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INFLUENCE OF THE FOOT-FLOOR INTERFACE ON SQUATTING PERFORMANCE

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The aim of this study was to investigate the influence of footwear on squatting performance. Eight athletes (age: 23.38 (± 7.52) years, mass: 88.41 (± 15.03) kg, height: 1.81 (±0.10) m) performed three back squats at 80% 1RM and three jump squats at 40% 1RM for each footwear condition (barefoot, Fivefingers and shod). Kinetics of squatting performance were recorded using two Kistler 9821 force plates. Results established that the shod condition elicited significantly ($p<0.05$) greater peak CM velocity (18%) and power (23%) than the Fivefingers condition during the back squat, with non-significant variations associated with the jump squat. Whilst further investigation is required to establish if changes in kinematics occur, findings from this study indicate that footwear can be used to significantly increase performance during the back squat.

KEY WORDS: Footwear, kinetics, strength, conditioning.

INTRODUCTION: Variations of the squat exercise form a large facet of both strength and conditioning training and competition. In particular, the back and jump squat has received large amounts of attention by researchers investigating the kinematics and kinetics of the movements (Dugan *et al.,* 2004; Flanagan and Salem, 2007; Harris *et al.,* 2008). The influence of equipment, in particular footwear has received minimal attention to date. Fortenbaugh *et al*. (2007) compared the influence of running shoes and weightlifting shoes on back squat kinematics establishing a significant difference in peak ankle flexion and horizontal displacement suggestive that weightlifting shoes, due to their increased heel height and material properties, may allow for safer and more efficient squatting performance.
A growing number of athletes are utilising barefoot and minimalist footwear such as Vibram Fivefingers during training. It is perceived that such methods aid in increasing lower limb proprioception and the lack of a compressible sole aids in power generation whilst preventing excessive trunk lean. The aim of this investigation was to investigate the influence of footwear through altering the foot-floor interface on squatting performance during both the back squat and jump squat using typical training loads. It was hypothesised that differences in performance would be observed between the three conditions investigated (barefoot, Fivefingers and shod), which would have implications towards both squatting performance and injury prevention.

METHODS: After gaining University of Chichester ethical approval, eight recreational athletes with prior experience in back squat and jump squat performance were recruited and provided informed consent. The mean (± SD) age, mass, height and one repetition maximum (1RM) of the participants were 23.38 (± 7.52) years, 88.41 (± 15.03) kg, 1.81 (±0.10) m and 139.06 (± 39.78) kg.
Ground kinetics of the squatting performance were recorded from both feet individually using two, Kistler 9851 force plates (Winterthur, Switzerland) recording at 500 Hz with Bioware 3.21 software. Changes to the foot-floor interface were elicited through three different footwear conditions: barefoot, Vibram Fivefingers Sprint (Vibram S.P.A., Milan, Italy), incorporating an 3.5 mm Vibram TC1 performance rubber sole and standardised indoor trainers (Nomis, Brisbane, Australia) incorporating an 8mm rearfoot to forefoot midsole incline (Figure 1).

Figure 1: Footwear conditions: a. Barefoot, b. Fivefingers and c. Shod.

Following an adequate, self selected warm-up participants were instructed to perform three partial back squats at 80 %1RM and three jump squats at 40 %1RM for each of the footwear conditions in a randomised order. The loads under investigation were selected due to being reflective of typical training loads, with a 1 minute rest between each squat and three minutes between each footwear condition following the guidelines of Bompa *et al.* (2003) to minimise the influence of fatigue. Participants were instructed to control their decent and perform the concentric phase as explosively as possible. Squat depth was standardised to 50% of participant leg length, a depth typical of a partial squat.

Following visual appraisal of each trial, two back squat trials were excluded from further analysis due to technical abnormalities. In agreement with the method used by Flanagan and Salem (2007), only the concentric phase of the movement was analysed as determined by the velocity-time curve as the point at which positive velocity of the body centre of mass (CM) began, with the conclusion of the phase defined using peak body CM for both the back squat and jump squat. To quantify kinetic changes in squatting performance, peak and average vertical ground reaction force (GRF), CM velocity and power were calculated. CM velocity and power was calculated using a forward dynamics approach based on the summed vertical GRF as detailed by Hori *et al.* (2007). In addition to the performance variables, to provide an indication of foot stability, centre of pressure (COP) excursion was calculated in both the x (medial-lateral) and y (anterior-posterior) directions using root mean squared error (RMSE).

Statistical analysis was undertaken using SPSS version 17 for windows with an alpha level set at $p \leq 0.05$. To investigate the affect of footwear on each variable, one way repeated measures ANOVAs were performed with post hoc paired t-tests incorporating Bonferroni adjustment to minimise type 1 error. For variables that violated the assumption of sphericity, Greenhouse-Geisser correction was used.

RESULTS: Several non-significant variations were observed between footwear conditions during the back squat, with the Fivefingers condition having the lowest peak and average performance outcomes followed by the barefoot and shod conditions respectively (Table 1). Whilst no significant differences were found between Fivefingers and barefoot conditions, significant differences between Fivefingers and shod conditions were established for peak CM velocity, power and both COP-x and COP-y excursion. Peak CM velocity ($t_{(22)}$= -3.485, p=0.002) was 0.23 $m.s^{-1}$ slower during the Fivefingers condition, with peak power ($t_{(22)}$= -3.999, p=0.001) 23% greater during the shod condition compared to Fivefingers. COP excursion in both x ($t_{(43)}$= -3.395, p=0.001) and y ($t_{(43)}$= -2.869, p=0.006) directions were greater during shod conditions.

Non-significant variations in performance variables were observed during the jump squat between footwear conditions (Table 2). A significant difference in COP-y excursion was established between footwear conditions ($F_{(2,76.202)}$ = 11.277, p<0.001). COP-y excursion during the barefoot condition was 20% less than Fivefingers ($t_{(47)}$= -3.538, p=0.001) and 21% less than shod ($t_{(47)}$= -3.846, p<0.001)

Table 1
Performance variables (mean ± SD) during 80%1RM back squat performance

	Barefoot	Fivefingers	Shod
Average GRF (BW)	2.56 ± 0.45	2.55 ± 0.44	2.62 ± 0.48
Average CM velocity ($m.s^{-1}$)	0.32 ± 0.15	0.30 ± 0.13	0.35 ± 0.14
Average Power ($W.Kg^{-1}$)	735.58 ± 392.73	667.93 ± 310.56	823.17 ± 395.85
Peak GRF (BW)	2.68 ± 0.49	2.69 ± 0.45	2.78 ± 0.53
Peak CM velocity ($m.s^{-1}$)	0.64 ± 0.30	0.59 ± 0.27*	0.72 ± 0.29
Peak Power ($W.Kg^{-1}$)	1374.48 ± 735.42	1254.64 ± 614.21*	1627.67 ± 795.25
COP-x excursion (cm)	0.47 ± 0.22	0.37 ± 0.28*	0.58 ± 0.38
COP-y excursion (cm)	1.19 ± 0.60	1.02 ±0.63*	1.45 ± 0.88

*** denotes a significant difference ($p \leq 0.05$) between Fivefingers and shod conditions.**

Table 2
Performance variables (mean ± SD) during 40%1RM jump squat performance

	Barefoot	Fivefingers	Shod
Average GRF (BW)	2.27 ± 0.41	2.34 ± 0.42	2.35 ± 0.42
Average CM velocity ($m.s^{-1}$)	0.70 ± 0.17	0.74 ± 0.13	0.73 ± 0.11
Average Power ($W.Kg^{-1}$)	1481.08 ± 519.35	1573.88 ± 443.76	1561.31 ± 427.67
Peak GRF (BW)	2.62 ± 0.53	2.65 ± 0.54	2.67 ± 0.54
Peak CM velocity ($m.s^{-1}$)	1.58 ± 0.31	1.57 ± 0.24	1.56 ± 0.23
Peak Power ($W.Kg^{-1}$)	3265.67 ± 1130.39	3242.09 ± 908.51	3258.18 ± 917.31
COP-x excursion (cm)	1.29 ± 0.67	1.43 ± 0.79	1.51 ± 0.79
COP-y excursion (cm)	2.99 ± 1.25§†	3.74 ± 1.29	3.78 ± 1.40

§,† denotes a significant difference ($p \leq 0.05$) between barefoot and Fivefingers, and barefoot and shod conditions respectively.

DISCUSSION: The influence of the foot-floor interface, as modified through changes in footwear during this investigation was found to have minimal influence during the jump squat with greater, significant changes established during the back squat. Although COP-y excursion during the jump squat was significantly less than the other footwear conditions, no apparent relationship between the foot-floor interface and performance variables was observed. This may be attributed to only investigating the movement at 40 %1RM, where the contribution of the foot-floor interface may either be minimal or participants may be able to adequately compensate for changes at this level of the kinetic chain to ensure jump squat performance is not impaired.
Findings from this investigation establish that the foot-floor interface can influence back squat performance at 80 %1RM as observed through significant changes in peak CM velocity and peak power. Whilst some researchers (Flanagan and Salem, 2007) question the representation of peak performance parameters to describe the movement of interest, within

this investigation peak values were found to follow similar trends to that of average performance variables. The significant increase in COP excursion in both the medial-lateral and anterior-posterior directions suggest that participants utilise the movement of the foot to aid in executing the back squat. These findings, when combined with the work of Fortenbaugh *et al.* (2010) suggest that although the indoor trainers used within this investigation incorporated a lower, less dense heel raise compared to weight lifting shoes, footwear which raise the rearfoot relative to the forefoot appear to aid in increasing and altering ankle joint position resulting in improved back squat performance.

This investigation emphasises that athletes should carefully consider their choice of training footwear. Anecdotally there are a growing number of athletes who prefer to train using Fivefingers due to increasing joint proprioception. The lower COP-excursion values for both directions would suggest that Fivefingers provide a stable base, which although resulting in a decrease in peak performance variables only result in non-significant variations in average performance variables. Such footwear, therefore may be more ideally suited not for performance but for individuals returning from injury or suffering from lower limb instability, where the change in foot-floor interface would enable them to maintain their average back squat performance whilst minimising potentially injurious foot movement.

Further research, utilising a combination of kinematics and inverse dynamics is required to quantify the influence of footwear on the kinematics of squatting across a range of loads. Such research would aid in establishing first, how changes in foot position may alter the kinematics of the squat, and second, would aid in quantifying the influence of foot position on joint loading in regards to injury risk.

CONCLUSION: Results from this investigation established that footwear can affect squatting performance during the back squat, with the shod condition eliciting greater peak CM velocity and peak power compared to Fivefingers. Whilst larger COP-excursion was associated with the shod condition, further kinematic based investigation is required to establish how alterations in the foot-floor interface, such as through changing ankle joint range of motion can improve performance whilst minimising the risk of injury.

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