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Influence of a training session on postural stability and foot loading patterns in soccer players

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Abstract

Sport specific movements coming along with characteristic plantar pressure distribution and a fatigue of muscles result in an increasing postural sway and therefore lead to a decrease in balance control. Although single soccer specific movements were expatiated with respect to these parameters, no information is available for a complete training session. The objective of the present observational study was to analyze the direct influence of soccer training on postural stability and gait patterns and whether or not these outcomes were altered by age. One hundred and eighteen experienced soccer players participated in the study and were divided into two groups. Group 1 contained 64 soccer players (age 13.31±0.66 years) and Group 2 contains 54 ones (age 16.74±0.73 years). Postural stability, static plantar pressure distribution and dynamic foot loading patterns were measured. Our results showed that the soccer training session, as well as the age, has relevant influence on postural stability, while the age only (excluding the training) has an influence on static plantar pressure distribution. The parameters of dynamic assessment seem therefore to be affected by age, training and a combination of both. Training and young age correlate with a decreased postural stability; they lead to a significant increase of peak pressure in the previously most loaded areas, and, after reaching a certain age and magnitude of absolute values, to a change in terminal stance and preswing phase of the roll-over. Moreover, younger players show an inhomogenous static plantar pressure distribution which might be the result of the decreased postural control in the young age.

Introduction

Soccer belongs to the most popular sports worldwide with about 200 000 professional and 240 million recreational players. Previous studies have shown that soccer specific movements like for example goal shot or cutting maneuver come along with characteristic plantar pressure distribution and that the graduation of for example a marathon or ultramarathon leads to a change of plantar loading patterns.[1-3] Furthermore, it is known that taking part in sport like for example soccer comes along with muscle fatigue and that fatigue of certain muscle groups leads to an increase in postural sway and therefore to a decrease in balance control.[4]

Beyond gait patterns and postural control are developed while growing up.[5] It is not known until when they are enveloped totally and if participation in sport like for example soccer has a different influence on these parameters in different age classes.

Postural control and gait patterns were examined in this study because decreases of these are known risk factors for ankle sprains (especially a decreased balance control)[6,7] and stress fractures (especially an individual gait pattern and an alignement of the lower extremity).[8] Thus the injury incidence while soccer playing is high it is important to examine known risk factors, so preventive care programs and behavior can be integrated.

The purpose of the present investigation was to analyze the direct influence of a full soccer training session on postural stability and gait patterns and whether the alterarion of postural stability and foot loading patterns are age related.

We hypothesize that a training session leads to a loss in postural stability and to a change in gait patterns. Furthermore we suppose that the effect of sport in changing these known injury risk factors is even more distinct in younger age because it is known that the injury incidence in soccer is age depending.

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Materials and Methods

A total amount of 118 male soccer players participated in the study. These 118 participants were divided into two groups, according to their age. Group 1 consisted of U15/U14 players and included 64 soccer players with a mean age of 13.31±0.66 years, a mean height of 1.67±0.09 m, a mean weight of 54.0±8.4 kg and a mean BMI of 19.31±2.01 kg/m^2. Group 2 composed of 54 U19/U18 players with a mean age of 16.74±0.73 years, a mean height of 1.79±0.07 m, a mean weight of 73.0±10.6 kg and a mean BMI of 22.59±2.78 kg/m^2. All participants reached 100 points in the AOFAS-Score and were active members of a soccer club.[9] Informed consent was signed in by the participants themselves or if they were younger than 18 years by their parents. The study was approved by the local ethic authorities (No. 108/10). None of the participants ever had an operation, injury or dysfunction of the lower extremity nor an imbalance or a known peripheral neuropathy.

The PDM-S system (Zebris medical GmbH, Isny, Germany) was used to measure postural sway and the static plantar pressure according to Eberle *et al.*[10] The generated signals were visualized with Win-PDMS Software System. According to Ohlendorf and Natrup,[2,11] we used the GP MultiSens platform (GeBioM mbH, Münster, Germany) for the measurement of the dynamic plantar loading patterns. The measurements were taken before and immediately after the defined training session which consists of a warming-up phase (15 min), a phase of training (25 min) and a 20 min lasting soccer match phase in the end.

Postural stability and static pressure distribution were measured in two-legged and single-leg stance on both sides. The participant's task was to stand barefoot on the PDM-S platform with as little sway as possible in two-legged stance for 20 sec and in single-leg stance for 10 sec. The participants were asked to look at a fixed point while the measurement was assessed. As parameters of the static assessment the area of center of pressure sway (COP) for appointment of the postural stability and the static percental pressure distribution between both feet and between fore- and rearfoot were measured. For the dynamic assessment the participants were requested to walk barefoot without respite along a 10 meter walkway in which the GP MultiSens platform was arranged in the middle. In the context of this dynamic measurement peak pressure, force-time integral and contact area were analyzed in the six anatomic regions: heel, midfoot, medial forefoot, central forefoot, lateral forefoot and toes. The medial forefoot region equates the area around metatarsal head I, the central forefoot region the one around metatarsal head II and III and the lateral region the one around metatarsal head IV and V. The comparisons of the parameters of static and dynamic measurement before and after graduation of the defined training session were evaluated via t-test for independent samples. The effect of age was examined by using the t-test for matched pairs. $P \leq 0.05$ interval was accepted as statistically significant.

Results

In group 1 COP increased significantly in two-legged stance of 83% and in single-legged stance left of 25% and right of 56% (Table 1). In group 2 this area increased significantly of 48% in two-legged and of 32% in single-legged stance right. In single-legged stance left an increase of 12% could be seen (Table 1). At both measuring times participants of group 1 showed higher values of area of COP sway than group 2 members. Before graduation of the defined training session group 1's area of COP sway is twice as large and after graduation 2.5 as large as those of group 2. These differences are significant. In single leg stance the same difference between both groups could be seen in both legs.

Compromising the static plantar pressure distribution in two-legged stance before and after training it could be seen that both groups load the rearfoot than the forefoot area. A significant difference could only be seen between the fore- and rearfoot area of group 2. In this group the plantar pressure in the forefoot area increased but always stayed on a lower value than the rearfoot (Table 1). No differences could be seen in the static loading between the both feet in group 1 and 2 and between the fore- and rearfoot area in group 1 due to training. In single-legged stance both groups also load the rearfoot more than the forefoot area but the difference in pressure distribution between forefoot and rearfoot is far less than in two-legged stance. Comparing the pressure distribution before and after the training session a significant increase could only be seen in group 1's forefoot area and according to this a significant decrease in rearfoot area of the left foot. Group 1's right forefoot also showed a minimal increase (Table 1). No difference in plantar pressure distribution before and after sport could be found in group 2's single-legged stance. Regarding age related effects it could be seen that at both measuring times group 1's participants stood significantly more on the left foot and loaded the forefoot area less and the rearfoot area more than participants of group 2 in two-legged stance. In single-legged stance no differences between both groups could be assessed (Table 1).

In the dynamic assessment of peak pressure it could be seen that in group 1 at both measuring points the largest values could be found in the heel, the central and lateral forefoot as well as in the toes. Participation in the training session leads to a significant increase of peak pressure in the heel of the right foot and the central forefoot of both sides. The largest values of group 2 could be found in central forefoot and toe region at both messuring times. Attendance at training results in a significant increase of peak pressure in the heel region of the right foot (Table 2).

Observing the force-time integral in both groups and at both measuring points the highest values could be found in the heel and the central forefoot region. In group 1's heel regions of both feet training leads to a significant increase of force-time integral. In the same group a significant decrease of this parameter was observed in the right foot's toe region. The second group showed a significant decrease of this parameter in the left foot's central forefoot region and in both feet's toe regions.

Regarding the contact area in both groups largest values could be seen in the heel at both measuring points. A significant training dependant change in size could only be seen in the medial forefoot region of group 1's left foot. In group 2 training didn't lead to any change of the contact area size (Table 2).

Comparing both groups in most of all foot regions and at both measuring times group 2 showed significant higher values of peak pressures and force-time integral as well as larger contact areas (Table 2).

Discussion

It is well known that regulary sport training improves the postural stability in long term.[12] The acute effect of a training session on postural control is yet not known. Aim of this study was to observe whether a training unit has an influence on postural stability and foot loading patterns.

Examining the center of pressure sway in single- and two-legged stance before and after soccer deterioration in postural stability was found in both age-classes. This could be seen in a significant increase of the area of center of pressure sway. Another parameter of the static assessment was the percental pressure distribution in two- and single-legged stance. In both groups training session had no influ-

Table 1. Area of center of pressure sway (COP: mm^2, mean ± standard deviation) and plantar pressure distribution (PPD: %, mean ± standard deviation) in both groups before and after the training session.

	Group 1 (N=64)		Group 2 (N=54)	
	Before	After	Before	After
Area of COP sway				
Both feet	126±124	230±220*	60±63°	89±109*,°
Left foot	270±252	336±202*	192±125°	214±121°
Right foot	248±203	388±282*	150±83°	197±126*,°
PPD in two-legged stance				
Left-/right foot	53.2/46.8±7.2	53.7/46.3 7.4	50.7/49.3±3.3°	50.5/49.5±3.2°
Fore-/ rearfoot left	35.2/64.8±11.5	35.4/64.6±10.8	40.2/59.8±9.4°	43.0/57.0±11.6*,°
Fore-/rearfoot right	37.2/62.8±13.8	37.2/62.8±12.7	43.6/56.4±10.6°	47.1/52.9±11.2*,°
PPD in single-legged stance				
Fore-/rearfoot left	45.7/54.3±8.7	49.4/50.6±7.6*	48.4/51.6±8.9	47.4/52.6±9.8
Fore-/rearfoot right	47.5/52.5±8.0	48.8/51.2±8.0	48.4/51.6±8.9	49.7/50.3±10.2

*Significant difference ($P \leq 0.05$) between the measurement before and after training; °significant difference ($P \leq 0.05$) between both age groups.

ence on the pressure distribution among right and left foot in two-legged stance. Equable pressure distribution was also observed in further studies not depending on sport,[13] indicating the accuracy of the chosen collective. Regarding every single foot in two-legged stance only in group 2 a minimal change between both measuring times could be seen. This change seems to have no or just a small clinical relevance because the larger part of plantar pressure still burdens the rearfoot area and the percental change is quite small. The same plantar pressure distribution as seen in both groups before sport was observed in the male participants of another study which investigated 14 year old youths.[13] According to that sport seems to have no clinically relevant influence on plantar pressure distribution in two-legged stance.

The control of postural stability depends on the integration of visual, vestibular and proprioceptive information and on the resulting efferences.[14] Proprioception, is an afferent part of postural stability and it could be seen that even after turning off all afferent information except the proprioceptive inputs of the leg muscles postural stability was still ensured.[15] So evidentially proprioceptive afferences are the essential components of center of pressure sway in calm posture.[15,16] The results of these studies suggest that the lack of postural stability found in the present investigation is caused by a decrease in proprioceptive abilities. In contrast localized fatigue effects of the triceps surae muscle as well as ankle joints and hip muscles fatigue effects lead also to a lack of postural stability.[4] These muscles were exposed by the training session. So the increase in the area of center of pressure sway could also be caused by fatigue effects. Therefore it is not clearly to verify whether the worsening in postural stability is the result of a decreased afferent or efferent function. To avoid this problem it is recommended to use simple motoric exercises for the measurement of postural stability.[16] In the context of the present investigation this was implemented by measuring the postural stability in two-legged stance, which is even a minor motoric challenge than standing in single-legged stance. This is reflected by the fact that in both of the groups the area of center of pressure sway is larger in single-legged than in two-legged stance. Given that in the present investigation the measured area of center of pressure sway in two-legged stance showed a significant increase due to training it is assumed that the decrease of postural stability results mainly from a decrease in proprioception and less from muscle fatigue.

Due to the fact that we can't see a shift in plantar pressure distribution during quite standing, the sport depending decrease of postural stability can't be the effect of a worsening efferent function, thus a worsening in efferent function would lead to a change in loading patterns. So this also counts for our hypothesis that the increase in area of center of pressure sway needs to result from a lack in afferent and not efferent function.

With respect to the dynamic assessment in the present investigation the typical *bipod* loading, which is already described exists before training.[17] In both groups training leads to an increase of peak pressure in the foot areas which feature the highest peak pressure values before and after training. These changes are significant but probably clinically irrelevant because they are with a range of 1.1 to 1.7N/cm^2 relatively low. In both groups the principle of bipod loading continues to exist even after soccer training. It has already been observed that participation in different kind of sports such as marathon leads to a change in peak pressure.[2,3,18] The manner and the location of these changes seem to depend on the sport. Natrup who observed participants of a marathon race described a significant increase in the central forefoot which is similar to group 1 of the present investigation. Furthermore he found a decrease in toe region which the soccer training participants only showed by trend and in contrast to the present results he observed an increase in lateral forefoot.[2] Karangounis *et al*. found out that ultramarathon leads to a significant increase of peak pressure in the whole forefoot area and especially in the area around metatarsal head II.[3] The measured difference there is considerably higher than the one found in medial forefoot region of group 1. The differences found between the results of Natrup and Karagounis on the one side and the ones of the present investigation on the other side could be a consequence of a different exposure during the

Table 2. Peak pressure (N/cm^2, mean ± standard deviation), force-time integral (Ns, mean ± standard deviation) and contact area (cm^2, mean ± standard deviation) in both groups before and after the training session.

	Group 1 (N=64)				Group 2 (N=54)			
	Left foot		Right foot		Left foot		Right foot	
	Before	After	Before	After	Before	After	Before	After
Peak pressure								
Heel	16.5±5.8	17.2±6.4	14.9±5.2	16.6±6.6*	17.7±5.9	18.0±6.4	16.8±5.1	18.2±6.5*
Midfoot	4.6±2.9	4.7±2.8	4.8±2.9	5.4±3.0	6.2±3.7°	6.1±3.0°	6.5±4.3°	6.9±4.5°
Medial forefoot	9.2±6.9	10.3±6.4	8.5±7.5	8.1±5.3	13.6±7.7°	13.2±7.6°	13.1±9.2°	13.5±9.6°
Central forefoot	15.8±4.2	16.9±4.7*	15.6±4.6	17.3±6.9*	21.3±6.3°	21.6±7.8°	20.4±5.8°	21.5±6.6°
Lateral forefoot	16.0±10.9	15.1±8.4	15.0±8.1	14.7±7.1	18.1±8.8	17.9±9.4	18.0±8.3	20.5±12.7°
Toes	14.6±8.5	15.2±8.6	16.4±7.4	15.1±7.8	18.1±10.2°	17.0±7.9	20.6±10.8°	18.0±8.2
Force-time integral								
Heel	54.5±25.0	60.6±26.9*	49.0±30.1	56.2±27.4*	72.3±28.3°	78.8±30.9°	71.8±30.3°	72.9±24.6°
Midfoot	10.2±8.6	10.7±8.4	11.4±11.0	13.4±11.7	16.4±13.7°	16.6±13.1°	21.4±20.7°	20.0±18.3°
Medial forefoot	14.1±11.9	16.7±14.7	11.9±12.1	11.3±10.2	25.1±18.3°	21.9±13.9	20.1±17.9°	17.9±13.8°
Central forefoot	55.0±24.3	55.5±22.1	52.0±23.5	54.5±24.4	78.1±26.8°	69.3±23.3*,°	78.1±28.9°	75.9±21.4°
Lateral forefoot	28.6±19.9	29.1±21.0	32.5±17.6	31.8±18.4	39.9±22.2°	36.0±20.2	46.1±24.2°	44.1±22.4°
Toes	15.5±12.4	14.7±15.7	17.3±9.7	14.3±9.3*	21.1±14.0°	16.4±9.0*	28.2±22.9°	19.0±10.7*,°
Contact area								
Heel	29.8±3.6	29.9±3.7	30.2±3.1	30.2±3.6	33.3±4.2°	33.2±3.8°	32.9±3.8°	33.0±4.2°
Midfoot	19.6±8.9	20.1±9.4	20.2±8.7	21.1±7.9	22.6±8.9	22.9±8.1	24.1±8.8°	24.5±8.4°
Medial forefoot	9.3±4.2	10.5±4.3*	7.9±3.8	7.8±3.7	11.7±3.8°	11.6±4.3	9.6±4.2°	9.5±4.2°
Central forefoot	22.2±4.0	22.2±3.7	21.6±4.5	22.5±3.5	23.9±4.7°	24.1±4.1°	24.2±3.5°	24.2±4.6°
Lateral forefoot	16.0±3.4	15.7±3.0	18.5±3.1	18.0±3.1	17.3±3.9	17.6±4.0°	19.7±3.5	19.5±2.4°
Toes	12.2±3.5	12.0±3.0	12.5±2.7	12.2±3.0	14.2±3.2°	14.2±3.0°	14.9±3.3°	14.4±3.1°

*Significant difference ($P \leq 0.05$) between the measurement before and after training; °significant difference ($P \leq 0.05$) between both age groups.

training session in comparison with running sports. While participants of a marathon- or an ultramarathon race run ideally with an almost steady speed and without fast changes in direction the participants of the present investigation had to run, sprint and kick the ball as well as to perform side- and crossover cuts. Peak pressure- and force-time integral distribution are dependent on the performed movement and differ strongly among the different motor activities.[1] According to this the training session loads all foot areas in a multifaceted way while running sports load the foot in an unchanging monotone way. It is reasonable to presume that due to the soccer training the muscle groups of the lower extremity are loaded in a different and not that kind of uniformed way like they are in a marathon race. Probably further factors such as age and footwear also have an influence on the change in peak pressure. This might explain differences to the study of Lampe *et al*., who found a pressure increase in midfoot in youths who walk barefoot.[18] This increase could be reproduced neither in the present investigation nor in the studies of Natrup and Karagounis.[2,3] The fact that Natrup and Karagounis didn't find this effect could be caused by the different participant's age, as both work with adults. But this doesn't offer an explanation why the participants of the present investigation do not show this. An explanation approach which gives a reason for these differences could be the fact that in the present investigation and in the other two studies the participants wore shoes while Lampes participants run barefootly.[2,3] It is known that different kind of shoes have an effect on sport depending changes in peak pressure. So the shoes having been worn in the present investigation as well as in the other studies could have partially buffered the foot.[2,3] Regarding force-time integral in opposite to group 1 group 2 offers a significant decrease in whole foot's force-time integral. This change mainly follows from a significant decrease in toe region of both feet. Indeed in every foot region except the heel an at least minimal decrease of force-time integral was seen but the one in the toe region is with about 28.7% on the left and 48.4% on the right side the most important. Such decrease in toe area was also found in other studies.[2,3] This suggests that training leads in this age group to a change in roll-over behavior in terminal stance- and preswing phase. Furthermore this decrease indicates that after training the hallux doesn't support the roll-off as much as it does before.

Changes in force-time integral due to sport seem to be dependent on load intensity. Karagounis observed in ultramarathon participants an increase of force-time integral in medial, central and lateral forefoot area.[3] Some authors consider that the combination of force-time integral decrease in the toe and increase in the area around the metatarsal heads is due to localized fatigue effects of the foot's flexor muscles.[19-21] So the reduction of group 2's toe area force-time integral could be a result of fatigue effects. Age depending growth of the absolute values of peak pressure and force-time integral could be the etiological factor for the facts that group 1's participants offer no or only a marginal increase of force time integral in the toe- and a decrease in the forefoot area, group 2's participants possess a significant decrease in the toe- but no increase in the forefoot area and adults feature a decrease in the toe- and an increase in the forefoot area. Due to the lower absolute values in younger age greater load might be necessary in order to achieve the onset of muscle fatigue. The rise in absolute value with age implies that equal loading causes a faster muscle fatigue with increasing age. This would appear to be confirmed by the theory that not only the fatigue of the triceps surae muscle, the plantar flexors and the dorsal extensor muscles as well as the one of the foot's short muscle group and the associated worsening of the efferent function lead to a decrease of postural stability. In this case the sport depending changes of peak pressure and force-time integral as well as the fatigue effects of the musculature would have to be clearer in younger age in which the worsening in postural stability is more pronounced.

Comparing both age groups with respect to the postural stability it could be seen that group 1's participants showed a significant larger area of postural sway in single- and two-legged stance. This means that the postural stability is less developed in younger persons. These results are in accordance with the current literature which assumes that a non-monotonic improvement of postural stability takes place during the childhood.[22,23] In this process maximal amplitude and mean velocity of center of pressure sway displacement decreases between 4-5 and 6-7 years as well as between 10 years and adult age. This increase in postural stability in childhood is the result of a decreasing magnitude and frequency of postural sway.[24] Rival considered the period between 8 and 11 years as critical resulting from an integration of reactive and predictive modes of postural control, from a better integration of sensory information and from the apparition of adult-like balance control strategies.[22] In line with the results of the present investigation, Sparto hypothesized that sensory integration of the somatosensory signals is still developing in the age of 12 years,[25] and also Olivier consumed that adult's level of postural control is still not reached at the age of 11. Bair concluded that the increase in postural stability with the age is due to a better ability in sensory reweighting.[26] He considered that mature sensory reweighting uses information from all sensory modalities and that a change in one sensory input leads to a change in response to all sensory inputs. This improvement in reweighting might lead to the increase in postural stability between the age of 13 and 17 years which had been observed here.

Regarding the static pressure distribution the actually found differences between both groups could be the result of the age depending developed ability of sensory integration and reweighting which lead to a decreased postural stability in younger age.[26] A less developed postural stability encourages a pathological or inhomogeneous loading.

Pertaining to the parameters of dynamic assessment it could be seen that both groups showed a similar distribution of peak pressure, force-time integral and contact area. According to this no different roll-over behavior was found comparing these both age-classes. Comparing children in the age of 4 to 6 years with adolescents in the age of 12 to 16 years Lampe et al. found a complete change in roll-over behavior and gait pattern.[18] Thus the development of roll-over behavior seems to be completed before finishing the 13th year of life. However the absolute values found in group 1 and 2 differ significantly given that participants of group 2 showed higher peak pressure, force-time integral- and contact are values in each examined foot region. The results suggest that between 13th and 17th year of life the amount of absolute values occurs without changing the load distribution of the different foot areas while walking. Recently Hennig et al. found considerably lower peak pressure values in children when compared with adults, indicating that the reduced foot pressures in children are due to the fact that these have larger foot dimensions with respect to the body weight, which means that the ground reaction forces are distinguished across larger contact areas. Furthermore he identified that in contrast to the findings in adults, body weight has a major influence on the magnitude of plantar pressure in children between 6 to 10 years.[27] Other studies found similar results.[13] With respect to the clinical relevance it is known that a decrease in postural stability as well as an individual gait pattern are known risk factors for ankle sprains or stress fractures and moreover the injury incidence is age depending.[7,8] Thus the injury type also differs with the age the different postural abilities might give an approach for the nature of injury.[28] Therefore the observed changes in postural stability and gait pattern might explain the results of Gianotti *et al*. who described different incidences for patterns of injuries in different age classes.[29]

Conclusions

The results of the present study show that participation in the soccer training session as well as age have a clinically relevant influence on postural stability. Training and young age correlate with a decreased postural stability. This change is leading consequence of a decrease in proprioception.

On static plantar pressure distribution only the age but not the training has a clinically relevant influence, hence younger player show an inhomogenous pressure distribution. This might be the result of the decreased postural control in the young age. Parameters of the dynamic assessment seem to be affected by age, training, a combination of both, as well as by other factors such as the kind of sport or the load intensity. Training leads to a significant but small increase of peak pressure in the previously most loaded areas and after reaching of a certain age and magnitude of absolute values to a change in terminal stance and preswing phase of the roll-over. These changes in roll-over behavior might lead to an increase in injury risk.

Taken together our results indicate that a balance- and proprioceptive training in addition to the usual soccer training might lead to a decrease in injury rate especially in younger soccer players.

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