15.6

The analysis of the velocity modulus revealed differences in velocities only at instant I3, which were higher during the 4gr task.

The right ankle presented significantly wider ranges of planta-flexion when using the MS shoes at all instants of time, irrespective to the test condition.

4 DISCUSSION

This pilot study compared the impact of using two different footwear types on the hammer throw entry phase technique and efficiency. Results on ankle angles, force exchanged with the ground, and hammer tangential velocity suggest that the effects of footwear are context-dependent and should not be generalized without considering specific surfaces, movements, and individual factors.

As no throwing phase was performed, performance outcomes such as release velocity or distance were not available in the present analysis. Therefore, no speculation can be made regarding the potential effects of these differences on overall performance. The limited sample size did not allow

neither to observe general traits, nor to cluster athletes across different behaviour and certainly requires expansion.

Some athletes presented a tendency worth further investigation. In some of them the use of MS, being a more flexible footwear than WA, promotes more excursion of the right ankle joint and induces a start in which the vertical components of force are predominant over the horizontal ones. With WA footwear, the thrower compensates with more horizontal expressions of force, especially in the second part of the entry phase with the left foot (Instants 3, 4 and 5). Considering that from instant 4 the hammer is in the ascending phase of the orbit, it is important that the footwear allows for an active action on the hammer in the most effective way possible, and therefore a greater efficiency in the development of horizontal components of the force could better support the tangential velocity of the hammer in this phase of the entry. In this phase of the throw, the rotary components of the throw are predominant over the translatory ones.

This study suggests that the contribution to speed generation in the entry phase may be greater with WA, in accordance with the evolution of footwear used in competition, which in the 1980s was light and flexible and over the years has been replaced by increasingly rigid models, that enhance the return of energy from the ground. The importance of footwear in enabling ground reaction force transmission and rotational efficiency has been discussed in relation to foot-ground interaction dynamics (Murofushi et al., 2007; Wang et al., 2014). Conversely, it is likely that the greater stresses to which the intrinsic and extrinsic musculature of the foot is subjected make the use of MS in training more proficient in the quest to improve the muscular capabilities of throwers.

Future research could investigate differences in muscle recruitment using a larger number of subjects and using EMG. They could also investigate with longitudinal studies the potential effects of habituation on muscle recruitment using different footwear.

5 CONCLUSION

Preliminary analyses of the hammer throw entry phase with two footwear types show that minimalist shoes can promote greater vertical force components, while World Athletics shoes favour horizontal forces. These effects appear context-dependent and preliminary due to the limited sample and the absence of performance outcomes. Overall, the results suggest

complementary roles for the two footwear types, with rigid shoes suited to competition and minimalist shoes potentially useful in training.

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