JOURNAL OF SPORTS SCIENCES
2021, VOL. 39, NO. 1, 108–114
https://doi.org/10.1080/02640414.2020.1808277

Routledge
Taylor & Francis Group

Check for updates

SPORTS MEDICINE AND BIOMECHANICS

Maximalist shoes do not alter performance or joint mechanical output during the countermovement jump

Luke D. Chowning, John Krzyszkowski and John R. Harry

Human Performance & Biomechanics Laboratory, Department of Kinesiology & Sport Management, Texas Tech University, Lubbock, TX, USA

ABSTRACT

This study examined potential differences between maximally cushioned (MAX) shoes and standard cushioned (STND) shoes during countermovement vertical jump (CMVJ) performance. Twenty-one males (23[2] y; 86.5[15.4] kg; 179.8[6.3] cm) completed eight jumps each in MAX and STND shoes while three-dimensional kinematic and kinetic data were collected. Paired-samples t-tests ($\alpha = 0.05$) and Cohen's d effect sizes (ES) were used to compare the following variables: vertical jump displacement, jump time, hip, knee and ankle joint angles at the start of the countermovement, the end of the unloading phase, the end of the eccentric phase, and at takeoff, peak joint power, and the joint contributions to total lower extremity work during the eccentric and concentric phases. The ankle was more dorsiflexed at the end of the countermovement in the MAX shoe ($p = 0.002$; ES = 0.55) but greater plantarflexion occurred in the STND shoes at takeoff ($p = 0.028$; ES = 0.56). No other differences were observed. The result of this study suggests that unique ankle joint angular positioning may be employed when wearing MAX versus STND shoes. Since the unique ankle joint positioning did not alter jump performance, potential MAX footwear users might not need to consider the potential for altered CMVJ performance when determining whether to adopt MAX footwear.

ARTICLE HISTORY
Accepted 4 August 2020

KEYWORDS
Maximal shoes; standard shoes; countermovement vertical jump

Introduction

Countermovement vertical jump (CMVJ) performance is commonly performed in many sports, such as volleyball (Gjinovci et al., 2017), basketball (Ostojic et al., 2006), soccer (Reilly et al., 1990), and gymnastics (Di Cagno et al., 2009). CMVJ performance can be positively influenced at kinematic, neuromuscular, and/or environmental levels (Arampatzis et al., 2004) using weight training (Channell & Barfield, 2008; Chelly et al., 2009) and plyometric training (Markovic, 2007) interventions. However, athletes may not have enough time to experience performance improvements from plyometric and resistance training interventions. As such, it may be useful for human performance professionals to consider interventions that do not require significant amounts of time to elicit performance improvements. Researchers have been searching for such non-invasive interventions while emphasizing the potential influence of different footwear types on metrics of CMVJ performance to determine whether changing footwear can facilitate CMVJ performance adaptations (Harry et al., 2015; LaPorta et al., 2013). Jump performance is likely to be optimized when wearing footwear designed for activities involving frequent jumping actions, such as basketball shoes (WK Lam et al., 2019; W-K Lam et al., 2018). However, numerous researchers appear focused on identifying a universal footwear type, commonly worn by recreationally active individuals, that can be used effectively during their design-focused tasks (e.g., running) and the CMVJ (Taylor et al., 2019; Worobets & Wannop, 2015).

LaPorta et al. (2013) examined differences in vertical jump and depth drop performance among standard shoes (STND), minimalist shoes, and barefoot. They observed no differences between minimalist shoes and barefoot conditions for relative ground reaction force (GRF) production and CMVJ performance (i.e., jump height). However, the minimalist and barefoot conditions produced greater jump heights during the CMVJ compared to STND shoes. More recent studies (Harry et al., 2015; Smith et al., 2020) have failed to observe jump height differences among barefoot, minimalist, and STND shoes or between STND and minimalist shoes despite different muscle activations among conditions and increased distal joint peak angular power production in STND versus minimal shoes, respectively. It is important to note that the aforementioned studies only examined STND footwear (e.g., tennis shoes, conventional athletic shoes, etc.) in comparison to minimalist footwear and/or barefoot. STND footwear tends to weigh between 283 g and 397 g, have a heel drop of 10–12 mm, and a stiff sole providing arch support (Bowles et al., 2012), while minimalist footwear tends to weigh < 170 g, have a heel drop of 0–4 mm, flexible cushioning and no arch support (Bowles et al., 2012; Esculier et al., 2015). Given recent findings, these general structural differences between STND and minimalist footwear may not be substantial enough to reveal consistent or meaningful performance changes during the CMVJ.

A shoe type with what appears to be general structural characteristics that are more notably different than those of STND shoes is maximalist (MAX) shoes. While MAX shoes might be an unexpected shoe type to wear during the CMVJ and other jump movements, plyometric training has become popular among runners and recreationally active individuals (Berryman et al., 2010; Mikkola et al., 2007) who might select MAX shoes for their growing popularity and potential to decrease impact loading rates without altering lower extremity

CONTACT John R. Harry john.harry@ttu.edu Department of Kinesiology & Sport Management, Texas Tech University, Lubbock, TX 79409

coordination patterns (Borgia et al., 2020; Sinclair et al., 2016). Research-based categorical definitions (e.g., mass, heel-toe drop, sole thickness, cushioning materials) for a shoe to be considered "maximally cushioned" are currently unavailable (Mercer et al., 2018), although commercial branding indicates the uniqueness of MAX shoes centres on a distinct increase in midsole material/cushioning compared to STND shoes. For example, MAX shoes that are currently available to consumers tend to have a similar heel-drop (~3–10 mm) and mass (170 g to 340 g) (Hoka One One, 2018; Skechers, 2018) when compared to the aforementioned characteristics of STND shoes, although MAX shoes have sole thicknesses that are much greater than STND shoes. It is reasonable to presume that the reduced impact loading observed in MAX shoes when striking the ground would coincide with altered force application when attempting to leave the ground. As such, we surmise that differences in mechanical output and ultimately CMVJ performance would be observed between STND and MAX shoes during the unloading and eccentric sub-phases of the countermovement due to both the unique midsole thicknesses of the two shoe types and the direct impact that these sub-phases have on mechanical output and CMVJ performance (Harry, Paquette et al., 2018; Krzyszkowski et al., 2020). Mechanical output qualities that have only recently been explored during jumping with respect to footwear changes are joint power production and work (Smith et al., 2020). Identifying footwear changes in joint power and work may be critical revelations, as they can expose changes in coordination of mechanical output that strongly influence CMVJ performance (Kipp et al., 2020), while isolating such changes to key "eccentric" and "concentric" CMVJ phases (JR Harry et al., 2020). This information would be especially useful to recreationally active individuals opting to use MAX shoes during physical activities and exercises involving jumping movements, whether it be to maintain consistency of footwear worn during main (e.g., running) and supporting (e.g., plyometric exercise) activities or for perceived fit and overall comfort.

The purpose of the current study was to investigate potential differences in CMVJ performance and lower limb mechanical output between MAX and STND shoe conditions to determine how much cushion/material a shoe must have in order to expect coinciding changes in mechanical output or jumping performance. We tested the following hypotheses: (1) no differences in CMVJ performance would be observed between STND and MAX shoes, and (2) lesser peak ankle and knee joint angular power would occur in MAX footwear compared to STND shoe conditions. Despite the reasonable expectation that the more substantial structural differences between STND and MAX shoes could facilitate CMVJ performance differences between the two shoe conditions, our two hypotheses were formed according to recent studies comparing STND to minimalist footwear and/or barefoot (Harry et al., 2015; Smith et al., 2020) and logical reasoning, respectively. As such, we had no strong hypothesis for whether CMVJ performance would decrease when changing from STND to MAX shoes, although we did anticipate mechanical output changes based on potential use of footwear-specific jumping strategies.

Methods

Subjects

An a priori power analysis using G*Power version 3.1.9.2 (Faul et al., 2007) and the total positive joint work produced by males during the CMVJ when wearing STND versus minimal footwear (Smith et al., 2020) indicated a sample of 11 participants would be required to achieve an estimated effect size of 0.96 (i.e., large effect), power of 0.90, and an alpha level of 0.05 for a comparison between dependent means. Because related literature only reported CMVJ performance changes between or among footwear types in figure form, we could not obtain the necessary inputs for the sample estimation based on jump height. In addition, the aforementioned differences between and among footwear conditions were very small. As such, we sought to ensure more than adequate power by recruiting 21 men (23 [2] y; 86.5 [15.4] kg; 179.8 [6.3] cm) to participate in this study. All were habitual STND footwear users and recreationally active, as defined by self-reported participation in a combination of lower body resistance training, recreational sports (specifically basketball, football, and soccer), or plyometric training at least twice per week for six months prior to participation in this study. All participants were free of injury within the previous year and did not suffer from any musculoskeletal disease/ailments that would limit their CMVJ abilities. Participants were asked to refrain from strenuous lower body exercise for 48 hours prior to testing. Written informed consent was provided to the researchers as approved by the Institutional Review Board at Texas Tech University.

Experimental protocol

Participants completed a single laboratory session. Age, mass, and height were recorded, and a demonstration of the testing protocol was provided. Participants completed a standardized warm-up consisting of five minutes of stationary cycling at a self-selected pace followed by 20 bodyweight squats, 20 lunges, and 20 squat jumps (JR Harry et al., 2015). Participants were then equipped with appropriately sized STND (Fresh Foam Veniz; New Balance Athletics, Inc., Boston, MA) and MAX shoes (Go Run Ultra R 2; Skechers USA, Inc., Manhattan Beach, CA) between US size 8 and size 12. Participants verbally confirmed that the shoes provided were appropriately sized, and participants who could not fit in shoes sized 8–12 or report an adequate fit were excluded. Three-dimensional (3D) kinematic and 3D GRF data were obtained synchronously using a 12-camera motion capture system (Vantage v5 cameras; Vicon Motion Systems, Ltd., Oxford, UK; 200 Hz) and a dual force platform system (Advanced Mechanical Technology, Inc., Watertown, MA, USA; 1000 Hz). To collect kinematic data, spherical reflective markers (14 mm) were adhered bilaterally over the following anatomical locations using hypoallergenic adhesive tape: acromion process, iliac crest, anterior superior iliac spine, posterior superior iliac spine, medial and lateral aspects of the knee, medial and lateral malleoli, the distal end of the second metatarsal, and the sacrum. Three non-collinear markers were adhered bilaterally over the shoes' heel counter, and thermo-plastic shells with four non-collinear markers were

Table 1. General characteristics of the Standard and Maximalist Shoes.

Variable	STND	MAX
Mass	181 g	244 g
Heel-drop	6 mm	4 mm
Midsole structure	Neutral	Neutral
Pronation	Neutral	Neutral
Arch	High	High

Characteristics presented here are based on size 9 for both shoe types.

adhered bilaterally over the lateral aspects of the thigh and shank segments using neoprene wraps and hypoallergenic adhesive tape (Table 1).

Static calibration trials were recorded for each shoe condition with all reflective markers secured on the participants. Then, the markers adhered to the iliac crest, anterior superior iliac spine, medial and lateral aspects of the knee, medial and lateral malleoli, and the metatarsals were removed while the remaining markers were retained to track motion data. Participants completed up to five practice trials to become accustomed to jumping and landing on the force platforms. Participants then completed eight maximum effort CMVJ trials in each shoe condition, for 16 total trials at self-selected pace. Participants were instructed to jump as high as possible while performance was monitored. If a subject gave what they perceived to be less than maximal effort, the trial was discarded and repeated. A two-minute break was provided between conditions. The shoe types were presented to the participants in a counterbalanced order (i.e. the first participant jumped in the MAX shoe before the STND shoe while the next participant jumped in the STND shoe before the MAX shoe). Approximately 20 seconds rest was provided between trials and approximately two-minutes of rest was provided between shoe conditions. Trials began with the participants in a quiet standing position with each foot on a force platform. To maintain consistency with recent work (Harry et al., 2015; Smith et al., 2020) participants initiated the CMVJ using a countermovement with a self-selected depth and arm swing. Upon completion of the countermovement, participants jumped for maximum vertical displacement before landing on the force platforms and returning to the quiet standing position. Trials were discarded and repeated if a participant was unable to return to a standing position after landing or the researchers determined that excessive horizontal translation occurred during flight (visually monitored by the researcher). No more than 20 trials were needed for any participant to complete 16 successful trials.

Data analysis

Visual3D biomechanical software (C-Motion, Inc., Germantown, MD) was used for data processing and analysis. A four-segment model was built from the kinematic data to include the pelvis, thigh, leg, and foot segments. Hip joint centres were defined using the equations presented by Bell et al. (1989, 1990). Knee and ankle joint centres were defined as the mid-point of the markers adhered over the medial and lateral aspects of the knee joint and medial and lateral malleoli, respectively (Choe et al., 2018). Only data from the right limb was analysed for all kinematic measurements to determine bilateral jumping performance as demonstrated elsewhere (Stephens et al., 2007). Data were interpolated using a third order polynomial with a maximum gap of 10 frames. Marker trajectories and GRF data were then smoothed using a low pass Butterworth digital filter with cut-off frequencies of 10 Hz and 50 Hz, respectively. The smoothed vertical GRF data from the two force platforms were summed to represent the vertical GRF at the total body centre of mass (COM). The pelvis COM was calculated from the smoothed marker trajectories to represent the total body COM, and vertical COM velocity was calculated as the derivative of the pelvis COM with respect to time (Chiu & Salem, 2010). From the vertical GRF and COM vertical velocity data, unloading, eccentric, and concentric phases were identified (Barker et al., 2018), as shown in Figure 1. Specifically, the unloading phase was defined as the time between the start of the CMVJ (COM velocity < –0.18 m/s) to the local minimum vertical GRF, sometimes referred to as the unload GRF. The eccentric phase was defined as the time between the end of the unloading phase and the lowest COM vertical position (i.e., vertical COM velocity crosses zero). The concentric phase was defined as the time between the end of the eccentric phase and takeoff (summed vertical GRF < 20 N).

All GRF variables were calculated from the summed vertical GRF data and normalized to body mass. Storage of elastic strain energy during the countermovement was represented by the GRF magnitude at the end of the eccentric phase (Bobbert et al., 1996), commonly referred to as the amortization GRF (Barker et al., 2018; Harry, Barker et al., 2018). The eccentric rate of

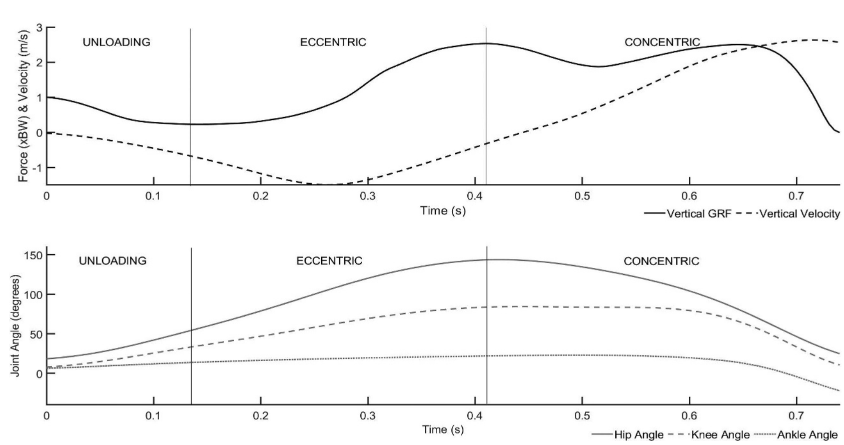

Figure 1. Exemplar force and velocity (top) and hip, knee, and ankle joint angle (bottom) curves to show the changes throughout the unloading, eccentric, and concentric phases.

force development (eRFD) was calculated as the difference between the amortization GRF and the unload GRF divided by the time between the two GRF magnitudes (Barker et al., 2018; Laffaye et al., 2014). CMVJ displacement (i.e., jump height) during flight was calculated as the square of the vertical COM velocity at takeoff divided by two times gravitational acceleration (Moir, 2008). CMVJ displacement was divided by the time between the start of the countermovement and takeoff (i.e., jump time) to obtain the modified reactive strength index (RSI_{MOD}) to provide a supplemental measure of CMVJ performance.

A Cardan rotational sequence (*X-Y-Z*) was used to compute 3D hip, knee, and ankle joint angles, where *X* represents the medial-lateral axis, *Y* represents the anterior-posterior axis, and *Z* represents the longitudinal axis. Angles were expressed in degrees such that positive values indicated the amount of flexion/dorsiflexion at the joint. Joint angles were extracted at the start of the CMVJ and at the end of the unloading, eccentric, and concentric (i.e., takeoff) phases. Joint angular velocities were calculated as the time-derivative of the joint angular positions. Joint angles were not normalized to the static calibration posture in order to maintain distinct local coordinate systems with respect to the laboratory coordinate system and preserve the participants' alignment information. Sagittal plane net joint moments were calculated at the hip, knee, and ankle joints using Newtonian inverse dynamics and resolved in the coordinate system of the proximal segment. Hip, knee, and ankle joint powers were calculated as the dot product of the net joint moments and the corresponding joint angular velocities. Peak negative and positive joint power magnitudes were extracted during the countermovement (unloading + eccentric phases) and concentric phases, respectively (Smith et al., 2020). Joint angular work was calculated during each phase as the time-integral of the joint angular power using the trapezoidal rule. Total joint work during each phase was calculated as a summation of the absolutes values for the joint work performance about the hip, knee, and ankle joints. The contributions of each individual joint relative to the total amount of joint work performed during the phases were calculated as the individual joint work magnitude divided by the total joint work magnitude (Hubley & Wells, 1983). All joint work data were obtained from the right limb and normalized to participant mass.

Statistical analysis

Data for one participant was discarded due to marker digitizing errors, resulting in a sample of n = 20 for analysis. Mean values were calculated across trials per participant for each variable of interest. Paired-samples t-tests ($\alpha = 0.05$) were conducted on the dependent variables using SPSS software (version 25; IBM Corp., Armonk, NY). Rather than applying a correction for Type 1 error (e.g., Holm-Bonferroni), Cohen's *d* effect sizes (ES) were calculated to determine the normalized magnitude of the mean differences and supplement the statistical tests and determine the meaningfulness of the comparisons. We chose this procedure because the meaningfulness of a test cannot be revealed by statistical probabilities alone (Sullivan & Feinn, 2012). In accordance with Cohen's scale (1992), the ES magnitudes were interpreted as follows: 0.2< small < 0.5 < moderate < 0.8 large.

Results

Jump height and all temporal and vertical GRF variables were not significantly different between STND and MAX, and all associated ES magnitudes were trivial to small ($p \geq 0.191$; ES ≤ 0.35; Table 2). Hip and knee joint angles at the start of the CMVJ and the end of the unloading, eccentric, and concentric phases were not significantly different between conditions and the associated *effect size* magnitudes were trivial to small ($p \geq 0.073$ ES ≤ 0.44; Table 3) However, moderate, statistically significant differences in ankle joint angles were observed between STND and MAX conditions at the end of both the eccentric phase ($p = 0.002$; ES = 0.55) and the end of the concentric (i.e., at takeoff) phase ($p = 0.028$; ES = 0.56). No statistically significant or greater-than small magnitude difference were observed for total lower extremity joint work during the unloading, eccentric, and concentric phases, or for the corresponding joint contributions to total work ($p \geq 0.098$; ES ≤ 0.29; Table 4). Similarly, no statistically significant or greater-than small magnitude differences were detected conditions for peak negative or peak positive joint power ($p \geq 0.300$; ES ≤ 0.26; Table 5).

Discussion

The aim of this study was to investigate potential differences in CMVJ performance and lower limb mechanical output between MAX and STND shoe conditions. The only significant differences observed was greater ankle dorsiflexion angles at the end of the eccentric phase when wearing MAX versus STND footwear in

Table 2. Jump Height, Temporal Durations, and GRF Variables.

	STND		MAX			
Variable	Mean	SD	Mean	SD	*p*	ES
Jump Height (m)	0.45	0.08	0.46	0.07	0.577	0.04
RSI_{MOD} (m/s)	0.62	0.13	0.62	0.13	0.955	0.02
Jump Time (s)	0.75	0.13	0.75	0.11	0.955	0.01
Unload Time (s)	0.08	0.03	0.08	0.03	0.209	0.21
Eccentric Time (s)	0.36	0.11	0.35	0.09	0.191	0.11
Concentric Time (s)	0.34	0.07	0.32	0.04	0.350	0.35
Amortization GRF (N/kg)	20.14	3.78	20.40	3.46	0.533	0.07
eRFD (N/kg/s)	51.30	26.02	51.98	24.43	0.772	0.03

mean: average across trials; SD: standard deviation; p = statistical probability; ES: effect size. RSI_{MOD} = modified reactive strength index (jump height (m)/landing time (s))

Table 3. Hip, Knee and Ankle Joint Angles at the Start of the CMVJ and the end of each CMVJ Phase.

		STND		MAX			
Time Point	Joint Angle	Mean	SD	Mean	SD	*p*	ES
Start of CMVJ	Hip	15.03	7.95	16.02	6.81	0.339	0.14
	Knee	8.90	5.51	10.34	4.97	0.096	0.28
	Ankle	7.78	3.88	9.25	2.87	0.148	0.44
Unload End	Hip	31.41	10.22	33.69	10.35	0.176	0.23
	Knee	22.33	8.33	24.66	8.66	0.073	0.28
	Ankle	11.72	4.77	13.26	3.94	0.153	0.36
Eccentric End	Hip	83.67	19.18	84.63	19.30	0.295	0.05
	Knee	82.32	19.28	82.42	19.00	0.898	0.00
	Ankle*	25.92	4.35	28.27	4.50	0.002	0.55
Concentric End	Hip	14.10	9.08	14.60	8.39	0.656	0.06
	Knee	−4.54	4.05	−5.01	4.25	0.418	0.12
	Ankle*	−33.05	5.26	−28.99	9.19	0.028	0.56

Unit of measure: degrees; mean: average across trials; SD: standard deviation; p = statistical probability; ES: effect size; * = significant difference between standard and maximal conditions ($p < 0.05$).

Table 4. Total lower limb joint work with respective joint contributions during the unloading, eccentric, and concentric phases.

	STND		MAX			
	Mean	SD	Mean	SD	p	ES
Unloading Work	0.08	0.05	0.09	0.07	0.098	0.19
Hip Contributions	0.52	0.14	0.50	0.12	0.390	0.17
Knee Contributions	0.38	0.14	0.41	0.10	0.198	0.29
Ankle Contributions	0.10	0.09	0.09	0.06	0.291	0.19
Eccentric Work	0.97	0.37	0.95	0.36	0.500	0.05
Hip Contributions	0.43	0.14	0.42	0.11	0.757	0.04
Knee Contributions	0.51	0.14	0.52	0.11	0.885	0.02
Ankle Contributions	0.06	0.03	0.06	0.03	0.479	0.09
Concentric Work	2.73	0.68	2.80	0.69	0.102	0.12
Hip Contributions	0.29	0.08	0.29	0.08	0.812	0.03
Knee Contributions	0.41	0.08	0.41	0.08	0.660	0.05
Ankle Contributions	0.30	0.07	0.30	0.07	0.770	0.03

unit of measurement for work: joules per kilogram body mass (J/kg); contribution: percentage of total work completed by each joint; mean: average across trials; SD: standard deviation; p = statistical probability; ES: effect size.

Table 5. Peak negative and positive joint power at the hip, knee, and ankle throughout the CMVJ.

	STND		MAX			
Variable	Mean	SD	Mean	SD	p	ES
Negative Hip	−5.33	2.34	−5.27	2.24	0.916	0.03
Negative Knee	−5.96	3.44	−5.58	2.49	0.643	0.13
Negative Ankle	−0.49	0.28	−0.42	0.15	0.185	0.32
Positive Hip	5.79	3.20	7.22	7.24	0.457	0.26
Positive Knee	11.18	11.18	11.57	3.22	0.300	0.05
Positive Ankle	9.84	2.39	9.82	2.38	0.960	0.01

unit of measure: Watts per kilogram of body mass (W/kg); mean: average across trials; SD: standard deviation; p = statistical probability; ES: effect size.

addition to significantly greater plantarflexion angles at the end of the concentric phase (i.e., at takeoff) when wearing STND versus MAX footwear, although the differences were only moderately meaningful. While this result suggests these footwear conditions coincide unique kinematic strategies at the ankle joint during the CMVJ, the differences did not coincide with altered CMVJ performance or joint mechanical output.

In support of our first hypothesis, no difference was observed between STND and MAX footwear for jump height. Both Harry et al. (2015) and Smith et al. (2020) noted similar results when comparing minimalist shoes and/or barefoot to STND shoes. We can surmise that recreationally active individuals who habitually wear STND shoes during training can wear a MAX shoe type and not experience any immediate decreases in jump performance or altered jumping mechanics. The mid-sole cushioning and stack height (e.g., the amount of shoe material between the foot and the ground) differences between STND and MAX shoes (~15 mm stack height) were expected to be more dramatic for the current participants than the mid-sole cushioning and stack height differences among barefoot, minimal, and STND (Harry et al., 2015) or between STND and minimal (Smith et al., 2020) (~10 mm). However, the absolute magnitude of mid-sole cushioning and stack height differences from STND to MAX do not appear to be dramatic enough to stimulate a CMVJ performance (i.e. jump height) effect. LaPorta and colleagues (LaPorta et al., 2013) observed a difference in jump height between barefoot and minimal shoe conditions compared to STND. However, in their CMVJ protocol, they restricted arm swing of the participants by having them complete their jumps with their hands akimbo (LaPorta et al., 2013). It appears as though restricting CMVJ technique (i.e., permitting or restricting arm swing) may be the critical factor for whether CMVJ performance differences are detected between or among footwear types (Mosier et al., 2019; Shetty & Etnyre, 1989). Since use of a self-selected arm swing positively influences CMVJ displacement (Harman et al., 1990), it is possible that participant adjust to a novel footwear condition by augmenting upper extremity motions to compensate for altered lower extremity joint angular positioning (as observed here), muscle activation (Harry et al., 2015), or mechanical output (Smith et al., 2020).

The lack of joint power production differences between STND and MAX footwear did not support our second hypothesis. Although Smith et al. (2020) observed increased peak positive knee angular power in STND compared to minimal footwear, they acknowledged that the observed difference was small (Smith et al., 2020). This may be related to two points. First, it is possible that joint power production may only occur with changes in the forefoot bending stiffness of a shoe, as demonstrated in basketball shoes (Stefanyshyn & Nigg, 2000). Second, joint mechanical output might not be affected by MAX footwear to a level in which CMVJ performance is different that when wearing STND footwear, whether it be during an acute transition between minimal and STND footwear or between STND and MAX footwear. A possible explanation for this result is the presumption that STND footwear elicits a knee-dominant jumping strategy in comparison to minimal footwear (Smith et al., 2020). When combined with the current data, it appears than MAX footwear does not change the knee-dominant strategy that may be favoured when wearing STND footwear.

There were moderately smaller amounts of dorsiflexion and greater amounts of plantarflexion in the STND condition compared to the MAX condition at the end of the eccentric and concentric phases, respectively. These results are consistent with previous work comparing different shoes with different sole thicknesses (Smith et al., 2020). This result may suggest unique kinematic response strategy characterize CMVJ performance when making an acute change between wearing MAX and STND shoe conditions. These kinematic adjustments may have been employed as an attempt to compensate for the subtle increase (small magnitude but approached statistical significance) in knee joint flexion at the start of the CMVJ and the end of unloading when wearing MAX footwear. This may be supported by our general observation of multiple participants noting how "different" the MAX condition felt throughout testing. While comfort was not examined here, different levels of perceived comfort among footwear types have been shown to coincide with altered lower-extremity muscle activation without altering CMVJ performance (JR Harry et al., 2015). As such, it is reasonable to presume that the observed kinematic differences between shoe conditions were associated with different levels of perceived comfort and potential differences in feedback from the shoe-ground interaction. Still, we must acknowledge that the moderate differences in joint angular positions between STND and MAX footwear may also be due to the fact that the MAX footwear had a heel-toe-drop of 4 mm while the STND footwear had a slightly larger heel-toe-drop of 6 mm.While it seems unlikely, it is possible that ankle joint angular position differences could be influenced by the heel-toe-drop differences.

A possible limitation to this study was the fact that the heel-toe-drop associated with the STND condition may not satisfy the structural recommendations reported previously (Bowles et al., 2012). Still, as described previously these participants did casually communicate to the researchers that the MAX condition was "different" than STND, suggesting the structural differences did create unique footwear environments. Another possible limitation was that all participants were habitual STND footwear users. A more complete description of the STND versus MAX footwear comparison could be obtained if habitual MAX users were also examined, though this sub-population would be difficult to obtain. In addition, we did not ask participants to complete a post-test questionnaire to document perceived comfort differences between STND and MAX footwear. Such a questionnaire could have strengthened our general observation of several participants commenting on the perceived difference between the STND and MAX types. It is also possible that the current study, while sufficiently powered for one dependent variable, might have been underpowered for other dependent variables, notably CMVJ height. Finally, we elected to use effect sizes to supplement the statistical probabilities as opposed to using corrected statistical comparisons (e.g., Holm-Bonferroni correction). Although this choice could mean the few statistically significant differences observed might have been the result of statistical error as the corrected alpha level for statistical significance would be quite small ($\alpha = 0.0013$), our use of effect sizes provides the meaningfulness of the comparisons so that specific interpretations can be made by the reader.

In summary, the results of the present study indicate that STND or MAX shoes can be utilized during unrestricted (i.e., preferred arm swing and countermovement depth) CMVJ performance without concern for acutely declined CMVJ performance or mechanical output by individuals who are recreational jumpers. When combined with recent results' (Harry et al., 2015; Smith et al., 2020), it seems reasonable for recreationally active individuals to select any shoe type (e.g., minimal STND, MAX) based on acute comfort and personal expectations prior to a CMVJ test rather than according to concerns for compromised jump performance. Recreationally active individuals interested in long-term use of MAX shoes during jumping movement should also consider the potential effects of MAX shoes on fatigue or musculoskeletal overuse injury risk. Future research might examine the potential effects of MAX shoes on landing from a CMVJ to obtain a robust understanding of the effects of MAX shoes during the CMVJ.

Acknowledgments

The authors would like to thank the participants who volunteered their time to participate in this experiment. This project was not supported by funding from the commercial, private, or not-for-profit sectors.

Disclosure statement

No potential conflict of interest was reported by the authors.

Funding

This project was not supported by funding from the commercial, private, or not-for-profit sectors.

ORCID

John R. Harry http://orcid.org/0000-0002-8207-426X

References

Arampatzis, A., Stafilidis, S., Morey-Klapsing, G., & Brüggemann, G.-P. (2004). Interaction of the human body and surfaces of different stiffness during drop jumps. *Medicine and Science in Sports and Exercise*, *36*(3), 451–459. https://doi.org/10.1249/01.MSS.0000117166.87736.0A

Barker, L. A., Harry, J. R., & Mercer, J. A. (2018). Relationships between countermovement jump ground reaction forces and jump height, reactive strength index, and jump time. *The Journal of Strength & Conditioning Research*, *32*(1), 248–254. https://doi.org/10.1519/JSC.0000000000002160

Bell, A. L., Brand, R. A., & Pedersen, D. R. (1989). Prediction of hip joint centre location from external landmarks. *Human Movement Science*, *8*(1), 3–16. https://doi.org/10.1016/0167-9457(89)90020-1

Bell, A. L., Pedersen, D. R., & Brand, R. A. (1990). A comparison of the accuracy of several hip center location prediction methods. *Journal of Biomechanics*, *23*(6), 617–621. https://doi.org/10.1016/0021-9290(90)90054-7

Berryman, N., Maurel, D., & Bosquet, L. (2010). Effect of plyometric vs. dynamic weight training on the energy cost of running. *The Journal of Strength & Conditioning Research*, *24*(7), 1818–1825. https://doi.org/10.1519/JSC.0b013e3181def1f5

Bobbert, M. F., Gerritsen, K. G., Litjens, M. C., & Van Soest, A. J. (1996). Why is countermovement jump height greater than squat jump height? *Medicine and Science in Sports and Exercise*, *28*(11), 1402–1412. https://doi.org/10.1097/00005768-199611000-00009

Borgia, B., Freedman Silvernail, J., & Becker, J. (2020). Joint coordination when running in minimalist, neutral, and ultra-cushioning shoes. *Journal of Sports Sciences*, *38*(8), 855–862. https://doi.org/10.1080/02640414.2020.1736245

Bowles, C., Ambegaonkar, J. P., Cortes, N., & Caswell, S. (2012). Footwear for distance runners: The minimalism trend. *International Journal of Athletic Therapy and Training*, *17*(6), 14–18. https://doi.org/10.1123/ijatt.17.6.14

Channell, B. T., & Barfield, J. (2008). Effect of Olympic and traditional resistance training on vertical jump improvement in high school boys. *The Journal of Strength & Conditioning Research*, *22*(5), 1522–1527. https://doi.org/10.1519/JSC.0b013e318181a3d0

Chelly, M. S., Fathloun, M., Cherif, N., Amar, M. B., Tabka, Z., & Van Praagh, E. (2009). Effects of a back squat training program on leg power, jump, and sprint performances in junior soccer players. *The Journal of Strength & Conditioning Research*, *23*(8), 2241–2249. https://doi.org/10.1519/JSC.0b013e3181b86c40

Chiu, L., & Salem, G. (2010). Pelvic kinematic method for determining vertical jump height. *Journal of Applied Biomechanics*, *26*(4), 508–511. https://doi.org/10.1123/jab.26.4.508

Choe, K. H., Coburn, J. W., Costa, P. B., & Pamukoff, D. N. (2018). Hip and knee kinetics during a back squat and deadlift. *The Journal of Strength & Conditioning Research*, *Publish Ahead of Print*. In Press. https://doi.org/10.1519/JSC.0000000000002908

Cohen, J. (1992). A power primer. *Psychological Bulletin*, *112*(1), 155. https://doi.org/10.1037/0033-2909.112.1.155

Di Cagno, A., Baldari, C., Battaglia, C., Monteiro, M. D., Pappalardo, A., Piazza, M., & Guidetti, L. (2009). Factors influencing performance of competitive and amateur rhythmic gymnastics—Gender differences. *Journal of Science and Medicine in Sport*, *12*(3), 411–416. https://doi.org/10.1016/j.jsams.2008.01.006

Esculier, J.-F., Dubois, B., Dionne, C. E., Leblond, J., & Roy, J.-S. (2015). A consensus definition and rating scale for minimalist shoes. *Journal of Foot and Ankle Research*, *8*(1), 42. https://doi.org/10.1186/s13047-015-0094-5

Faul, F., Erdfelder, E., Lang, A.-G., & Buchner, A. (2007). G* Power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behavior Research Methods*, *39*(2), 175–191. https://doi.org/10.3758/BF03193146

Gjinovci, B., Idrizovic, K., Uljevic, O., & Sekulic, D. (2017). Plyometric training improves sprinting, jumping and throwing capacities of high level female volleyball players better than skill-based conditioning. *Journal of Sports Science & Sedicine*, *16*(4), 527. https://www.jssm.org/hfabst.php?id=jssm-16-527.xml#

Harman, E. A., Rosenstien, M. T., Frykman, P. N., & Rosenstein, R. M. (1990). The effects of arms and countermovement on vertical jumping. *Medicine and Science in Sports and Exercise*, *22*(6), 825–833. https://doi.org/10.1249/00005768-199012000-00015

Harry, J. R., Barker, L. A., & Paquette, M. R. (2018). Sex and acute weighted vest differences in force production and joint work during countermovement vertical jumping. *Journal of Sports Sciences*, *37*(12), 1318–1326. https://doi.org/10.1080/02640414.2018.1557825

Harry, J. R., Barker, L. A., & Paquette, M. R. (2020). A joint power approach to define countermovement jump phases using force platforms. *Medicine and Science in Sports and Exercise*, *52*(4), 993–1000. https://doi.org/10.1249/MSS.0000000000002197

Harry, J. R., Paquette, M. R., Caia, J., Townsend, R. J., Weiss, L. W., & Schilling, B. K. (2015). Effects of footwear condition on maximal jumping performance. *The Journal of Strength & Conditioning Research*, *29*(6), 1657–1665. https://doi.org/10.1519/JSC.0000000000000813

Harry, J. R., Paquette, M. R., Schilling, B. K., Barker, L. A., James, C. R., & Dufek, J. S. (2018). Kinetic and electromyographic subphase characteristics with relation to countermovement vertical jump performance. *Journal of Applied Biomechanics*, *34*(4), 291–297. https://doi.org/10.1123/jab.2017-0305

Hoka One One. (2018). www.hokaoneone.com.

Hubley, C. L., & Wells, R. P. (1983). A work-energy approach to determine individual joint contributions to vertical jump performance. *European Journal of Applied Physiology and Occupational Physiology*, *50*(2), 247–254. https://doi.org/10.1007/BF00422163

Kipp, K., Kiely, M., Giordanelli, M., Malloy, P., & Geiser, C. (2020). Joint-and subject-specific strategies in male basketball players across a range of countermovement jump heights. *Journal of Sports Sciences*, *38*(6), 652–657. https://doi.org/10.1080/02640414.2020.1723374

Krzyszkowski, J., Chowning, L. D., & Harry, J. R. (2020). Phase-specific predictors of countermovement jump performance that distinguish good from poor jumpers. *The Journal of Strength & Conditioning Research*, *Publish Ahead of Print*. In Press. https://doi.org/10.1519/JSC.0000000000003645

Laffaye, G., Wagner, P. P., & Tombleson, T. I. L. (2014). Countermovement jump height: Gender and sport-specific differences in the force-time variables. *The Journal of Strength & Conditioning Research*, *28*(4), 1096–1105. https://doi.org/10.1519/JSC.0b013e3182a1db03

Lam, W. K., Kan, W. H., Chia, J. S., & Kong, P. W. (2019). Effect of shoe modifications on biomechanical changes in basketball: A systematic review. *Sports Biomechanics*, 1–27. https://doi.org/10.1080/14763141.2019.1656770

Lam, W.-K., Lee, W.-C.-C., Lee, W. M., Ma, C. Z.-H., & Kong, P. W. (2018). Segmented forefoot plate in basketball footwear: Does it influence performance and foot joint kinematics and kinetics? *Journal of Applied Biomechanics*, *34*(1), 31–38. https://doi.org/10.1123/jab.2017-0044

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. *The Journal of Strength & Conditioning Research*, *27*(3), 733–737. https://doi.org/10.1519/JSC.0b013e318280c9ce

Markovic, G. (2007). Does plyometric training improve vertical jump height? A meta-analytical review. *British Journal of Sports Medicine*, *41*(6), 349–355. https://doi.org/10.1136/bjsm.2007.035113

Mercer, M. A., Stone, T. M., Young, J. C., & Mercer, J. A. (2018). Running economy while running in shoes categorized as maximal cushioning. *International Journal of Exercise Science*, *11*(2), 1031–1040.

Mikkola, J., Rusko, H., Nummela, A., Pollari, T., & Häkkinen, K. (2007). Concurrent endurance and explosive type strength training improves neuromuscular and anaerobic characteristics in young distance runners. *International Journal of Sports Medicine*, *28*(7), 602–611. https://doi.org/10.1055/s-2007-964849

Moir, G. L. (2008). Three different methods of calculating vertical jump height from force platform data in men and women. *Measurement in Physical Education and Exercise Science*, *12*(4), 207–218. https://doi.org/10.1080/10913670802349766

Mosier, E. M., Fry, A. C., & Lane, M. T. (2019). Kinetic contributions of the upper limbs during counter-movement verical jumps with and without arm swing. *The Journal of Strength & Conditioning Research*, *33*(8), 2066–2073. https://doi.org/10.1519/JSC.0000000000002275

Ostojic, S. M., Mazic, S., & Dikic, N. (2006). Profiling in basketball: Physical and physiological characteristics of elite players. *The Journal of Strength & Conditioning Research*, *20*(4), 740. https://journals.lww.com/nsca-jscr/Abstract/2006/11000/PROFILING_IN_BASKETBALL__PHYSICAL_AND.3.aspx

Reilly, T. N. R., Secher, P., Snell, P., & Williams, O. (1990). Physiology of sports: An overview. In *Physiology of sports* (pp. 465–485).

Shetty, A. B., & Etnyre, B. R. (1989). Contribution of arm movement to the force components of a maximum vertical jump. *Journal of Orthopaedic & Sports Physical Therapy*, *11*(5), 198–201. https://doi.org/10.2519/jospt.1989.11.5.198

Sinclair, J., Fau-Goodwin, J., Richards, J., & Shore, H. (2016). The influence of minimalist and maximalist footwear on the kinetics and kinematics of running. *Footwear Science*, *8*(1), 33–39. https://doi.org/10.1080/19424280.2016.1142003

Skechers. (2018). www.skechers.com

Smith, R. E., Paquette, M. R., Harry, J. R., Powell, D. W., & Weiss, L. W. (2020). Footwear and sex differences in performance and joint kinetics during maximal vertical jumping. *The Journal of Strength & Conditioning Research*, *34*(6), 1634–1642. https://doi.org/10.1519/JSC.0000000000002740

Stefanyshyn, D. J., & Nigg, B. M. (2000). Influence of midsole bending stiffness on joint energy and jump height performance. *Medicine and Science in Sports and Exercise*, *32*(2), 471. https://doi.org/10.1097/00005768-200002000-00032

Stephens, T. M., Lawson, B. R., DeVoe, D. E., & Reiser, R. F. (2007). Gender and bilateral differences in single-leg countermovement jump performance with comparison to a double-leg jump. *Journal of Applied Biomechanics*, *23*(3), 190–202. https://doi.org/10.1123/jab.23.3.190

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

Taylor, J. B., Kantor, J. L., Hockenjos, T. J., Barnes, H. C., & Dischiavi, S. L. (2019). Jump load and landing patterns of collegiate female volleyball players during practice and competition. *The Journal of Sports Medicine and Physical Fitness*, *59*(11), 1892–1896. https://doi.org/10.23736/S0022-4707.19.09650-6

Worobets, J., & Wannop, J. W. (2015). Influence of basketball shoe mass, outsole traction, and forefoot bending stiffness on three athletic movements. *Sports Biomechanics*, *14*(3), 351–360. https://doi.org/10.1080/14763141.2015.1084031