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Research Article

Interaction of Overweight and Pronated Foot on Ground Reaction Force Frequency Content During Running

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ABSTRACT

Being overweight can influence the occurrence of pronated feet (PF). This research aimed to assess the interaction effect of overweight and PF along with sex on the frequency content of ground reaction forces (GRFs). 104 young male and female adults were allocated to four groups: normal body-mass-index/normal feet, normal body-mass-index/PF, excessive weight/normal feet, and excessive weight/PF. Subjects ran at constant speed over the walkway while an embedded force plate was located at the midpoint of the walkway. GRFs were recorded during 20 running trials. Findings demonstrated the significant main effect of "sex" ($P<0.001$; ɲ2 = 0.392) and "group" ($P<0.001$; ɲ2 = 0.264) and "sex-by-group interaction" ($P<0.001$; ɲ2 = 0.442) for an essential number of harmonic in the vertical direction. Overall, our results showed sex, body mass index, and foot type could possibly affect GRF frequency content while running. The paired-wise comparison demonstrated lower Ne in the vertical direction in the females than in the males. The paired-wise comparison demonstrated the greatest Ne in the vertical direction in the normal weight/normal foot group than the of other groups. These findings could be used for designing rehabilitation protocols (e.g., strength training) for individuals with overweight/obesity or PF and or both of them.

INTRODUCTION

Obesity/overweight (OB/OW) is a risk factor for lower extremity injuries (Browning & Kram, 2007; Powell et al., 2005). Anecdotally, most of the people who are OB/OW have taken up running for recreation. Running exercise improves well-being, weight loss, and cardiovascular health (Hazell et al., 2014; Lee et al., 2017). Severe OB/OW could alter running biomechanics and it could lead to greater rear foot motion (Ghait et al., 2020; Sarkar et al. , 2011). Greater rear foot motion may be associated with a flat foot, loss of postural stability, and change in the gait pattern (Ghait et al., 2020; Sarkar et al., 2011).

Pronated feet (PF) are associated with a decrease of medial longitudinal arch during weight-bearing tasks such as running. The prevalence of foot pronation is also high in OB/OW adults (Wu, 2015). OB/OW walking was associated with higher rearfoot eversion. A high association between rearfoot eversion and greater body mass index (BMI) was reported (Wearing et al., 2006). PF is problematic in OB/OW versus healthy ones (Browning & Kram, 2007; Ghait et al., 2020). It has been reported that PF function affected the whole lower limb kinematic chain during gait (Dodelin et al., 2020). Anterior-posterior pelvic tilt range of motion, peak knee internal rotation, forefoot dorsiflexion range of motion, peak forefoot abduction, and rearfoot eversion were all increased in those with PF (Dodelin et al., 2020).

Ground reaction force (GRF) is one of the kinetic variables that is useful for evaluating running mechanics (Gottschall & Kram, 2005; Zadpoor & Nikooyan, 2011). It has been used in a variety of experiments. High lateral GRF values could lead to over-pronation during running or vice versa (Rodrigues et al., 2013; Willems et al., 2006).

OB/OW affects the GRF magnitudes during running (Sylvestre, 2019). Sylvestre et al. reported greater abduction of the knee during the running in OB/OW children than healthy ones (Sylvestre, 2019). Therefore, impact forces cause changes in the lower limb mechanics while running (Dicharry, 2010; Dugan & Bhat, 2005; Rodrigues et al., 2013; Willems et al., 2006). For example, greater GRF amplitude altered the peak rear-foot eversion angle, which may lead to an increase in stress on more proximal structures (Dierks et al., 2011; Mousavi et al., 2019; Munteanu & Barton, 2011). The GRF frequency content provides evidence for running-related injuries (Gruber et al., 2017; Matijevich et al., 2019). Therefore, it is important to evaluate these variables in order to find potential instruments to improve running mechanics in individuals with both OB/OW and PF. It was hypothesized that individuals with both OB/OW and PF have greater ground reaction force frequency content than other groups during running.

METHODS

Participant

Total of 104 male and female participants were allocated into 4 groups. NN: Participants with normal body mass (e.g., 20≤BMI<25 kg/m²) and normal foot (e.g., foot posture index between 0-6); NP: individuals with normal body mass and PF (e.g., foot posture index >10); ON: individuals with OB/OW (e.g., 35≥BMI≥25 kg/m²) with the normal foot; OP: individuals with both OB/OW and PF (Table 1). The study protocol was affirmed by the local ethics committee (IR.UMA.REC.1401.095 and IR.UMA.REC.093 for both females and males, respectively), and samples were provided their written informed consent in order to participate in the research.

Procedure

Participants were familiarized with the runway at the first. All GRFs during twenty running trials (~ 3.2 m/s) were recorded and filtered with a 20 Hz cut-off frequency and normalized to the subjects' body mass.

Data Collection Tools

A Bertec force plate (Bertec et al., 4060-07 Model, OH, United States) embedded at the runway midpoint was used for data collection. The sampling rate of Bertec force plate was 1000 Hz.

Frequency content

The GRF values (Fx, Fy, Fz) were analysed. The MATLAB software used an FFT to extract the frequency content of GRF data (Winter, 2009). The full description of the Fourier series of GRF data can be found in other sources (Giakas & Baltzopoulos, 1997; White et al., 2005). The frequency with a power of 99.5% (F99.5%) contains 99.5% of the power of the signal (Eq. (1); McGrath et al., 2012).

$$\int \int_0^{f99.5} P\,(f)\,df = 0.995 \times \int_0^{fmax} \times P(\,f)df \qquad (1)$$

Where P is the frequency power against amplitude, F_{max} is the peak frequency, and P (f) is the power at frequency f (McGrath et al., 2012). The essential number of harmonics (Ne) showed for 99.5% possibility of reconstruction of data (Eq. (2); Schneider & Chao, 1983). In this equation n showed the number of harmonic; An and Bn demonstrated coefficients of Fourier.

$$\sum_{n=1}^{n_e} \frac{\sqrt{A_n^2 + B_n^2}}{\sum_{n=1}^{m} \sqrt{A_n^2 + B_n^2}} \leq 0.995 \qquad (2)$$

Data Analysis

The normal distribution of data was confirmed through the Kolmogorov-Smirnov test. All analyses were done using MATLAB software. The group (four groups) and sex (male versus female) effects were assessed through two-way ANOVA with repeated measures test. Effect size values were calculated through ɲ^2 (0.01< ɲ^2< = 0.06: small); 0.06> ɲ^2<0.14 = moderate; ɲ^2> = 0.14: high). The Alpha value was p< 0.05. All analysis were done using SPSS 23.

RESULTS

Findings showed a significant main effect of the "sex" (P<0.001; ɲ2 = 0.217) and "group" (P<0.001; ɲ2 = 0.530) for the weight (Table 1). The paired-wise comparison demonstrated greater weight in males compared with females. Moreover, paired-wise comparison demonstrated the greatest value of the weight in overweight groups than that of other groups (Table 1). Significant effect of "sex" (P = 0.011; ɲ^2 = 0.069 and "group" (P<0.001; ɲ^2 = 0.672) and "sex by group interaction" (P = 0.005; ɲ^2 = 0.129) for BMI was found (Table 1). The paired-wise comparison demonstrated greater BMI in females compared with males. Moreover, paired-wise comparison demonstrated the greatest value of the BMI in overweight groups than that of other groups (Table 1). Findings demonstrated a significant effect of the "sex" (P<0.001; ɲ2 = 0.366) on heart rate. The paired-wise comparison demonstrated greater heart rates in females compared with males (Table 1). Findings demonstrated a significant main effect of the "sex" (P<0.001; ɲ^2 = 0.813) and "group" (P = 0.001; ɲ^2 = 0.017) for navicular drop. The paired-wise comparison demonstrated a greater navicular drop in males compared with females. Moreover, paired-wise comparison demonstrated the greatest value of the navicular drop in pronated foot groups than that of other groups (Table 1).

Findings revealed a significant main effect of "group" for frequency 99.5 in the mediolateral direction (P = 0.017; ɲ^2 = 0.104). The paired-wise comparison demonstrated the lowest frequency of 99.5 in the mediolateral direction for the normal weight and normal foot group and the greatest values in overweight and normal foot group. Significant effect of "group" (P<0.001; ɲ^2 = 0.190) and "sex-by-group interaction" (P<0.001; ɲ^2 = 0.332) for Ne in the mediolateral direction (Table 2). The paired-wise comparison demonstrated the greatest Ne in the mediolateral direction for normal weight and normal foot group than that of other groups.

Post-hoc analysis showed greater Ne in the mediolateral direction in males than in females in the normal weight and normal foot group. However, post-hoc analysis showed greater Ne in the mediolateral direction in females than in males in other groups.

Findings demonstrated a significant main effect of the “sex” ($P<0.001$; $\eta^2 = 0.248$) and “group” ($P = 0.027$; $\eta^2 = 0.094$) for frequency 99.5 in the anterior-posterior direction (Table 2). The paired-wise comparison demonstrated a lower frequency of 99.5 in the anterior-posterior directions in females compared with the males. Moreover, paired-wise comparison demonstrated the greatest value of frequency 99.5 in the anterior-posterior directions in overweight with normal feet group than that other groups (Table 2).

There was a significant effect of “sex” ($P<0.001$; $\eta^2 = 0.258$) and “group” ($P<0.001$; $\eta^2 = 0.242$) and “sex” by group interaction” ($P<0.001$; $\eta^2 = 0.202$) for Ne in the anterior-posterior direction (Table 2). The paired-wise comparison demonstrated greater Ne in the anterior-posterior direction in the females than in the males. The paired-wise comparison demonstrated the greatest Ne in the anterior-posterior direction for the overweight/pronated foot group than that of other groups. Post-hoc analysis showed greater Ne in the anterior-posterior direction in females than in males in the overweight/pronated foot group (Table 2).

Results din not demonstrate any significant difference for Fz (99.5) between groups during running ($P>0.05$). Significant effect of “sex” ($P<0.000$; $\eta^2 = 0.392$) and “group” ($P<0.001$; $\eta^2 = 0.264$) and “sex by group interaction” ($P<0.001$; $\eta^2 = 0.442$) for Ne in vertical direction (Table 2). The paired-wise comparison demonstrated lower Ne in the vertical direction in the females than in the males. The paired-wise comparison demonstrated the greatest Ne in the vertical direction in the normal weight/normal foot group than the of other groups. Post-hoc analysis showed greater Ne in the vertical direction in males than in females in the overweight/normal foot group. Post-hoc analysis showed greater Ne in the vertical direction in males than in females in all groups except for the normal weight/normal foot group (Table 2).

Table 1
Mean and Standard Deviation of the Demographic Characteristic

Demographic Characteristics	Normal weight normal foot		Normal weight pronated foot		Over weight/Obesity normal foot		Over weight/Obesity pronated foot		Gender Sig (Eta)	Group Sig (Eta)	Gender by Group interactions Sig. (Eta)
	Male	Female	Male	Female	Male	Female	Male	Female			
Age (years)	22.30 ± 2.71	24.15 ± 3.02	23.92± 4.48	23.25 ± 4.18	24.58± 4.81	25.38±4.29	25.50± 5.83	27.33±5.74	0.291(0.012)	0.057(0.078	0.725(0.014)
Weight (kg)	68.84 ± 7.36	56.78±4.55	70.15±8.99	58.29±5.83	84.58±7.70	80.45±10.06	89.58±15.92	78.41±12.64	**0.000(0.217)***	**0.000(0.530)***	0.414(0.030)
Height (cm)	179.69±5.70	161.23±6.35	178.30±5.89	163.54±5.45	179.25±5.75	161.53±5.65	175.58±9.18	162.75±7.65	**0.000(0.617)***	0.810(0.010)	0.401(0.031)
Body mass index (kg/m²)	21.30±1.39	21.88±1.52	22.03±2.18	21.69±1.83	26.29±1.41	30.92±4.48	28.85±3.15	29.40±3.07	**0.011(0.069)***	**0.000(0.672)***	**0.005(0.129)***
Harte Rate (beat per minute)	117.47±9.48	132.53±14.08	114.08±9.61	135.87±15.98	111.53±12.57	141.56±21.16	118.96±18.12	139.67±15.40	**0.000(0.366)***	0.716(0.015)	0.364(0.034)
Navicular drop(mm)	6.69±1.10	5.07±1.115	12.69±1.60	11.25±1.13	7.00±1.53	6.53±1.6	12.91±2.10	12.25±1.54	**0.000(0.813)***	**0.001(0.017)***	0.444(0.029)

Note. *Stand for significant difference p<0.05

Table 2

Mean and Standard Deviation of the Frequency of Three Medio-lateral (Fx), Anterior-posterior (Fy), and Vertical (Fz) Ground Reaction Force Components During Running

Direction (Component)	Normal weight normal foot		Normal weight pronated foot		Over weight/Obesity normal foot		Over weight/Obesity pronated foot		Gender Sig (Eta)	Group Sig (Eta)	Gender by Group interactions Sig. (Eta)
	Male	Female	Male	Female	Male	Female	Male	Female			
Fx (99.5)	15.34 ± 4.25	20.27' ± 4.52	21.42± 9.83	16.68 ± 2.81	20.70± 7.13	20.41±2.62	18.29± 3.65	19.02±3.42	0.882(0.000)	**0.017(0.104)***	0.314(0.128)
Fx (Essential)	22.69 ± 6.74	12.68±4.29	12.76±7.50	14.76±2.29	11.04±3.48	14.00±1.92	9.70±3.20	15.65±3.06	0.806(0.001)	**0.000(0.190)***	**0.000(0.332)***
Fy (99.5)	21.84±8.48	9.38±1.77	17.34±6.39	17.69±4.68	23.45±5.42	17.54±2.22	20.54±9.35	12.86±3.25	**0.000(0.248)***	**0027(0.094)***	0.002(0.149)
Fy(Essential)	10.03±4.81	13.24±3.29	12.38±6.33	14.30±2.02	13.54±5.97	15.92±1.38	11.95±5.42	24.32±2.91	**0.000(0.258)***	**0.000(0.242)***	**0.000(0.202)***
Fz(99.5)	12.53±5.81	15.30±2.92	9.98±3.62	12.37±1.28	9.85±1.81	14.03±2.05	15.33±3.10	9.12±3.10	0.233(0.015)	0.025(0.096)	0.000(0.292)
Fz(Essential)	20.98±4.60	25.00±1.74	23.28±3.12	15.60±1.38	24.25±2.3	15.75±2.32	21.54±3.50	15.25±3.55	**0.000(0.392)***	**0.000(0.264)***	**0.000(0.442)***

Note. *Stand for significant difference p<0.05

DISCUSSION

The study aimed to evaluate the interaction effect of OB/OW and PF on GRF frequency content during running. The finding demonstrated the lowest frequency of 99.5 in the mediolateral direction for the normal weight and normal foot group and the greatest values in OB/OW and normal foot group. Jafarnezhadgero et al. reported that the excessive body weight groups with and without PF presented lower mediolateral loading rates and peak lateral forces when compared to the non-overweight groups with and without PF (Jafarnezhadgero et al., 2023). A previous study reported that the load values imposed on the knee joint alter in the presence of overweight (Harding et al., 2012). Results demonstrated the greatest Ne in the mediolateral direction for normal weight and normal foot group than that of other groups. It is stated that frequency 99.5 and Ne in the mediolateral direction, the frequency spectrum of GRF components that occur during stance, has a high effect on running injury prevalence (Gruber et al., 2017). Results showed greater Ne in the medio-lateral direction in males than that female. It has been reported that female athletes had weaker thigh muscles (Huston & Wojtys, 1996). Moreover, our results showed greater ne in the medio-lateral direction in females than that males in other groups. Consistent with our results, literature reported that vertical GRFs frequency values show less variability than in both the anterior-posterior and mediolateral directions (White et al., 1999). It has been showing that females had larger ankle eversion, knee abduction, and internal rotation than males (Hunter et al., 2005). Phinyomark et al. (2014) demonstrated that females show higher hip internal rotation and adduction and greater maximum abduction of the knee than that males. Also, it has been mentioned that the tibia internal rotation and maximum eversion during running were greater among females (Sinclair & Taylor, 2014).

Findings demonstrated a lower frequency of 99.5 in the anterior-posterior directions in females compared with the males. It is stated that a decrease in frequency values of anterior-posterior GRFs component may be caused by the alteration in the gait speed (Stergiou et al., 2002). These authors reported that walking mostly occurs in the sagittal plane, and differences in speed are mostly reflected in the anterior-posterior GRF component (Stergiou et al., 2002). However, in our study participants' running velocity was similar. Moreover, results demonstrated greatest value of frequency 99.5 in the anterior-posterior directions in overweight with normal feet group than that other groups. Jafarnezhadgero et al., reported individuals with excessive body weight presented lower peak amplitude of braking and propulsion forces (Jafarnezhadgero et al., 2023). However, these authors did not evaluate the frequency content of GRF components.

Findings demonstrated greater ne in the anterior-posterior direction in the females than in the males. Results demonstrated the greatest ne in the anterior-posterior direction for the overweight/pronated foot group than that of other groups. Findings showed greater ne in the anterior-posterior direction in females than in males in the overweight/pronated foot group. Results demonstrated the greatest ne in the vertical direction in the normal weight/normal foot group than in the other groups. Obesity was related to a longer time of activation in the quadriceps and gastrocnemius muscle (Amiri et al., 2015), which can result in lower ne in the vertical direction of OB/OW groups.

Findings showed greater Ne in the vertical direction in males than in females in all groups except for the normal weight/normal foot group. Stergiou et al. (2002) reported that the less frequency content are associated with less vertical displacement of the center of mass (Wurdeman et al., 2011). Frequency content of GRFs could be applied as a suitable tool for introducing pathological running pattern in different sex (Wurdeman et al., 2011). A suitable treatment (e.g., training) could lead to a better frequency value of the GRF data. Further researches are needed to evaluate the use of GRF frequency values in individuals with OB/OW or different sexes as dependent variables for rehabilitation and its application as a screening method (Wurdeman et al., 2011).

The limitations of this study include; Firstly, the absence of kinematic data and the relatively homogeneous age group of participants may limit the generalizability of the findings. Secondly, all participants were young. This caution is necessary when discussing our results because our results may not be generalized to the general population.

CONCLUSION

Overall, our results showed that sex, body mass index, and foot type could possibly affect ground reaction force frequency content while running. These findings could be used to design rehabilitation protocols for individuals with overweight/obesity or pronated feet or both. These findings could be used for designing rehabilitation protocols for individuals with overweight/obesity or pronated feet and or both of them.

Limitations

This sudy had limitatiotions that should be regarded. Firstly, we did not record kinematics data. Secondly, we did not record electromyography data. Future studies were needed in regard to the both kinematic and muscle activity data to better establish this issue.

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Declaration of conflict interest

No potential conflict of interest was reported by the author(s).

Authors' contributions

The first, second and third authors collected the data, analyzed the data, and wrote the manuscript; the first author analyzed the data and wrote the manuscript. All authors have read and approved the final version of the manuscript, and agree with the order of presentation of the authors.

Ethics Statement

The study protocol was affirmed by the local ethics committee (IR.UMA.REC.1401.095 and IR.UMA.REC.093 for both females and males, respectively), and samples were provided their written informed consent in order to participate in the research.

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