Medicine & Science in Sports & Exercise

The Official Journal of the American College of Sports Medicine
www.acsm-msse.org

. . . Published ahead of Print

ACCEPTED

Effects of Exercise on Plantar Pressure during Walking in Children with Overweight/Obesity

Pablo Molina-Garcia[1,2], Damian Miranda-Aparicio[1], Alejandro Molina-Molina[3], Abel Plaza-Florido[1], Jairo H Migueles[1], Jose Mora-Gonzalez[1], Cristina Cadenas-Sanchez[1], Irene Esteban-Cornejo[1,4], Maria Rodriguez-Ayllon[1], Patricio Solis-Urra[1,5], Jos Vanrenterghem[2], Francisco B Ortega [1,6]

[1]PROFITH "PROmoting FITness and Health through physical activity" research group, Sport and Health University Research Institute (iMUDS), Department of Physical and Sports Education, Faculty of Sport Sciences, University of Granada, Granada, Spain; [2]Department of Rehabilitation Sciences, KU Leuven – University of Leuven, Belgium; [3]Research Group CTS-545 ERGOLAB "Sport Physical Activity and Ergonomy to Life Quality", Department of Physical and Sports Education, Faculty of Sports Science, University of Granada, Granada, Spain; [4]Center for Cognitive and Brain Health, Department of Psychology, Northeastern University, Boston, MA; [5]IRyS Research Group, School of Physical Education, Pontificia Universidad Católica de Valparaíso, Valparaiso, Chile. [6]Department of Biosciences and Nutrition, Karolinska Institute, Sweden

Accepted for Publication: 30 August 2019

***Medicine & Science in Sports & Exercise*® Published ahead of Print** contains articles in unedited manuscript form that have been peer reviewed and accepted for publication. This manuscript will undergo copyediting, page composition, and review of the resulting proof before it is published in its final form. Please note that during the production process errors may be discovered that could affect the content.

Copyright © 2019 American College of Sports Medicine

Medicine & Science in Sports & Exercise, Publish Ahead of Print
DOI: 10.1249/MSS.0000000000002157

Effects of Exercise on Plantar Pressure during Walking in Children with Overweight/Obesity

Pablo Molina-Garcia[1,2], Damian Miranda-Aparicio[1], Alejandro Molina-Molina[3], Abel Plaza-Florido[1], Jairo H. Migueles[1], Jose Mora-Gonzalez[1], Cristina Cadenas-Sanchez[1], Irene Esteban-Cornejo[1,4], Maria Rodriguez-Ayllon[1], Patricio Solis-Urra[1,5], Jos Vanrenterghem[2], Francisco B. Ortega[1,6]

[1]PROFITH "PROmoting FITness and Health through physical activity" research group, Sport and Health University Research Institute (iMUDS), Department of Physical and Sports Education, Faculty of Sport Sciences, University of Granada, Granada, Spain; [2]Department of Rehabilitation Sciences, KU Leuven – University of Leuven, Belgium; [3]Research Group CTS-545 ERGOLAB "Sport Physical Activity and Ergonomy to Life Quality", Department of Physical and Sports Education, Faculty of Sports Science, University of Granada, Granada, Spain; [4]Center for Cognitive and Brain Health, Department of Psychology, Northeastern University, Boston, MA; [5]IRyS Research Group, School of Physical Education, Pontificia Universidad Católica de Valparaíso, Valparaiso, Chile. [6]Department of Biosciences and Nutrition, Karolinska Institute, Sweden

ACCEPTED

Copyright © 2019 by the American College of Sports Medicine. Unauthorized reproduction of this article is prohibited.

Corresponding author:

Pablo Molina-Garcia, Department of Physical and Sports Education, Faculty of Sports Science, University of Granada, Carretera de Alfacar s/n, Granada 18071, Spain. Tel. +34 958 244353. E-mail: pablomolinag5@ugr.es

This study was funded by the Spanish Ministry of Economy and Competitiveness/FEDER (DEP2013-47540, DEP2016-79512-R, RYC-2011-09011). JM-G and JHM were funded by the Spanish Ministry of Education, Culture and Sport (FPU14/06837 and FPU15/02645, respectively). IE-C was funded by a grant from the Alicia Koplowitz Foundation. CC-S was funded by a grant from the Spanish Ministry of Economy and Competitiveness (BES-2014-068829). PM-G was funded by a grant from European Union's Horizon 2020 research and innovation program (No 667302). Additional support was obtained from the University of Granada, *Plan Propio de Investigación 2016*, *Excellence actions*: Units of Excellence, Unit of Excellence on Exercise and Health (UCEES); the SAMID III network, RETICS, the PN I+D+I 2017-2021 (Spain), ISCIII- Sub-Directorate General for Research Assessment and Promotion, the European Regional Development Fund (ERDF) (Ref. RD16/0022), and the EXERNET Research Network on Exercise and Health in Special Populations (DEP2005-00046/ACTI). The results of the present study do not constitute endorsement by the American College of Sports Medicine. **CONFLICTS OF INTEREST:** None to declare.

ACCEPTED

Copyright © 2019 by the American College of Sports Medicine. Unauthorized reproduction of this article is prohibited.

ABSTRACT

Purpose. To investigate the effect of a 13-week exercise program, based on "movement quality" and "multigames" work, on plantar pressure during walking in children with overweight/obesity (OW/OB). **Method.** Seventy children (10.8 ± 1.2 years, 58.5% girls) with OW/OB, as defined by the World Obesity Federation, were assigned to either a 13-week exercise program (intervention group [EG]; n=39), or to a usual lifestyle control group (CG) (n=31). Children underwent assessments of basic anthropometry (weight and height) and plantar pressure during walking before and after the intervention period, recording plantar surface area (cm^2), maximum force (N), and force-time integrals (N/s). **Results.** After the 13-week intervention period, the EG participants showed no significant change in total plantar surface area, while the CG participants experienced an increase in this variable (small effect size: -2.5 SDs; p=0.015). Compared to the GC participants, the EG participants showed a greater increase in the maximum force supported beneath the forefoot during walking at the end of the intervention period (small effect size: 0.33 SDs; p=0.012), specifically under the lateral and medial forefoot (both p<0.05). Force-time changed similarly in both groups by the end of the intervention period (all regions p>0.05). **Conclusions:** These results suggest the exercise program led to positive structural and functional changes in plantar pressure during walking. The increase in maximum force supported by the forefoot in the EG children might indicate a change towards a more normal foot rollover pattern and a more adult gait. **Keywords:** Gait Analysis; Flatfoot; Pediatric Obesity; Exercise Therapy; Resistance Training; Foot Injuries.

ACCEPTED

Copyright © 2019 by the American College of Sports Medicine. Unauthorized reproduction of this article is prohibited.

INTRODUCTION

Nearly a third of 11 year-old children in the European Union are overweight/obese (OW/OB) (1). Increasing levels of physical activity is widely accepted as one of the most feasible strategies for preventing childhood OW/OB. This can be achieved by increasing the time spent walking - the most common physical activity of daily life (2). However, children with OW/OB are prone to experience alterations in their plantar pressure while walking (3–5). Indeed, there is now good evidence that, compared to their normal weight counterparts, children with OW/OB experience increases in a range of plantar pressure variables, especially over the midfoot and over the second to fifth metatarsal heads (4–8). These high pressures are associated with a pronated foot pattern (5, 9), leaving children with OW/OB at risk of developing movement-derived musculoskeletal disorders (10). This might induce a vicious circle in which children with OW/OB undertake less physical activity, increasing their risk of gaining weight (11).

Physical activity guidelines for children recommend weight-bearing activities to strengthen their musculoskeletal system (12). However, the biomechanical alterations described above suggest that programs for children with OW/OB need to be carefully designed in order to avoid exercise-derived foot pain and discomfort. Two recent studies tested the effectiveness of specific exercise programs for children with OW/OB on modifying plantar pressures towards the profile of normal weight children (13, 14). One, which involved a 10 week face-to-face physical activity program, followed by a further 12 weeks of unaccompanied physical activity (13), reported no significant improvement. The other, however, which involved a 6-month intensive multi-component (exercise, diet, and locomotion-emphasis) program, reported more successful results (14). Given such contradictory findings, and the scarcity of studies in this area, further studies to examine the effects of exercise interventions on plantar pressure in children with OW/OB are warranted. The

ACCEPTED

Copyright © 2019 by the American College of Sports Medicine. Unauthorized reproduction of this article is prohibited.

aim of the present work was to analyze the effect of a 13-week exercise program based on "movement quality" and "multigames" work, on plantar pressure during walking in children with OW/OB.

METHOD

Study design and participants

This non-randomized controlled trial named *'MUévete Bien'* project (MUBI) ("Move well" in English) was approved by the Review Committee for Research Involving Human Subjects at the University of Granada (Spain) (nº 279/CEIH/2017). The study sample were 70 children (10.8 ± 1.2 years, 32 girls) who met the following criteria: 1) to be 8-12.9 years-old; 2) to be classified as children with OW/OB as defined by sex and age-specific World Obesity Federation cut-offs (15); 3) to suffer no physical disabilities or neurological disorders that might impede them doing exercise; 4) in the case of girls, to have *not* reached menarche at the moment of baseline assessment; 5) to take no medications that might influence central nervous system function; 6) to be right-handed (as measured by the Edinburgh inventory) (16) (the brain hemisphere structure of right-handed children differs substantially from that of left-handed children); and 7) to have *not* been diagnosed with attention-deficit hyperactivity disorder (ADHD). Further information on the study design can be found at (http://profith.ugr.es/mubi?lang=en). Of these 70 children, 51 were included in a per-protocol analysis (see Statistical Analysis) after 1) completing the pre- and post-exercise assessments; and 2) completing at least 70% of the recommended 3 exercise sessions/week (for the exercise intervention group; see below) (**Figure 1**).

The exercise intervention group of the MUBI project was made up of children who had participated during the previous year as control group participants in the ActiveBrains study (17). For ethical reasons, these children were offered the chance to take part in the present study as

ACCEPTED

Copyright © 2019 by the American College of Sports Medicine. Unauthorized reproduction of this article is prohibited.

members of the intervention group; they did not have the opportunity to exercise in ActiveBrains study due its randomization process. The present MUBI project control group was recruited from public and private schools in Granada (Spain) adhering to the above-mentioned inclusion/exclusion criteria. Parental informed consent was required for all children to participate in the study. The participants' anthropometric and plantar pressure variables were measured before and after the intervention period.

Anthropometric measurements

Body height (cm) and weight (kg) were determined in a quiet room by trained evaluators using a stadiometer (SECA Instruments, Hamburg, Germany); body mass index (BMI [kg/m²]) was then calculated. The maturational stage of the participants was determined via their peak height velocities, calculated as per Moore's equations (18).

Plantar pressure during walking

Participants were asked to walk barefoot 10 times along a 10 m-long corridor with a 0.4 x 1.84 m long FreeMed® Pro pressure platform (Sensormedica, Rome, Italy) in the middle. This platform had 450,000 pressure sensors (resolution 2 sensors/cm^2; monitoring frequency 200 Hz). Familiarization trials were performed to ensure participants walked at a comfortable pace, and that they did so naturally. Participants struck the platform no sooner than their fourth step to ensure that a constant velocity had been reached prior to first contact (19). FreeStep® software v.1.5 (Sensormedica, Rome, Italy) was used to automatically generate individual foot masks, dividing the foot into 11 regions. Plantar pressure variables were measured in the three areas most commonly analyzed in the literature: the forefoot (from 1st to 5th metatarsal heads, toes and hallux), midfoot (medial and lateral midfoot), and rearfoot (medial and lateral rearfoot) (See Figure, **Supplemental Digital Content 1**, the eleven-region foot division provided by

ACCEPTED

Copyright © 2019 by the American College of Sports Medicine. Unauthorized reproduction of this article is prohibited.

FreeStep® software, http://links.lww.com/MSS/B761). Measurements of foot length (mm), plantar surface area (cm^2), maximum force (N), and force-time integrals (N/s) were calculated by averaging all trials for each foot. Between 8 and 20 (maximum available) valid footprints were included for each subject. Footprints were deemed valid when: 1) the subject did not lose balance during gait; 2) was not distracted (e.g., looking around or speaking) while walking; and 3) the whole plantar surface was recorded. The first two criteria were controlled during the assessment; the third was later checked visually by the same evaluator. The use of a minimum eight footprint per child adheres to the recommendations of McPoil et al. (20) who reported a reliability plateau being reached when 5-7 trials were averaged. To avoid problems derived from paired data, plantar pressure outcomes of left and right feet were averaged into a single observation (21).

Foot pain

The Pediatric Pain Questionnaire™ was used to record self-reported musculoskeletal pain (22). Children were categorized as reporting the "presence of foot pain" when they indicated any pain intensity (i.e., mild, moderate or severe) on a body map, or "no-presence of foot pain" when no pain was indicated. Before completing the questionnaire, a trained evaluator explained to the children the type of pain they should report. All reported pain was reviewed to discard non-musculoskeletal pain.

Exercise program

Thirty-nine children were assigned as described above to a 13-week exercise intervention group (EG). The exercise program was undertaken at the Sport and Health University Research Institute (iMUDS) (iMUDS – University of Granada) between 1st March and 29th May 2017. Group sessions were run from Monday to Friday, and participants were asked to attend a minimum of three per week. Sessions lasted 90 min and were divided into two different parts: 30

ACCEPTED

Copyright © 2019 by the American College of Sports Medicine. Unauthorized reproduction of this article is prohibited.

min of “movement quality” work and 60 min of “multi-games”. The “movement quality” component had the aims of allowing children to acquire an awareness of analytical movement patterns (e.g., anterior and posterior pelvic tilt) and body posture (e.g., optimal spine position), to gain body segment mobility (e.g., hip flexion mobility) and stability (e.g., core stability), to gain muscular strength over a functional range of motion (e.g., bilateral lower limb push strength), and to learn basic exercise patterns (e.g., squat pattern). The “multi-games” component had the aims of allowing children to reach a moderate-to-vigorous intensity of aerobic exercise, to help them learn a wide range of fundamental movement skills (e.g., sprinting, hopping or throwing), and to make physical exercise more enjoyable. **Figure 2** describes a typical session. Further details of the exercise program are available at (http://profith.ugr.es/pages/investigacion/recursos/mubi?lang=en#__doku_exercise_program). No specific dietary intervention was conducted.

The control group, formed as described above, was comprised of 31 children.

Statistical analysis

Prior to performing the analyses, the data were winsorized to limit the influence of outlier values (23). One of the participants was excluded due to extreme values being returned for all plantar pressure variables. All variables were then checked for normal distribution via the visual inspection of histograms. The plantar surface area, maximum force and force-time integrals for the midfoot, as well as the modified arch index, showed non-normal distributions; the data were therefore square root- or Napierian logarithm-transformed as required. Raw continuous variables were recorded as means and standard deviations (SDs), normalized continuous variables were recorded as medians and interquartile ranges, and categorical variables as percentages.

The pre-intervention differences between the EG and CG participants were examined via

ACCEPTED

Copyright © 2019 by the American College of Sports Medicine. Unauthorized reproduction of this article is prohibited.

independent *t* tests and Chi-squared tests (continuous and categorical variables respectively). The effects of the exercise program were tested according to per-protocol analysis, which required EG participants to complete a minimum 70% of their exercise sessions (23). Pre-intervention z-scores were calculated for each variable for all participants. Post-intervention z-scores were calculated contemplating the pre-intervention z-scores, via the following formula: (subject post-intervention score – sample mean pre-intervention score) / sample pre- intervention SDs. One-way analysis of covariance (ANCOVA) was used to examine differences in anthropometric and plantar pressure outcomes during walking between the EG and CG groups in the post-intervention assessment, adjusting for pre-intervention values. Differences (pre-intervention – post-intervention) in all outcomes were presented as raw scores and z-transformed values; these latter values were interpreted as the change in SD since the pre- intervention period and were used as an indicator of effect size (value around 0.2=small effect size; 0.5=medium effect size; and 0.8=large effect size) (24). Additional confounders such as age, gender, maturational stage, body mass index, foot length and gait speed were included in the ANOVA models but discarded after verifying that they had no influence. Supplementary analyses were conducted using the intention-to-treat principle, which included the whole initial sample of 70 children. Multiple imputation was performed for missing values (23). From this point the intention-to-treat analysis followed the same process as the per-protocol analysis. McNemar's test was used to examine differences in pre- and post-intervention foot pain between the EG and CG groups. All analyses were performed using SPSS software v.24.0. Significance was set at $p<0.050$.

RESULTS

Table 1 shows the pre-intervention characteristics of the entire sample and of the EG and CG groups. The EG participants were older, their weight, height and BMI were higher, and the

ACCEPTED

Copyright © 2019 by the American College of Sports Medicine. Unauthorized reproduction of this article is prohibited.

proportion of girls was higher than in the CG group (all p<0.05). The EG participants also had a greater plantar surface area for the total foot, forefoot, midfoot and rearfoot, and returned higher force-time integrals for beneath the forefoot (all p<0.05).

Table 2 shows the results of the one-way ANCOVA analyses to explore the post-intervention differences between the EG and CG groups, adjusting for pre-intervention values. **Figure 3** provides a schematic overview of the main significant changes in plantar pressure characteristics. Similar anthropometric growth (i.e., weight, height, BMI and foot length) was recorded for both groups after the 13-week intervention period (all p>0.05). Compared to the CG participants, the EG participants showed a significantly smaller increase in plantar surface area (small effect size: -0.25 SDs; p=0.015). The forefoot and midfoot surfaces, as well as the modified arch index, remained unaltered for both groups after the study period (all p>0.05). A border-line difference was seen between the groups after the intervention period in terms of the rearfoot surface area, with the EG participants showing a slightly smaller increase (small effect size: -0.26 SDs; p=0.054). After the intervention period, the EG participants showed a significantly greater increase in maximum force (small effect size: 0.33 SDs; p=0.012) applied beneath the forefoot area, specifically beneath the lateral and medial forefoot than observed for the CG participants (See Figure, Supplemental Digital Content 2, differences in maximum force between EG and CG beneath the three regions of the forefoot, http://links.lww.com/MSS/B762**)**. These significant differences in total plantar surface area and forefoot maximum force results remained significant after adjusting for subject maturational stage (data not shown). No significant differences were seen between the groups for any remaining maximum force variables (all p>0.05). No differences in force-time integrals were seen between the EG and CG participants at the end of the intervention period (p>0.05). Both the EG and CG participants reported reduced foot pain

ACCEPTED

Copyright © 2019 by the American College of Sports Medicine. Unauthorized reproduction of this article is prohibited.

(from 37 and 19% at pre-intervention, to 26 and 7% at post-intervention respectively), although no change was significant (both p>0.05).

Supplemental Digital Content 3 (see Table, effects on plantar pressure in the whole sample, http://links.lww.com/MSS/B763) shows the intention-to-treat analysis. Briefly, all significant results found in the per-protocol analysis disappeared. On the contrary, the increase in the maximum force supported by the EG participants beneath the rearfoot was greater than that observed for the CG participants (p=0.025).

DISCUSSION

By the end of the intervention period, the EG participants showed no significant change in total plantar surface area during walking, whereas the CG participants experienced a significant increase. The maximum force supported beneath the forefoot (specifically beneath the lateral and medial forefoot) increased in the EG participants more than in the CG participants, while the force-time integrals changed similarly in both groups.

To our knowledge, only two previous studies have reported on the effects of exercise interventions on plantar pressures in children with OW/OB during walking (13, 14). Steinberg et al. (14) reported significant reductions in total plantar surface area, maximum force and force-time integrals in children who took part in an obesity management/locomotion-emphasis program, while no reductions were seen among those who took part in obesity management alone. In the present study, no change in plantar surface area was seen for the EG participants, but it increased in the CG participants. It is important to remember that children's feet grow, thus, a reduction in plantar surface area might be deemed unlikely to occur (4). Unlike Steinberg et al. (14), no reduction was seen in maximum force or force-time integrals for the present EG

ACCEPTED

Copyright © 2019 by the American College of Sports Medicine. Unauthorized reproduction of this article is prohibited.

participants; rather, an increase in maximum force was recorded beneath the forefoot. The fact that the exercise program proposed by Steinberg et al. (14) was twice as long as the present intervention might could indicate that longer intervention programs are necessary for force reductions to be detected.

The findings of Riddiford-Harland et al. (13) contrast with those of Steinberg et al. (14); they detected no change in foot anthropometric measurements induced by their exercise program, and an increase in the force-time integrals for the medial and lateral regions of the forefoot in those who followed it (13). In the present work, the force-time integrals increased similarly in both groups, but the change in the maximum force applied beneath the forefoot in the EG participants was greater than that seen in the CG participants. It should be noted that the children examined by Steinberg et al. (14) wore shoes, while those examined by Riddiford-Harland et al. (13), and the present children, were barefoot. Shoe-wearing is known to impact the biomechanics of gait (i.e., impact forces, contact surface and plantar pressure distribution) (25); the present findings are therefore more comparable with those of Riddiford-Harland et al. (13).

A greater plantar surface area has been related to pediatric obesity - partially explained by the greater prevalence of pes planus in this population (4, 26). It is therefore reasonable to assume that the present plantar surface area values for the EG group imply positive changes in the morphology and functionality of their feet (26). This finding cannot be attributed to different foot growth between the groups, since foot length had changed similarly in both the EG and CG groups by the end of the intervention period, suggesting exercise related adaptation to be the cause. Neither can these changes be explained by differences in maturation between the groups, since the results remained similar after taking into account subject maturational stage at pre- and post-intervention.

ACCEPTED

Copyright © 2019 by the American College of Sports Medicine. Unauthorized reproduction of this article is prohibited.

The maximum force increase under the medial and lateral forefoot recorded for the EG participants might indicate a change towards a more normal foot rollover pattern, specifically during the push-off phase during which forces shift from the lateral (5^{th} and 4^{th} metatarsal) to the medial (1^{st} metatarsal and hallux) regions of the forefoot (27, 28). In fact, studies in adults with normal foot functionality during walking reveal that the medial and lateral forefoot are the regions that support the greatest forces; they are therefore the structures best prepared to absorb mechanical stress (28). However, it could also be that the EG participants had begun to acquire a more adult gait pattern. The literature records a shift towards forefoot forces in children with increasing age, and in adults compared to children (4, 29). This increase in maximum force in the EG participants cannot, however, be attributed to changes in anthropometric measures; both groups experienced similar changes in weight, height and BMI.

Some authors have suggested that an increase in the forces supported by the foot while walking - as observed for the forefoot maximum force in the EG participants - could be a risk factor in the development of foot pain (3, 13). However, it has also been suggested that force-time integrals are more important than maximum force when assessing risk factors of foot structural damage, since the former take into account the accumulation of forces being applied in a certain region of the foot over time (30). In this regard, the force-time integrals recorded for both the EG and CG participants had increased similarly by the end of the intervention period, which might be attributable to the natural maturation of their gait (29). The children of both groups reported the presence of less foot pain at post-intervention, although the difference was not statistically significant in either group. It is important to note that children with OW/OB normally experience lower limb pain (e.g., foot pain) during sports or physical activities, and have an injury risk per exposure of >35% (31). The reason underlying the reduced foot pain in the CG participants

ACCEPTED

Copyright © 2019 by the American College of Sports Medicine. Unauthorized reproduction of this article is prohibited.

(though this did not reach significance) might be that the pre-intervention assessment was conducted in February; Spanish children typically practice greater physical activity in February than in July (when the academic year and after-school activities have ended). Interestingly, the EG participants also reported a reduced presence of foot pain prevalence even though the children exercised more intensely during last phase of the intervention. However, the foot pain reported in the present work was mostly mild or moderate, and did not limit the daily physical functioning or physical activity of any subject. Follow-up studies might determine whether physical exercise helps in the prevention of more severe foot pain in children with OW/OB.

A recent systematic review reported that children with OW/OB experience biomechanical (i.e., spatiotemporal, kinetic, kinematic and muscle activation) alterations of the lower limbs that could play a role in the development of musculoskeletal disorders (10). These alterations are commonly connected. For example, foot dysfunctions during walking in children have been shown linked to lower limb malalignment such as dynamic knee valgus (32). The improvement in foot dynamics observed in the EG participants might not, therefore, be occurring in isolation, but in combination with other biomechanical changes. Although the evidence is limited, physical exercise and gastrectomy weight-loss interventions have been shown effective in counteracting the biomechanical malalignments of the lower extremities experienced by children with OW/OB (33, 34). Future research should test whether positive effects of exercise on foot loading patterns are related to other lower limb biomechanical changes (e.g., kinetics or kinematics) in this population group.

Four explanations may be contemplated for the plantar pressure changes induced by the exercise program. The first derives from the logical assumption that any weight-loss induced would reduce the forces supported by the foot while walking (13). This idea must be rejected, however,

ACCEPTED

Copyright © 2019 by the American College of Sports Medicine. Unauthorized reproduction of this article is prohibited.

since neither the EG participants nor the CG experienced any fall in body weight. The second suggests a strengthening of key muscles involved in raising the foot arch, such as the tibialis posterior or flexor hallucis longus (35, 36). The third is related to the "movement quality" work of the session. Performed barefoot, this could have helped in the activation of the flexor digitorum brevis and abductor hallucis muscles, with positive adaptations in the bone and ligament configurations of the foot (35, 36). Finally, there may have been an improvement in the capacity to generate power through explosive tasks (such as jumping or sprinting) performed in the "multigames" work; this could have led to more optimal balance and functioning of the ankle and foot muscles (37). A combination of the last three possibilities would seem the most plausible.

Exercise interventions are an effective treatment for childhood obesity, with positive benefits for the overall health of children (38). The fact that the present intervention improved foot functionality during walking shows that exercise interventions based on "movement quality" and "multigames" may be an effective means of treating dysfunctional foot dynamics in this population. However, caution should be exercised when drawing conclusions; further research is needed if the present results are to be reliably interpreted.

The present findings add to those reported by Riddiford-Harland et al. (13) and Steinberg et al. (14), and provide yet more reasons to promote physical exercise as a means of preventing foot discomfort and pain, especially at this critical stage of life when the feet are still developing (29). Traditionally, in-shoe orthoses have been the most-used conservative treatment for foot dysfunction, but a recent systematic review has highlighted the limited evidence of their effectiveness (39). Future studies should try to confirm whether physical exercise offers an

ACCEPTED

Copyright © 2019 by the American College of Sports Medicine. Unauthorized reproduction of this article is prohibited.

alternative way of preventing - or even reversing - dysfunctional foot dynamics in children with OW/OB, or whether it should be seen as a complementary treatment.

The present work suffers from three main limitations. First, no foot anthropometric measurements were taken via imaging (such as X-ray or magnetic resonance imaging) which would have allowed the impact of the intervention on foot bone structural changes to be determined. Second, the pressure platform used was of medium range resolution, which could have influenced the plantar pressure results. Third, assignment to the EG or CG was ethically determined rather than via a randomization process; consequently, pre-intervention differences between the groups existed. Although these were subject to statistical control (adjustment for the pre-intervention values of the study variables), they may have had some influence on the primary outcomes.

CONCLUSION

This study shows that a 13-week exercise program, based on "movement quality" and "multigames" work, maintained the total plantar pressure surface and increased the maximum force supported beneath the forefoot (specifically beneath the lateral and medial forefoot) in a sample of children with OW/OB. These results suggest the exercise program led to positive functional changes in foot dynamics during walking. However, the increased maximum force supported beneath the forefoot - even though it might indicate a change towards a normal foot rollover pattern and a more mature gait - has the potential to cause foot pain and discomfort. Further work should attempt to confirm whether (and how) physical exercise can used as an effective means of preventing, and even reversing, foot dysfunctions in children with OW/OB.

ACCEPTED

Copyright © 2019 by the American College of Sports Medicine. Unauthorized reproduction of this article is prohibited.

ACKNOWLEDGEMENT

This study was funded by the Spanish Ministry of Economy and Competitiveness/FEDER (DEP2013-47540, DEP2016-79512-R, RYC-2011-09011). JM-G and JHM were funded by the Spanish Ministry of Education, Culture and Sport (FPU14/06837 and FPU15/02645, respectively). IE-C was funded by a grant from the Alicia Koplowitz Foundation. CC-S was funded by a grant from the Spanish Ministry of Economy and Competitiveness (BES-2014-068829). PM-G was funded by a grant from European Union's Horizon 2020 research and innovation program (No 667302). Additional support was obtained from the University of Granada, *Plan Propio de Investigación 2016*, *Excellence actions*: Units of Excellence, Unit of Excellence on Exercise and Health (UCEES); the SAMID III network, RETICS, the PN I+D+I 2017-2021 (Spain), ISCIII- Sub-Directorate General for Research Assessment and Promotion, the European Regional Development Fund (ERDF) (Ref. RD16/0022), and the EXERNET Research Network on Exercise and Health in Special Populations (DEP2005-00046/ACTI). The results of the present study do not constitute endorsement by the American College of Sports Medicine.

CONFLICTS OF INTEREST

None to declare.

ACCEPTED

Copyright © 2019 by the American College of Sports Medicine. Unauthorized reproduction of this article is prohibited.

REFERENCES

1. World Health Organization (WHO) | Obesity data and statistics2019; [cited 2019 Mar 19] Available from: http://www.euro.who.int/en/health-topics/noncommunicable-diseases/obesity/data-and-statistics.

2. Oude Luttikhuis H, Baur L, Jansen H, et al. Interventions for treating obesity in children. *Cochrane Database Syst Rev*. 2009;(1):CD001872.

3. Cousins SD, Morrison SC, Drechsler WI. Foot loading patterns in normal weight, overweight and obese children aged 7 to 11 years. *J Foot Ankle Res*. 2013;6(1):36.

4. Mueller S, Carlsohn A, Mueller J, Baur H, Mayer F. Influence of Obesity on Foot Loading Characteristics in Gait for Children Aged 1 to 12 Years. *PLoS One*. 2016;11(2):e0149924.

5. Yan S, Zhang K, Tan G, Yang J, Liu Z. Effects of obesity on dynamic plantar pressure distribution in Chinese prepubescent children during walking. *Gait Posture*. 2013;37(1):37–42.

6. Butterworth PA, Landorf KB, Gilleard W, Urquhart DM, Menz HB. The association between body composition and foot structure and function: a systematic review. *Obes Rev*. 2014;15(4):348–57.

7. Chang H-W, Chieh H-F, Lin C-J, Su F-C, Tsai M-J. The Relationships between Foot Arch Volumes and Dynamic Plantar Pressure during Midstance of Walking in Preschool Children. *PLoS One*. 2014;9(4):e94535.

8. da Rocha ES, Bratz DTK, Gubert LC, de David A, Carpes FP. Obese children experience higher plantar pressure and lower foot sensitivity than non-obese. *Clin Biomech*. 2014;29(7):822–7.

ACCEPTED

Copyright © 2019 by the American College of Sports Medicine. Unauthorized reproduction of this article is prohibited.

9. Mahaffey R, Morrison SC, Bassett P, Drechsler WI, Cramp MC. The impact of body fat on three dimensional motion of the paediatric foot during walking. *Gait Posture*. 2016;44:155–60.

10. Molina-Garcia P, Migueles JH, Cadenas-Sanchez C, et al. A systematic review on biomechanical characteristics of walking in children and adolescents with overweight/obesity: Possible implications for the development of musculoskeletal disorders. *Obes Rev*. 2019;obr.12848.

11. Tsiros MD, Coates AM, Howe PRC, Grimshaw PN, Buckley JD. Obesity: the new childhood disability? *Obes Rev*. 2011;12(1):26–36.

12. World Health Organization (WHO) | Physical activity and young people*WHO*. 2015; [cited 2019 Mar 19] Available from: https://www.who.int/dietphysicalactivity/factsheet_young_people/en/.

13. Riddiford-Harland DL, Steele JR, Cliff DP, Okely AD, Morgan PJ, Baur LA. Does participation in a physical activity program impact upon the feet of overweight and obese children? *J Sci Med Sport*. 2016;19(1):51–5.

14. Steinberg N, Rubinstein M, Nemet D, et al. Effects of a Program for Improving Biomechanical Characteristics During Walking and Running in Children Who Are Obese. *Pediatr Phys Ther*. 2017;29(4):330–40.

15. Cole TJ, Lobstein T. Extended international (IOTF) body mass index cut-offs for thinness, overweight and obesity. *Pediatr Obes*. 2012;7(4):284–94.

16. Oldfield RC. The assessment and analysis of handedness: the Edinburgh inventory. *Neuropsychologia*. 1971;9(1):97–113.

ACCEPTED

Copyright © 2019 by the American College of Sports Medicine. Unauthorized reproduction of this article is prohibited.

17. Cadenas-Sánchez C, Mora-González J, Migueles JH, et al. An exercise-based randomized controlled trial on brain, cognition, physical health and mental health in overweight/obese children (ActiveBrains project): Rationale, design and methods. *Contemp Clin Trials*. 2016;47:315–24.

18. Moore SA, Mckay HA, Macdonald H, et al. Enhancing a Somatic Maturity Prediction Model. *Med Sci Sport Exerc*. 2015;47(8):1755–64.

19. Bryant Singer, K., & Tinley, P. A. Comparison of the reliability of plantar pressure measurements using the two-step and midgait methods of data collection. *Foot Ankle Int*. 1999;20(10):646–50.

20. McPoil T, Cornwall M, Dupuis L, Cornwell M. Variability of plantar pressure data. A comparison of the two-step and midgait methods. *J Am Podiatr Med Assoc*. 1999;89(10):495–501.

21. Menz HB. Two feet, or one person? Problems associated with statistical analysis of paired data in foot and ankle medicine. *Foot*. 2004;14(1):2–5.

22. Varni JW, Thompson KL, Hanson V. The Varni/Thompson Pediatrie Pain Questionnaire. I. Chronic musculoskeletal pain in juvenile rheumatoid arthritis. *Pain*. 1987;28(1):27–38.

23. Sink KM, Espeland MA, Castro CM, et al. Effect of a 24-month physical activity intervention vs health education on cognitive outcomes in sedentary older adults: The LIFE randomized trial. *JAMA - J Am Med Assoc*. 2015;314(8):781–90.

24. Nakagawa S, Cuthill IC. Effect size, confidence interval and statistical significance: a practical guide for biologists. *Biol Rev*. 2007;82(4):591–605.

ACCEPTED

Copyright © 2019 by the American College of Sports Medicine. Unauthorized reproduction of this article is prohibited.

25. Franklin S, Grey MJ, Heneghan N, Bowen L, Li F-X. Barefoot vs common footwear: A systematic review of the kinematic, kinetic and muscle activity differences during walking. *Gait Posture*. 2015;42(3):230–9.

26. Stolzman S, Irby MB, Callahan AB, Skelton JA. Pes planus and paediatric obesity: a systematic review of the literature. *Clin Obes*. 2015;5(2):52–9.

27. van Deursen R. Mechanical Loading and Off-Loading of the Plantar Surface of the Diabetic Foot. *Clin Infect Dis*. 2004;39(Supplement_2):S87–91.

28. Rai D V, Aggarwal LM. The Study of Plantar Pressure Distribution in Normal and Pathological Foot. *Polish J Med Phys Eng*. 2006;12(1):25–34.

29. Bosch K, Nagel A, Weigend L, Rosenbaum D. From "first" to "last" steps in life – Pressure patterns of three generations. *Clin Biomech*. 2009;24(8):676–81.

30. Bus SA, Waaijman R. The value of reporting pressure–time integral data in addition to peak pressure data in studies on the diabetic foot: A systematic review. *Clin Biomech*. 2013;28(2):117–21.

31. Adams AL, Kessler JI, Deramerian K, et al. Associations between childhood obesity and upper and lower extremity injuries. *Inj Prev*. 2013;19(3):191–7.

32. Kothari A, Dixon PC, Stebbins J, Zavatsky AB, Theologis T. Are flexible flat feet associated with proximal joint problems in children? *Gait Posture*. 2016;45:204–10.

33. Horsak B, Schwab C, Baca A, et al. Effects of a lower extremity exercise program on gait biomechanics and clinical outcomes in children and adolescents with obesity: A randomized controlled trial. *Gait Posture*. 2019;70(February):122–9.

ACCEPTED

Copyright © 2019 by the American College of Sports Medicine. Unauthorized reproduction of this article is prohibited.

34. Summa S, De Peppo F, Petrarca M, et al. Gait changes after weight loss on adolescent with severe obesity after sleeve gastrectomy. *Surg Obes Relat Dis*. 2019;15(3):374–81.

35. Carr JB, Yang S, Lather LA. Pediatric Pes Planus: A State-of-the-Art Review. *Pediatrics*. 2016;137(3):e20151230.

36. Hollander K, de Villiers JE, Sehner S, et al. Growing-up (habitually) barefoot influences the development of foot and arch morphology in children and adolescents. *Sci Rep*. 2017;7(1):8079.

37. Lizis P, Posadzki P, Smith T. Relationship Between Explosive Muscle Strength and Medial Longitudinal Arch of the Foot. *Foot Ankle Int*. 2010;31(9):815–22.

38. García-Hermoso A, Ramírez-Vélez R, Saavedra JM. Exercise, health outcomes, and pædiatric obesity: A systematic review of meta-analyses [Internet]. *J Sci Med Sport*. 2018; available from: https://doi.org/10.1016/j.jsams.2018.07.006. doi:10.1016/j.jsams.2018.07.006.

39. Jane MacKenzie A, Rome K, Evans AM. The Efficacy of Nonsurgical Interventions for Pediatric Flexible Flat Foot. *J Pediatr Orthop*. 2012;32(8):830–4.

ACCEPTED

Copyright © 2019 by the American College of Sports Medicine. Unauthorized reproduction of this article is prohibited.

Figure captions

Figure 1. Flow diagram describing the configuration of the per-protocol and intention-to-treat analyses.

Figure 2. Example of the two parts of the training program.

INT: Integrative neuromuscular training; DNS: dynamic neuromuscular stabilization; FMS: functional movement skills.

Figure 3. Changes (all $p<0.05$) in plantar pressure during walking experienced by the EG and CG participants.

ANCOVA was used to examined the differences in maximum force and contact surface area between EG and CG groups, adjusting for pre-intervention values.

The colored bar provides a qualitative representation of the pressure values, from lower (black-blue) to higher (orange-red) pressure.

ACCEPTED

Copyright © 2019 by the American College of Sports Medicine. Unauthorized reproduction of this article is prohibited.

Table 1. Pre-intervention characteristics of the total sample and divided by intervention and control group for the per-protocol analysis

	All (n=51)	Intervention (n=23)	Control (n=28)	*P*
	Mean ± SD	Mean ± SD	Mean ± SD	
Age (years)	10.8 ± 1.2	11.3 ± 1.0	10.4 ± 1.1	**0.002**
Weight (kg)	57.1 ± 13.2	62.8 ± 9.2	52.4 ± 14.2	**0.004**
Height (cm)	148.0 ± 9.3	151.5 ± 6.7	145.2 ± 10.2	**0.015**
Body mass index (kg/m^2)	25.7 ± 3.8	27.3 ± 3.3	24.4 ± 3.7	**0.005**
Gender				**0.002**
Girls	63%	39%	82%	
Boys	37%	61%	18%	
Dynamic plantar pressure				
Foot length (mm)	222.4 ± 17.3	230.5 ± 13.6	215.7 ± 17.4	**0.002**
Footprint Surface (cm^2)				
Total foot	46.4 ± 10.	51.7 ± 7.1	42.1 ± 10.1	**<0.001**
Forefoot	25.4 ± 5.1	28.2 ± 4.0	23.2 ± 4.8	**<0.001**
Midfoot [a]	2.22 ± 1.26	2.53 ± 1.24	2.07 ± 0.92	**0.019**
Rearfoot	15.8 ± 3.1	17.1 ± 2.5	14.7 ± 3.1	**0.005**
Modified arch index [b]	0.3 ± 0.1	0.3 ± 0.1	0.3 ± 0.1	0.114
Maximal force (N)				
Forefoot	326.9 ± 75.3	347.2 ± 73.0	310.3 ± 74.3	0.082
Midfoot [a]	6.43 ± 4.17	7.87 ± 4.42	5.65 ± 3.78	0.077
Rearfoot	244.6 ± 55.4	256. ± 42.8	235.2 ± 63.3	0.187
Time-force integral (N/s)				
Forefoot	185.8 ± 68.9	217.8 ± 55.1	159.6 ± 68.7	**0.002**
Midfoot [a]	4.46 ± 3.93	5.66 ± 3.93	4.07 ± 2.84	0.066
Rearfoot	144.2 ± 48.7	155.6 ± 46.3	134.9 ± 49.4	0.131
Musculoskeletal pain				
Presence of foot pain *	26%	37%	19%	0.171
Additional confounders				
Peak high velocity (yr)	-1.03 ± 1.14	-1.15 ± 1.14	-0.96 ± 1.16	0.560
Gait speed (km/h)	3.78 ± 0.50	4.06 ± 0.43	3.62 ± 0.55	**0.007**

SD = standard deviation; n=sample size; N = Newton.

[a] Outcome normalized through square root, and expressed in Median ± interquartile range.

[b] Outcome normalized through Neperian logarithm, and expressed in Median ± interquartile range.

* N was 47 (19 exercise group and 28 control group) for presence of foot pain at pre- and post-exercise.

Values are presented as mean ± SD or percentages. For continuous variables, p value was obtained by an independent samples T-test, whereas for categorical variables, p value was obtained by chi-square test. Significant differences ($p < 0.05$) are highlighted in bold.

ACCEPTED

Copyright © 2019 by the American College of Sports Medicine. Unauthorized reproduction of this article is prohibited.

Table 2. Per-protocol intervention effects on plantar pressure.

	Adjusted post-intervention mean (95% CI)			
Total sample = 51	Intervention group (n = 23)	Control group (n = 28)	Groups difference (IG – CG)	*P*
Anthropometry				
Body weight (kg)				
Raw score	59.12 (58.13 to 60.11)	58.23 (57.36 to 59.1)	0.88	0.203
z Score	0.15 (0.08 to 0.23)	0.09 (0.02 to 0.15)	0.07	
Height (cm)				
Raw score	150.91 (150.22 to 151.61)	150.43 (149.82 to 151.04)	0.48	0.315
z Score	0.31 (0.23 to 0.38)	0.26 (0.19 to 0.32)	0.05	
BMI (kg/m^2)				
Raw score	25.59 (25.2 to 25.99)	25.44 (25.1 to 25.79)	0.15	0.593
z Score	-0.04 (-0.14 to 0.07)	-0.08 (-0.17 to 0.02)	0.04	
Foot length (mm)				
Raw score	230.87 (228.84 to 232.91)	231.92 (230.1 to 233.75)	-1.05	0.465
z Score	0.49 (0.37 to 0.61)	0.55 (0.45 to 0.66)	-0.06	
Dynamic plantar pressure				
Surface (cm^2)				
Total foot				
Raw score	53.89 (52.51 to 55.27)	56.36 (55.13 to 57.6)	-2.47	**0.015**
z Score	0.75 (0.61 to 0.89)	0.99 (0.87 to 1117.)	-0.25	
Forefoot				
Raw score	30.07 (28.94 to 31.2)	30.28 (29.28 to 31.29)	-0.21	0.793
z Score	0.91 (0.69 to 1134.)	0.95 (0.76 to 1152.)	-0.04	
Midfoot [a]				
Raw score	2.78 (2.69 to 2.87)	2.86 (2.77 to 2.94)	-0.08	0.239
z Score	0.63 (0.47 to 0.78)	0.73 (0.59 to 0.87)	-0.11	
Rearfoot				
Raw score	17.1 (16.52 to 17.67)	17.88 (17.37 to 18.39)	-0.78	0.054
z Score	0.43 (0.25 to 0.62)	0.69 (0.52 to 0.85)	-0.26	
Modified arch index [b]				
Raw score	0.35 (0.34 to 0.36)	0.36 (0.34 to 0.37)	-0.01	0.437

ACCEPTED

Copyright © 2019 by the American College of Sports Medicine. Unauthorized reproduction of this article is prohibited.

z Score	0.41 (0.26 to 0.56)	0.51 (0.38 to 0.65)	-0.10	
Maximal force (N)				
Forefoot				
Raw score	331.32 (317.36 to 345.27)	306.54 (293.94 to 319.15)	24.78	**0.012**
z Score	0.06 (-0.13 to 0.24)	-0.27 (-0.44 to -0.1)	0.33	
Midfoot [a]				
Raw score	7.83 (7.5 to 8.16)	7.77 (7.47 to 8.07)	0.07	0.774
z Score	0.31 (0.19 to 0.43)	0.27 (0.16 to 0.38)	0.04	
Rearfoot				
Raw score	231.4 (218.8 to 244.)	221.55 (210.15 to 232.95)	9.85	0.254
z Score	-0.24 (-0.47 to -0.01)	-0.42 (-0.62 to -0.21)	0.18	
Force-time integral (N/S)				
Forefoot				
Raw score	229.49 (209.92 to 249.05)	207.6 (190.04 to 225.16)	21.89	0.117
z Score	0.63 (0.35 to 0.92)	0.32 (0.06 to 0.57)	0.32	
Midfoot [a]				
Raw score	6.14 (5.81 to 6.47)	6.11 (5.81 to 6.41)	0.03	0.898
z Score	0.59 (0.36 to 0.82)	0.47 (0.27 to 0.68)	0.12	
Rearfoot				
Raw score	1.76 (1.57 to 1.95)	1.74 (1.57 to 1.91)	0.02	0.865
z Score	0.49 (0.15 to 0.84)	0.17 (-0.14 to 0.49)	0.32	

CI = confidence interval; n=sample size; N=Newton.

[a] Outcome normalized through square root.

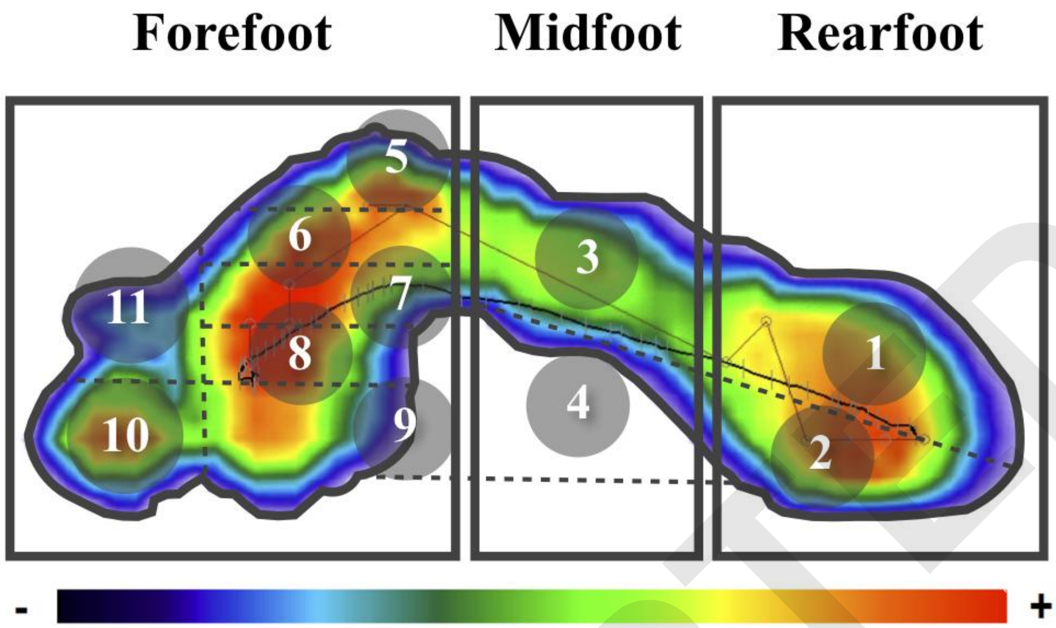
[b] Outcome normalized through Neperian logarithm.

A one-way analysis of covariance (ANCOVA) was used to test raw and z-score differences between the intervention and control group at the post-intervention, adjusting for basic pre-intervention values. Adjusted means and confidence intervals of the mean are represented. Differences between groups are presented as: post-intervention mean minus pre-intervention mean. Significant differences ($p < 0.05$) are highlighted in bold.

ACCEPTED

Copyright © 2019 by the American College of Sports Medicine. Unauthorized reproduction of this article is prohibited.

SDC 1 (Figure). The eleven-region foot division provided by FreeStep® software.



1: lateral rearfoot; 2: medial rearfoot; 3: lateral midfoot; 4: medial midfoot; 5: 5th metatarsal; 6: 4th metatarsal; 7: 3rd metatarsal; 8: 2nd metatarsal; 9: 1st metatarsal; 10: hallux; 11: 2nd to 5th toes.

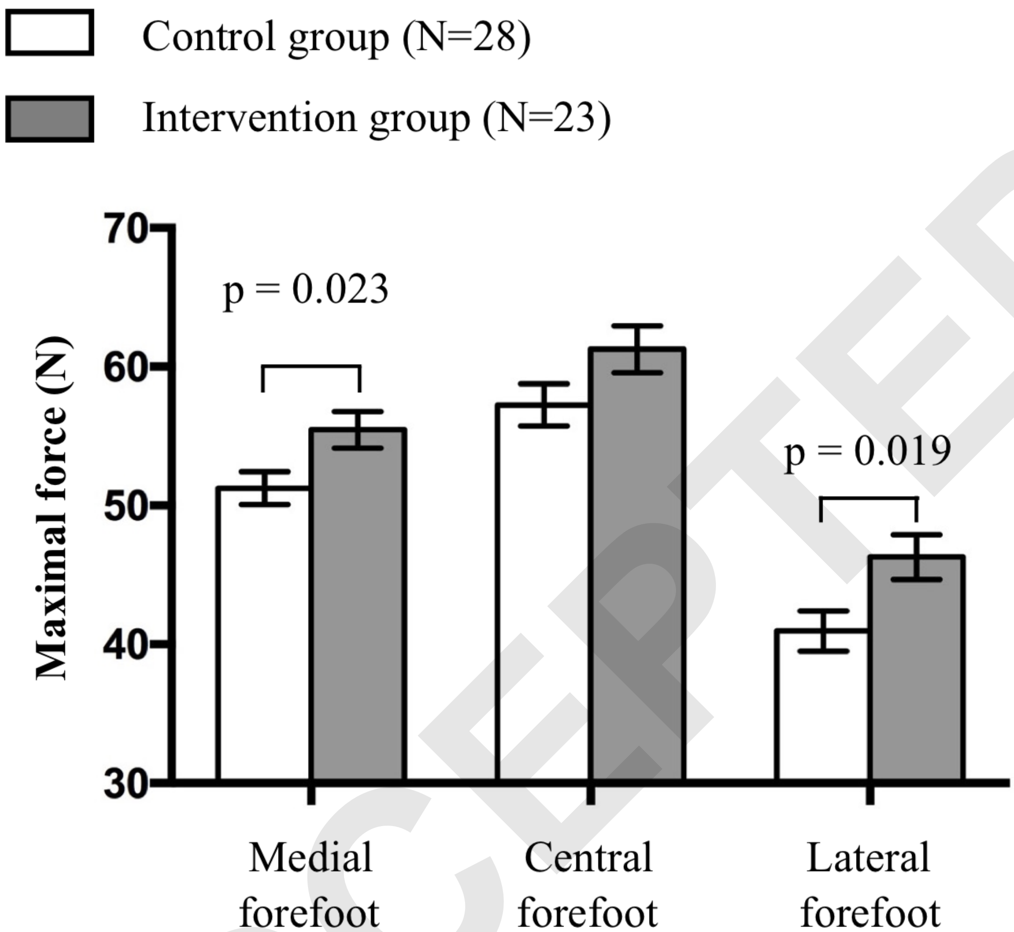
Medial forefoot (1st and 2nd metatarsal), central forefoot (3rd metatarsal) and lateral forefoot (4th and 5th metatarsal).

The colored bar shows a qualitative representation of the pressure values, from lower (black-blue) to higher (orange-red) pressure.

ACCEPTED

Copyright © 2019 by the American College of Sports Medicine. Unauthorized reproduction of this article is prohibited.

SDC 2 (Figure). Differences in maximum force between the intervention and control groups



beneath the three regions of the forefoot.

A one way analysis of covariance (ANCOVA) was used to test differences in maximum force on the three regions of forefoot between intervention and control groups, adjusting for pre-intervention values. Adjusted means and standard error of the mean are represented.

ACCEPTED

Copyright © 2019 by the American College of Sports Medicine. Unauthorized reproduction of this article is prohibited.

Table S1. Intention-to-treat intervention effects on plantar pressure.

	Adjusted post-intervention mean (95% CI)			
Total sample = 70	Intervention group (n = 39)	Control group (n = 31)	Groups difference (IG – CG)	*P*
Anthropometry				
Body weight (kg)				
Raw score	60.27 (58.85 to 61.68)	58.48 (56.88 to 60.08)	1.79	0.109
z Score	0.16 (0.06 to 0.27)	0.03 (-0.10 to 0.15)	0.14	
Height (cm)				
Raw score	151.27 (150.7 to 151.85)	150.94 (150.29 to 151.59)	0.33	0.456
z Score	0.31 (0.25 to 0.38)	0.28 (0.20 to 0.35)	0.04	
BMI (kg/m^2)				
Raw score	26.01 (25.48 to 26.55)	25.42 (24.81 to 26.02)	0.60	0.156
z Score	-0.02 (-0.16 to 0.13)	-0.17 (-0.33 to -0.01)	0.16	
Foot length (mm)				
Raw score	232.21 (230.31 to 234.11)	232.73 (230.58 to 234.88)	-0.52	0.727
z Score	0.52 (0.41 to 0.63)	0.55 (0.42 to 0.68)	-0.03	
Dynamic plantar pressure				
Surface (cm^2)				
Total foot				
Raw score	55.23 (53.72 to 56.74)	55.96 (54.25 to 57.67)	-0.73	0.541
z Score	0.81 (0.65 to 0.96)	0.88 (0.71 to 1.05)	-0.07	
Forefoot				
Raw score	29.8 (28.95 to 30.66)	30.18 (29.2 to 31.15)	-0.37	0.584
z Score	0.86 (0.68 to 1.04)	0.94 (0.74 to 1.14)	-0.08	
Midfoot [a]				
Raw score	2.05 (2. to 2.11)	2.07 (2.01 to 2.13)	-0.01	0.740
z Score	0.56 (0.47 to 0.65)	0.58 (0.48 to 0.68)	-0.02	
Rearfoot				
Raw score	17.63 (17.07 to 18.2)	17.57 (16.94 to 18.21)	0.06	0.891
z Score	0.52 (0.35 to 0.7)	0.50 (0.30 to 0.70)	0.02	
Modified arch index [b]				
Raw score	0.36 (0.35 to 0.37)	0.36 (0.35 to 0.38)	-0.01	0.443
z Score	0.39 (0.27 to 0.51)	0.46 (0.33 to 0.60)	-0.07	

ACCEPTED

Copyright © 2019 by the American College of Sports Medicine. Unauthorized reproduction of this article is prohibited.

Maximal force (N)				
Forefoot				
Raw score	319.99 (309.18 to 330.8)	305.86 (293.7 to 318.01)	14.13	0.091
z Score	-0.09 (-0.24 to 0.06)	-0.29 (-0.46 to -0.12)	0.20	
Midfoot [a]				
Raw score	4.09 (4.01 to 4.17)	4.01 (3.93 to 4.1)	0.08	0.178
z Score	0.34 (0.25 to 0.43)	0.25 (0.16 to 0.35)	0.09	
Rearfoot				
Raw score	233.25 (224.24 to 242.26)	217.61 (207.49 to 227.74)	15.64	**0.025**
z Score	-0.19 (-0.35 to -0.03)	-0.46 (-0.64 to -0.29)	0.27	
Force-time integral (N/S)				
Forefoot				
Raw score	221.85 (206.1 to 237.61)	212.2 (194.38 to 230.02)	9.65	0.437
z Score	0.49 (0.24 to 0.73)	0.34 (0.06 to 0.61)	0.15	
Midfoot [a]				
Raw score	3.56 (3.46 to 3.67)	3.51 (3.4 to 3.63)	0.05	0.526
z Score	0.40 (0.30 to 0.50)	0.35 (0.24 to 0.47)	0.05	
Rearfoot				
Raw score	1.81 (1.66 to 1.96)	1.8 (1.64 to 1.96)	0.01	0.920
z Score	0.54 (0.38 to 0.70)	0.53 (0.35 to 0.71)	0.01	

CI = confidence interval; n=sample size; N=Newton.

[a] Outcome normalized through square root.

[b] Outcome normalized through Neperian logarithm.

A one-way analysis of covariance (ANCOVA) was used to test raw and z-score differences between the intervention and control group at the post-intervention, adjusting for basic pre-intervention values. Adjusted means and confidence intervals of the mean are represented. Differences between groups are presented as: post-intervention mean minus pre-intervention mean. Significant differences ($p < 0.05$) are highlighted in bold.

ACCEPTED

Copyright © 2019 by the American College of Sports Medicine. Unauthorized reproduction of this article is prohibited.