Pressure Pain Threshold is Increased in Young Male Football Players when Using Shock Absorbing Insoles

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We hypothesize lower VAS ratings and a higher pressure pain threshold (PPT) with the use of shock absorbing insoles compared to no insoles for young football players training on artificial turf.

A total of 55 male young football players from AaB football club participated. Participants were block randomized into two groups (with insoles and without insoles). We used pressure algometry and a visual analogue scale (VAS) as methods of measurement of pain. PPT was measured over 13 locations of the plantar foot, leg and lower back on the non-preferred kicking leg. VAS rating included three situations: (1) during activity, (2) at rest, and (3) comfort intensity. Assessments were made before and after three weeks when using polyurethane gel shock absorbing insoles while training on artificial turf. We found that the usage of shock absorbing insoles caused a tendency for improvement of comfort intensity by 0.8cm (P=0.053) on a VAS. The shock absorbing insoles caused a significant reduction in pain. VAS ratings decreased by 1cm (P=0.012) for "during activity" and 0.8cm (P=0.027) "at rest" after the intervention within the groups with insoles. The average PPT increased significantly by 58kPa (P=0.046) after the intervention for the group with insoles. Moreover, three specific measurement points had a significant increase in PPT by the use of insoles; erector spinae muscle 126kPa (P<0.001), tibialis anterior muscle 89kPa (P=0.014) and metatarsal bone 5 (head) 68kPa (P=0.049).

In conclusion we found a reduction of pain intensity and sensitivity in young football players when using shock absorbing insoles for three weeks on artificial turf.

Introduction

The game of football among other things depends on the ability to perform a high number of sprints and cutting movements. The demands for explosive strength, speed, high intensity exercise, endurance, and coordination are high for football players. These demands for football players' physical abilities can cause muscular pain and several types of injuries [Bangsbo et al. 2006]. Complications relating to muscular pain typically manifest in the lower extremities for football players because the workload peaks occur in these areas [Eils et al. 2004, Krustrup et al. 2011]. The intensity and duration of activity affect the degree of muscular pain [Cheung et al. 2003]. Factors such as intensity and duration are difficult to downgrade because the training volume amongst football players is often at a maximum physical level. The players' contact with the playing surface is an adjustable parameter related to developing of muscular pain. The surfaces for football players are constantly improved, and artificial surfaces are becoming more common for new football fields. Compared to natural turf, the usage of third-generation artificial turf has the benefit of not being affected by weather conditions. Unlike natural turf, the hardness of artificial turf does not change significantly by changes in temperature and rain [Orchard, 2002; Stiles et al., 2009]. Third generation artificial turf is an approved surface by the Danish Football Union to play league matches for the 2012-13 season. The development of existing third generation artificial turf, has resulted in a reduction of muscular injuries compared to natural turf [Ekstrand et al. 2006, 2011a, 2011b; Meyers et al. 2010; Soligard et al. 2010]. Ekstrand et al. [2011b] and Dominguez-Martin et al. [2012] find pain sensitivity by assessment of pressure algometry to be reduced when playing on third generation artificial turf compared to natural turf.

Cheung et al. [2003] have shown that there is a relationship between contact to the playing surface and developing delayed onset muscle soreness (DOMS) and overuse injuries. Muscular pain as DOMS is defined as sensitivity changes in muscular tissue and around the painful area [Fernandez et al. 2010; Kawczynski et al. 2011, Svensson et al. 1995]. Furthermore, Armstrong et al. [1993] have shown that there is a direct correlation between eccentric muscle work and the development of DOMS. Interestingly football players' game play depends on continuous sprint and cuttings which result in repeated surface contact.

The usage of insoles and their function in relation to muscular pain are the essence of this project. Several studies have investigated the relationship between muscular pain and insoles. The fundamentals of optimal insoles are; function of reducing muscle activity, comfortable feeling, and improved performance [Nigg et. al. 1999]. Madeleine et al. [1998] find that the usage of a polyurethane mat for standing work tasks contra on a hard surface reduces muscle activity in lower extremity. Interestingly Cheung et al. [2003] detect that a decrease in the magnitude of shocks from the surface will reduce the eccentric muscle activity. Furthermore, it is emphasized that eccentric muscle activity reduces the development of DOMS, and thereby lowers the sensitivity of the nociceptors [Itoh et al. 2002]. This indicates that reduced eccentric muscle activity can in turn result in lower risk of muscular pain.

Insoles are often used as equipments for absorption of shocks from the surface. Faunø et al. [1993] find that the use of shock absorbing insoles in the heel region reduces football referees' number of pain complaints in the lower extremities. Shock absorbing insoles have a reducing effect of peak pressure at the heel (37%) and the forefoot (24%) in military personnel after long distance running [House et al. 2002]. Madeleine et al. [1998] find that working on a shock absorbing mat lowered pain intensity for experimentally induced pain by the Visual Analog Scale (VAS) rating assessment method. A conducted pilot study indicates that the usage of polyurethane gel shock absorbing insoles has a reducing effect of muscular pain amongst young football players in relation to training on artificial turf [Kaalund et al. 2011]. Their assessment is restricted to VAS, and they have no control group. However, to the best of our knowledge, there have been no other reports than the subjective method of VAS rating for assessment regarding the effect when using shock absorbing insoles for young football players. Therefore, to investigate the effect of using shock absorbing insoles on muscular pain, we used pressure algometry and VAS rating as methods of measurement. Pressure algometry is defined as a valid measuring technique for pain sensitivity of deep somatic structures. The sensation of pain is the result of stimulation of nocieptive nerve endings in deeper tissues, such as deep somatic structures [Fischer, 1987a; 1987b; 1990]. Pressure pain threshold (PPT) is defined as the amount of pressure where a sense of pressure changes to a feeling of pain [Vanderween et al. 1996]. The reliability is to be good within the same day [Potter et al. 2008; Nussbaum et al. 1998], and between days [Potter et al. 2008; Nussbaum et al. 1998; Jones et al. 2007; Ylinen et al. 2007]. Chesterson et al. [2007] find the reliability of measurement between examiners to be high.

We hypothesize lower VAS ratings and a higher PPT with the use of shock absorbing insoles compared to no insoles for young football players training on artificial turf.

Method

The population of the study included a total of 72 male adolescent players from the Danish elite football club AaB U15, U17 and U19 teams (14-18 years of age). Subject anthropometrics are showed in Table 1. The participants were asked to fill out a questionnaire regarding personal information in combination with the first measuring period. The inclusion criteria for participation in this study were; (1) field players (i.e., no goalkeepers), (2) they must be able to fully participate in practice and have experience in training on artificial turf (3) no prior leg or foot surgery, (4) have no medical condition that could influence muscle soreness and pain, (5) cannot be in a psychological state that would not allow them to participate, (6) be able to read and write in Danish, (7) no steroid injections for the last 12 weeks. A signed consent form was obtained for participants under the age of 18 years. The informed consent was in relation to an agreement of the protocol to this study. In relation to the consent, participants and their parents were given written and verbal information about the study, and it was emphasized that participation was voluntary. Participants could withdraw at any time from the study. The study was conducted according to the rules of the Helsinki Declaration and was approved by the local ethical committee (N-20100084).

<u>Experimental Protocol</u>

The experimental design was restricted to the club policy regarding a surface switch from natural turf to artificial turf and the beginning of the season's winter break (between October 11 and December 6, 2011). In case of adaptations to the change in playing surface, participants trained on the artificial turf for approximately three weeks prior to the first measuring period. In combination with the first measuring period, participants were randomized into two groups (with insoles and without insoles) according to the principles of block randomization. The measurements took place from November 1 to December 6, 2011. The intervention period was approximately three weeks. The protocol for experimental design is shown in figure 1.

<u>Materials</u>

Polyurethane shock absorbing insoles (Rehband Technogel® 93430, Otto Bock Scandinavia, 60114 Norrköping, Sverige) were used. All participants used their preferred football shoes during training on artificial turf.

Artificial turf is a steady parameter compared to natural turf regarding weather conditions and hardness, as well the shock absorbing ability. Therefore, artificial turf was the preferred surface for investigations of shock absorbing insoles. The artificial turf in this study was placed on AaB A/S training facilities (Hornevej 2, 9220 Aalborg, Denmark). The artificial turf (Polytan Ligaturf 260, Polytan Sportstättenbau GMbH, D-86666 Burgheim, Germany) was third generation turf, settled in 2005, and maintained every second year in accordance with the FIFA Quality.

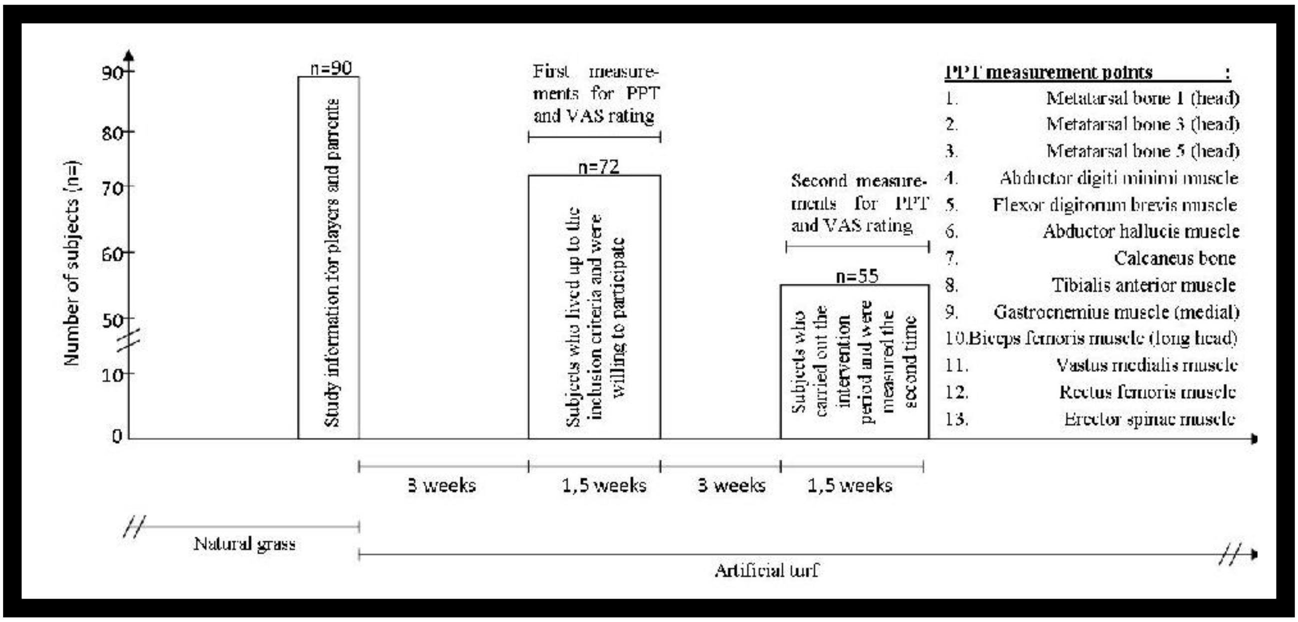

Figure 1: The x axis shows the whole time of the study. The y axis indicates the number of participants (change also in the figure) that completed the given procedure in the study. The first measurement period processed from November 1-11, 2011 and the second measurement period was from November 28 to December 6, 2011. 90 participants took part in the information meeting. 72 participants were available to attend the study and fulfilled the inclusion criteria. Between the two measurement periods, 17 participants dropped out (see Table 2). A total of 55 participants (23 in group with insoles and 32 in group with no soles) were available for the second measurement. VAS was rated (1) during activity, (2) at rest, and (3) comfort intensity. 13 PPT measurement points were chosen on the non-preferred kicking leg, respectively plantar foot (1-7), lower leg (8, 9) upper leg (10-12) and lower back (13).

Type II pressure algometers (Somedic Production AB, S-192 05 Sollentuna, Sweden), with a $1cm^2$ wide rubber tip, were used for the PPT measurements. The handheld electronic pressure algometer was calibrated with manufacturer instructions prior to each data collection day. The pressure algometer was pressed perpendicularly to a marked point on the skin with a constant slope of 30 kPa/s. The algometer has a wire connecting to a stop button. When the button was pressed, the pressure value was instantly frozen.

The non-preferred kicking leg and the ipsilateral lower back were chosen for measuring PPT because Ekstrand et al. [2011b] find a higher risk of muscle injuries in the preferred kicking leg, and a particular risk of quadriceps strains. Therefore, the influence of the PPT measurements was minimized. Markings on muscular measurement points were on the muscle belly. Three non-recorded measurements were performed on the subject's shoulder and neck to secure that the subject understood the procedure of pressure algometry. The 13 points were measured in a similar sequence. Each point was measured twice over two rounds. Approximately 7.5 minutes separated the first and second measuring for each point to avoid temporal summation [Nie et al. 2009; Binderup et al. 2010b]. Measurements took place within two hours following a normal training session. The mean value of the two PPT measurements at each point was used for statistical processing.

Three test pair teams with two examiners were equipped with a pressure algometer. Examiner 1 identified the measurement points and marked the participants by following the internal test protocol. Examiner 2 informed the participants about how to act during the PPT measurements, and executed these in a quiet room. Examiners were blinded regarding groups (with insoles / without insoles). Examiners were instructed not to give information about recorded data to the participants. To minimize examiner effects, recorded PPT values from first measuring period were unavailable for examiners at the second measuring period.

Participants were given a description of how to act during the PPT measurements. The following phrase was said: "*You are about to be exposed to 29 PPT measurements executed with a pressure algometer. At the first sense of change from pressure to pain, you shall press the button that fixes the value for data registration.*" Similar instructions to participants in PPT studies have previously been used [Binderup et al. 2010a, Andersen et al. 2006].

In combination with the PPT measuring, the participants were asked to rate their pain intensity on a VAS. This included three situations: (1) during activity, (2) at rest, and (3) comfort intensity. The VAS was ranged from 0cm ("no pain") to 10cm ("worst thinkable pain").

Statistical Analysis

The statistical power was calculated as 0.83 (G*Power 3.1.3, Franz Faul, Kiel University, Germany) and considered acceptable [Cohen 1992].

Results are expressed as means ± standard deviation for PPT and VAS. Analysis of variance (ANOVA) and repeated measures ANOVA tests were used for multiple comparisons for PPT and VAS. Post-hoc tests were performed with the Bonferroni t-test. Data violating the Shapiro-Wilk test for normality of distribution were corrected with the square root to achieve a normal distribution.

The statistical analyses were conducted with a confidence interval of 95%. Data is presented with F and p values and a p value < 0.05 was considered statistically significant. All statistical calculations were performed with Sigmaplot 12.2 (Systat Software Inc., 1735 Techno Drive, San Jose, USA).

Results

Table 1 Subject anthropometrics

	Numbers (n)	Age (years)	Weight (kg)	Height (cm)	BMI (index)
Group Insoles	23	15.9±1.6	65.5±10.5	177.5±8.4	20.6±2
Group No insoles	32	15.9±1.4	67.3±9.6	176.5±8.3	21.5±1.8

Table 1: Distribution for the two test groups, and anthropometric data of the participants who completed the experimental part of the study. 17 participants dropped out during the study.

Table 2 Dropouts during the study

Numbers (n)	Reason for dropout
1	Been active for less than a week
1	Due discomfort with using the insoles
3	Club transfer
3	Noshow for post measuring
4	Injured / sickness
5	The cause is not known

Table 2: Reasons for dropouts. 13 participants dropped out of the group with insoles, while four participants dropped out of the group without insoles.

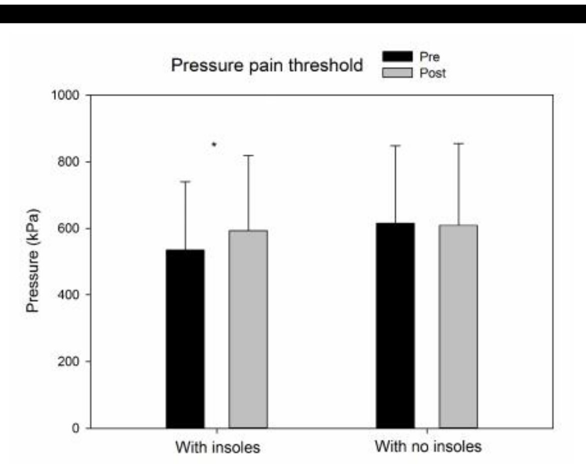

Figure 2: The x axis shows the two within pre and post measurements. The y axis shows pressure (kPa). * indicates a significant difference for the group with insoles (P=0.046) before and after three weeks of training with insoles.

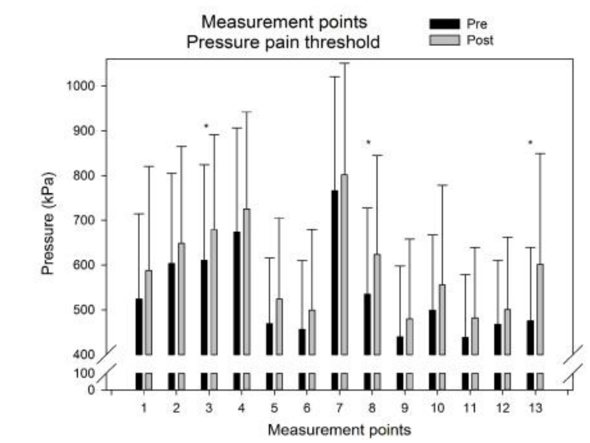

Figure 3: The x axis shows the within the 13 measurement points. The y axis shows pressure (kPa). * indicate a significant difference for metatarsal bone 5 (head) (P=0.049), tibialis anterior (P=0.014), and erector spinae (P<0.001) after three weeks of training with insoles.

The One Way ANOVA showed significant spatial difference in PPT with data from both groups' pre measurements, and the group without insoles post measurements (F=32.827, P<0.001). Post-hoc analysis showed significantly higher PPT for non-muscular measurement points on plantar foot for calcaneus (805±249kPa) compared with metatarsal bone (head) 1 (617±247kPa; P<0.001), metatarsal bone (head) 3 (679±229kPa; P<0.001), and metatarsal bone (head) 5 (706±240kPa; P=0.005). Furthermore, the post-hoc analyses showed significantly higher PPT for the muscular measurement points on the plantar foot for abductor digiti minimi muscle (721±236kPa) compared with flextor digitorum brevis muscle (537±197kPa; P<0.001) and abductor hallucis muscle (721±236kPa; P<0.001). Leg post-hoc analyses, significantly higher PPT was found for tibialis anterior muscle (611±217kPa) compared with gastrocnemius muscle (medial) (495±188kPa; P<0.001), vastus medialis muscle (481±173kPa; P<0.001), and rectus femoris muscle (551±208kPa; P<0.001).

A two-way repeated measures ANOVA was used to determine changes in PPT in usages of insoles. Significant effects within measurement points for the group with insoles were found (F=40.020, P<0.001). Furthermore, there was a significant difference between pre measurements (535±205kPa) and post measurements (593±226kPa) (F=4.486, P=0.046), see Figure 2. Post-hoc analyses showed a significant effect for metatarsal bone 1 (head) pre (611±213kPa) and post (679±212kPa; P=0.049), tibialis anterior muscle pre (535±193kPa) and post (624±221kPa; P=0.014), erector spinae muscle pre (475±164kPa) and post (601±248kPa; P<0.001), see Figure 3. For the group without insoles, no significant effect was found for pre (615±233kPa) and post (609±246kPa) measurements, see Figure 2.

For the comfort intensity, the one-way repeated measures ANOVA showed a tendency of a lower VAS rating for the group who used insoles - pre(2.2±1.8), post1.4±1.3) (F=4.244, P=0.0.53.).

The two-way repeated measures ANOVA was used for pain intensity and showed a significant difference within measuring period, within the group with insoles (F=7.594, P=0.012). Post-hoc analyses showed a significant effect for “during activity” - pre(2.0±1.6), post(1.0±1.1) (P=0.012) and “at rest” - pre(18±1.8), post(1.0±1.3) (P=0.027) see figure 4.

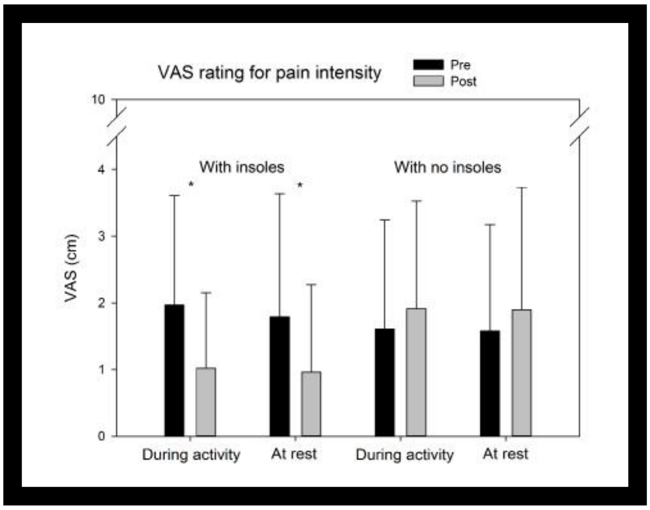

Figure 4: The x axis is the situation of VAS rating. The y axis is the Visual Analog Scale (cm). * indicate a significant difference in pain intensity for “during activity” (P=0.012) and “at rest” (P=0.027) after three weeks of training with insoles.

Discussion

We found that the usage of shock absorbing insoles caused a tendency for enhanced comfort intensity as well as a significant reduction in pain. during physical activity and at rest. These changes in comfort and pain perception were associated with higher PPT after using shock absorbing insoles for three weeks. More specifically, the PPTs of the erector spinae muscle, tibialis anterior muscle and metatarsal bone 5 increased significantly underling important changes in pain sensitivity after three weeks of insoles usage.

Spatial Differences in PPT

We found that the spatial differences in PPT are consistent with previous studies on the plantar surface of the foot. For the non-muscular points, the calcaneus has a significantly higher PPT compared to metatarsal bone (head) 1, metatarsal bone (head) 3 and metatarsal bone (head) 5 [Xiong et al. 2011]. For the muscular points on the plantar surface of foot, the abductor digiti minimi muscle was significantly less sensitive compared to the flexor digitorum brevis and abductor hallucis muscles, which is also consistent with the findings of Xiong et al. [2011]. The calcaneus had a significantly higher PPT compared to the other measurement points on the plantar surface of the foot, which is in line with studies of Xiong et al. [2011] and Messing et al. [2001]. Swedish retail workers PPT on the plantar surface of the foot is investigated by Messing et al. [2001]. Higher loading patterns for football players performing sprint and cutting movements are detected on the forefoot compared to the heel [Ford et al. 2006]. Eils et al. [2004] find that the plantar forefoot is the most loaded region during sprinting, and the central part of the foot is the most loaded region during cutting movements, compared with the heel. The lower loading pattern for the heel region is in agreement with our result of higher PPT for calcaneus. Furthermore, non-muscular points are less sensitive to mechanical pressure than muscular points [Andersen et al. 2006].

In between the measurement points on the lower extremity there was a significant difference. The tibialis anterior had a significantly higher PPT compared to the gastrocnemius (medial), vastus medialis, and rectus femoris muscles. These results are in agreement with the study of Dominguez-Martin et al. [2012].

The spatial differences in mechanical pain sensitivity can be explained by a different perspective. The tissue thickness can affect the difference in PPT [Andersen et al. 2006]. Moreover, the underlying bone structures in relation to musculo-tendinous junctions can also cause higher PPT levels due to increased tissue hardness. Another explanation can be the differences in the density of group III and IV afferents among the muscle belly [Andres et al. 1985].

The Short Time Effects of Insoles on Comfort, Pain Intensity and Sensitivity

Comfort intensity showed a tendency for improvement by 36% during the usage of polyurethane gel insoles. This result was in agreement with Madeleine et al. [1998]. No decrease in comfort intensity was of most importance, and the tendency of higher comfort intensity indicates that the insoles are functional. Nigg et al. [1999] states that an optimal insole feels comfortable, which was the case in our study. Biomechanical and ergonomical differences affect comfortable perception [Mündermann et al. 2001]. Still, biomechanical and ergonomical issues may have had an influence on our study, even though the majority of the participants were comfortable. One participant left the study for reason of pain caused by usage of the insoles. However, it should be noted that a total of eight players were no-shows and dropped out for unknown reasons. The majority of dropouts were found in the group with insoles, and this could lead to speculation that the insoles caused these dropouts. Still, the overall tendency by the usage of insoles was increased comfort intensity. Despite the positive tendency of comfort, this specific insole may not fit all foot types.

We found that the usage of shock absorbing insoles caused a significant reduction of pain intensity. VAS ratings decreased by 50% for "during activity" and 44% "at rest" after the intervention within the groups with insoles. These results are consistent with VAS results of Kaalund et al. [2011] and Madeleine et al. [1998], who also investigate the shock absorbing material of polyurethane gel. Our VAS ratings were in accordance with the PPT results. The average PPT increased significantly by 11% after the intervention for the group with insoles. Increased PPT was found for all measurement points on the plantar surface of the foot, leg and lower back. This result was of vast importance because an overall increase in PPT could be the result of variance between increased and decreased PPT for the 13 measurement points. A measurement point with decreased PPT will be an indication of increased muscular pain by wearing insoles, which is an unacceptable outcome. A distribution of increased PPT and decreased PPT could be directed to change the pressure distribution. Che et al. [1993] found that a change of pressure distribution in regions of the plantar surface of the foot can result in lower comfort.

Metatarsal bone 5 (head) had a significant increase of 11% in PPT when using insoles. Orendurff et al. [2008] find that metatarsal bone 5 is exposed to an increase of peak pressure during cuttings for male college athletes on artificial turf. There could be a relation between shock absorbing insoles and lower peak pressure on metatarsal bone 5. To conclude further investigations are needed.

A significant increase of 17% in PPT was found for tibialis anterior muscle. To the authors' knowledge there is not reported any similar results or particular issues for tibialis anterior muscle for football players or athletes. More investigations are needed to evidence the importance of this result. Studies found that shock absorbing insoles have an effect on tibialis stress syndrome. Schwellnus et al. [1990] find that the shock absorbing insoles have a preventing effect of overuse injuries in tibialis stress syndrome for military personnel. Jones et al. [2002] find that absorbing insoles have a preventing effect for athletes and soldiers for tibialis stress syndrome. A speculation between higher PPT and lower risk of tibialis stress syndrome could lead to further investigations.

Erector spinae muscle had a significant increase in PPT by the usage of insoles (27%). This result was in accordance with Faunø et al. [1993], who find a reduction in pain intensity in lower back for football referees by the usage of shock absorbing insoles in heel region. Aoki et al. [2010] and Soligard et al. [2010] show that the pain complaints in the lower back are common for young football players playing on artificial turf. The increased use of new artificial turfs arises speculation that lower back pain issue will be at rising problem for young football players. Shock absorbing insoles could be useful in relation to the prevention of lower back pain.

Several studies have shown to have a reducing effect on pain intensity by the usage of shock absorbing insoles. Faunø et al. [1993] find a reduction in pain intensity of the calf, thigh and lower back. House et al. [2002] detect that the insoles reduce peak pressure of the plantar surface of the foot. The uses of a polyurethane mat decrease pain intensity for experimentally induced pain and reduce muscle activity in the lower extremities [Madeleine et al. 1998].

Interestingly, Cheung et al. [2003] detect that a decrease in the magnitude of shocks from the surface up through the lower extremities would reduce eccentric muscle activity. Eccentric muscle activity affects the magnitude of DOMS [Armstrong, et al. 1993]. Therefore, lower eccentric muscle activity could be related to a decrease in risk of muscular injuries. Itoh et al. [2002] find that lower eccentric muscle activity reduces the development of DOMS, thereby lowering the sensitivity of nociceptors. Lower pain sensitivity indicates a higher PPT and lower pain intensity (VAS) as found in our study.

We found a higher average PPT (58kPa) with the usage of the insoles. To determine the changes in PPT as clinically relevant, the values should be approx. equal or higher than 150kPa in healthy humans [Chesterson et al. 2007; Fischer 1987]. The restricted time period for our study applies to short term effect on muscular pain when using the insoles. Clinical significance in PPT may be achieved with a longer intervention period. Considering pain intensity, clinical significance was achieved and we observed an overall a decrease of 0.9cm. According to Kelly [2001] and Powell et al. [2001], approximately 1 cm changes are of clinical significance for young and adult humans.

Limitations

The PPT limit was set to 1000kPa for protection against tissue damage of the participants. The 1000kPa limit was achieved more than the 0kPa limit. VAS 0 “no pain” limit was achieved more than 10 “worst thinkable pain”. It would be unlikely that one would be able to complete football training and mark their perception of pain intensity at 10 "worst thinkable pain". Data was non-normally distributed for spatial difference in PPT and VAS for the group without insoles. This increased the risk of type II error when using parametric tests. We have limited our discussion to the interpretation of the sole significant differences. The group with insoles had a lower mean PPT than the group without insoles before the intervention. This was most likely a coincidence resulting from the block randomization process.

The experimental design did not allow a double blinded placebo-controlled process. As such the statistical power would have been too low (three groups with the same number of players). Further Investigations of shock absorbing insoles on pain sensitivity for football players would be of value for an understanding the long-term effects of insoles.

In conclusion the use of shock absorbing insoles for a period of three weeks caused a reduction of pain intensity and sensitivity among young football players when training on artificial turf. We found that shock absorbing insoles can be helpful in reducing pain, highlighted with an increase in PPT and a decrease in pain intensity.

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References

Andersen H., Arendt-Nielsen L., Danneskiold-Samsøe B., Graven-Nielsen T., **Pressure pain sensitivity and hardness along human normal and sensitized muscle**, Somatosensory and Motor Research, 23, 4, 97–109, **2006**.

Andres K.H., von Düring M., Schmidt R.F., **Sensory innervation of the achilles tendon by group III and IV afferent fibers**, Anatomy and Embryologi, 172, 2, 145-156, **1985**.

Aoki H., Kohno T., Fujiya H., Kato H., Yatabe K., Morikawa T., Seki J., **Incidence of injury among adolescent soccer players: a comparative study of artificial and natural grass turfs**, Clinical Journal of Sport Medicine, 20, 1, 1–7, **2010**.

Armstrong R.B., Warren III G.L., **Strain-induced skeletal muscle fibre injury. In: Macleod D, editor, Intermittent high intensity exercise: preparation stresses and damage limitation**, London E & FN Spon, 275-285, **1993**.

Bangbo J., Mohr M., Poulsen A., Perez-Gomez J., Krustrup P., **Training and testing the elite athlete**, Journal of Exercise and Fitness, 4,1, **2006**.

Binderup A.T., Arendt-Nielsen L., Madeleine P., **Pressure pain sensitivity maps of the neck – shoulder and the low back regions in men and women**, BMC Musculoskeletal Disorders,11, 234, **2010a**.

Binderup A.T., Arendt-Nielsen L., Madeleine P., **Pressure pain threshold mapping of the trapezius muscle reveals heterogeneity in the distribution of muscular hyperalgesia after eccentric exercise**, European Journal of Pain, 14, 705-712, **2010b**.

Che H., Nigg B.M., Koning J.D., **Relationship between plantar pressure distribution under the foot and insole comfort**, Clinical Biomechanics, 9, 6, 335-341, **1993**.

Chesterson L.S, Sim J., Wright C.C, Foster N.E., **Interrater reliability of algometry in measuring pressure pain thresholds in healthy humans, using multiple raters**, The Clinical Journal of Pain, 23, 760–766, **2007**.

Cheung K., Hume P., Maxwell L., **Delayed onset muscle soreness - treatment strategies and performance factors**, Sports Medicine, 33, 2, 145-164, **2003**.

Domínguez-Martín M.A., López-Ruiz F., Reyes-López M.V., Valenza G., Fernández-de-las-Peñas C., Madeleine P., **Differences in pressure pain sensitivity of elite male football players on artificial turf and natural grass**, (Personal communication), **2012**.

Eils E., Streyl M., Linnenbecker S., Thorwesten L., Volker K., Rosenbaum D., **Characteristic plantar pressure distribution patterns during soccer-specific movements**, American Journal of Sports Medicine, 32, 1, 140-145, **2004**.

Ekstrand J., Timpka T., Hägglund M., **Risk of injury in elite football played on artificial turf versus natural grass: a prospective two-cohort study**, British of Journal Sports Medicine, 40, 975-980, **2006**.

Ekstrand J., Hägglund M., Fuller CW., **Comparison of injuries sustained on artificial turf and grass by male and female elite football players**, Scandinavian Journal of Medicine and Science in Sports, 21, 6, 824-832, **2011a**.

Ekstrand J., Hägglund M., Waldén M., **Epidemiology of muscle injuries in professional football (soccer)**, American Journal of Sports Medicine, 39, 1226-1231, **2011b**.

Faunø P., Kaalund S., Andreasen I., Jørgensen U., **Soreness in lower extremities and back is reduced by use of shock absorbing heel inserts**, International Journal of Sports Medicine, 14, 5, 288-290, **1993**.

Fernandez-Carnero J., Binderup A.T., Ge H.Y., Fernandez-De-Las-Penas C., Arendt-Nielsen L., Madeleine P., **Pressure pain sensitivity mapping in experimentally induced lateral epicondylalgia**, Medicine and Science in Sports and Exercise, 42, 922-927, **2010**.

Fischer A., **Pressure threshold measurement for diagnosis of myofascialpain and evaluation of treatment results**, Clinical Journal of Pain, 2, 207-214, **1987a**.

Fischer A., **Pressure algometry over normal muscles: standard values, validity and reproducibility**, Journal of Pain, 30, 115-126, **1987b**.

Fischer A., **Application of pressure algometry in manual medicine**, Journal of Manual Medicine, 5, 4,145-150, **1990**.

Ford K.R., Manson A.N., Evans B.J., Myer G.D., Gwin R.C., Heidt R.S. Jr., Hewetta T.E., **Comparison of inshoe foot loading patterns on natural grass and synthetic turf**, Journal of Science and Medicine in Sport, 9, 433 - 440, **2006**.
House C.M., Waterworth C., Allsopp A.J., Dixon S.J., **The influence of simulated wear upon the abililty of insoles to reduce peak pressures during running when wearing military boots**, Gait & Posture, 16, 3, 297-303, **2002**.
Itoh K., Kawakita K., **Effect of indomethacin on the development of eccentric-induced localized sensitive region in fascia of the rabbit**, The Japanese Journal of Physiology, 52, 2, 173-180, **2002**.
Jones B.H., Thacker S.B., Gilchrist J., Kimsey C.D., Sosin D.M., **Prevention of lower extremity stress fractures in athletes and soldiers: A systematic review**, Epidemiologic Reviews, 24, 2, **2002**.
Jones D.H., Kilgour R.D., Comtois A.S., **Test-retest reliability of pressure pain threshold measurements of the upper leg and torso in young healthy women**, The Journal of Pain, 8, 650-656, **2007**.
Kaalund S., Faunø P., Olsen S.S., Olesen C.G., **Pain reduction by using Insoles when playing soccer on artificial turf**, Dansk Idræts Medicinsk Årsmøde, Odense, Denmark, **2011**.
Kawczynski A., Samani A., Fernandez-de-las-Penas C., Chmura J., Madeleine P., **Sensory mapping of the upper trapezius muscle in relation to consecutive sessions of eccentric exercise**, Journal of Strength and Conditioning Reseach, 0, 0, 1-7, **2011**.
Kelly A.M., **The minimum clinically significant difference in visual analogue scale pain score does not differ with severity of pain**, Emergency Medicine Journal, 18, 205–207, **2001**.
Krustrup P., Ørtenblad N., Nielsen J., Nybo L., Gunnarsson T.P., Iaia F.M., Madsen K., Stephens F., Greenhaff P., Bangsbo J., **Maximal voluntary contraction force, SR function and glycogen resynthesis during the first 72 h after a high-level competitive soccer game**, European Journal of Applied Physiology, 111, 2987–2995, **2011**.
Madeleine P., Lundager B., Voigt M., Arendt-Nielsen L., **Sensory manifestations in experimental and work-related chronic neck-shoulder pain**. European Journal of Pain, 2, 251 - 260, **1998**.
Messing K., Kilblom Å., **Standing and very slow walking: foot pain-pressure threshold, subjective pain experience and work activity**, Applied Ergonomics, 32, 81-90, **2001**.
Meyers M.C., **Incidence, mechanisms, and severity of game-related college football injuries on FieldTurf versus natural grass - A 3-Year Prospective Study**, The American Journal of Sports Medicine, 38, 4, **2010**.
Mündermann A., Stefanyshyn D., Nigg, B.M., **Relationship between footwear comfort of shoe inserts and anthropometric and sensory factors**, Medicine & Science in Sports & Exercise, 33, 11, 1939-1945, **2001**.
Nigg B.M., Nurse M.A., Stefanyshyn D.J., **Shoe inserts and orthotics for sport and physical activities**, Medicine and Science in Sports and Exercise, 31, 7, 421-428, **1999**.
Nie H., Graven-Nielsen T., Arendt-Nielsen L., **Spatial and temporal summation of pain evoked by mechanical pressure stimulation**, European Journal of Pain, 13, 592-599, **2009**.
Nussbaum E.L., and Downes L., **Reliability of clinical pressure-pain algometric measurements obtained on consecutive days**, Physical Therapy, 78, 160-169, **1998**.
Orchard J., **Is there a relationship between ground and climatic conditions and injuries in football?**, Sports Medicine, 32, 419–32, **2002**.
Orendurff M.S., Rohr E.S., Segal A.D., Medley J.W., Green J.R., Kadel N.J., **Regional foot pressure during running, cutting, jumping, and landing**, The American Journal of Sports Medicine, 36, 3, **2008**.
Potter L.J., McCarthy C, Oldham J., **Algometer reliability in measuring pressure pain threshold over normal spinal muscles to allow quantification of anti-nociceptive treatment effects**, Journal of Bone and Joint Surgery British Volume, 90b, 223, **2008**.
Powell C.V., Kelly, A., Williams, A., **Determining the minimum clinically significant difference in visual analog pain score for children**, Annals of emergency Medicine, 37, 1, **2001**.
Schwellnus M.P., Jordaan G., Noakes T.D., **Prevention of common overuse injuries by the use of shock absorbing insoles**, American Journal of Sports Medicine, 18, 6,636-641, **1990**.
Soligard T., Bahr R., Andersen T.E., **Injury risk on artificial turf and grass in youth tournament football**, Scandinavian Journal of Medicine and Science in Sports, 22, 3, 356-61, **2010**.
Stiles V.H., James I.T., Dixon S.F. and Guisasola I.N., **Natural turf surfaces the case for continued research**, Sports Medicine, 1, 65-84, **2009**.
Svensson P., Arendt-Nielsen L., Nielsen H., Larsen J.K., **Effect of chronic and experimental jaw muscle pain on pain- pressure thresholds and stimulus-response curves**, Journal of Orofacial Pain, 9, 347-356, **1995**.
Vanderweeen L., Oostendorp R.B., Vaes P., Duquet W., **Pressure algometry in manual therapy**, Manual Therapy, 1, 258-265, **1996**.
Xiong, S., Ravindra S.G., Jiang Z., **Pressure thresholds of the human foot: Measurement reliability and effect of stimulus characteristics**, Ergonomics, 282-293, **2011**.
Ylinen J, Nykanen M, Kautiainen H, Hakkinen A., **Evaluation of repeatability of pressure algometry on the neck muscles for clinical use**, Manual Therapy, 12, 192-197, **2007**.