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Title: Running quietly reduces ground reaction force and vertical loading rate and alters foot strike technique.

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2nd Revision

ABSTRACT

This study aimed to determine if a quantifiable relationship exists between the peak sound amplitude and peak vertical ground reaction force (vGRF) and vertical loading rate during running. It also investigated whether differences in; peak sound amplitude, contact time, lower limb kinematics, kinetics and foot strike technique existed when participants were verbally instructed to run quietly compared to their normal running. Twenty-six males completed running trials for two sound conditions; normal running and quiet running. Simple linear regressions revealed no significant relationships between impact sound and peak vGRF in the normal and quiet conditions and vertical loading rate in the normal condition. T-tests revealed significant within subject decreases in peak sound, peak vGRF and vertical loading rate during the quiet compared to the normal running condition. During the normal running condition, 15.4% of participants utilized a non-rearfoot strike technique as compared to 76.9% in the quiet condition, which was corroborated by an increased ankle plantarflexion angle at initial contact. This study demonstrated that quieter impact sound is not directly associated with a lower peak vGRF or vertical loading rate. However, given the instructions to run quietly, participants effectively reduced peak impact sound, peak vGRF and vertical loading rate.

Keywords: augmented feedback, locomotion, biomechanics, ground reaction force, running technique, foot strike technique

INTRODUCTION

Running is a popular sport, however the prevalence of lower limb injuries has been reported to be between 19% to 79% in long distance runners.(Van Gent et al., 2007) Although risk factors for injuries in runners are multifaceted,(Fredericson, Jennings, Beaulieu, & Matheson, 2006) ground reaction forces and vertical loading rate on impact have been the focus of many studies that investigate the mechanisms of injuries in runners. (Davis, Bowser, & Mullineaux, In Press; Ferber, Davis, Hamill, Pollard, & McKeown, 2002; Grimston, Engsberg, Kloiber, & Hanley, 1991; Milner, Ferber, Pollard, Hamill, & Davis, 2006; van der Worp, Vrielink, & Bredeweg, In Press; Zadpoor & Nikooyan, 2011) Cross-sectional studies have demonstrated that runners with previous stress fractures have a significantly greater peak vertical ground reaction force (vGRF) and vertical loading rate compared to runners with no history of stress fractures.(Ferber et al., 2002; Grimston et al., 1991; Milner et al., 2006) A recent prospective study by Davis et al. found that female runners with greater vGRF impact peaks and loading rate experienced a greater number of medically diagnosed stress fractures and muscles strain injuries.(Davis et al., In Press) Interventions aimed at reducing vGRF and vertical loading rate should therefore be investigated to potentially reduce lower limb injuries in runners.

In a case-series by Cheung and Davis (2011) a novel intervention was employed to decrease vertical loading rate in three female runners with patellofemoral pain. In this study, the runners used an audio biofeedback device affixed to the heel of their shoe insole that emitted a sound whenever their heel contacted the ground. This audio feedback guided them in changing their foot strike technique from a rearfoot strike (RFS) to a non-RFS. In changing their foot strike, vertical loading rate and knee pain were significantly reduced. The results of this study provide preliminary evidence to support the use of auditory feedback to alter running kinetics and reduce injury symptoms.

Anecdotally, some running coaches already use the sound of impact during running as auditory feedback to change habitual RFS runners' to a non-RFS technique with the intention of altering ground reaction forces and injury risk. Despite no established link between foot strike technique and injury incidence, injury location has been shown to vary between RFS and non-RFS runners (Walther, 2005) which may in part be related to the different vGRF profiles they elicit. Rearfoot strike runners typically create a vGRF impact peak while non-RFS (forefoot) runners only create an active vGRF peak.(Boyer, Rooney, & Derrick, 2014) However, to the best of the authors' knowledge, no studies have investigated the amplitude of impact sound during different foot strike techniques and the effect verbal instructions to change the sound of impact has on lower limb kinematics and kinetics and furthermore whether verbal instruction causes a change in the runners foot strike.

Literature has lent support to the use of verbal instructions to change the sound of impact in drop landings, which resulted in altered kinematics and kinetics. McNair, Prapavessis, and Callender (2000) and Prapavessis and McNair (1999) demonstrated that healthy adults and children, respectively, were able to significantly decrease their peak vGRF during drop landings when using impact sound as a qualitative feedback mechanism. This task was performed initially with no instructions regarding sound and then repeated with the instruction to try and land more "softly". Therefore, it was postulated that impact sound and peak vGRF are related qualitatively during drop landings.(McNair, Prapavessis, & Callender, 2000; Milner, Fairbrother, Srivatsan, & Zhang, 2012) Recently, Wernli, Ng, Phan, Davey, & Grisbrook (2016) established a quantitative relationship between peak impact sound amplitude and vGRF during drop landing, with the higher impact sound amplitude, the greater the vGRF and vice versa.(Wernli et al., 2016) Little is known about the relationship between sound and peak vGRF or vertical loading rate during more complex locomotive tasks such as running.

Therefore, the primary aim of this study was to investigate if a quantitative relationship exists between peak sound amplitude, peak vGRF and vertical loading rate during barefoot running. It was hypothesized that a small impact sound amplitude during running would be associated with a small peak vGRF and vertical loading rate and vice versa. The secondary aim of this study was to investigate if there were any significant differences in; peak sound amplitude, vGRF, vertical loading rate, contact time and lower limb kinematics (more specifically; ankle, knee and hip sagittal plane joint angles at initial contact and peak) when runners were asked to run quietly compared to their normal running technique. It was hypothesized that when asked to run quietly, runners would decrease their; peak sound amplitude, vGRF, vertical loading rate and contact time. It was further hypothesized that habitual RFS runners would increase their plantarflexion angle at initial contact and thereby change to a non-RFS technique, but that the joint kinematics of non-RFS runner's would be unaffected.

METHODS

Participants

Twenty-six healthy male participants were recruited from the local community and via word of mouth. Participants were excluded if they had an allergy to tape, a history of lower limb surgery or injuries of musculoskeletal origin within the six weeks prior to data collection.

Instrumentation

An 18-camera Vicon MX motion analysis system (Oxford Metrics, Inc.), sampling at 250 Hz, and an AMTI (Watertown, MA) force plate, sampling at 1000 Hz, were used to collect the kinematic and kinetic data.(Szczerbik & Kalinowska, 2011) A Sennheiser ME66 shotgun microphone (Wedermark, Germany) with a K6 powering module connected to the Vicon Nexus software, sampling at the maximum 24 kHz, was used to collect impact sound data in voltage (V). Impact sound was defined as the peak sound that was created between the runners' foot and the ground during the weight acceptance phase of running. The shotgun microphone was positioned on the same side as the striking leg (right) and the tip of the microphone was at a standardized 300 mm distance away from the centre of the force plate. The position of the microphone was determined during pilot testing such that the microphone was placed as close as possible to the participants' contact foot without interfering with the run, to ensure a consistent sound amplitude was captured. A Rion NL-11 sound calibrator (Tokyo, Japan), which provided a consistent 94.1dB amplitude sound, was used to enable calibration of the sound recorded from the microphone from voltages to decibels. Measures were taken during testing to ensure that background noise was minimal; the motion analysis laboratory where all the testing was conducted is located in an isolated building, all testing was conducted outside of work hours and a unidirectional microphone was used.

Procedure

Ethical approval was obtained from the institution's Human Research Ethics Committee and all participants provided written informed consent prior to participation. Data collection occurred at the institution's Motion Analysis Laboratory, where participants' measurement of body height and mass, ankle width, leg length, knee width, wrist width, hand thickness, elbow width, and shoulder offset were taken to calibrate the Vicon Plug in Gait system (Oxford Metrics, Inc). Each participant was then fitted with the Vicon full body Plug-in-Gait retro reflective marker set and allowed ten minutes to perform a standardized warm-up. The warm-up consisted of five minutes of run throughs, walking lunges, high knees and bounding tasks, with retro-reflective markers in place. This ensured that the participants were familiar with the laboratory environment and the speed of running required in this study.

Each participant was required to perform a series of barefoot running trials with the instruction to run in a straight line from one marker to another, which were positioned 10 m apart. The runway was a hard surface that consisted of a vinyl sports flooring over concrete and a predominantly aluminium AMTI force platform. The starting marker was positioned so that the participant would strike the force plate with their right foot to achieve a successful trial. However, the participant was not informed of the location of the force plate to avoid them altering their running style to target it. Running velocity was calculated by tracking the right Anterior Superior Iliac Spine marker using the Vicon system to confirm the participants were running at a velocity of 5.0 ± 0.5 m/s. This running speed was chosen as it has been used in various running studies, as outlined in a systematic review by Schache et al. (2010). Trials in which the running speed was not achieved or the participant failed to make full foot contact on the force plate were deemed unsuccessful and removed from the sample group. The number of trials was limited to ten per condition and participants were given two minutes rest between trials to avoid fatigue.

The running task was performed under two different sound conditions: normal and quiet. The normal sound condition was always performed first so that a baseline measurement of running sound could be obtained. For the normal sound condition, the researchers only provided instruction on how to perform the task without any reference to sound as described above. For the quiet sound condition, participants were asked to "perform the task as before but this time make a quieter sound when you land". These instructions were derived from a similar study regarding qualitative relationship of impact sound and landing forces in drop-landing studies (McNair et al., 2000; Wernli et al., 2016). Five successful trials were recorded for each sound condition, with a one-minute rest period after each condition to minimise the effect of fatigue.

Data management

The Vicon Nexus software (v1.7.1, Vicon Motion Analysis Systems) was used to manage the anthropometric data and inspect for any breaks that may occur due to marker occlusion. A Woltering filtering routine was then performed. The Vicon

Plug-in-Gait model (Oxford Metrics, Inc.) was then utilized to calculate kinematic and kinetic variables. Sound data collected from the shotgun microphone was converted from V to dB via a custom-written program developed in LabVIEW v2011 SP1 (National instruments, Texas). Sound amplitude was calculated using the equation;

$$20*LOG10\ (V2/V1), \qquad \text{(Eq.1)}$$

where V1 is the Root Mean Square of the voltage recorded for the 94.1 dB standard and V2 is the voltage reading collected by the microphone.(Rao, 2010) Peak impact sound amplitude, peak vGRF, vertical loading rate, contact time and sagittal plane joint kinematic data (ankle, knee and hip angle at initial contact, and peak ankle and knee angle) were then extracted via a separate custom-written program developed in LabVIEW.

Vertical loading rate was calculated as the change in vGRF from the first frame it exceeded 200 N to where it reached 90% of the impact peak magnitude, this was calculated with respect to time. If no impact peak was present, the average percentage of stance that 90% of the impact peak typically occurred was used (5.3%). This method of calculating loading rate has been previously utilized in the running literature. (Caulfield et al., In Press; Lieberman, Venkadesan, & Werbel, 2010) Following the loading rate calculation vGRF data was normalized to body mass and then time normalized to 101 data points.

Foot strike technique was determined in Vicon using markers placed on the participant’s right heel and toe. The vertical height offset between these markers was calculated during standing. This offset was then applied to the markers at initial contact during running trials to determine the technique. If the toe marker was higher than the heel marker at initial contact it was classified as a RFS and if the heel marker was higher it was classified as a non-RFS. The non-RFS group included both midfoot and forefoot strike techniques. Foot strike technique was determined for each running trial.

Statistical Analysis

IBM SPSS Statistics for Windows Version 22 (IBM Corp, 2013, Armonk, NY) was used for the statistical analysis. Descriptive statistics were performed for the participant demographics. A Chi-Square test was conducted to examine if there were any significant difference in foot strike technique used by the participants between the normal and quiet running conditions.

The within subject reliability of the dependent variables across the five running trials for each of the running conditions was assessed by calculating the intra-class correlation coefficient ($ICC_{3,5}$) using a two-way mixed effects model. An ICC value of <0.75 was interpreted as moderate, 0.75-0.89 as high, and ≥ 0.9 as excellent (Landis & Koch, 1977).

Individual mean values from the five successful running trials from each sound condition were calculated for each of the dependent variables including; peak impact sound amplitude, peak vGRF, vertical loading rate, contact time, ankle knee and hip angle at initial contact, and peak ankle and knee angle. The normality of these variables were assessed using the Shapiro-Wilk test and all variables were found to be normally distributed. Two separate simple linear regression analyses were conducted to determine the coefficients of determination (r^2) between; peak impact sound amplitude and peak vGRF, and peak impact sound amplitude and vertical loading rate. A series of paired samples t-tests were then conducted to determine if there were any within-subject differences in the dependent variables between the normal and quiet running conditions. The alpha level was set to $p < 0.05$ for all analyses.

RESULTS

Participants

Twenty-six healthy males aged 21.1 ± 2.0 years old were recruited. They were on average 1.79 ± 0.05 m tall, and 78.3 ± 12.2 kg in body mass. During the normal running condition, 22 of the participants (84.6%) utilized a RFS technique, and four participants (15.4%) used a non-RFS technique. When instructed to run quietly, 16 of the 22 RFS runners adopted a non-RFS, with six participants maintaining a RFS. All four of the non-RFS runners maintained this technique during the quiet running condition. Therefore, 76.9% of the participants utilized a non-RFS during the quiet running condition. The results of the Chi- square confirmed that there was a significant difference in foot strike pattern between the normal and quiet running condition (Chi- square = 19.81, $p < 0.001$).

Within subject reliability

The ICC’s for each of the dependent variables for both of the running conditions are presented in Table 1. All variables were found to have high or excellent within subject reliability for both the normal and quiet running conditions, with the exception of peak knee angle during the normal running condition, which had low reliability.

INSERT TABLE 1 ABOUT HERE

Relationship between peak impact sound and kinetics

The time-normalized vGRF during the stance phase of running under the two sound conditions is presented in Figure 1. In general, there was an impact peak during the normal running condition, while the quiet running condition displayed only an active vGRF peak. Separate simple linear regressions were calculated to predict peak vGRF based on peak impact sound in normal and quiet conditions. No significant relationships were found in the normal condition ($F(1, 24) = 1.102$, $p=0.304$, 95%CI; -0.012, 0.037; r^2 of 0.044) or the quiet condition peak ($F(1, 24) = 0.327$, $p=0.573$, 95%CI; -0.014, 0.025 r^2 of 0.013). Separate simple linear regressions were also calculated to predict peak vertical loading rate based on peak impact sound in normal and quiet conditions. No significant relationship was found in the normal condition ($F(1, 24) = 2.211$, $p=0.150$, 95%CI = -3.855, 23.729 r^2 is 0.084). However a significant regression was found to predict vertical loading rate based on peak impact sound in the quiet condition ($F(1,24) = 5.476$, $p=0.028$, 95%CI;1.055, 16.825 r^2 of 0.186). The participants predicted vertical loading rate (BW/sec) = -888.0 + (8.940 x peak impact sound (dB)) in the quiet condition. (Figure 2B) Participant's average vertical loading rate increases by 8.9 BW/sec for every dB increase in sound.

INSERT FIGURE 1 ABOUT HERE

INSERT FIGURE 2A, 2B, 2C and 2D ABOUT HERE

Difference in sound, kinematics and kinetics between running conditions

The paired samples t-tests demonstrated that peak sound amplitude (mean difference = 9.1 dB, $p < 0.001$), peak vGRF (mean difference = 0.2 BW, $p = 0.001$), and vertical loading rate (mean difference = 275.1 BW/sec, $p < 0.001$) were significantly lower during the quiet running condition compared with the normal running condition (Table 2). Figure 3 shows the time-normalized ankle, knee and hip joint sagittal motion during the stance phase of running under the two sound conditions. Ankle angle changed from 0.2° dorsiflexion at initial contact during normal running to 8.6° plantarflexion during quiet running ($p < 0.001$, Table 2) and hip flexion at initial contact was greater in the normal compared to the quiet condition (mean difference = 2.2˚, $p = 0.039$, Table 2). Peak ankle dorsiflexion (mean difference = 3.5˚, $p = 0.001$) and peak knee flexion (mean difference = 2.6˚, $p = 0.014$) angles were significantly reduced in the quiet condition compared with the normal running condition. There was no significant difference in contact time ($p = 0.712$) and knee angle at initial contact ($p = 0.883$), between the normal and quiet running conditions (Table 2).

INSERT TABLE 2 ABOUT HERE

INSERT FIGURE 3 ABOUT HERE

DISCUSSION

The results of this study demonstrate that individuals can significantly reduce their peak vGRF, vertical loading rate and peak sound amplitude when instructed to run quietly. When running quietly runners were also more likely to use a non-RFS than a

RFS technique and exhibited the vGRF profile and lower limb kinematics to support this. However, despite the significant effect running quietly has on an individual's vGRF and vertical loading rate, this effect cannot be generalized. We found weak and mostly insignificant correlations between peak impact sound and peak vGRF and vertical loading rate. Therefore, a quieter impact sound is not directly associated with a lower peak vGRF or vertical loading rate.

This is the first study to investigate impact sound during running and hence there is no literature to directly compare our results. Wernli et al. (2016) examined the impact sound during a drop-landing task where participants were asked to land normally, softly and loudly and they found a significant relationship between peak impact sound and peak vGRF. An explanation for why Wernli et al. (2016) found a significant relationship where the current study did not may be that they combined the results of their three sound conditions into one regression model rather than conducting individual analyses. The contrasting findings may also be owing to the fact that running is a more complex motor skill than drop-landing. Additionally, the participants in the current study had not received any formal running coaching; it is therefore likely that individual technique variation existed between trials. However, despite the fact participants were not highly trained runners, intra-class correlation coefficients (Table 1) for all variables recorded were high. A stronger relationship between impact sound and peak vGRF and vertical loading rate may exist in well-trained runners, however this requires further investigation.

Numerous studies have confirmed that runners who have previously experienced a lower limb stress fracture have greater peak vGRF and vertical loading rates than uninjured runners (Ferber et al., 2002; Grimston et al., 1991; Milner et al., 2006). More recently, a prospective study by Davis et al. (Davis et al., In Press) found that runners with greater peak vGRF and vertical loading rates experienced a greater number of stress fractures and muscle strains than runners who had never been medically diagnosed with an injury. This suggests that these GRF variables are risk factors for injury rather than a result of changed movement patterns following the injury. The results of the current study may have significant implications for athletes, as it demonstrated that 'loud' runners do not necessarily have greater peak vGRF and vertical loading rates than 'quiet' runners. Nevertheless individuals can reduce their vGRF and vertical loading rate simply by running quietly, however whether this type of intervention can effectively reduce running injuries requires further investigation.

Lower limb kinematics were altered when runners were instructed to run quietly. Most notably the average ankle angle at initial contact changed from a dorsiflexion angle to plantarflexion when participants ran quietly (normal 0.2° dorsiflexion vs quiet 8.6° plantarflexion, $p < 0.001$). The changes in ankle angle at initial contact suggest that when participants were instructed to run quietly, majority adopted a non-RFS running pattern. This was confirmed by the foot marker positions recorded in Vicon. Ankle range of motion also increased during the quiet condition (normal 27.7° vs quiet 33.0°), and peak ankle dorsiflexion, peak knee flexion and hip flexion at initial contact decreased from the normal to quiet condition, these changes are all consistent with a change from a RFS to a non-RFS technique (Kulmala, Avela, Pasanen, & Parkkari, 2013; Nunns, House, Fallowfield, Allsopp, & Dixon, 2013). Adding further support, only one peak was evident in the vGRF (Figure 1) in the quiet running condition compared to two seen in the normal condition, which is consistent with a non-RFS technique (Bobbert, Schamhardt, & Nigg, 1991; Boyer et al., 2014; Rooney & Derrick, 2013). Anecdotally, some coaches already instruct their athletes to run softly in order to change from a RFS to a non-RFS technique, and the results of the current study suggest that this may be effective. Although, while this study found that an imposed non-RFS technique initially produces a quieter sound than a habitual RFS, whether this effect is long term and whether a habitual non-RFS is quieter than a habitual RFS is unknown. It is also important to note that not all habitual RFS participants changed to a non-RFS when asked to run quietly yet were still able achieved a reduction in impact sound, peak vGRF and vertical loading rate. Changing foot strike technique is therefore not the only mechanism for reducing these variables. How participants who did not change technique reduced impact sound warrants further investigation.

Participants in this study ran barefoot in both the normal and quiet conditions, this was enforced in order to control for variable shoe cushioning and support characteristics. A possible limitation of barefoot running however is the difference in tissue composition between the heel pad and forefoot, which may alter the impact sound. Although as mentioned previously not all participants changed to a non-RFS when asked to run quietly yet still reduced their impact sound suggests that the influence of varied foot composition was minimal. Future research should investigate if the results of this study are repeatable when wearing shoes and on varied surfaces. Softer surfaces (such as grass) and shoe midsole cushioning will increase the time over which contact occurs and therefore vertical loading rate may be reduced, which based on the findings of the current study we postulate will also reduce impact sound amplitude.

This study was conducted in a laboratory setting where background noise was minimal and the sound created at foot contact during both the normal and quiet running conditions was clearly audible to the assessor and the shotgun microphone collected clean raw data. While the authors feel that the laboratory nature of the study allowed for the collection of quality data they acknowledge that the findings may be limited to a metallic surface (force platform). The results may also be limited to amateur male barefoot runners running at 5.0 m/s. It is very likely that different surfaces, footwear, speeds and running ability will alter the impact sound amplitude. We postulate that due to the effect of speed on vGRF (Hamner & Delp, 2013) when individuals run slower they will generate a quieter impact sound and when they run faster (whilst maintaining a habitual RFS) a louder sound. Based on our results we believe this will be an individual response and not a general relationship. Furthermore, for practical application it is important to determine whether an athlete or a coach can detect differences in sound amplitude without the use of an expensive microphone. Future research should investigate runners of different abilities, female runners, different surfaces, shod running, running speeds and an outdoor environment.

Conclusion

This study demonstrated that running quietly is not directly associated with a lower vGRF or vertical loading rate. However, when healthy male participants were asked to intentionally run quietly, compared to their normal running, peak impact sound amplitude, peak vGRF and vertical loading rate were reduced. This may have important injury prevention implications for coaches, athletes and clinicians.

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TABLES

Table 1: Intra-class correlation coefficients (ICC's) and 95% confidence intervals (95% CI) for the dependent variables during the normal and quiet running conditions.

Variable	Normal (ICC (95%CI))	Quiet (ICC (95%CI))
Peak sound amplitude (dB)	0.877 (0.780 – 0.939)	0.876 (0.773 – 0.941)
Peak vGRF (BW)	0.868 (0.763 – 0.935)	0.949 (0.907 – 0.976)
Vertical loading rate (BW/ sec)	0.891 (0.808 – 0.945)	0.885 (0.797 – 0.943)
Contact time (sec)	0.943 (0.899 – 0.972)	0.960 (0.927 – 0.981)
Ankle° at IC	0.947 (0.904 – 0.975)	0.976 (0.958 – 0.988)
Knee° at IC	0.944 (0.899 – 0.972)	0.965 (0.939 – 0.983)
Hip° at IC	0.968 (0.943 – 0.984)	0.948 (0.908 – 0.974)
Peak Ankle°	0.973 (0.951 – 0.987)	0.967 (0.942 – 0.983)
Peak Knee°	0.670 (0.406 – 0.838)	0.944 (0.900 – 0.972)
Peak Hip°	0.967 (0.941 – 0.984)	0.943 (0.899 – 0.971)

Abbreviations: dB= decibels, BW= body weight's, IC= initial contact.

Table 2: Difference in dependent variables between the normal and quiet running conditions.

Variable	Normal (Mean (SD))	Quiet (Mean (SD))	Mean Difference	Standard Error	95% CI of differences	p value
Peak sound amplitude (dB)	121.24 (6.36)	112.18 (6.19)	9.06	1.17	6.64, 11.48	<0.001*
Peak vGRF (BW)	2.71 (0.38)	2.53 (0.28)	0.18	0.05	0.08, 0.29	0.001*
Vertical loading rate (BW/sec)	390.17 (214.14)	115.04 (125.89)	275.14	40.45	191.84, 358.45	<0.001*
Contact time (sec)	0.20 (0.02)	0.20 (0.02)	-0.001	0.003	-0.007, 0.005	0.712
Ankle° at IC	0.17 (5.76)	-8.57 (9.12)	8.74	1.88	4.87, 12.61	<0.001*
Knee° at IC	24.91 (6.01)	25.12 (8.96)	-0.21	1.43	-3.17, 2.74	0.883
Hip° at IC	50.46 (8.41)	48.23 (7.74)	2.22	1.02	0.13, 4.32	0.039*
Peak Ankle°	27.88 (6.58)	24.43 (6.88)	3.45	0.89	1.61, 5.29	0.001*
Peak Knee°	44.67 (5.22)	42.11 (6.10)	2.56	0.97	0.56, 4.56	0.014*
Peak Hip°	48.69 (12.93)	48.46 (7.44)	0.24	2.41	-4.72, 5.19	0.923

Abbreviations: dB= decibels, BW= body weight's, IC= initial contact. Ankle angle: positive denotes dorsiflexion, negative denotes plantarflexion; knee angle: positive denotes flexion; hip angle; positive denotes flexion, negative denotes extension. * indicates $p < 0.05$.

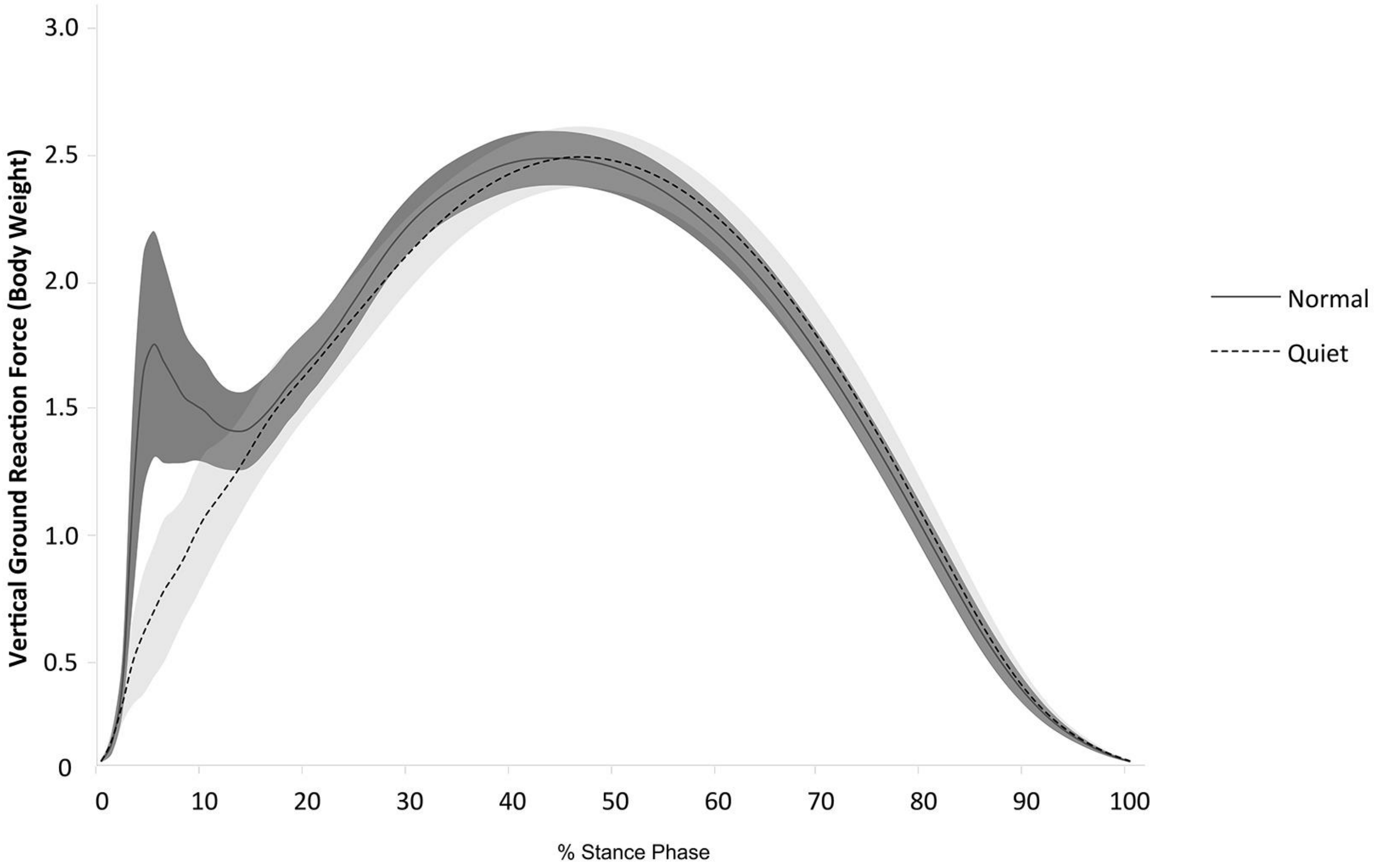
FIGURE CAPTION

FIGURE 1 – Time and body weight normalized vertical ground reaction force during the stance phase of running under normal (solid line) and quiet (broken line) sound conditions.

FIGURE 2 - The relationship between impact sound amplitude and; A) normalized vertical ground reaction force (vGRF) in normal sound condition B) normalized vGRF in quiet condition, C) vertical loading rate in normal sound condition and, D) vertical loading rate in quiet sound condition.

FIGURE 3 - Time normalized sagittal ankle (top), knee (middle) and hip (bottom) joint angles during the stance phase of running under the two different sound conditions; normal (solid line) and quiet (broken line).

Fig. 1



Vertical Ground Reaction Force (Body Weight)
3.0
2.5
2.0
1.5
1.0
0.5
0
0
10
20
30
40
50
60
70
80
90
100
% Stance Phase
Normal
Quiet

Figure 2A

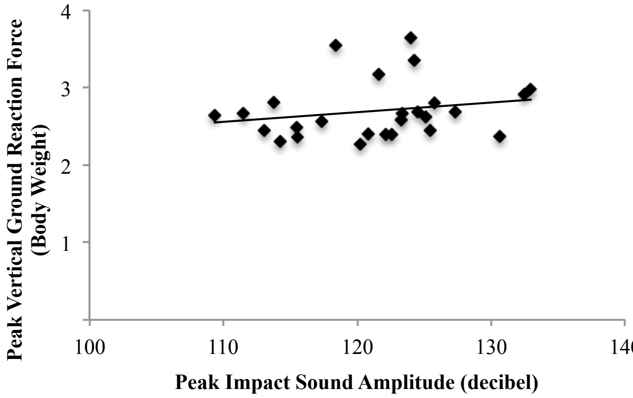


Figure 2B

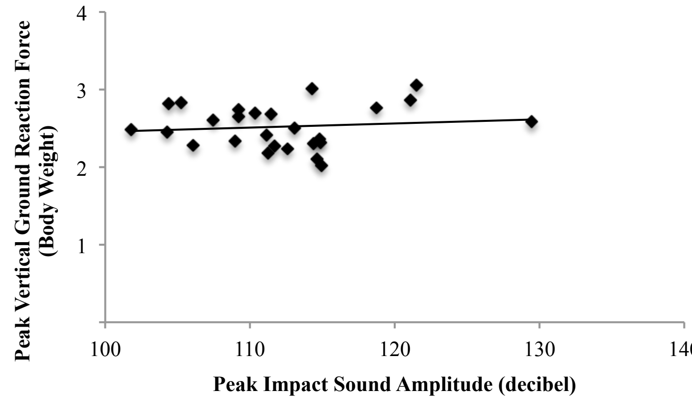


Figure 2C

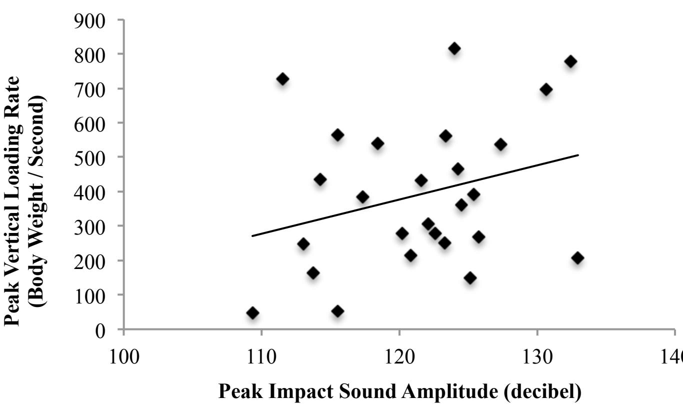


Figure 2D

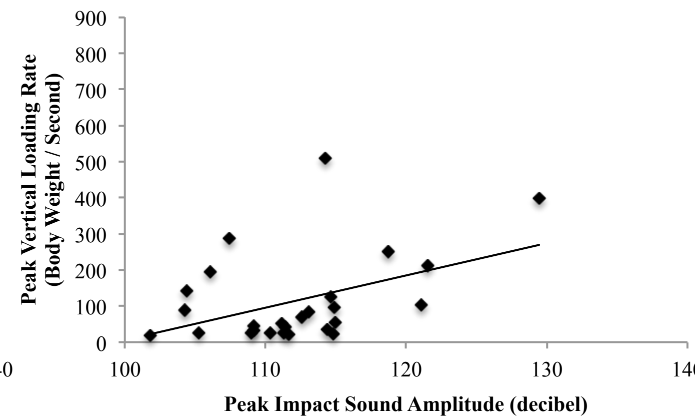


Fig. 3


Ankle
40
30
20
10
0
-10
-20
-30
-40
0 10 20 30 40 50 60 70 80 90 100
Joint Angle (degrees)
(Plantar Flexion / Dorsiflexion)
% Stance Phase
Normal
Quiet
Knee
50
45
40
35
30
25
20
15
10
5
0 10 20 30 40 50 60 70 80 90 100
Joint Angle (degrees)
(Flexion)
% Stance Phase
Normal
Quiet
Hip
60
50
40
30
20
10
0
10
20
0 10 20 30 40 50 60 70 80 90 100
Joint Angle (degrees)
(Extension / Flexion)
% Stance Phase
Normal
Quiet