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Visual feedback gait re-training in overweight children can reduce excessive tibial acceleration during walking and running: An experimental intervention study

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ABSTRACT

Background: Being overweight may increase the risk for developing stress fracture, as overweight adults and children were reported to have greater pressure peaks and rates under the heel during walking when compared with their normal-weight counterparts. Biofeedback gait retraining was shown to reduce ground impact magnitude in adults but not yet in children.
Research question: The study examined whether overweight children have greater tibia peak positive acceleration (PPA) at ground impact during fast walking and running compared to healthy weight children, and whether visual feedback gait retraining program can be used to reduce PPA in overweight children.
Methods: Twenty five overweight and 12 healthy weight children participated in the study. Overweight children were randomly assigned into either feedback group or control no-feedback group of 8 sessions training program over 2-weeks. Tibia PPA at ground impact output from a wearable inertial sensor attached to the tibia was the feedback displayed on a monitor placed in front of the treadmill during walking and running.
Results: Compared to healthy weight children, overweight participants showed significant greater PPA values in running ($p < 0.05$), but not in fast walking. Feedback group significantly reduced PPA by 16% ($p < 0.01$), and these changes persisted at the 1-month follow-up.
Significance: Tibia PPA may be used in evaluating overweight children as a risk assessment to potential injuries due to high ground impact during running. Gait retraining using real-time feedback of tibia PPA may be useful in rehabilitation programs to reduce ground impact in overweight children.

1. Introduction

Young adult runners who developed tibial stress fractures are reported to have higher tibia peak positive acceleration (PPA) at ground impact and higher average and instantaneous vertical ground reaction force (GRF) loading rates than a group of age and mileage matched control subjects [1,2]. Being overweight may also increase the risk for developing stress fracture, as overweight adults were reported to have greater GRF at comfortable walking and at fast walking speed compared with normal-weight adults [3,4]. Similar to adults, overweight children (7–12 years of age) were reported having greater pressure peaks and rates under the heel during walking when compared with their normal-weight counterparts [5–7]. The authors commented that higher plantar pressures in overweight children may result in foot discomfort and possibly deformity, which may increase the risk of injury or further discourage the child from physical activity that ironically escalate the overweight cycle. This may become a serious problem worldwide and further burden to the health system as recent report showed that the prevalence of child overweight and obesity has grown dramatically [8].

It is suggested that reducing the loading rate of the GRF by 10–15% may help in prevention and treatment of stress fracture [9]. Ground reaction force typically are measured using force-plates. Alternatively, skin-mounted accelerometer attached to the distal tibia can be used to measure PPA, which was shown to be valid in evaluating GRF during running [10], and pose a viable alternative to force-plates. The benefits of using tibial mounted accelerometers to estimate GRF in running compared to force-plates are: less expensive, user friendly and accessible to the general population, not restricted to specific indoor space, and not restricted to the number of gait strides they are able to measure [10].

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In the 1980s inertial sensors were used to capture ground impact loading during running [11] with high correlation with peak ground reaction force [12]. Inertial sensors attached to the tibia were used to investigate the influence of various surfaces [13], shoes [14], fatigue [15], orthotics and insoles [16,17], and stride length [18] on lower extremity ground impact loading. Montgomery et al. [19] showed that PPA increase with increased gait speed by 2 fold from walking at comfortable speed (1.56 ± 0.15 m/s) to jogging (2.88 ± 0.35 m/s) and by 2 fold from jogging to running (4.28 ± 0.36 m/s). Overweight individuals were reported to have approximately 60% greater GRF compared to normal weight individuals and both groups significantly decrease GRF at slower walking speeds [3].

The use of lightweight accelerometer attached to the anteromedial aspect of the distal tibia was reported to be a useful gait retraining method in adults for reducing PPA [20] and to be an effective means of eliciting reductions in impact loading without negatively affecting running economy [21]. Crowell et al. [20], for example, used this method to identify and re-train young adults at high risk of stress fracture (PPA above 8 g) in reducing the magnitude of PPA during running. During the two-week 8 gait retraining sessions participants ran on a treadmill and received on a monitor the real-time visual display of their PPA from an accelerometer attached to their distal tibia. Horizontal threshold line was placed across the display at approximately 50% of the pre training PPA value. Participants were instructed to "run softer," make their footfalls quieter, and to keep the acceleration peaks below the line. Following the two-week gait retraining intervention participants significantly reduced PPA by 50% that was retained in 1-month follow-up.

Today there is only one study that reported PPA of the tibia in children during walking and running [22]. Tirosh et al. [22] analysed PPA of the tibia in children across a range of age and gait speeds using wireless Inertial Measurement Unit (IMU) taped to the anteromedial aspect of the distal tibia. Significant increase in PPA with increased gait speed was noted. In addition, only in running, greater variability in young children (between 7 and 9 years of age) compared to older children (between 10 and 12 years of age) was found, suggesting that running is a more complex gait pattern compared to walking and matures later.

The success of Crowell et al. [20] study in reducing running PPA using real-time feedback in young adults motivated this study to explore real-time tibia PPA gait retraining feedback in overweight children. The research questions addressed in this study were; first, whether, overweight children show greater tibia PPA during fast walking and running compared to healthy weight children. The second question to be addressed was whether relative to an initial baseline condition, overweight children could reduce tibia PPA with augmented information using the real-time visual presentation. The third question was whether changes in PPA would persist at a 1-month follow-up.

2. Methods

2.1. Participants

Twenty-five overweight and 12 healthy weight (NOG) children aged 9.05 ± 1.64 years with no gait pathology participated in the study. Overweight children were characterised having BMI measured at or above 85% percentile while NOG were at the middle 50% percentile. This study was integrated at the beginning of the first week of a 6-month-multidisciplinary childhood obesity treatment program at Meir Medical Center Kfar-Saba, Tel-Aviv University, Israel that overweight children participated in. The intervention program included dietary intervention and an exercise program. The exercise program comprised of a twice-weekly training session (1 h each). The activities varied in duration and intensity throughout the program, and were designed primarily as games to encourage the enthusiasm and participation of the subjects. Endurance-type activities accounted for most of the time spent in training (~50% team sports and 50% running games), with attention given, as noted, to coordination and flexibility skills. Throughout the program the subjects were encouraged by the staff to reduce their sedentary activities (e.g., to reduce television viewing and video-game participation, to use stairs instead of elevators, and to play outside instead of sitting inside). The healthy weight children participated in a swimming class activity (non- competitive) twice a week, 1 h each. Their activity included 10–15 min warm up (games that includes running, jumping and stretching) and 45 min of swimming in a varied duration and intensity. All participating children had to be free of lower extremity injuries or other conditions that would affect their gait.

Overweight children were randomly assigned with the function for random number into two groups including; overweight feedback group (OFG, n = 14) and overweight control group (OCG, n = 11). The study was approved by the Ethics Committee of Meir Medical Center, Kfar-Saba, Israel. All participants and their parents provided written informed consent for participation. None of the participants suffered from any neurological or orthopaedics disorder that might interfere with the goals of the study.

2.2. Equipment

Wireless Inertial Measurement Units (IMU) comprising of a tri-axial accelerometer device (YEI 3-space sensor, YEI Corporation) was aligned in the long axis of the subject's tibia and attached using Fabrifoam® Velcro strip securely taped to the anteromedial aspect of the distal tibia to measure the magnitude and direction of acceleration in 3 dimensions. The device is small (35 mm × 60 mm × 15 mm) and light (28 g). For this study the IMU was set up to sample at 150 Hz with range ± 16 g using in-house software written in python (Python Software Foundation, www.python.org). A 21-in. monitor was positioned infront of the treadmill to allow the real-time display of the IMU signal while walking and running on the treadmill. Participants wore their own running shoes during all data collections sessions.

2.3. Procedure

Initially participants undertook the "Talk Test" to identify their individual baseline walking speed. The "Talk Test" is a method for recommending exercise intensity based on the ability to maintain conversation during exercise and it has been used to define the recommended exercise intensity limit for cardiorespiratory training [23,24]. In this study participants were allocated to groups of three, walking together along a 1 km track. The instruction was to "walk as fast as possible, but not run, at a speed in which it is difficult to talk comfortably to your walking partner". Baseline walking speed (Bs) for each participant was calculated by dividing the 1 km walking distance by the time to complete the walk.

Following the "Talk Test" all participants, both overweight and healthy weight children, performed initial gait session (S1) that included two 3 min treadmill trials differ by speed; baseline (Bs), and 20% above baseline (+20Bs), multiples of 1.0, and 1.2 respectively from the walking speed established in the "Talk Test". From each of the 3 min trials the initial 1 min was to allow the participant reaching a steady state gait followed by 30 s of acceleration data that was used to capture acceleration data from the tibia IMU for further analysis. The 30 s data capture was sufficient to capture the number of strides to calculate the average PPA.

Only the overweight children (OFG and OCG groups) were further asked to attend additional 8 gait sessions (S2–S9) with 2 sessions per week having the last session S9 (retention) as 1-month follow-up. Similar to S1, gait sessions S2–S9 were 3 min treadmill walking at Bs speed and then 3 min treadmill running at +20Bs speed with 30 s data capture from the tibia IMU in each speed trial. From S2 to S8, only the OFG received real-time visual feedback of the tibia acceleration signal from the IMU displayed on a monitor in front of the treadmill. A

horizontal threshold line was also displayed at the mean PPA of the tibia value calculated from the first gait session S1, while participants were instructed to "walk/run softer," make their footfalls quieter, and to keep the PPA below the horizontal threshold line. The rational was to encourage the OFG to reduce the maximum PPA below their mean PPA. In the last gait session S9 (retention) the OFG did not receive feedback.

2.4. Data processing

Data processing and analysis was performed using MATLAB® version R2014b (MathWorks, Inc). A fourth order, recursive, Butterworth, low-pass filter was used to filter the tibia accelerometer data at 60 Hz. The PPA tibial acceleration during each stance phase was then identified using in house MATLAB code from the filtered tibia acceleration data.

2.5. Data analysis

To explore significant PPA differences between overweight and healthy weight children at Bs and +20Bs gait speed conditions, a 2 × 2 Analysis of Variance (ANOVA) was performed from PPA measurements obtained during the initial gait session, S1. To identify the effect of real-time feedback on PPA, a second ANOVA with repeated measures was performed exploring PPA differences between sessions (S1–S9), gait speed condition (Bs and +20Bs), and groups (OFG, OCG). Bonferroni post hoc test was used with level of significance for the statistical tests set at 0.05 and correction factor = 0.003.

3. Results

Participant's characteristics and gait speeds are shown in Table 1. The mean speed in all 3 groups was not statistically significant (1.66 ± 0.18 m/s, 1.71 ± 0.15 m/s and 1.75 ± 0.12 m/s at Bs, and 2.00 ± 0.12 m/s, 2.05 ± 0.18 m/s and 2.10 ± 0.14 m/s at +20Bs, for OFG, OCG, and NOG, respectively). Effect of speed on PPA showed significant greater PPA values in the +20Bs speed condition compared to Bs (3.53 ± 0.89 g and 2.12 ± 0.52 g for +20Bs and Bs speeds, respectively, $F(1,70) = 56.1$, $p < 0.01$).

3.1. Over weight vs healthy weight

Fig. 1 shows PPA values for the overweight and healthy weight children at both Bs and +20Bs speed conditions at first trial, S1. While PPA values during the Bs speed condition were not significant between overweight and healthy weight groups (2.16 ± 0.57 g and 2.03 ± 0.41 g for overweight and healthy weight, respectively), the post hoc analysis did show significant greater PPA values at the +20Bs speed condition in the obese group compared to healthy weight group (3.75 ± 0.95 g and 3.07 ± 0.54 g, respectively, $F(1,70) = 2.5$, $p < 0.05$).

3.2. Biofeedback gait retraining

Fig. 2 shows PPA values with 95% confidence interval for both OFG and OCG during the 8 sessions (S1–S8) and the retention (S9) for both Bs and +20Bs speed conditions. Significant session X group interaction was found ($p < 0.01$) indicating significant cumulative decrease in PPA in the OFG group compared to no change in the OCG group following repeated sessions. The post hoc analysis revealed that this was primarily due to significant lower PPA in the OFG from the 5th session onwards i.e. S5–S9 ($p < 0.01$).

Table 1
Participant's characteristic.

	Overweight feedback group	Overweight control group	Healthy weight control group
Age (years)	8.64 ± 1.34	8.27 ± 1.29	10.7 ± 1.27
Weight (kg)	45.46 ± 8.46	44.93 ± 5.89	33.51 ± 6.81
Height (cm)	135.42 ± 8.64	136 ± 8.05	145.75 ± 11.45
BMI	24.09 ± 3.47	24.02 ± 3.48	17.4 ± 1.9
Bs speed (m/s)	1.66 ± 0.10	1.71 ± 0.15	1.75 ± 0.12
+20Bs speed (m/s)	2.00 ± 0.22	2.05 ± 0.18	2.10 ± 0.14

4. Discussion

The present study investigated the use of wearable sensor real-time visual feedback gait retraining to reduce tibia PPA in overweight children. Initially this study explored differences in tibia PPA between overweight and healthy children. Following the obese children commenced an eight gait retraining sessions over 4 weeks to explore the feasibility in reducing PPA.

Earlier work of Mickle et al. [6] and Yan et al. [7] found that during walking overweight children display significantly larger forces on the plantar surface of their foot and heel compared to the healthy weight children. Our study is the first to report differences in ground impact, by means of tibia PPA, between overweight and healthy weight children during walking and running. This study found significant 22% greater PPA values in obese children during running that may expose the children to greater risk of ground impact loading injuries. Running is a common, vigorous intensity physical activity participated in by several individuals across the world. While running may be great physiologically to reduce obesity, our findings may be a concern regarding the participation of running by overweight individuals. Crowell et al. [20], for example, reported greater tibia PPA values in young adults that experienced stress fracture injuries. It may be argued here that the greater tibia PPA values found in overweight children may expose them to greater injury risk compared with healthy weight children.

Real-time visual feedback for the correction of gait is not new and has already been established [20,25]. As an example, Noehren et al. [25] studied a group of runners with a patellofemoral pain syndrome running on a treadmill with real-time kinematic feedback of the hip adduction during stance. Following a total of 8 training sessions over 2 weeks there was 18% and 20% reduction in instantaneous and average vertical load rates. Similarly, Crowell et al. [20] used 8 real time feedback gait retraining sessions to reduce tibia PPA in runners with PPA greater than 8 g. Peak positive acceleration of the tibia, vertical force loading rates, and vertical force impact peak were reduced by 50%, 30%, and 20%, respectively, immediately following the gait retraining. These reductions were maintained at the 1-month follow-up. The results of this study in overweight children expands Crowell et al. [20] findings in young adults. For the overweight children that received real-time feedback in the current study, 16% reduction in PPA was found. Although our results are lower compared to 50% reduction reported in Crowell et al. [20], our results were significant and may be sufficient in the prevention and treatment of stress fracture as suggested by van der Worp et al. [9]. The reason for our lower percentage reduction in tibia PPA may be related to the initial lower baseline tibia PPA values in our children participants (3.8 g compared to ~8 g in Crowell et al. [20] at baseline), and/or differences in the feedback threshold between the studies. In the current study feedback threshold was set to the average tibia PPA obtained in baseline session while in Crowell et al. [20] study the feedback threshold was set to 50% of the average PPA at baseline. The reason why the current study did not use a 50% threshold is related to the low tibia PPA values that children naturally have due to their low mass compared to young adults.

The current study found that reduction in tibia PPA due to real-time feedback gait retraining became significant only from the 5th training session and onward. A comparison with other studies is impossible as the trajectory of changes in values were not reported. Similar to other gait retraining studies [20,21,25] the current study provided 8 training

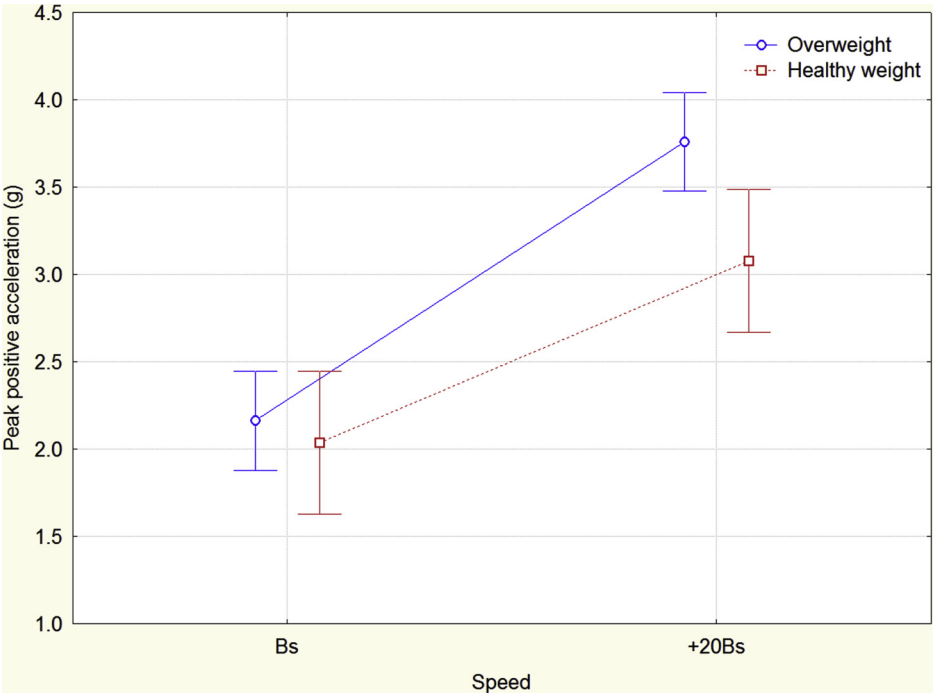

Fig. 1. Mean peak positive acceleration (PPA) values for the overweight and healthy weight children at both baseline (Bs), and 20% above baseline (+20Bs) gait speed conditions at the first testing trial. Error bars denote 0.95 confidence intervals. Asterisk (*) denote significant differences ($p < 0.05$) between overweight and healthy weight children only at +20Bs gait.

sessions with 1-month retention test to allow significant reduction in PPA. The current study confirms that similar to young adults 8 gait training session in overweight children are sufficient to elicit positive changes in gait. Furthermore, the positive retention output in this study suggests that similar to young adult children are able to retain gait adaptation 1 month following intervention.

One general limitation about the use of accelerometers is the indirect measure of impact force and the lack of information regarding

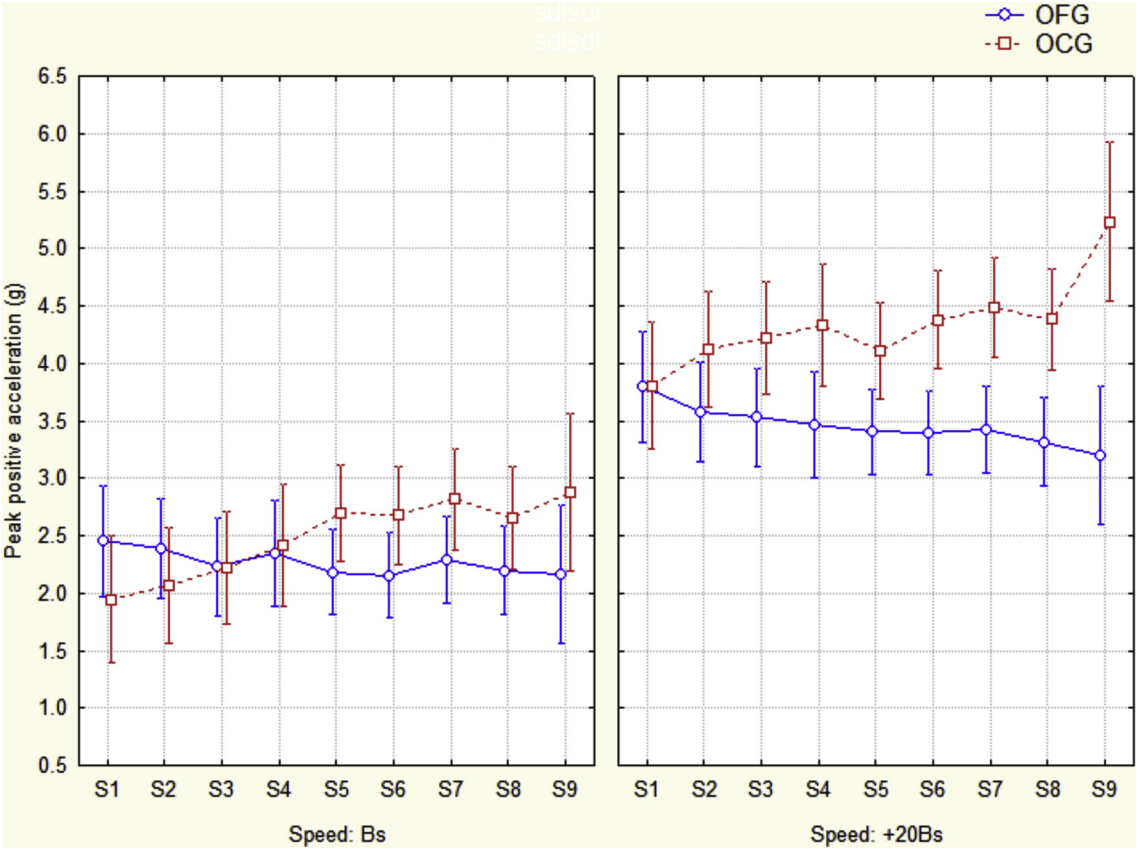

Fig. 2. Mean peak positive acceleration (PPA) values with 95% confidence interval error bars for both overweight feedback group (OFG) and overweight control no feedback group (OCG) during the 8 sessions (S1–S8) and one month retention (S9) for both Bs and +20Bs gait speed conditions. Significant lower PPA in OFG compared with OCG were found only from the 5th session onwards i.e. S5–S9, at the +20Bs gait speed ($p < 0.01$, shaded area).

the foot strike pattern. Accelerometers have been used to calculate ground reaction force and tibial acceleration during running by various means [26]. Raper et al. [10] indicated that estimations of ground reaction force measured by accelerometers do not directly correlate to those measured by the reference standard force plate. Foot strike pattern was also shown to affect tibia acceleration at foot ground contact, with inconsistent results. For example, Laughton et al. [16] found that fore-foot strike induce significant increase in tibial acceleration compared to rear-foot strike (7.82 ± 3.16 and 6.15 ± 2.96 g, respectively), conversely Gruber et al. [27] showed that rear-foot strike PPA is significantly greater than PPA during fore-foot running (5.07 ± 1.49 and 3.87 ± 1.36 g, respectively). In our study foot strike pattern was not evaluated, thus it may be that the significant reduction in tibial acceleration observed in the intervention group was due to changes in foot strike patterns.

One limitation of this study is that only the short-term (1 month post) effects of real-time tibia acceleration gait retraining on reducing PPA were reported. Therefore, future longer duration prospective studies are needed to establish whether tibia PPA gait retraining is an effective long-term solution for reducing the risk of ground impact-related injuries in children. Given the nature of the intervention that was presented when running on a treadmill, an obvious question arises regarding the transfer to a free-running, non-laboratory environment. From this perspective, it might be that the reduction of tibia PPA is treadmill specific and non-transferable to overground running. However, until more is known, the real time gait retraining presented in this study may be useful to reduce tibia PPA in overweight children. Further work to establish long-term retention and transfer of laboratory training to the children's more natural running environments is needed.

5. Conclusion

The present study presented for the first time the use of real-time tibia PPA gait retraining intervention in overweight children. Overweight children were found to have significantly greater tibia PPA compared to healthy weight children. The intervention was found to significantly reduce tibia PPA by 16% following 8 training sessions, and these changes appear to persist at the 1-month follow-up. The method described here may be used in evaluating overweight children as a risk assessment to potential injuries due to high ground impact during running. Furthermore, the real-time feedback may be used to reduce tibia PPA in overweight children that are running with excessive tibia PPA values.

References

[1] M.W. Anderson, A. Greenspan, Stress fractures, Radiology 199 (1996) 1–12.
[2] B.H. Jones, J.M. Harris, T.N. Vinh, C. Rubin, Exercise-induced stress fractures and stress reactions of bone: epidemiology, etiology, and classification, Exerc. Sport Sci. Rev. 17 (1989) 379–422.
[3] R.C. Browning, R. Kram, Effects of obesity on the biomechanics of walking at different speeds, Med. Sci. Sports Exerc. 39 (2007) 1632–1641.
[4] D.J. Haight, Z.F. Lerner, W.J. Board, R.C. Browning, A comparison of slow, uphill and fast, level walking on lower extremity biomechanics and tibiofemoral joint loading in obese and nonobese adults, J. Orthop. Res. 32 (2014) 324–330.
[5] B. McGraw, B.A. McClenaghan, H.G. Williams, J. Dickerson, D.S. Ward, Gait and postural stability in obese and nonobese prepubertal boys, Arch. Phys. Med. Rehabil. 81 (2000) 484–489.
[6] K.J. Mickle, J.R. Steele, B.J. Munro, Does excess mass affect plantar pressure in young children? Int. J. Pediatr. Obes. 1 (2006) 183–188.
[7] S.H. Yan, K. Zhang, G.Q. Tan, J. Yang, Z.C. Liu, Effects of obesity on dynamic plantar pressure distribution in Chinese prepubescent children during walking, Gait Posture 37 (2013) 37–42.
[8] A. Bereket, Z. Atay, Current status of childhood obesity and its associated morbidities in Turkey, J. Clin. Res. Pediatr. Endocrinol. 4 (2012) 1–7.
[9] H. van der Worp, J.W. Vrielink, S.W. Bredeweg, Do runners who suffer injuries have higher vertical ground reaction forces than those who remain injury-free? A systematic review and meta-analysis, Br. J. Sports Med. 50 (2016) 450–457.
[10] D.P. Raper, J. Witchalls, E.J. Philips, E. Knight, M.K. Drew, G. Waddington, Use of a tibial accelerometer to measure ground reaction force in running: a reliability and validity comparison with force plates, J. Sci. Med. Sport 21 (1) (2018) 84–88, https://doi.org/10.1016/j.jsams.2017.06.010 Epub 2017 Jun 16.
[11] T.E. Clarke, E.C. Frederick, L.B. Cooper, Effects of shoe cushioning upon ground reaction forces in running, Int. J. Sports Med. 4 (1983) 247–251.
[12] N.G. Elvin, A.A. Elvin, S.P. Arnoczky, Correlation between ground reaction force and tibial acceleration in vertical jumping, J. Appl. Biomech. 23 (2007) 180–189.
[13] W. Kim, A.S. Voloshin, Dynamic loading during running on various surfaces, Hum. Mov. Sci. 11 (1992) 675–689.
[14] P.J. Mcnair, R.N. Marshall, Kinematic and kinetic-parameters associated with running in different shoes, Br. J. Sport Med. 28 (1994) 256–260.
[15] O. Verbitsky, J. Mizrahi, A. Voloshin, J. Treiger, E. Isakov, Shock transmission and fatigue in human running, J. Appl. Biomech. 14 (1998) 300–311.
[16] C.A. Laughton, I.M. Davis, J. Hamill, Effect of strike pattern and orthotic intervention on tibial shock during running, J. Appl. Biomech. 19 (2003) 153–168.
[17] K. O'Leary, K.A. Vorpahl, B. Heiderscheit, Effect of cushioned insoles on impact forces during running, J. Am. Podiatr. Med. Assoc. 98 (2008) 36–41.
[18] J.A. Mercer, J. Vance, A. Hreljac, J. Hamill, Relationship between shock attenuation and stride length during running at different velocities, Eur. J. Appl. Physiol. 87 (2002) 403–408.
[19] G. Montgomery, G. Abt, C. Dobson, T. Smith, M. Ditroilo, Tibial impacts and muscle activation during walking, jogging and running when performed overground, and on motorised and non-motorised treadmills, Gait Posture 49 (2016) 120–126.
[20] H.P. Crowell, I.S. Davis, Gait retraining to reduce lower extremity loading in runners, Clin. Biomech. 26 (2011) 78–83.
[21] A.C. Clansey, M. Hanlon, E.S. Wallace, A. Nevill, M.J. Lake, Influence of tibial shock feedback training on impact loading and running economy, Med. Sci. Sport Exerc. 46 (2014) 973–981.
[22] O. Tirosh, G. Orland, A. Eliakim, D. Nemet, N. Steinberg, Tibial impact accelerations in gait of primary school children: the effect of age and speed, Gait Posture 57 (2017) 265–269.
[23] R. Persinger, C. Foster, M. Gibson, D.C. Fater, J.P. Porcari, Consistency of the talk test for exercise prescription, Med. Sci. Sports Exerc. 36 (2004) 1632–1636.
[24] T.J. Quinn, B.A. Coons, The talk test and its relationship with the ventilatory and lactate thresholds, J. Sports Sci. 29 (2011) 1175–1182.
[25] B. Noehren, J. Scholz, I. Davis, The effect of real-time gait retraining on hip kinematics, pain and function in subjects with patellofemoral pain syndrome, Br. J. Sports Med. 45 (2011) 691–696.
[26] M.A. Lafortune, M.J. Lake, E. Hennig, Transfer function between tibial acceleration and ground reaction force, J. Biomech. 28 (1995) 113–117.
[27] A.H. Gruber, K.A. Boyer, T.R. Derrick, J. Hamill, Impact shock frequency components and attenuation in rearfoot and forefoot running, J. Sport Health Sci. 3 (2014) 113–121.